CASE 5762: ATLANTIC RICHFIELD COMPANY for a waterflood project, Lea County, New Mexico

CASE NO.

5762

Application,
Transcripts,
Small Exhibits,

ETC.

ARCO Oil and Gas Company
Permian District
Post Office Box 1610
Midland, Texas 79702
Telephone 915 684 0100

May 4, 1982

Oil Conservation Division of the
New Mexico Dept. of Energy and Minerals
P. O. Box 2088
Santa Fe, New Mexico

Attention Mr. Ramey

Dear Mr. Ramey:

RE: Case No. 5762; Order No. R-5295
ARCO Oil and Gas Company
State Vacuum Unit - Waterflood Project
T17S, R34E, Lea County, New Mexico

Dear Mr. Ramey:

In the Order dated October 12, 1976, establishing the waterflood project, wellhead injection pressure was limited to 860 psi. Approval of a higher wellhead pressure could be obtained by showing that the increase in pressure would not fracture the confining strata. On April 14, 1980, evidence was offered to show that a wellhead injection pressure of 1422 psi would not fracture the formation. This proposal was approved administratively and the current limitation is 1422. As operator of the unit, ARCO Oil and Gas Company applies for administrative approval of a wellhead injection pressure of 1550 psi. The attached exhibits are offered as evidence that this pressure will not fracture the confining strata.

The exhibits are based on parting pressure tests run on April 19-26, 1982. Exhibit No. 1 is a map of the unit area showing the five injection wells which were tested. Four of the five wells were tested last time and provide reference for comparison purposes. The tests on these five wells indicate a range of surface parting pressures from 1600 to 2198 psi as shown in Exhibit No. 2. The necessary equipment and well data is included on Exhibit No. 3

The paper "Step-Rate Tests Determine Safe Injection Pressures in Floods"[1] was used as a reference to help determine proper testing procedures and analysis methods. The tests were run by Atlantic Richfield Company using a downhole pressure recorder, surface pressure recorder and a Halliburton turbine flowmeter. Individual well data and results are shown in Exhibits 4 through 8.

Some injection wells exhibit non-D'Arcy flow characteristics which prevents determination of the parting pressure by the normal rate vs. pressure graphical technique. Two of the wells tested exhibited this behavior. By using the technique outlined in the reference paper

Called Hobbs office 6-2-82 Fracture pressure raised up because of flood, - problems in area but not in Arco Unit - thinks this application is OK.

($q = D'q^2$) parting pressures were determined for the two wells and are included as Exhibits 5A and 8A. Exhibits 9 and 10 are graphical solutions of the Williams and Hazen formula for determining the pressure drop due to friction in the injection tubing. Data for the individual wells is listed on Exhibit 2.

Some of the wells tested do not contain enough data points for a well-defined line after the formation parts. This is due to the limitation of the surface equipment during the tests. The wellheads have a 2000 psi working pressure limitation and this limited the injection rate during the test.

We feel that an increased wellhead injection pressure is necessary if we are to maintain adequate injection rates to promote the timely production of the secondary reserves in the unit. Our application for administrative approval of a wellhead injection pressure of 1550 psi should insure that we are not fracturing the formation strata but also allow us to increase our current injection rates. We will gladly forward any additional information which may be required and ask for your prompt consideration.

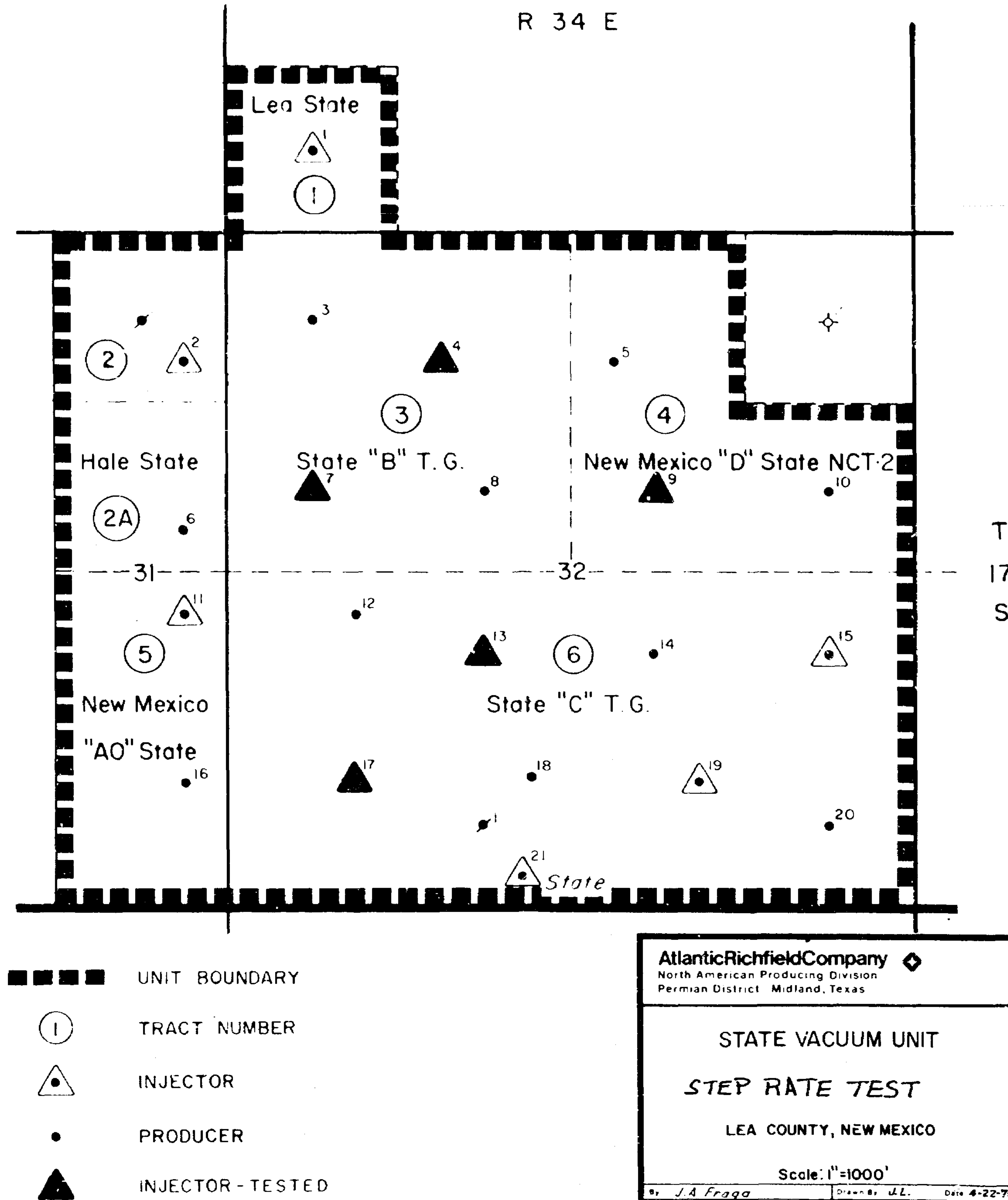
Very truly yours,

J. L. Tweed
District Engineer

JAF:JLT:cn

Attachments

EXHIBIT I



AtlanticRichfieldCompany
North American Producing Division
Permian District Midland, Texas

STATE VACUUM UNIT

STEP RATE TEST

LEA COUNTY, NEW MEXICO

Scale: 1"=1000'

By J.A Fraga	Drawn By J.L. Date 4-22-79
Date	Revised By RCT Date 5-1-82
Dept WEST AREA ENGR.	Dwg No

STATE VACUUM UNIT
PRESSURE PARTING TESTS

1	2	3	4	5	6	7	8	9	10
WELL NO.	CUM.INJ. 3/1/82 (MB)	PRESS. BOMB SETTING DEPTH (FT)	HYDRO-STATIC HEAD[1] (PSI)	INJ. RATE @ PTG.PRES. (BPD)	PRESS. DROP FRICTION[2] ΔP_f (PSI/100 FT)	ΔP_f TOTAL @ SETTING Depth(psi)	BTM HOLE PTG.PRES. (psi)	SURF. PTG.[3] PRESSURE (psi)	PTG. GRAD-IENT (psi/ft)
4	11.7	4609	1997.5	1200	2.30	106.0	Mn 4072 Ex 4	2180.5	.884
7	592.0	4694	2034.4	2600	5.20	244.1	Mn 3390 Ex 5A	1599.7	.722
9	1201.3	4622	2003.2	1633	2.22	102.6	3510 Ex 6	1609.4	.759
13	178.1	4685	2030.5	2000	3.20	149.9	Mn 4079 Ex 7	2198.4	.870
17	57.1	4717	2044.3	2060	3.26	153.8	Mn 3874 Ex 8A	1983.5	.821

1. Injection water has specific gravity equal to 1.001; pressure gradient = ~~.433 psi/ft.~~ .4334 psi/ft
2. Taken from Exhibit 10/11 (Williams and Hazen formula).
3. Surface parting pressure = bottom hole parting pressure - hydrostatic head + ΔP_f

Col. 4 = Col 3 x .4334
Col 6 extrapolated from Ex 10 and 11
Col 7 = Col 6 x Col 3 ÷ 100
Col 8 taken from Exhibits as indicated
Col 9 = Col 8 - Col 4 + Col 7
Col 10 = Col 8 ÷ Col 3

Exhibit 3

STATE VACUUM UNIT
PRESSURE PARTING TESTS
INJECTION WELL DATA

WELL NO.	COMPLETION CASING SIZE (DEPTH)	TUBING SIZE* IN.	DEPTH SET	PERFORATIONS
4	3 ½" liner (3440-4700')	2 3/8"	1153'	
7	3½" liner (4422-4728')	2 1/16" 2 3/8"	4550' 4429'	4594-4624' 4671-4718'
9	3½" liner (4436-4765')	2 3/8"	4436'	4605-4639'
13	3½" liner (4421-4717')	2 3/8"	4421'	4660-4710'
17	3½" liner (4429-4761')	2 3/8"	4429'	4721-4761'

* All tubing is internally plastic coated

Exhibit 4

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-26-82

WELL NUMBER: 4

ELEMENT: 36391

COUNTY: Lea

TEST DEPTH: 4609

TIME/ ~~AM~~ PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:12	0	2823	833
12:32	350	3300	1050
12:49	650	3458	1458
1:04	1000	3878	1820
1:19	1200	4072	2030
1:34	1450	4174	2270

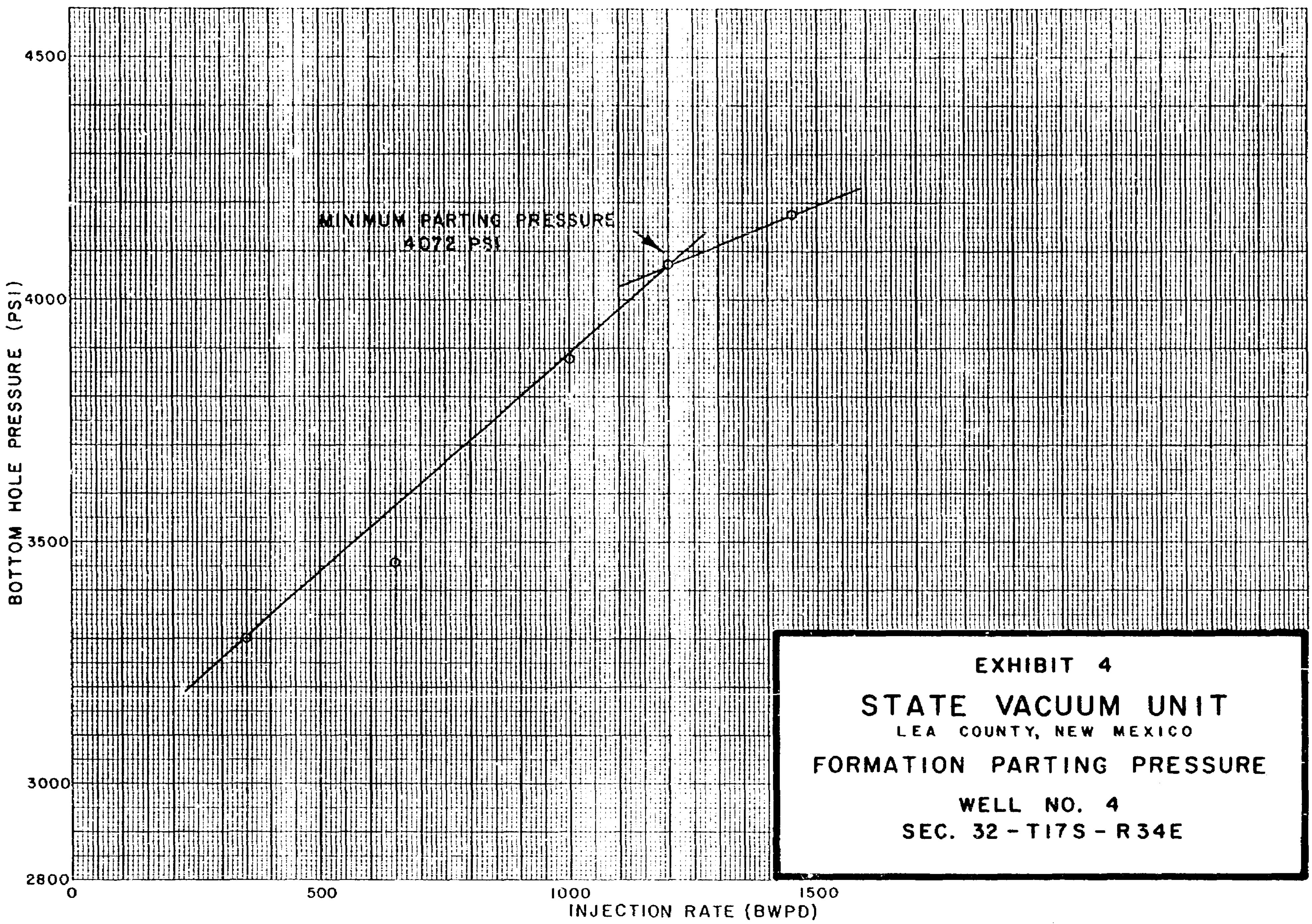

MINIMUM PARTING PRESSURE
4072 PSI
BOTTOM HOLE PRESSURE (PSI)
4500
4000
3500
3000
2800
0
500
1000
1500
INJECTION RATE (BWPD)
EXHIBIT 4
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 4
SEC. 32 - T17S - R34E

Exhibit 5

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-23-82

WELL NUMBER: 7

ELEMENT: 6941

COUNTY: Lea

TEST DEPTH: 4694

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:16	0	2758	659
11:50	700	2851	890
12:06	1000	2919	920
12:21	1200	2971	1000
12:37	1450	3028	1050
12:53	1800	3122	1120
1:10	2000	3215	1230
1:19	2450	3306	1360
1:35	2600	3390	1500
1:44	3200	3540	1950
2:00	3500	3676	2020

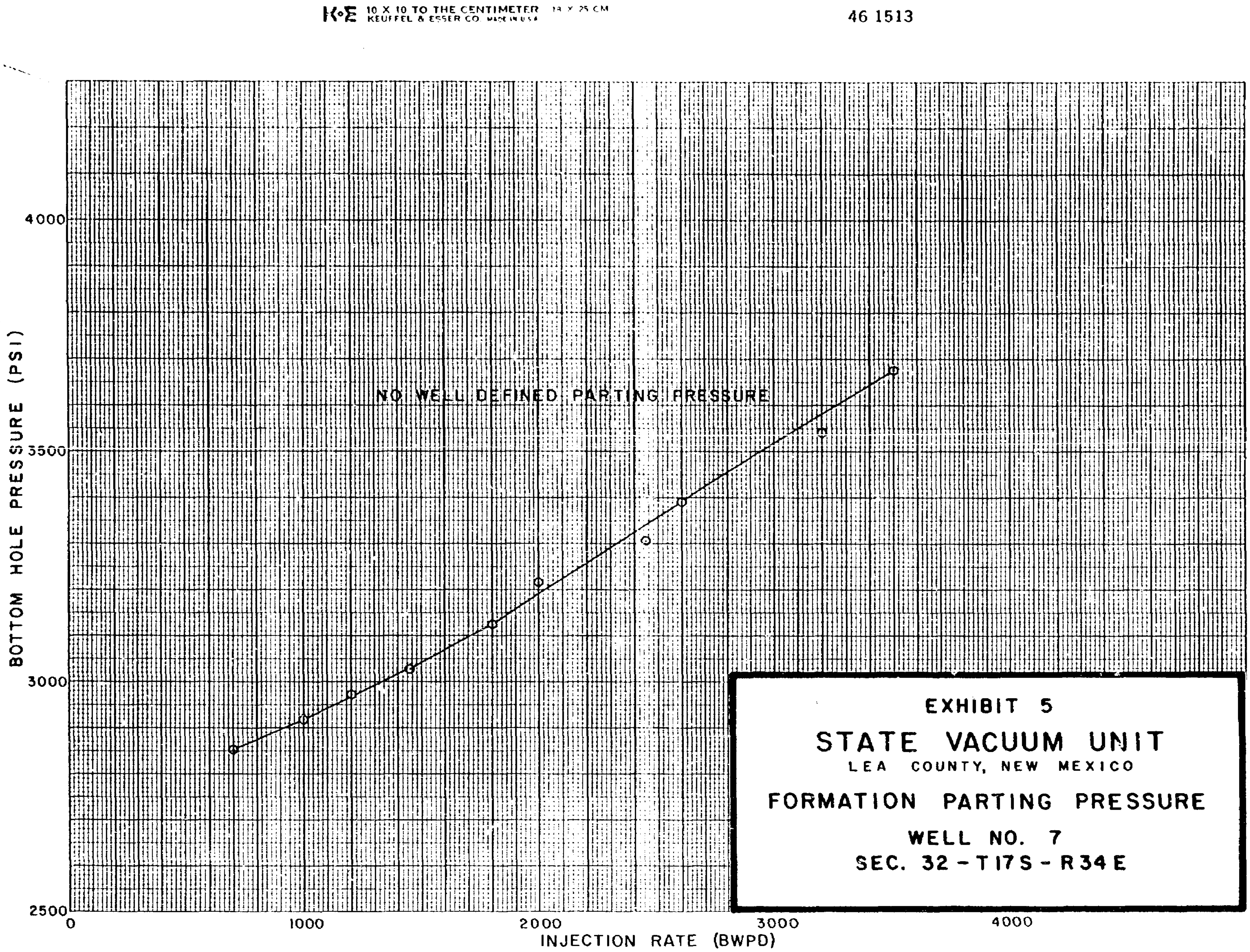

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
NO WELL DEFINED PARTING PRESSURE
BOTTOM HOLE PRESSURE (PSI)
INJECTION RATE (BWPD)
4000
3500
3000
2500
0
1000
2000
3000
4000
EXHIBIT 5
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 7
SEC. 32 - T17S - R34E

Exhibit 6

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-21-82

WELL NUMBER: 5

ELEMENT: 6941

COUNTY: Lea

TEST DEPTH: 4622

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:43	0	3090	1001
12:54	860	3270	1240
1:10	1100	3327	1500
1:25	1300	3411	1650
1:43	1500	3472	1750
1:58	1700	3529	1840
2:13	2000	3605	1970

46 1513

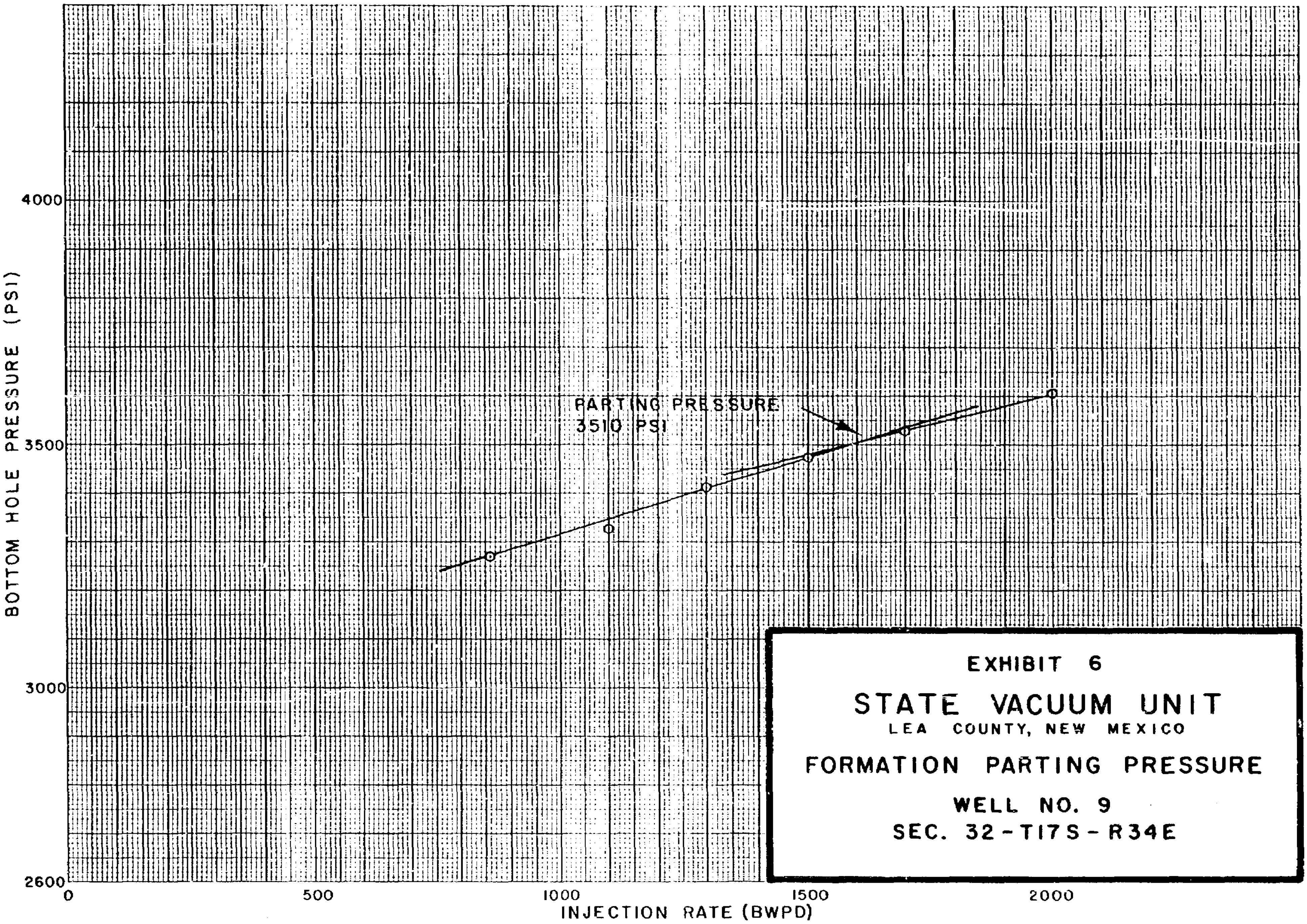


EXHIBIT 6

STATE VACUUM UNIT

LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE

WELL NO. 9

SEC. 32-T17S-R34E

Exhibit 7

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

WELL NUMBER: 13

COUNTY: Lea

DATE OF TEST 4-15-82

ELEMENT: 36391

TEST DEPTH: 4685

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
9:56	0	2630	560
11:51	860	2932	950
12:08	1000	3062	1160
12:24	1200	3249	1250
12:43	1400	3480	1400
12:57	1700	3656	1750
1:13	2000	4079	2100
1:30	2400	4243	2360

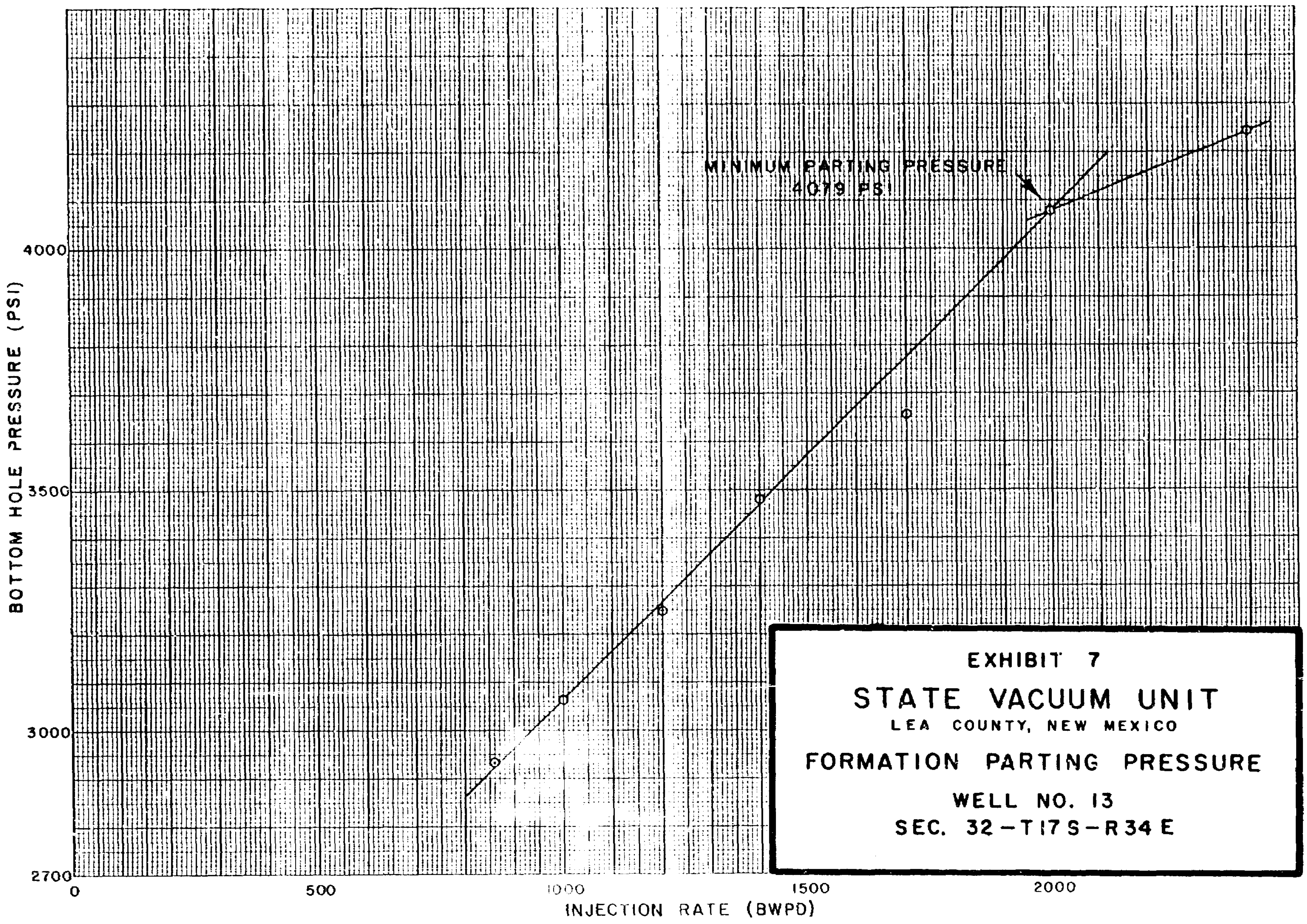

MINIMUM PARTING PRESSURE
4079 PSI
BOTTOM HOLE PRESSURE (PSI)
4000
3500
3000
2700
0
500
1000
1500
2000
INJECTION RATE (BWPD)
EXHIBIT 7
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 13
SEC. 32-T17S-R34E

Exhibit 8

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-19-82

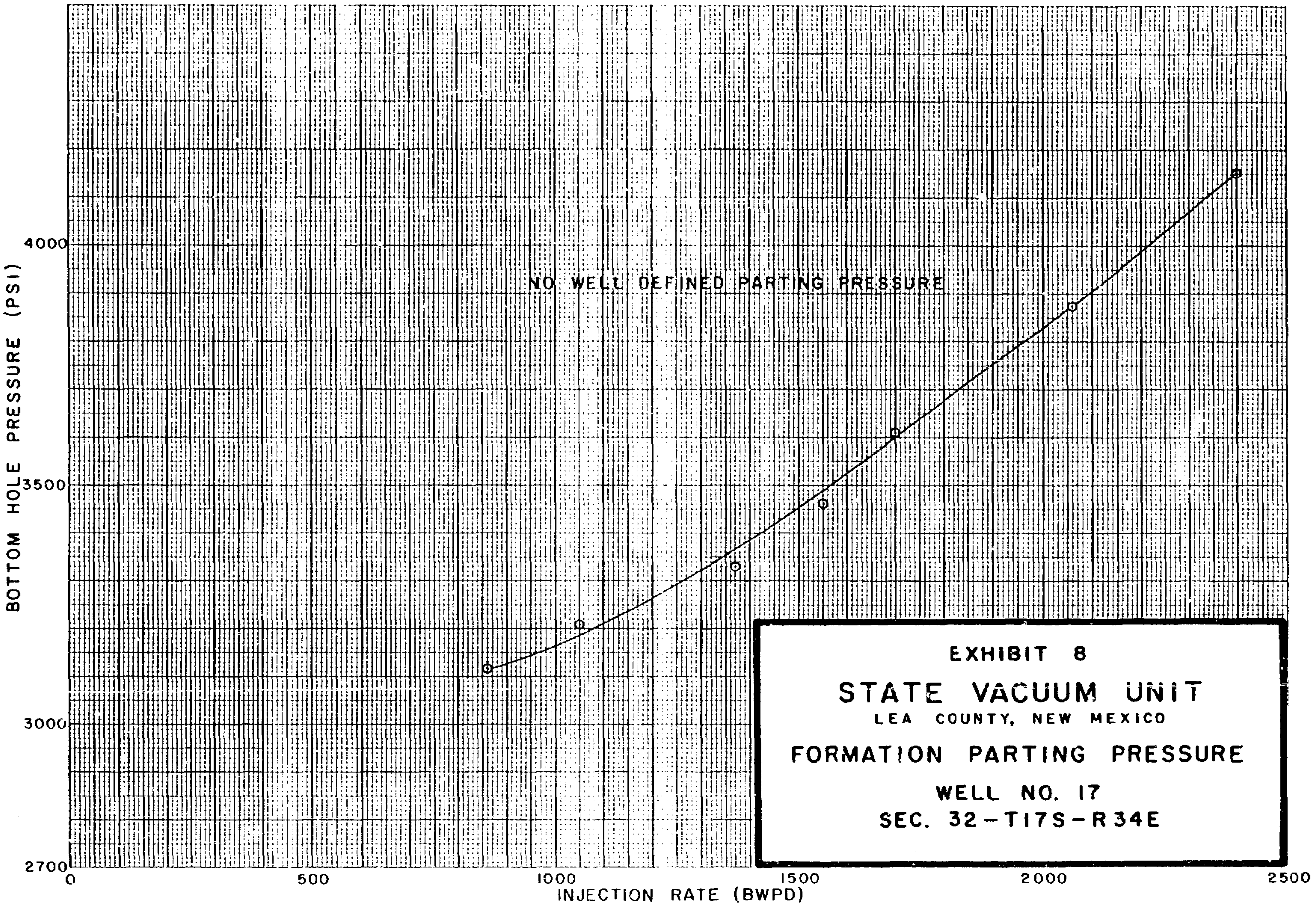
WELL NUMBER: 17

ELEMENT: 6941

COUNTY: Lea

TEST DEPTH: 4717

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:23	0	2851	754
11:32	860	3117	1100
11:47	1050	3208	1300
12:03	1370	3330	1500
12:19	1550	3462	1650
12:34	1700	3610	2025
12:49	2060	3874	2200
12:59	2400	4152	2400


NO WELL DEFINED PARTING PRESSURE
BOTTOM HOLE PRESSURE (PSI)
4000
3500
3000
2700
0
500
1000
1500
2000
2500
INJECTION RATE (BWPD)
EXHIBIT 8
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 17
SEC. 32-T17S-R34E

STATE VACUUM UNIT
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE

Well No. 17

From Exhibit :

$$D' = (q_2 \Delta P_1 - q_1 \Delta P_2) / (q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: q_1 = 860 BPD P_1 = 3117 ΔP_1 = 237

q_2 = 1050 BPD P_2 = 3208 ΔP_2 = 328

Injection Rate BPD	$D' = .0018\ (b/d)^{-1}$ BHP @ TEST DEPTH (psi)	$q + D'q^2$ (BPD)
0	2851	
860	3117	2191
1050	3208	3035
1370	3330	4748
1550	3462	5875
1700	3610	6902
2060	3874	9699
2400	4152	12768

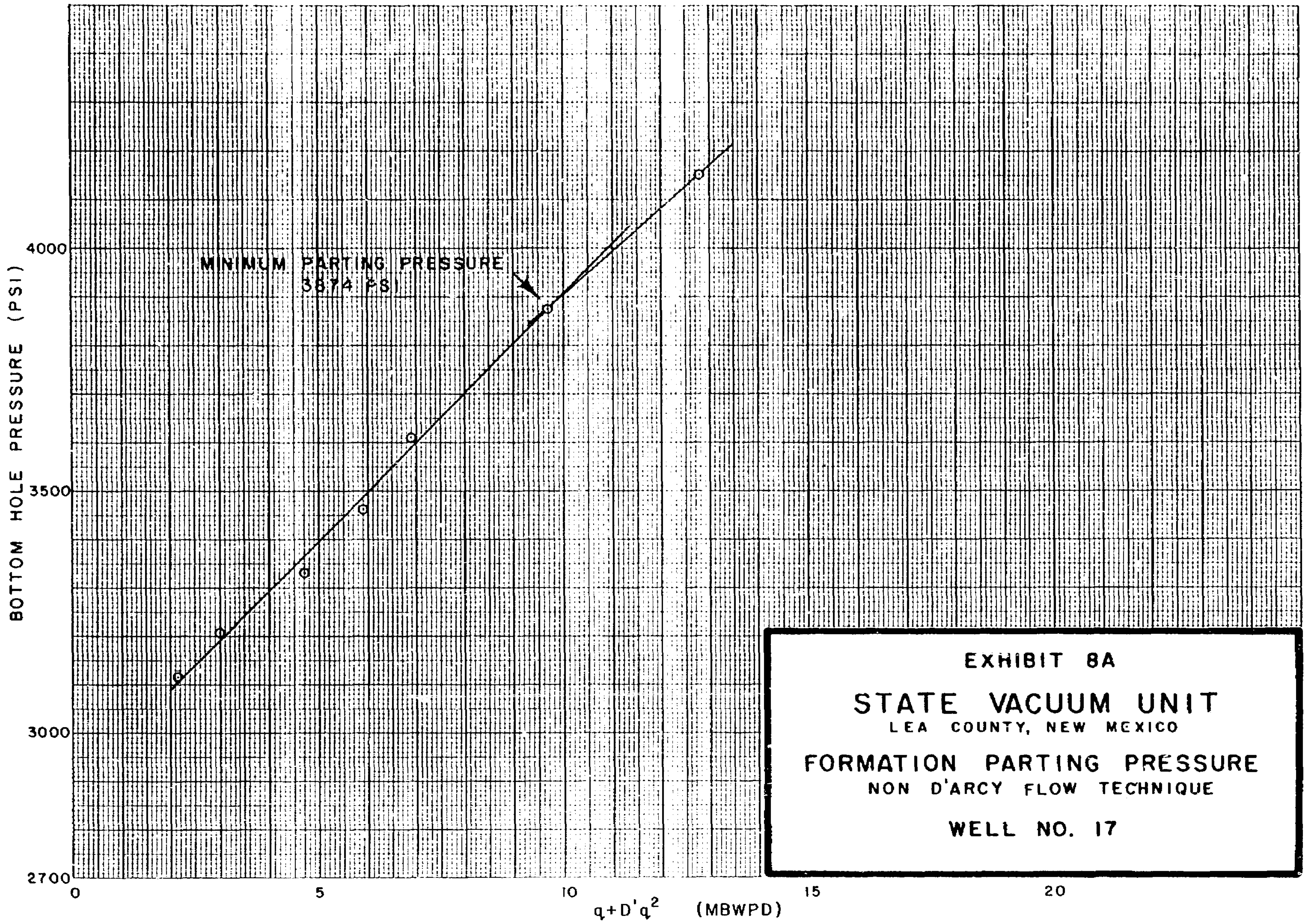


EXHIBIT 8A

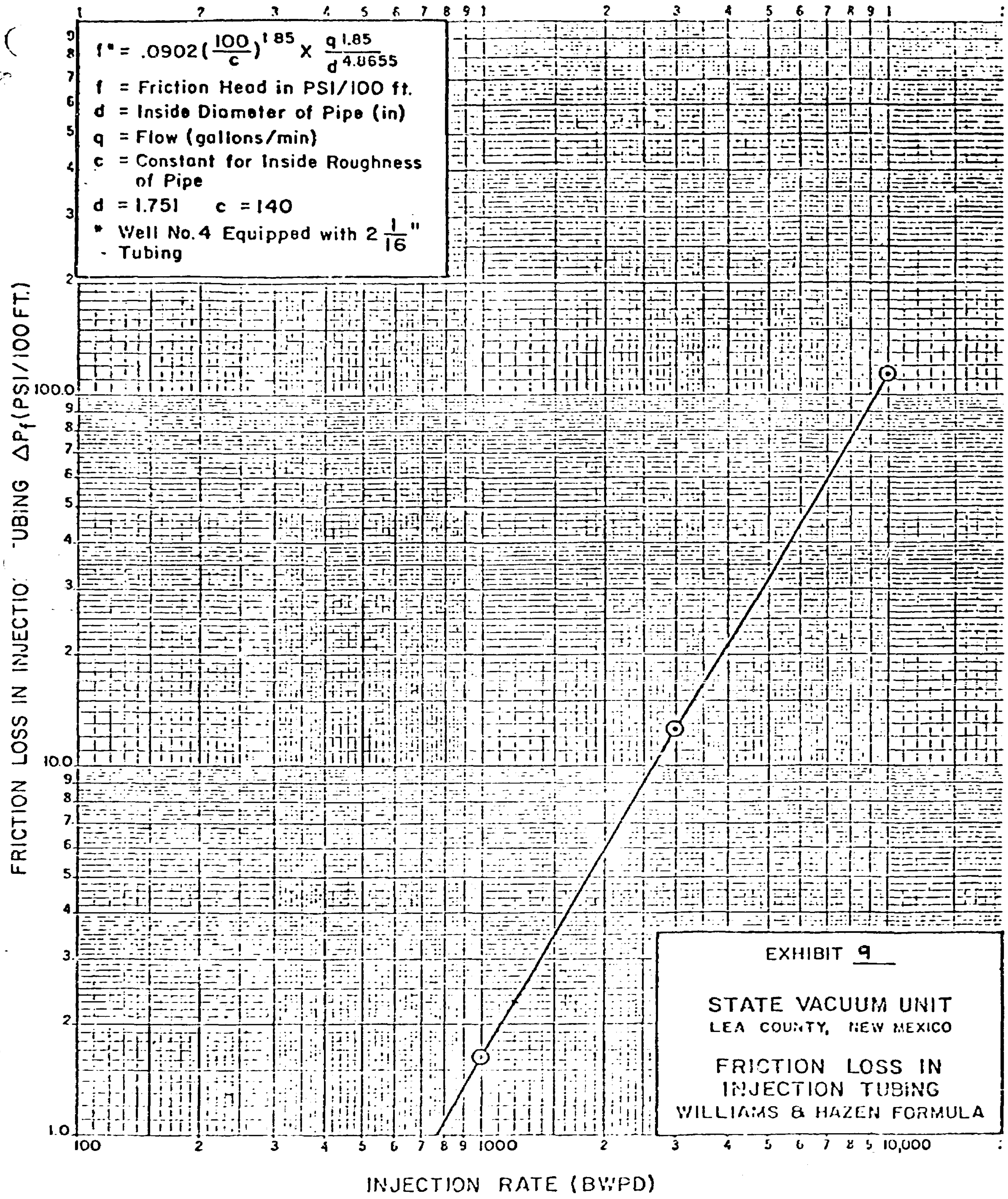
STATE VACUUM UNIT

LEA COUNTY, NEW MEXICO

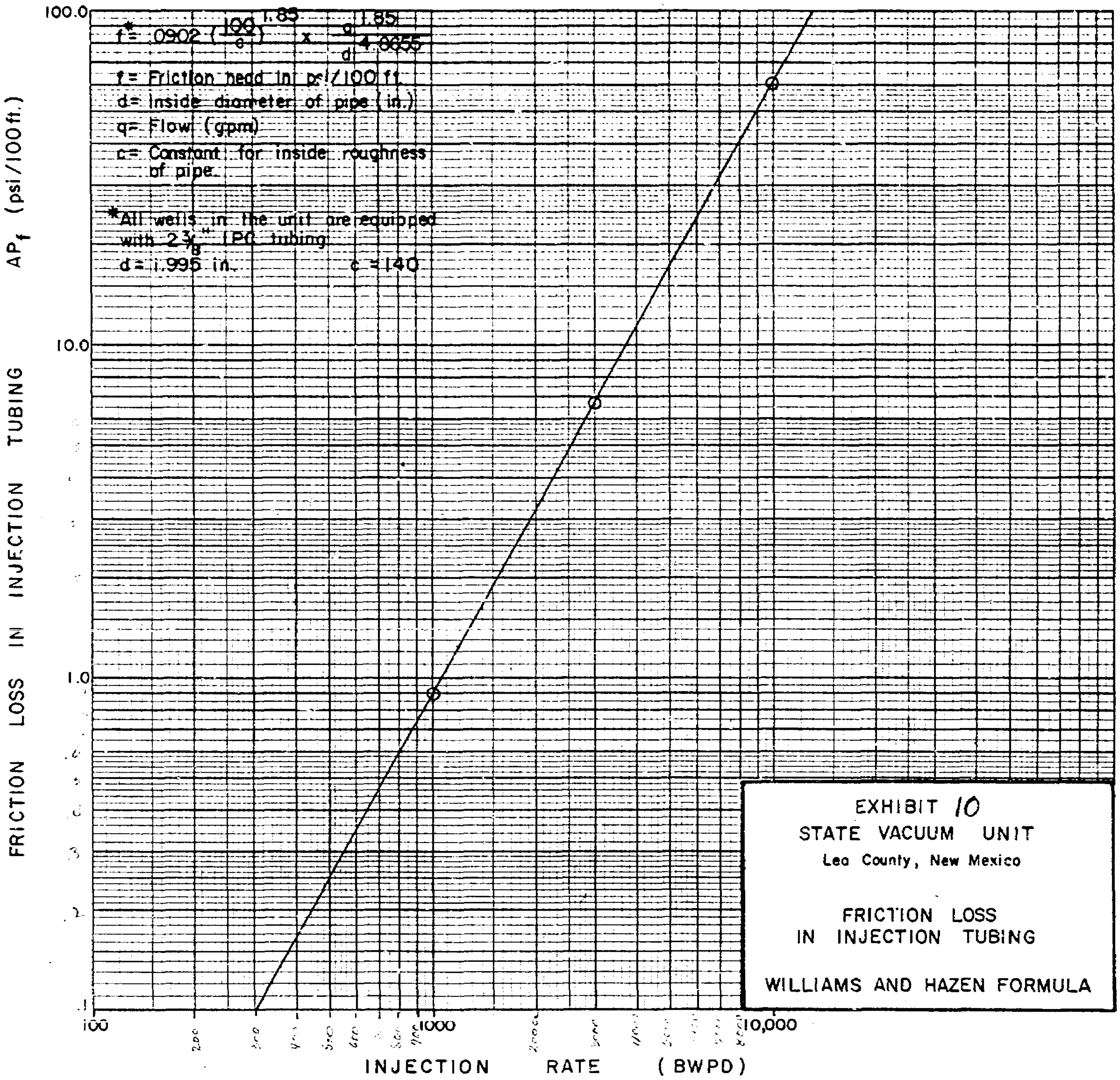
FORMATION PARTING PRESSURE

NON D'ARCY FLOW TECHNIQUE

WELL NO. 17



f* = .0902 (100/c)^1.85 X q^1.85 / d^4.8655
f = Friction Head in PSI/100 ft.
d = Inside Diameter of Pipe (in)
q = Flow (gallons/min)
c = Constant for Inside Roughness of Pipe
d = 1.751 c = 140
* Well No. 4 Equipped with 2 1/16" Tubing
FRICTION LOSS IN INJECTIO TUBING ΔPf (PSI/100 FT.)
100.0
10.0
1.0
100
1000
10,000
INJECTION RATE (BWPD)
EXHIBIT 9
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FRICTION LOSS IN INJECTION TUBING
WILLIAMS & HAZEN FORMULA



f* = .0902 (100/c)^1.85 x q^1.85 / d^4.8655
f = Friction head in psi/100 ft.
d = inside diameter of pipe (in.)
q = Flow (gpm)
c = Constant for inside roughness of pipe.
*All wells in the unit are equipped with 2 3/8" IPC tubing
d = 1.995 in.
c = 140
100.0
10.0
1.0
.1
FRICTION LOSS IN INJECTION TUBING ΔPf (psi/100 ft.)
100
1000
10,000
INJECTION RATE (BWPD)
EXHIBIT 10
STATE VACUUM UNIT
Lea County, New Mexico
FRICTION LOSS
IN INJECTION TUBING
WILLIAMS AND HAZEN FORMULA

BIBLIOGRAPHY

Felsenthal, Martin: "Step-Rate Tests Determine Safe Injection Pressures in Floods," Oil & Gas Journal (October 28, 1974) pg. 49-54

STATE VACUUM UNIT
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE

Well No. 7

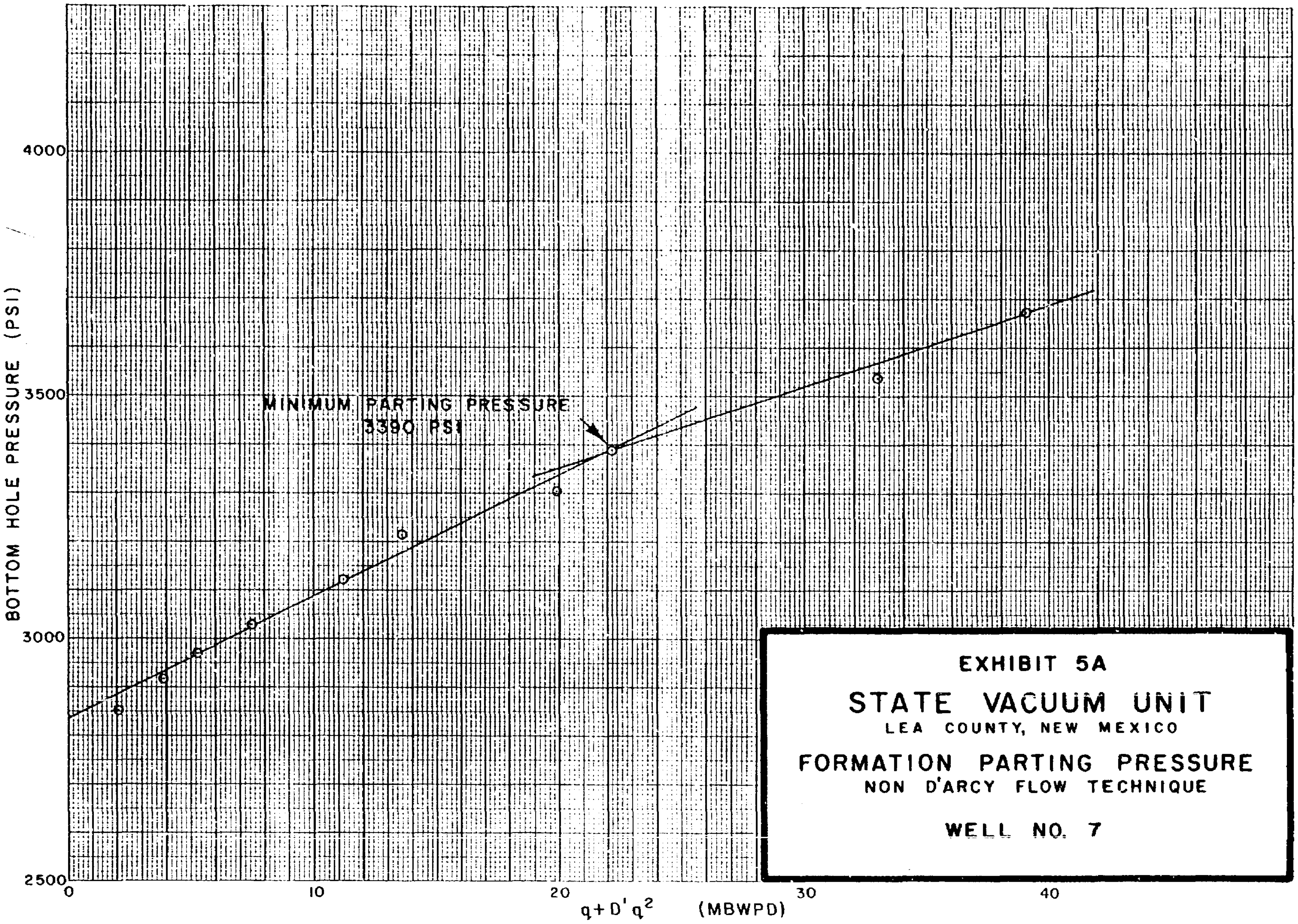
From Exhibit :

$$D' = (q_2 \Delta P_1 - q_1 \Delta P_2) / (q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: q_1 = 700 BPD P_1 = 2851 ΔP_1 = 81

q_2 = 1000 BPD P_2 = 2919 ΔP_2 = 149

Injection Rate BPD	D' = .0029 $(b/d)^{-1}$ BHP @ TEST DEPTH (psi)	$q + D'q^2$ (BPD)
0	2758	
700	2851	2121
1000	2919	3900
1200	2971	5376
1450	3028	7547
1800	3122	11196
2000	3215	13600
2450	3306	19857
2600	3390	22204
3200	3540	32896
3500	3676	39025



BOTTOM HOLE PRESSURE (PSI)
4000
3500
3000
2500
0
10
20
30
40
q+D'q²   (MBWPD)
MINIMUM PARTING PRESSURE
3390 PSI
EXHIBIT 5A
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE
WELL NO. 7

STATE OF NEW MEXICO
ENERGY AND MINERALS DEPARTMENT
OIL CONSERVATION DIVISION

BRUCE KING
GOVERNOR

POST OFFICE BOX 2088
STATE LAND OFFICE BUILDING
SANTA FE, NEW MEXICO 87501
(505) 827-2434

July 13, 1982

ARCO Oil and Gas Company
Box 1610
Midland, Texas 79702

Attention: Mr. J. L. Tweed, District Engineer

Re: Case No. 5762
Order No. R-5295

Gentlemen:

This is in reference to your letter of May 4, 1982, wherein you request administrative approval to increase the injection pressure in your State Vacuum Unit in Lea County, New Mexico.

By the authority granted me in Order No. R-5295, you are hereby authorized to increase the injection pressure to 1550 psi.

Yours very truly,

JOE D. RAMEY
Director

JDR/fd

cc: OCD Hobbs
✓Case 5762 File

ARCO Oil and Gas Company
Permian District
Post Office Box 1610
Midland, Texas 79702
Telephone 915 681 0100

JUL 07 1982
OIL CONS... SANTA FE

July 1, 1982

Mr. M. Stogner
Oil Conservation Division
P. O. Box 2088
Santa Fe, New Mexico 87501

Dear Mr. Stogner:

ARCO Oil and Gas Company
Case No. 5762; Order No. R-5295
State Vacuum Unit - Waterflood Project
T17S, R34E, Lea County, New Mexico

Attached please find a copy of our proposal to increase the injection pressure on our State Vacuum Unit waterflood. Per your phone conversation with our secretary today, we understood that you never did receive the original sent May 4, 1982. Since production from the subject unit is decreasing more rapidly than anticipated, we would appreciate your most prompt consideration of this request.

Very truly yours,

J. A. Fraga

Juan A. Fraga
Engineer

JAF/MJB:dmm
Attachments

ARCO Oil and Gas Company
Permian District
Post Office Box 1610
Midland, Texas 79702
Telephone 915 684 0100

JUL 02 1982

May 4, 1982

Oil Conservation Division of the
New Mexico Dept. of Energy and Minerals
P. O. Box 2088
Santa Fe, New Mexico

Attention Mr. Ramey

Dear Mr. Ramey:

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State Vacuum Unit - Waterflood Project
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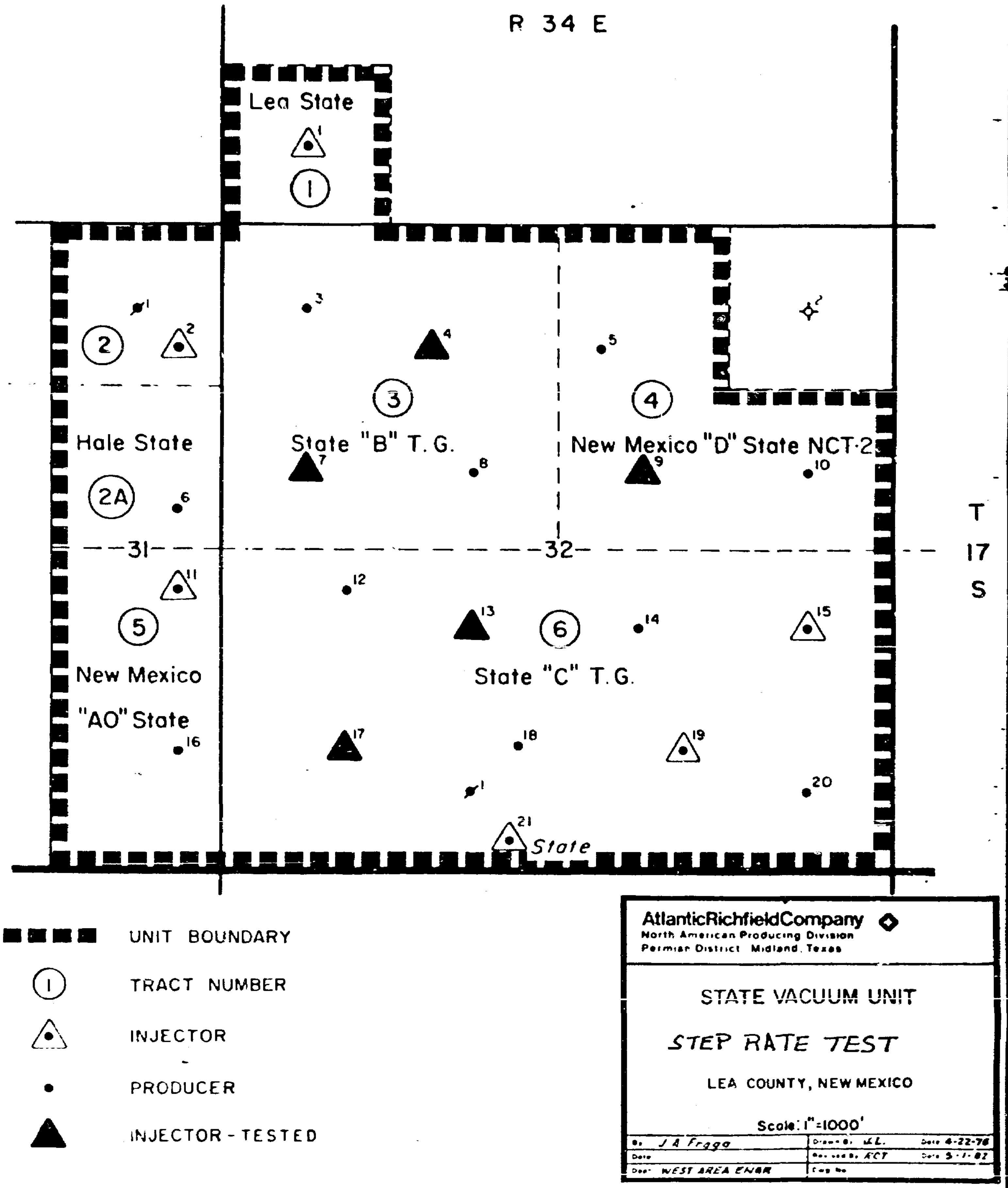
J. L. Tweed
District Engineer

JAF:JLT:cn

Attachments

EXHIBIT I



R 34 E
Lea State
1
Hale State
2
2A
State "B" T. G.
3
New Mexico "D" State NCT-2
4
5
New Mexico
"AO" State
State "C" T. G.
6
State
31
32
T
17
S
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
UNIT BOUNDARY
TRACT NUMBER
INJECTOR
PRODUCER
INJECTOR - TESTED
AtlanticRichfieldCompany
North American Producing Division
Permian District Midland, Texas
STATE VACUUM UNIT
STEP RATE TEST
LEA COUNTY, NEW MEXICO
Scale: 1"=1000'
J A Fraga
WEST AREA ENGR
4-22-76
5-1-82

Exhibit 2

STATE VACUUM UNIT
PRESSURE PARTING TESTS

WELL NO.	CUM. INJ. 3/1/82 (MB)	PRESS. BOMB SETTING DEPTH (FT)	HYDRO-STATIC HEAD[1] (PSI)	INJ. RATE @ PTG. PRES. (BPD)	PRESS. DROP FRICTION[2] ΔP_f (PSI/100 FT)	ΔP_f TOTAL @ SETTING Depth (psi)	BTM HOLE PTG. PRES. (psi)	SURF. PTG.[3] PRESSURE (psi)	PTG. GRAD-IENT (psi/ft)
4	11.7	4609	1997.5	1200	2.30	106.0	Mn 4072	2180.5	.884
7	592.0	4694	2034.4	2600	5.20	244.1	Mn 3390	1599.7	.722
9	1201.3	4622	2003.2	1633	2.22	102.6	3510	1609.4	.759
13	178.1	4685	2030.5	2000	3.20	149.9	Mn 4079	2198.4	.870
17	57.1	4717	2044.3	2060	3.26	153.8	Mn 3874	1983.5	.821

1. Injection water has specific gravity equal to 1.001; pressure gradient = .433 psi/ft.

2. Taken from Exhibit 10/11 (Williams and Hazen formula).

3. Surface parting pressure = bottom hole parting pressure - hydrostatic head $+\Delta P_f$

Exhibit 3

STATE VACUUM UNIT
PRESSURE PARTING TESTS
INJECTION WELL DATA

WELL NO.	COMPLETION CASING SIZE (DEPTH)	TUBING SIZE* IN.	DEPTH SET	PERFORATIONS
4	3 ½" liner (3440-4700')	2 3/8" 2 1/16"	1153' 4550'	4594-4624'
7	3½" liner (4422-4728')	2 3/8"	4429'	4671-4718'
9	3½" liner (4436-4765')	2 3/8"	4436'	4605-4639'
13	3½" liner (4421-4717')	2 3/8"	4421'	4660-4710'
17	3½" liner (4429-4761')	2 3/8"	4429'	4721-4761'

* All tubing is internally plastic coated

Exhibit 4

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

WELL NUMBER: 4

COUNTY: Lea

DATE OF TEST 4-26-82

ELEMENT: 36391

TEST DEPTH: 4609

TIME/ ~~AM~~ PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:12	0	2823	833
12:32	350	3300	1050
12:49	650	3458	1458
1:04	1000	3878	1820
1:19	1200	4072	2030
1:34	1450	4174	2270

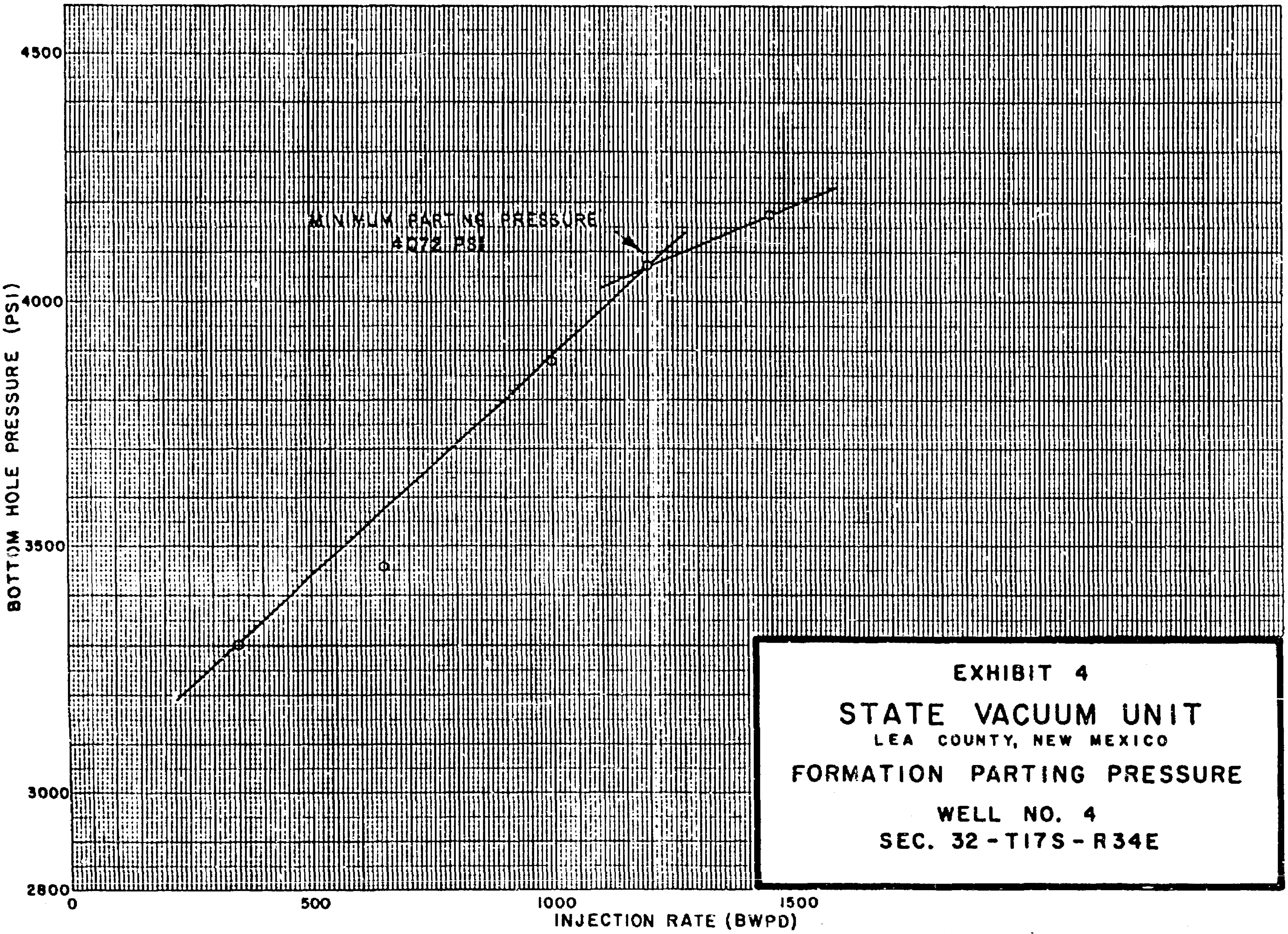

MINIMUM PARTING PRESSURE
4072 PSI
BOTTOM HOLE PRESSURE (PSI)
4500
4000
3500
3000
2800
0
500
1000
1500
INJECTION RATE (BWPD)
EXHIBIT 4
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 4
SEC. 32-T17S-R34E

Exhibit 5

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-23-82

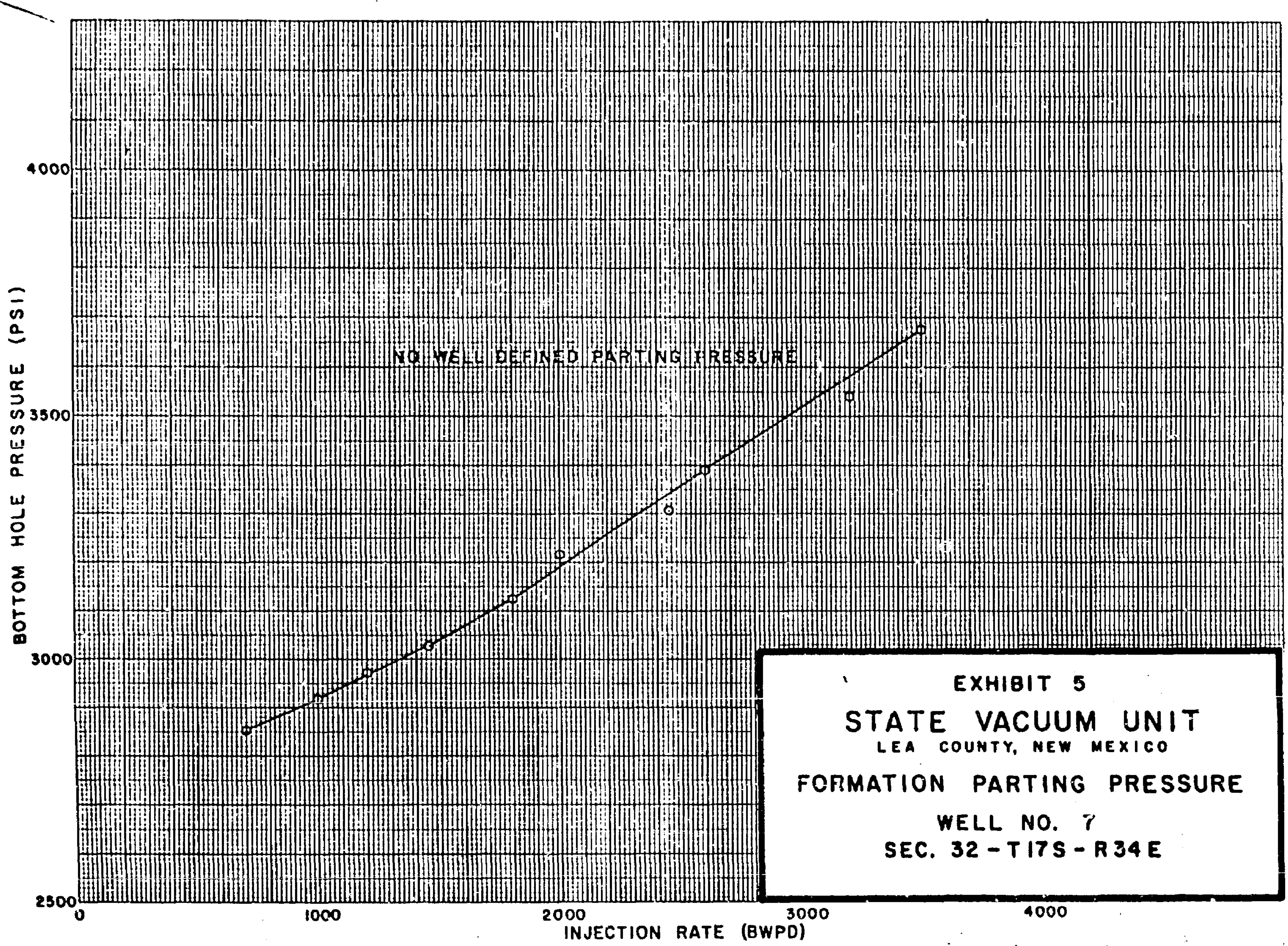
WELL NUMBER: 7

ELEMENT: 6941

COUNTY: Lea

TEST DEPTH: 4694

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:16	0	2756	659
11:50	700	2851	890
12:06	1000	2919	920
12:21	1200	2971	1000
12:37	1450	3028	1050
12:53	1800	3122	1120
1:10	2000	3215	1230
1:19	2450	3306	1360
1:35	2600	3390	1500
1:44	3200	3540	1950
2:00	3500	3676	2020


NO WELL DEFINED PARTING PRESSURE
BOTTOM HOLE PRESSURE (PSI)
4000
3500
3000
2500
0
1000
2000
3000
4000
INJECTION RATE (BWPD)
EXHIBIT 5
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 7
SEC. 32 - T17S - R34E

STATE VACUUM UNIT
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE

Well No. 7

From Exhibit :

$$D' = (q_2 \Delta P_1 - q_1 \Delta P_2) / (q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: q_1 = 700 BPD P_1 = 2851 ΔP_1 = 81

q_2 = 1000 BPD P_2 = 2919 ΔP_2 = 149

Injection Rate BPD	$D' = .0029\ (b/d)^{-1}$ BHP @ TEST DEPTH (psi)	$q + D'q^2$ (BPD)
0	2758	
700	2851	2121
1000	2919	3900
1200	2971	5376
1450	3028	7547
1800	3122	11196
2000	3215	13600
2450	3306	19857
2600	3390	22204
3200	3540	32896
3500	3676	39025

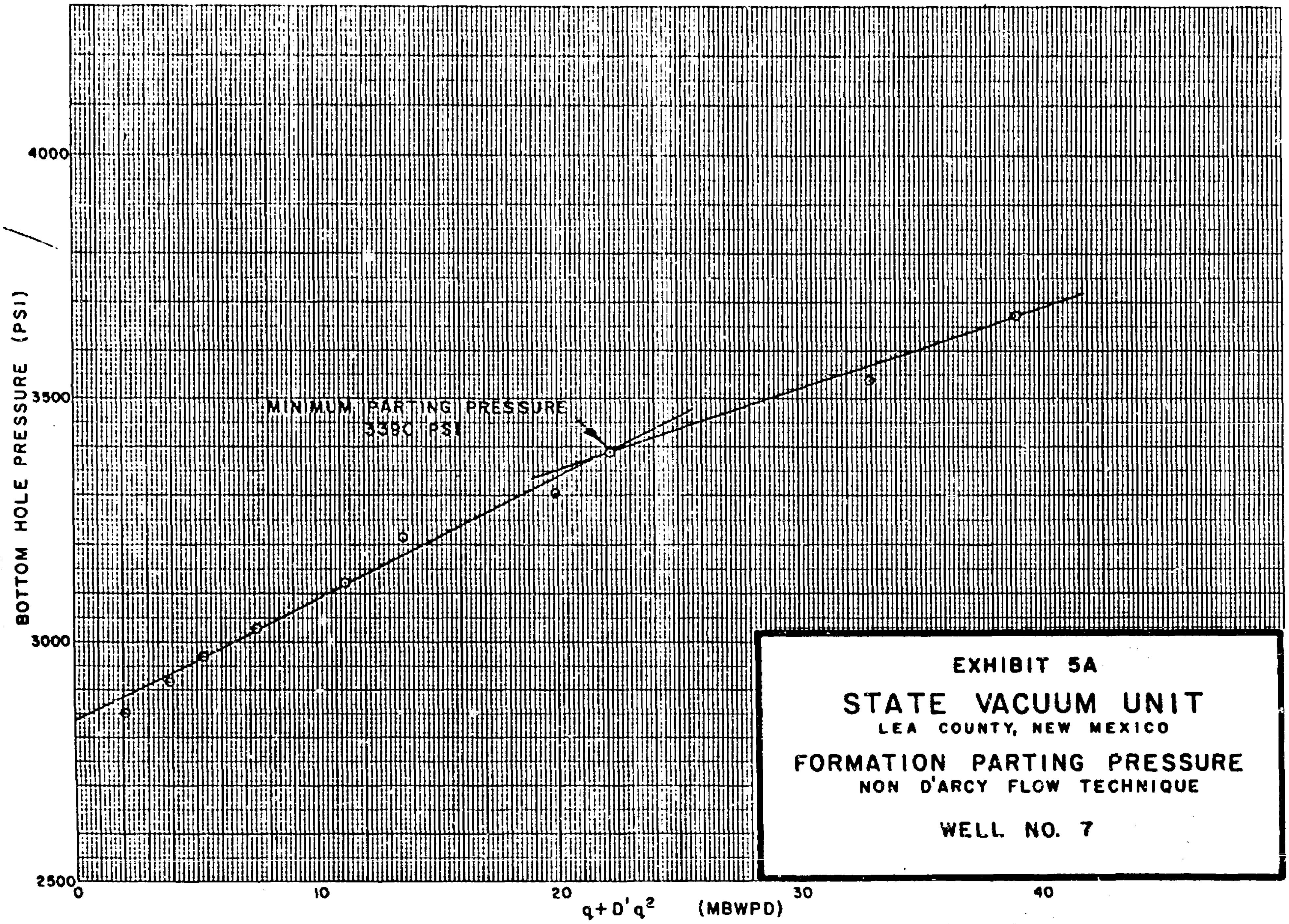


EXHIBIT 5A

STATE VACUUM UNIT

LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE

NON D'ARCY FLOW TECHNIQUE

WELL NO. 7

Exhibit 6

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-21-82

WELL NUMBER: 9

ELEMENT: 6941

COUNTY: Lea

TEST DEPTH: 4622

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:43	0	3090	1001
12:54	860	3270	1240
1:10	1100	3327	1500
1:25	1300	3411	1650
1:43	1500	3472	1750
1:58	1700	3529	1840
2:13	2000	3605	1970

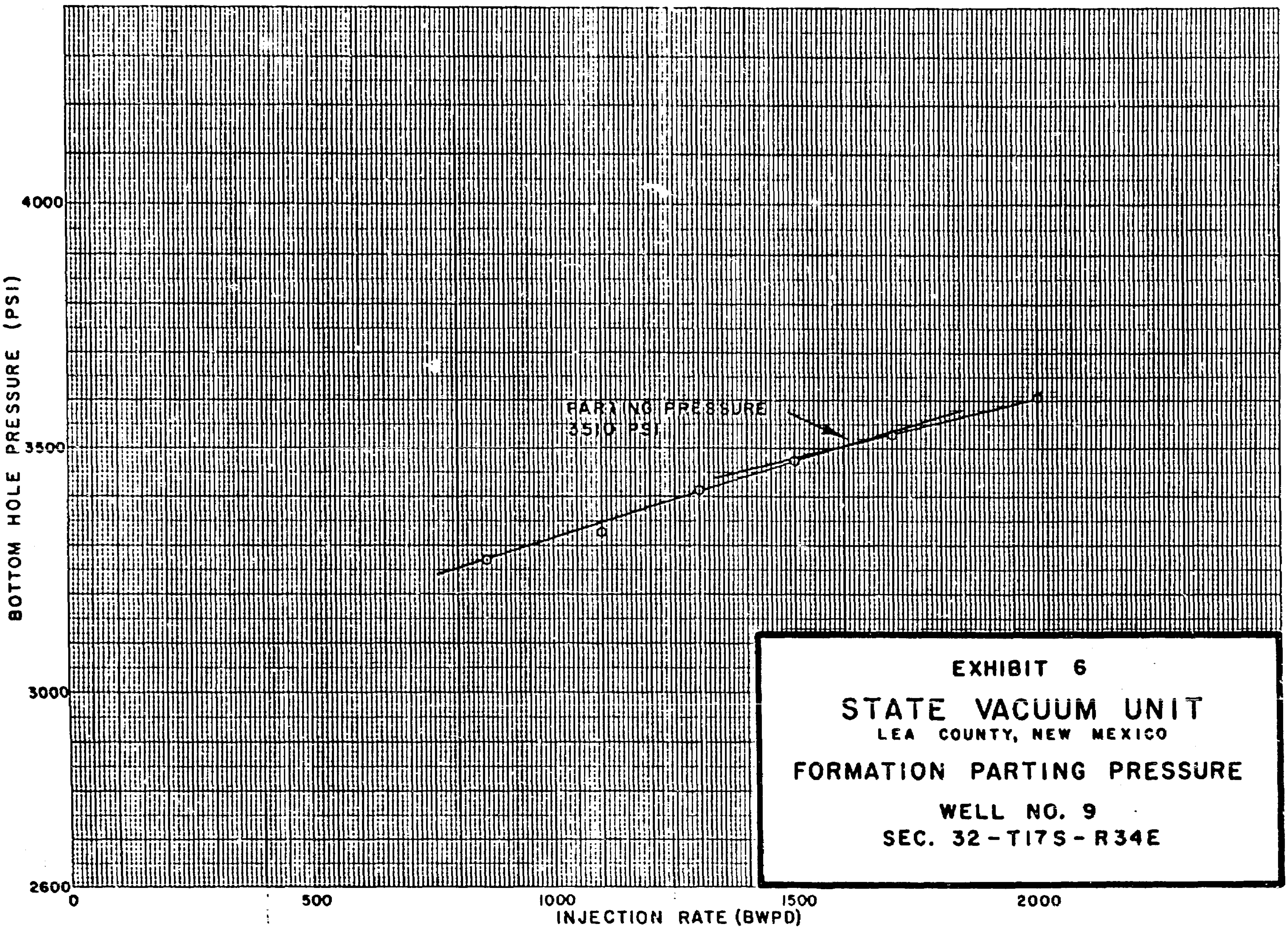


EXHIBIT 6

STATE VACUUM UNIT

LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE

WELL NO. 9

SEC. 32-T17S-R34E

Exhibit 7

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-15-82

WELL NUMBER: 13

ELEMENT: 36391

COUNTY: Lea

TEST DEPTH: 4685

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
9:56	0	2630	560
11:51	860	2932	950
12:08	1000	3062	1160
12:24	1200	3249	1250
12:43	1400	3480	1400
12:57	1700	3656	1750
1:13	2000	4079	2100
1:30	2400	4243	2360

46 1513

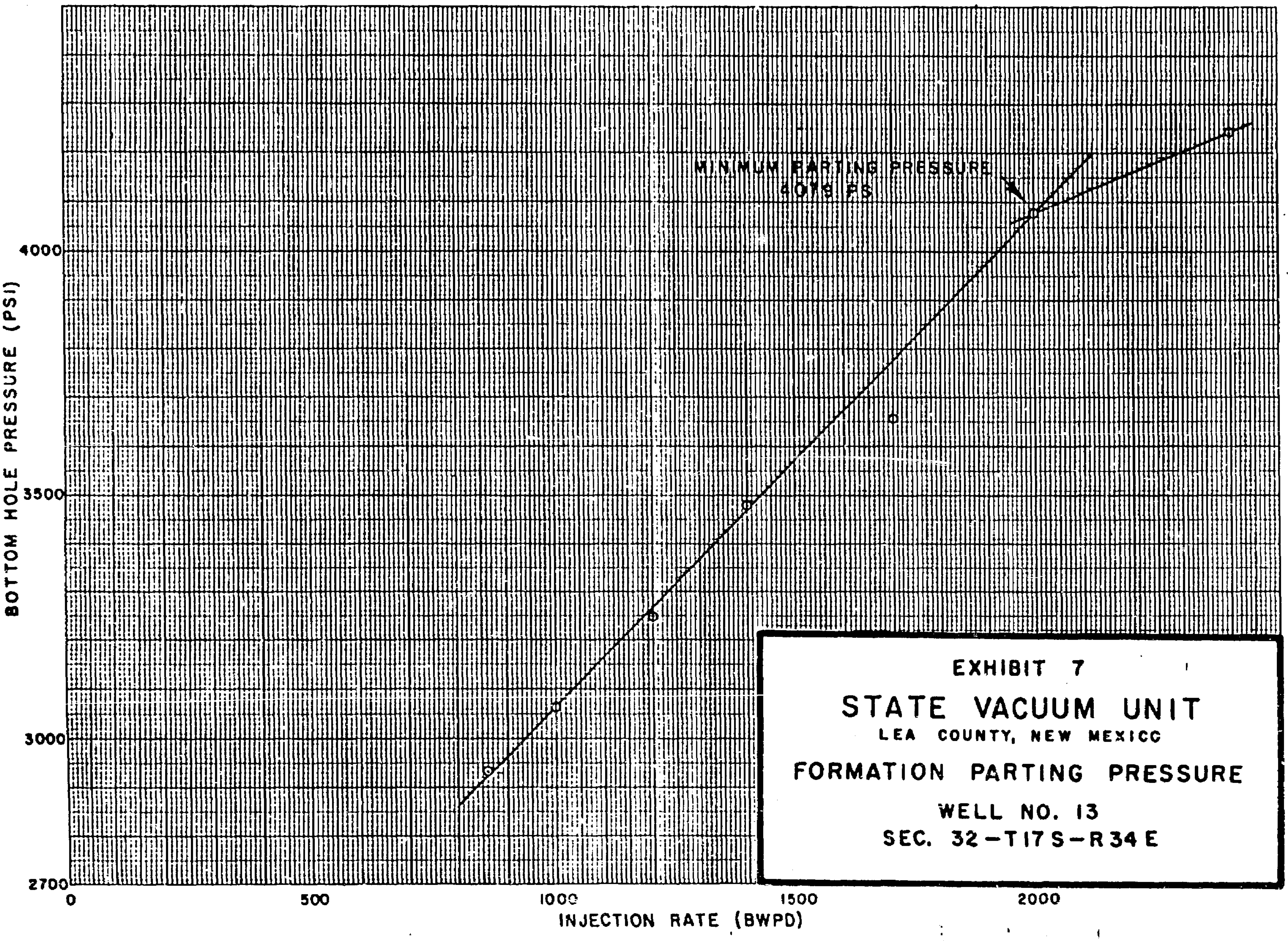

MINIMUM PARTING PRESSURE
BOTTOM HOLE PRESSURE (PSI)
4000
3500
3000
2700
0
500
1000
1500
2000
INJECTION RATE (BWPD)
EXHIBIT 7
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 13
SEC. 32-T17S-R34E

Exhibit 8

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 4-19-82

WELL NUMBER: 17

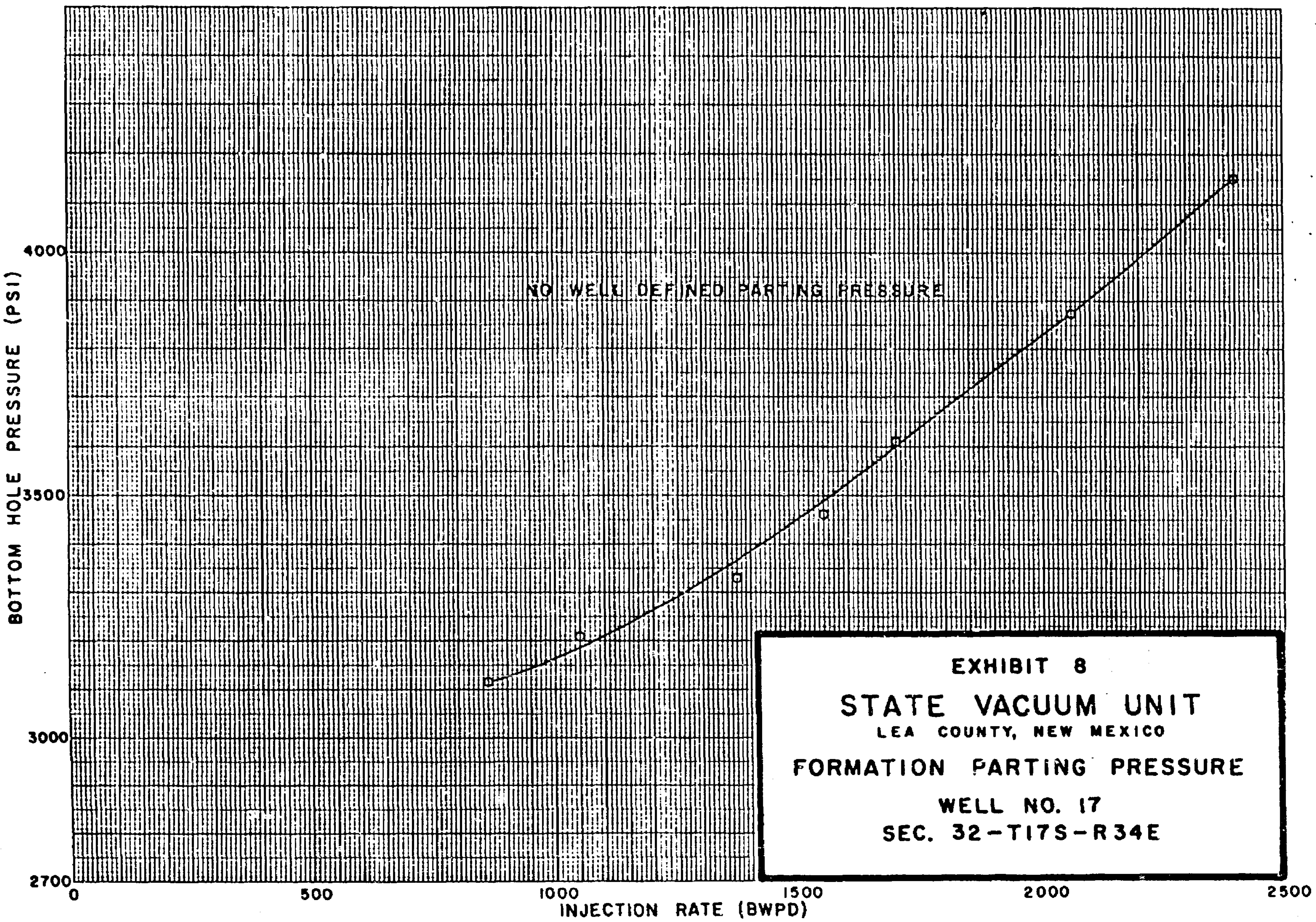
ELEMENT: 6941

COUNTY: Lea

TEST DEPTH: 4717

TIME/ AM PM	APPROXIMATE RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:23	0	2851	754
11:32	860	3117	1100
11:47	1050	3208	1300
12:03	1370	3330	1500
12:19	1550	3462	1650
12:34	1700	3610	2025
12:47	2060	3874	2200
12:59	2400	4152	2400

K•E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1513



STATE VACUUM UNIT
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE

Well No. 17

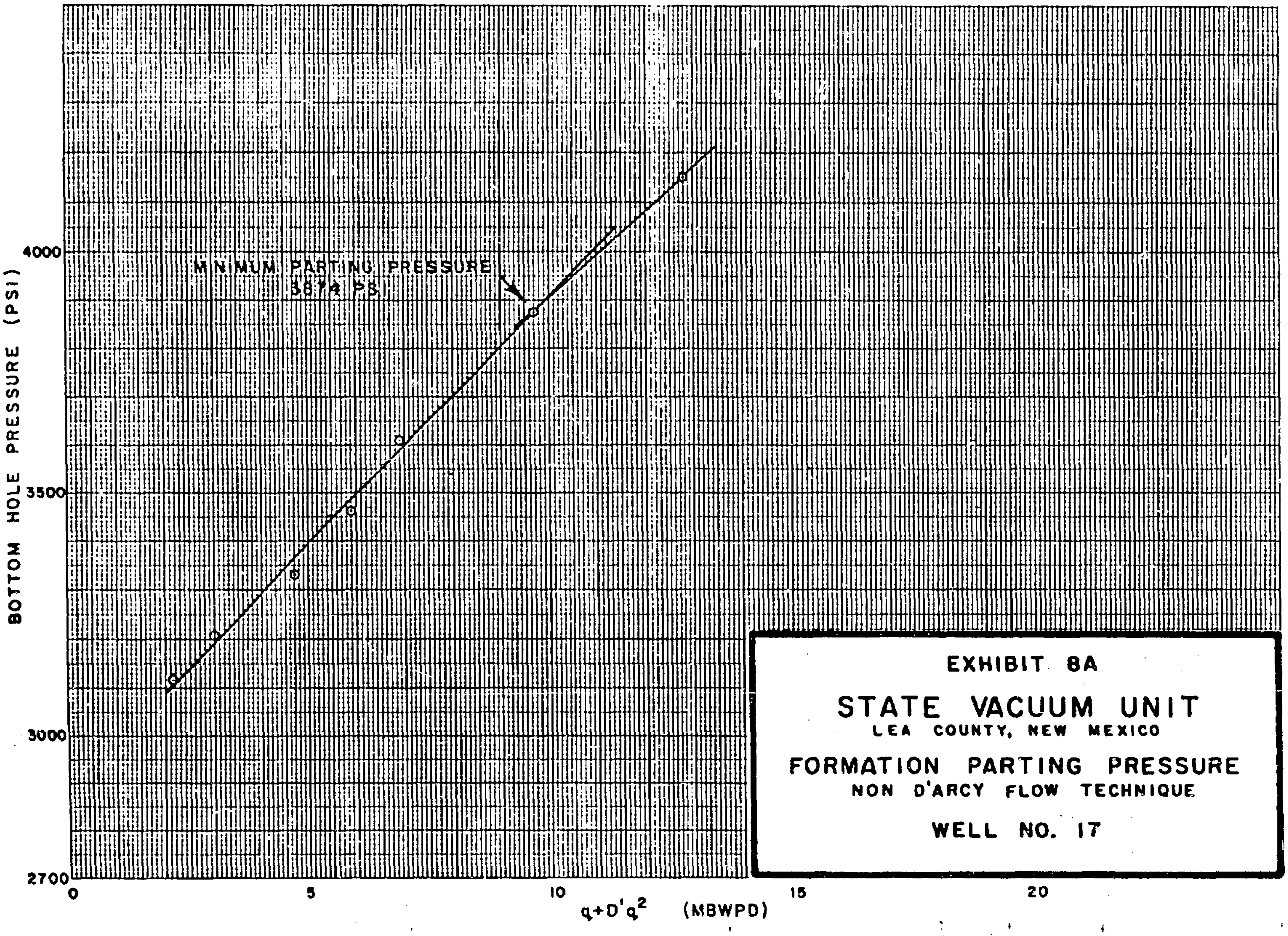
From Exhibit :

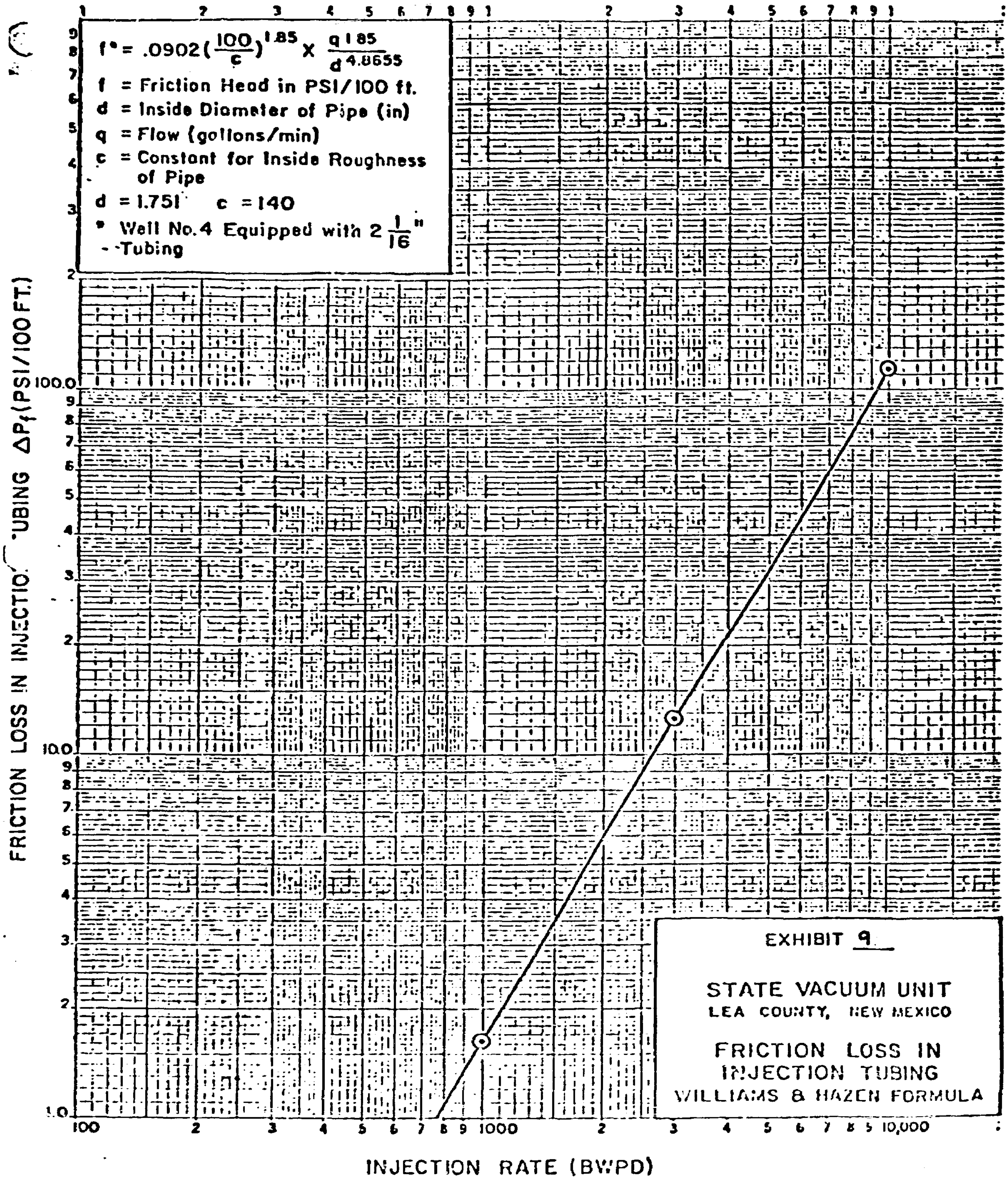
$$D' = (q_2 \Delta P_1 - q_1 \Delta P_2) / (q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: q_1 = 860 BPD P_1 = 3117 ΔP_1 = 237

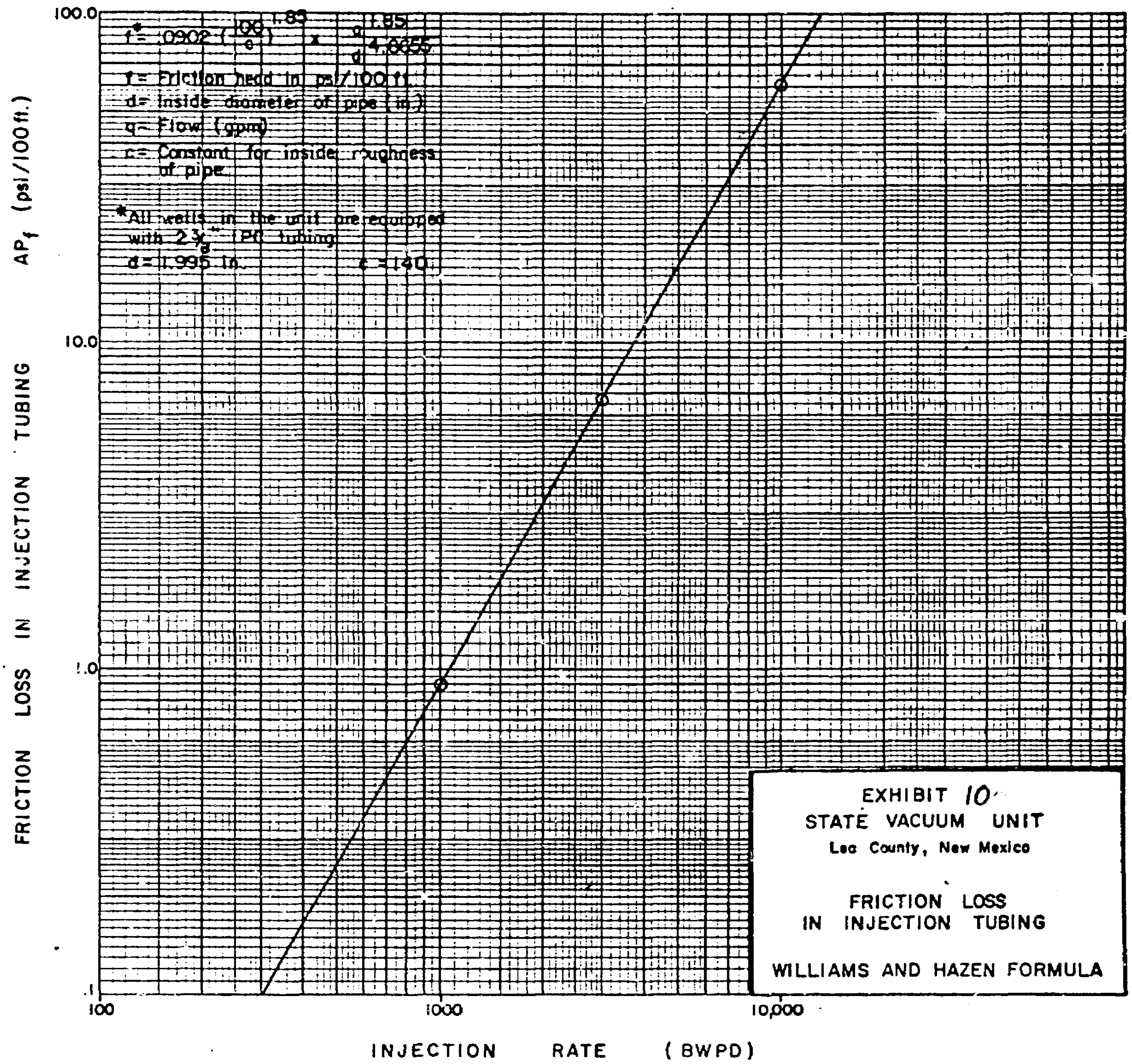
q_2 = 1050 BPD P_2 = 3208 ΔP_2 = 328

Injection Rate BPD	D' = .0018 $(b/d)^{-1}$ BHP @ TEST DEPTH (psi)	$q + D'q^2$ (BPD)
0	2851	
860	3117	2191
1050	3208	3035
1370	3330	4748
1550	3462	5875
1700	3610	6902
2060	3874	9699
2400	4152	12768


BOTTOM HOLE PRESSURE (PSI)
4000
3500
3000
2700
0
5
10
15
20
$q+D'q^2$ (MBWPD)
MINIMUM PARTING PRESSURE
3874 PS
EXHIBIT 8A
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE
WELL NO. 17



$f^* = .0902\left(\frac{100}{c}\right)^{1.85} \times \frac{q^{1.85}}{d^{4.8655}}$
f = Friction Head in PSI/100 ft.
d = Inside Diameter of Pipe (in)
q = Flow (gallons/min)
c = Constant for Inside Roughness of Pipe
d = 1.751" c = 140
* Well No. 4 Equipped with $2\frac{1}{16}$" Tubing
FRICTION LOSS IN INJECTION TUBING ΔPf (PSI/100 FT.)
INJECTION RATE (BWPD)
100.0
10.0
1.0
100
1000
10,000
EXHIBIT 9
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FRICTION LOSS IN INJECTION TUBING
WILLIAMS & HAZEN FORMULA



$f^* = .0902 \left(\frac{100}{c}\right)^{1.85} \times \frac{q^{1.85}}{d^{4.8655}}$
f= Friction head in psi/100 ft.
d= Inside diameter of pipe (in.)
q= Flow (gpm)
c= Constant for inside roughness of pipe
*All wells in the unit are equipped with 2 3/8" IPC tubing
d = 1.995 in. c = 140
100.0
10.0
1.0
.1
100
1000
10,000
FRICTION LOSS IN INJECTION TUBING AP_f (psi/100 ft.)
INJECTION RATE (BWPD)
EXHIBIT 10
STATE VACUUM UNIT
Lea County, New Mexico
FRICTION LOSS
IN INJECTION TUBING
WILLIAMS AND HAZEN FORMULA

BIBLIOGRAPHY

Felsenthal, Martin: "Step-Rate Tests Determine Safe Injection Pressures in Floods," Oil & Gas Journal (October 28, 1974) pg. 49-54

OIL CONSERVATION DIVISION
P. O. BOX 2088
SANTA FE, NEW MEXICO 87501

May 19, 1980

ARCO Oil and Gas Company
Box 1610
Midland, Texas 79702

Attention: Mr. J. L. Tweed

Re: Case No. 5762
Order No. R-5295

COPY

Gentlemen:

This is in reference to your letter of April 14, 1980, wherein you request administrative approval to increase the injection pressure in your State Vacuum Unit in Lea County, New Mexico.

By the authority granted me in Order No. R-5295, you are hereby authorized to increase the injection pressure to 1422 psi.

Yours very truly,

JOE D. RAMEY
Director

JDR/fd

ARCO Oil and Gas Company
Permian District
Post Office Box 1610
Midland, Texas 79702
Telephone 915 684 0100

April 14, 1980

Oil Conservation Division of the
New Mexico Department of Energy
and Minerals
P. O. Box 2088
Santa Fe, New Mexico 87501

Attn: Mr. Joe Ramey

RE: Case No. 5762: Order No. R-5295
ARCO OIL AND GAS COMPANY
State Vacuum Unit
Waterflood Project
T17S, R34E, Lea County, New Mexico

Dear Mr. Ramey:

In the Order dated October 12, 1976 establishing the waterflood project, wellhead injection pressure was limited to 860 psi. It was stated that higher wellhead pressure could be approved if it could be shown that the increase in pressure would not fracture the confining strata. In May, 1978, evidence was offered to show that a wellhead injection pressure of 1134 psi would not fracture the formation. This proposal was approved administratively and the current limitation is 1134 psi. As operator of the unit, ARCO Oil and Gas Company applies for administrative approval of a wellhead injection pressure of 1422 psi. This pressure was determined from a key well parting pressure test survey of the injection wells. The attached exhibits are offered as evidence that this pressure will not fracture the confining strata.

The exhibits are based on parting pressure tests run on March 4-18, 1980. Exhibit 1 is a map of the unit area showing the five injection wells which were tested. We feel that these 5 wells are a good representation of the injection wells in the field. Four of the five wells were tested last time and provide references for comparison purposes. The tests on these 5 wells indicated a range of surface parting pressures from 1572 psi to 2241 psi as shown on Exhibit 2. The necessary equipment and well data is included on Exhibit 3.

The paper "Step-Rate Tests Determine Safe Injection Pressures in Floods" (Exhibit 9) was used as a reference to help determine proper testing procedures and analysis methods. The tests were run by ARCO Oil and Gas Company using a downhole pressure recorder, a surface pressure recorder, and a Halliburton turbine flowmeter. Individual well data and results are shown in Exhibits 4 through 8.

Some of the wells exhibit non-D'Arcy flow characteristics which prevents determination of the parting pressure by normal rate vs. pressure graphical technique. Two of the wells tested exhibited this behavior. By using the technique outlined in the reference paper ($q + D'q^2$) parting pressures were determined for the two wells and are included as Exhibits 5A and 6A. Exhibits 10 and 11 are graphical solutions of the Williams and Hazen formula for determining the pressure drop due to friction in the injection tubing. Data for the individual wells is listed on Exhibit 2.

Many of the wells tested do not contain enough data points for a well-defined line after the formation parts. This is due to the limitation of the surface equipment during the tests. The wellheads have a 2000 psi working pressure limitation and this limited the injection rate during the test. Well No. 15 showed no break during the test (Exhibit 7). This well required extremely high injection rates during the tests and the pump capacity of the pump truck was reached before the formation parted. The slope of this line is very similar to the slope of the line before the break the last time the tests were run on this well. The slope last time was.6 psi/BWPD and it was .53 psi/BWPD this time (Exhibit 12). This supports the fact that the parting pressure had not been reached yet. Since there is no well-defined line after the break, the last point of the line before the break was chosen as the parting pressure. We feel that this is legitimate since the parting pressure is at least this high. The actual parting pressures are probably higher than these numbers.

We feel that an increased wellhead injection pressure is necessary if we are to maintain adequate injection rates to promote the timely production of the secondary reserves in the unit. Our application for administrative approval of a wellhead injection pressure of 1422 psi should insure that we are not fracturing the formation strata but also allow us to increase our current injection rates. We will gladly forward any additional information which may be required and ask for your prompt consideration.

Very truly yours,

J. L. Tweed

J. L. Tweed
District Engineer

JLT:ad

Exhibit 1

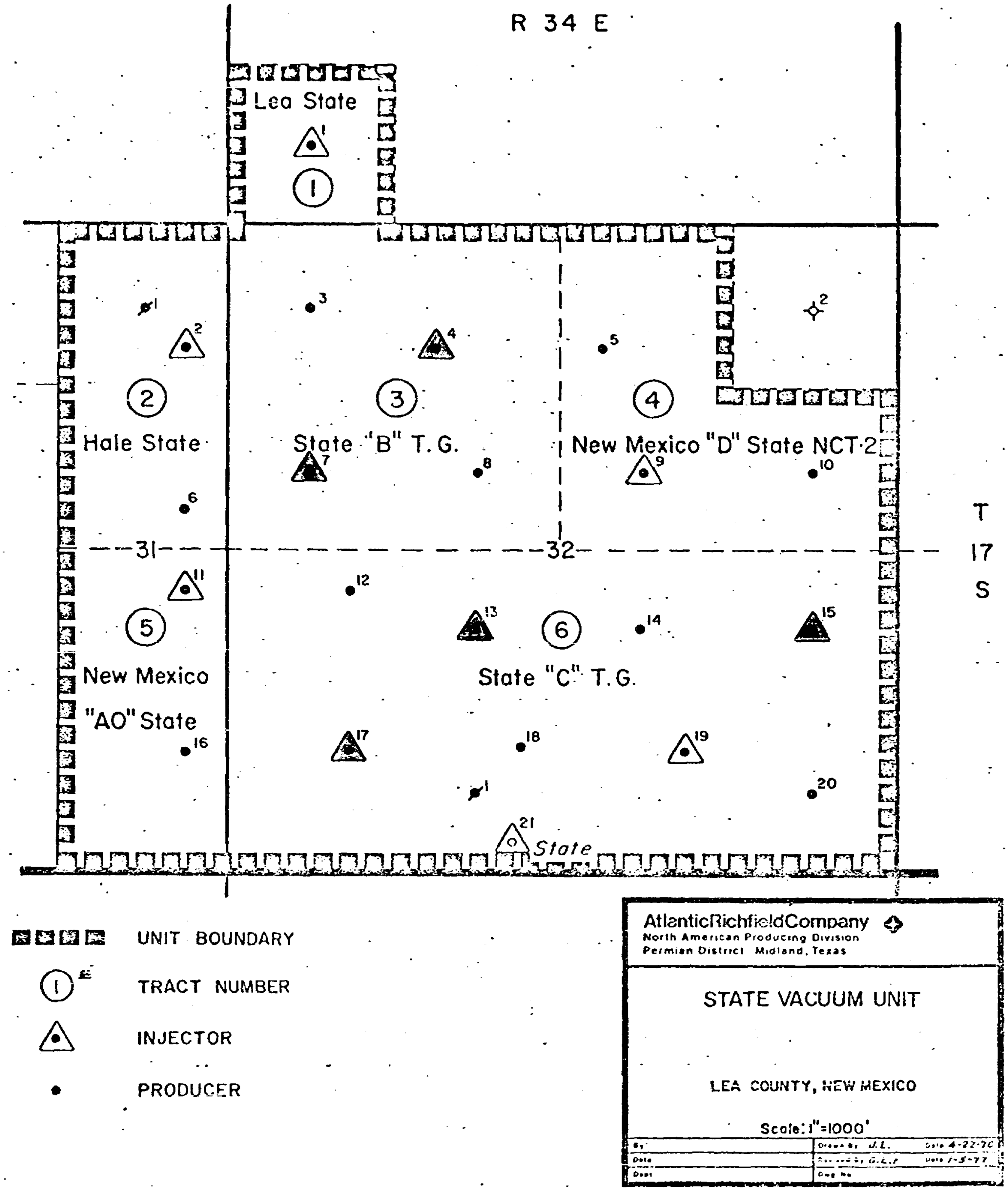

R 34 E
T
17
S
Lea State
1
Hale State
2
State "B" T. G.
3
New Mexico "D" State NCT-2
4
New Mexico
"AO" State
5
State "C" T.G.
6
31
32
State
UNIT BOUNDARY
TRACT NUMBER
INJECTOR
PRODUCER
AtlanticRichfieldCompany
North American Producing Division
Permian District Midland, Texas
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
Scale: 1"=1000'
By
Date
Dept
Drawn By J.L.
Dwg No

EXHIBIT 2

STATE VACUUM UNIT
PRESSURE PARTING TESTS

WELL NO.	CUM.INJ. 3/1/80 (MB)	PRESS.BOMB SETTING DEPTH (FT)	HYDRO-STATIC HEAD[1] (PSI)	INJ.RATE@ PTG.PRES. (BPD)	PRESS.DROP FRICTION[2] ΔP_f (PSI/100 FT)	ΔP_f TOTAL @ SETTING DEPTH(psi)	BTM HOLE PTG.PRES. (psi)	SURF.PTG.[3] PRESSURE (psi)	PTG.GRAD-IENT (psi/ft)
4	8.4	4609	1995.7	1000	1.63	75.1	Mn 3865	1944.4	.838
7	385.9	4574	1980.5	2800	6.0	274.4	Mn 3278	1571.9	.717
13	99.3	4685	2028.5	1900	2.95	138.2	Mn 3975	2084.7	.848
15	643.0	4661	2018.2	3800	10.5	489.4	Mn 3770	2241.2	.809
17	32.6	4741	2052.8	1145	1.15	54.5	3580	1581.7	.755

1. Injection water has specific gravity equal to 1.001; pressure gradient = .433 psi/ft.

2. Taken from Exhibit 10 (Williams and Hazen formula).

3. Surface parting pressure = bottom hole parting pressure - hydrostatic head + ΔP_f

EXHIBIT 3

STATE VACUUM UNIT
PRESSURE PARTING TESTS
INJECTION WELL DATA

WELL NO.	COMPLETION CASING SIZE (DEPTH)	TUBING SIZE* IN.	DEPTH SET	PERFORATIONS
4	3½" liner (3440-4700)	2-3/8" 2-1/16"	1153' 4550'	 4594-4624'
7	3½" liner (4426-4728)	2-3/8"	4426'	4671-4718'
13	3½" liner (4241-4717)	2-3/8"	4241'	4660-4710'
15	3½" liner (4249-4708)	2-3/8"	4249'	4636-4686'
17	3½" liner (4416-4750)	2-3/8"	4416'	4692-4742'

* All tubing is internally plastic coated.

EXHIBIT 4

STEP RATE TEST REPORT

LEASE: State Vacuum Unit

DATE OF TEST 3-18-80

WELL NUMBER: 4

ELEMENT: 41838

COUNTY: Lea

TEST DEPTH: 4609

AM TIME/PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:04	0	1982	Vacuum
10:18	250	2299	260
10:34	400	2652	635
10:49	600	3020	1010
11:04	800	3424	1425
11:19	1000	3864	1925
11:36	1200	4192	2250

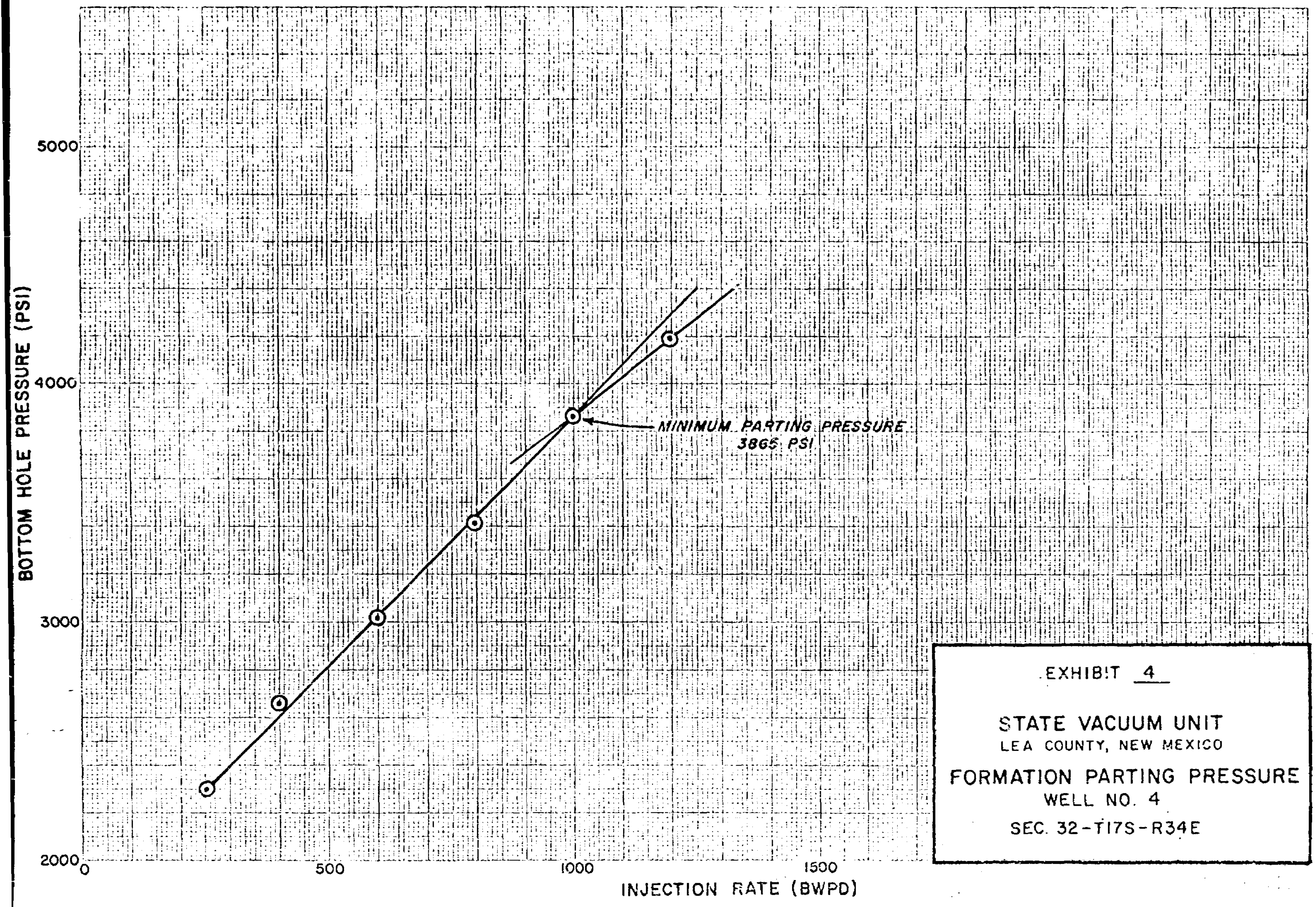


EXHIBIT 4

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 4
SEC. 32-T17S-R34E

EXHIBIT 5

STEP RATE TEST REPORT

LEASE: State Vacuum

DATE OF TEST 3-17-80

WELL NUMBER: 7

ELEMENT: 5505

COUNTY: Lea

TEST DEPTH: 4574

AM TIME/PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:42	0	1839	Vacuum
12:16	400	1978	Vacuum
12:33	700	2079	130
12:48	1000	2191	280
1:03	1200	2299	390
1:20	1400	2392	500
1:34	1600	2507	620
1:49	1800	2600	730
2:05	2000	2692	850
2:20	2175	2836	1015
2:36	2450	2790	1240
2:51	2600	3107	1390
3:05	2800	3277	1650
3:20	3000	3397	1830

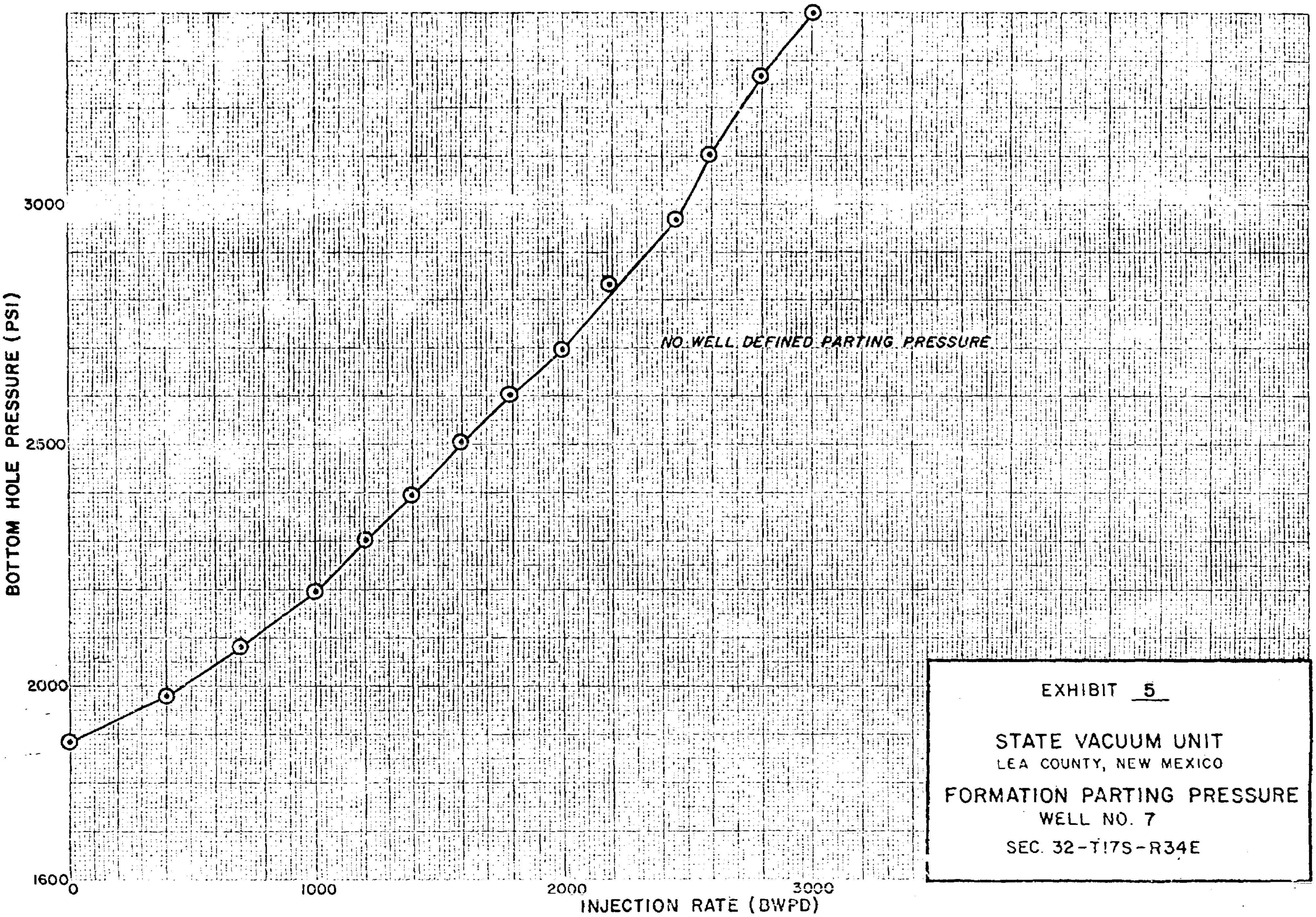


EXHIBIT 5

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE
WELL NO. 7

SEC. 32-T17S-R34E

STATE VACUUM UNIT
FORMANTION PARTING PRESSURE
NON D'ARFY FLOW TECHNIQUE
WELL NO. 7

From Exhibit 9:

$$D' = (q_2 \Delta P_1 - q_1 \Delta P_2) / (q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: $q_1 = 400$ BPD $P_1 = 1978$ $\Delta P_1 = 88$

$q_2 = 700$ BPD $P_2 = 2079$ $\Delta P_2 = 189$

Injection Rate BPD	$D'=.00109\ B/D^{-1}$ BHP @ TEST DEPTH (psi)	$q + D'q^2$ (BPD)
0	1839	
400	1978	573
700	2079	1233
1000	2191	2087
1200	2299	2765
1400	2392	3530
1600	2507	4383
1800	2600	5322
2000	2692	6348
2175	2836	7331
2450	2790	8974
2600	3107	9948
2800	3277	11321
3000	3397	12783

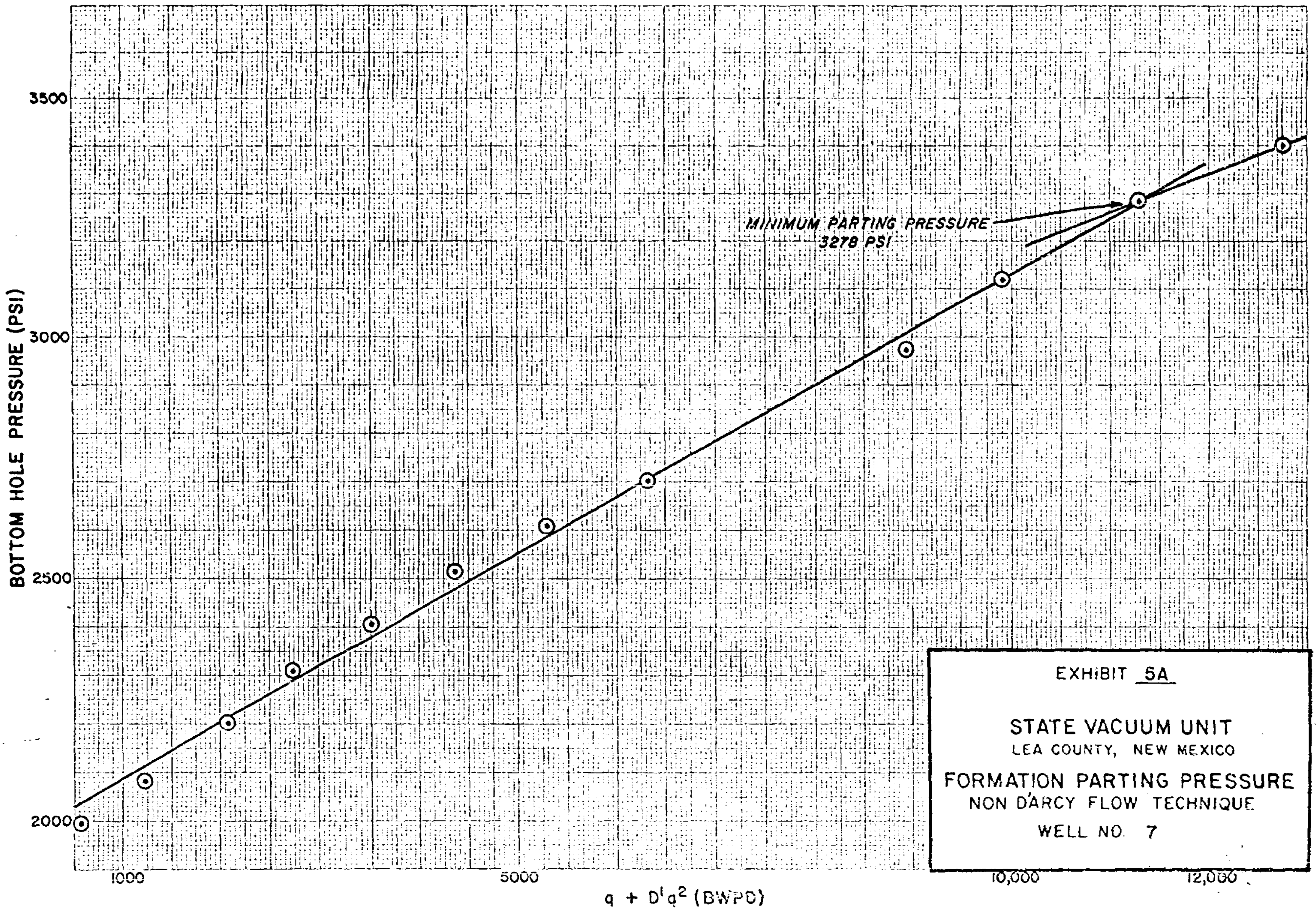


EXHIBIT 5A

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE
WELL NO. 7

EXHIBIT 6 ✓

STEP RATE TEST REPORT

LEASE: State Vacuum

DATE OF TEST 3-11-80

WELL NUMBER: 13

ELEMENT: 7287

COUNTY: Lea

TEST DEPTH: 4685

AM TIME/PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:56	0	1844	Vacuum
11:22	400	2555	280
11:42	600	2788	640
12:03PM	800	2995	960
12:23	1000	3305	1300
12:44	1200	3618	1650
1:05	1400	3971	2160
1:21	1700	4198	2280

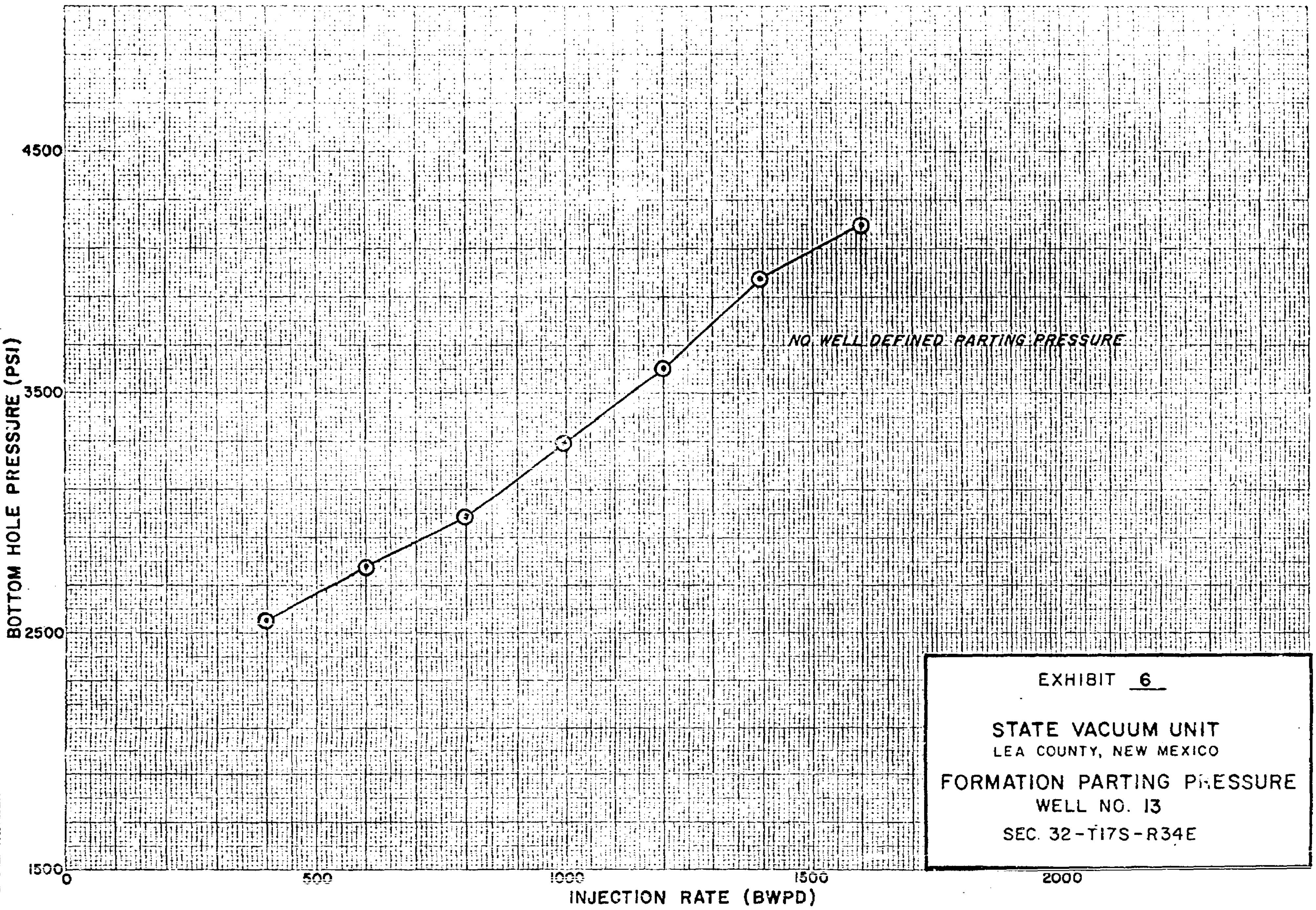


EXHIBIT 6

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE
WELL NO. 13
SEC. 32-T17S-R34E

EXHIBIT 6A

STATE VACUUM UNIT
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE
WELL NO. 13

From Exhibit 9 :

$$D' = (q_2 \Delta P_1 - q_1 \Delta P_2) / (q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: $q_1 = 600$ $P_1 = 2788$ $\Delta P_1 = 528$

$q_2 = 800$ $P_2 = 2995$ $\Delta P_2 = 735$

$D' = .00254$

Injection Rate (BPD)	BHP @ TEST DEPTH (PSI)	$q+D'q^2$ (BPD)
0	1844	
400	2555	441
600	2788	691
800	2995	962
1000	3305	1254
1200	3618	1566
1400	3971	1898
1700	4198	2434

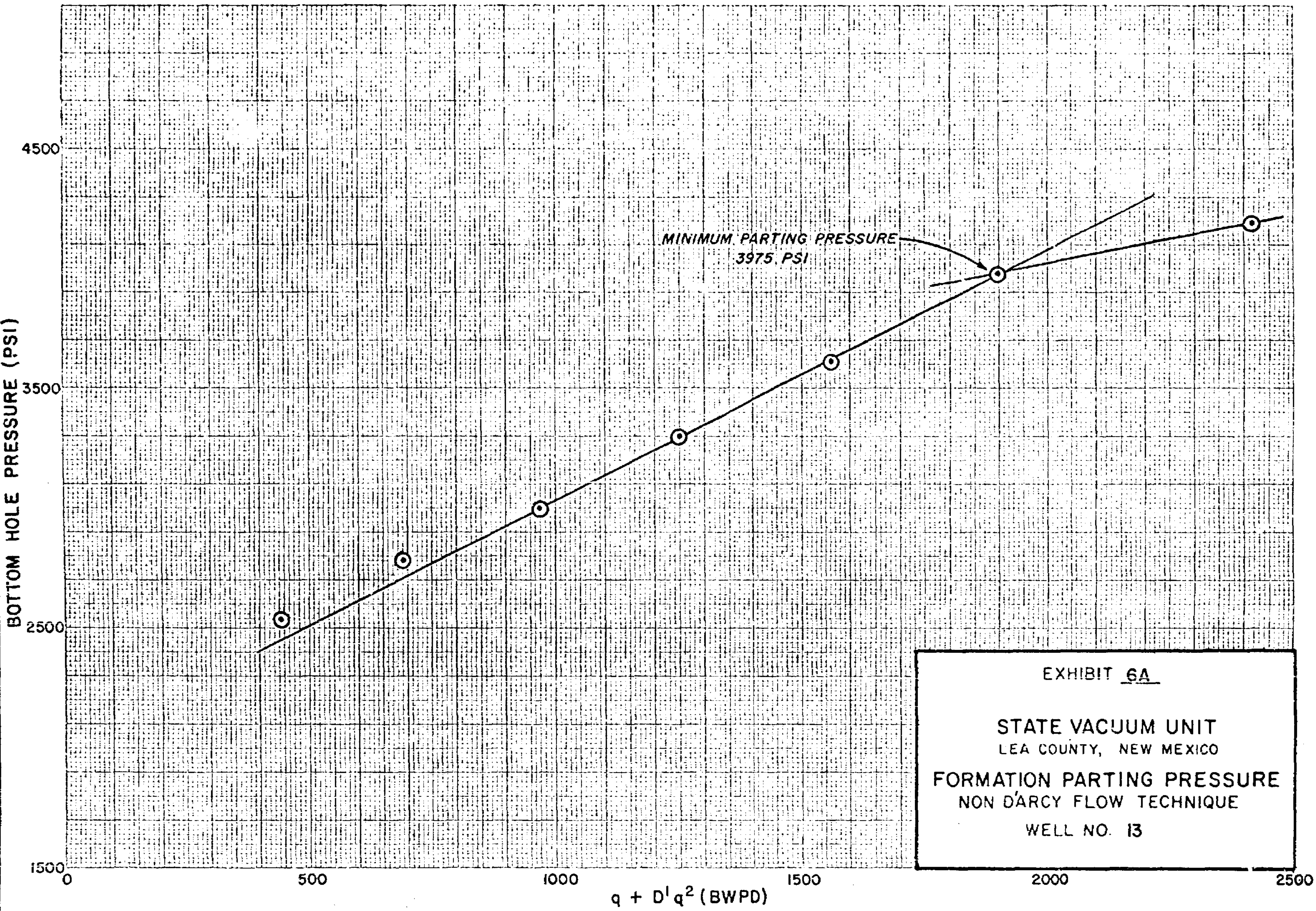


EXHIBIT 6A

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
NON D'ARCY FLOW TECHNIQUE
WELL NO. 13

EXHIBIT 7

STEP RATE TEST REPORT

LEASE: State Vacuum

DATE OF TEST 3-10-80

WELL NUMBER: 15

ELEMENT: 5505

COUNTY: Lea

TEST DEPTH: 4661

AM TIME/PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:55	0	1727	Vacuum
1:25 PM	600	2155	150
1:41	1000	2312	340
2:02	1475	2508	560
2:23	1800	2687	775
2:42	2250	2919	1080
3:02	2600	3129	1340
3:22	3000	3359	1650
3:42	3350	3540	1900
4:01	3600	3645	2010
4:15	3800	3776	2225

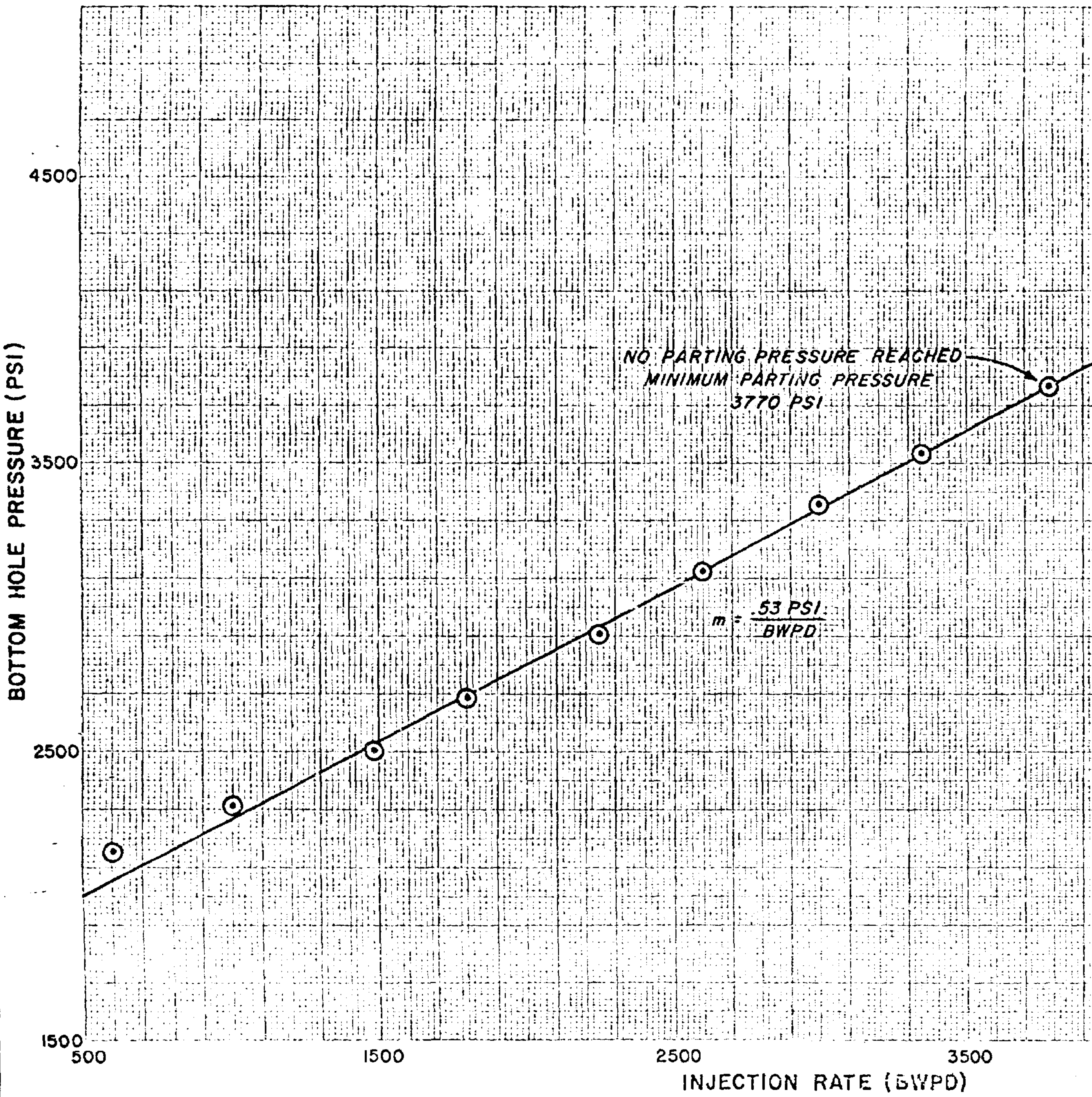


EXHIBIT 7

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO

FORMATION PARTING PRESSURE
WELL NO. 15
SEC. 32-T17S-R34E

EXHIBIT 8

STEP RATE TEST REPORT

LEASE: State Vacuum

DATE OF TEST 3-4-80

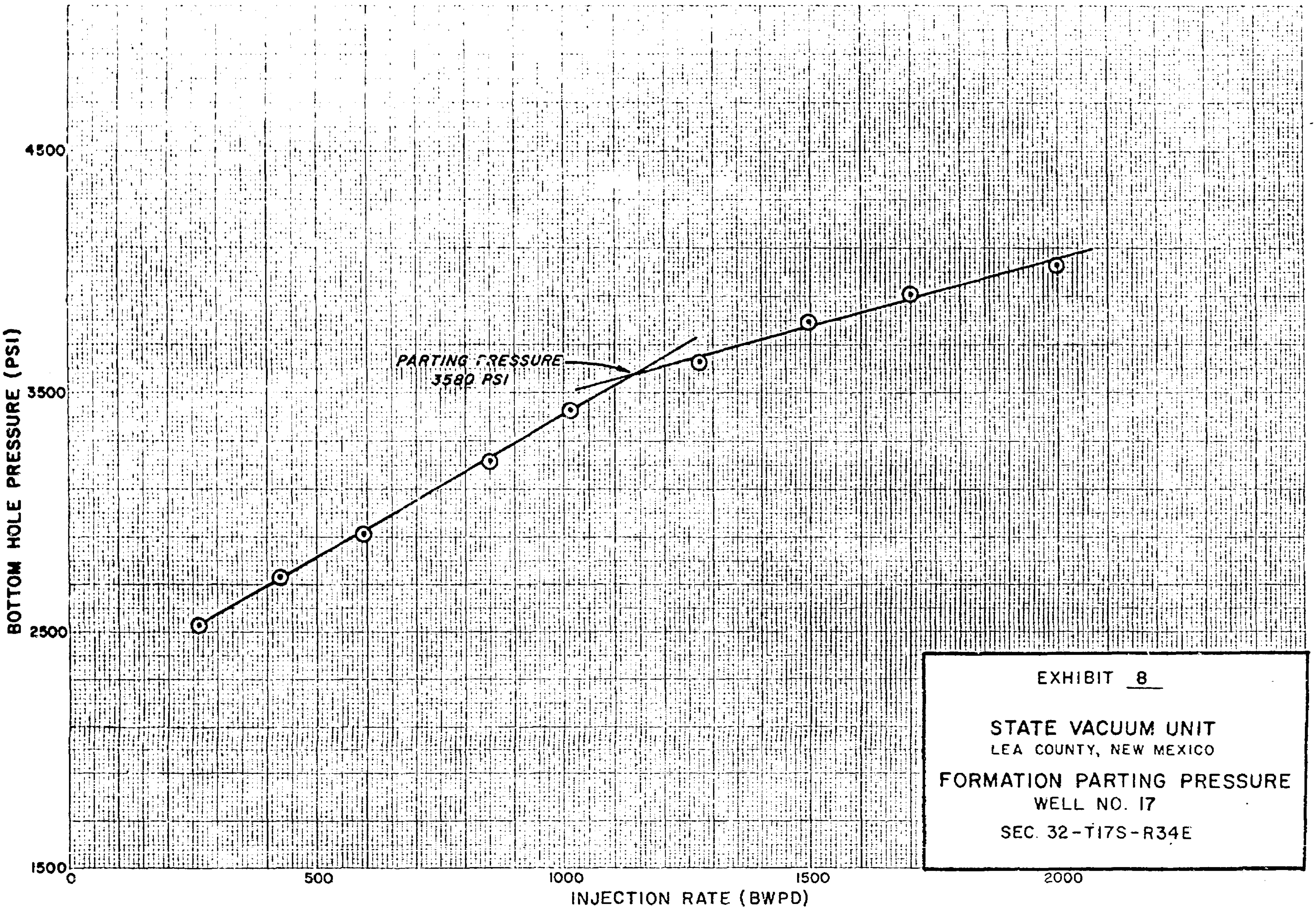
WELL NUMBER: 17

ELEMENT: 5505

COUNTY: Lea

TEST DEPTH: 4741

AM TIME/PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
10:51	0	2335	220
11:08	260	2539	360
11:24	425	2713	537
11:39	590	2918	750
11:56	850	3221	1090
12:11 PM	1015	3427	1300
12:26	1275	3635	1540
12:42	1500	3796	1750
12:57	1700	3913	1900
1:12	2000	4039	2075



BOTTOM HOLE PRESSURE (PSI)
4500
3500
2500
1500
0
500
1000
1500
2000
INJECTION RATE (BWPD)
PARTING PRESSURE
3580 PSI
EXHIBIT 8
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION PARTING PRESSURE
WELL NO. 17
SEC. 32-T17S-R34E

Step-rate tests determine safe injection pressures in floods

The author . . .

Martin Felsenthal is a senior research engineer with Continental Oil Co. in Ponca City, Oklahoma. He works in the areas of formation evaluation, waterflooding and tertiary recovery. A petroleum engineering graduate from University of California, he also holds an MS from Penn state.

Felsenthal

STEP-RATE injectivity tests can define the maximum safe injection pressures that can be used without fracturing the reservoir rock.

This information is important in waterfloods. It is of critical importance in tertiary-recovery projects where we cannot afford to lose costly injection fluids through uncontrolled induced fractures.

Recently, we tried the step-rate test in a number of projects. Although the test concept is simple, results were conclusive only if proper procedures and equipment were used. From this experience, a recommended procedure has been developed.

This article presents the recommended procedure and shows typical data.

A remarkable point brought out by these data is that formations sometimes fracture near hydrostatic head in pressure-depleted reservoirs.

The procedure. The early literature references [1,2] generally talked about pressure parting rather than fracturing during step-rate injectivity tests. It was pointed out, however, at the outset that the two expressions are synonymous.

The test well should be shut in long enough so that the bottom-hole pressure is near the shut-in formation pressure. The step-rate injectivity test that follows consists of a series of constant-rate injections with rates increasing from low to high in stepwise fashion.

In tight formation ($K_{air} \sim 5$md) each step should last 60 min. Shorter time spans can be used in higher-permeability formations as shown in Table 1 of the appendix. The time-step duration itself is not critical. It only should be reasonably close to the recommended values shown. Also, each step should last exactly as long as the preceding step.

In selecting rates for the test, one possible rule of thumb is to use 5, 10, 20, 40, 60, 80, and 100% of the desired maximum test rate. The above schedule may be varied to suit the conditions of the test. For instance, it may be difficult to control accurately a very low rate in which case, the test may be started at a somewhat higher rate than shown above.

Equipment. Injection rates during the test should be controlled with a constant flow-rate regulator. We have used regulators made by three different companies and obtained useful data. All regulators should be tested before use.

Use of a throttling valve as a flow-rate regulating device is not recommended. Reason is that this valve acts like an orifice. Pressures and rates will thus interact continuously during the transient flow conditions of each rate step. Consequently, as well pressures rise, injection rates will tend to decline.

Flow rates should be measured with a turbine flowmeter and a rate meter such as those made by Halliburton. It is advisable to calibrate this equipment by timing flow into a 5-gal container (b/d = 10,286 ÷ seconds to fill a 5-gal container).

In critically important tests, it is advisable to record rates throughout the test. For this purpose, we have fed a signal from a rate meter through a dampening circuit to a strip-chart recorder. Use of a rate recorder is desirable but not mandatory.

Our experience has shown that best results were obtained when pressures were measured with a down-hole instrument. For instance, we used

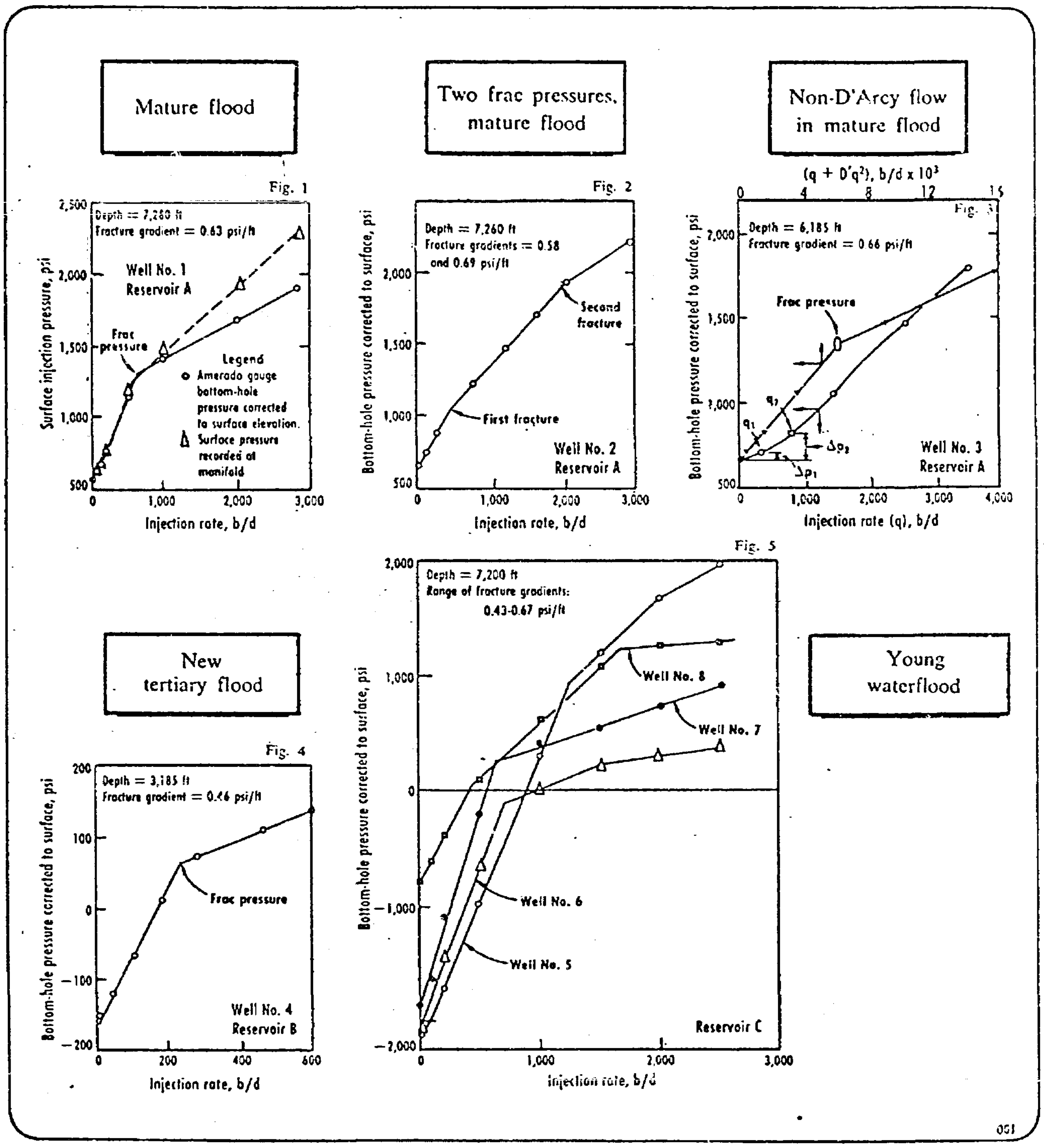
Amerada-type pressure-recording devices in all tests shown in Figs. 1-5. Other down-hole devices may be equally suitable. In addition, it is advisable to observe surface pressures with a surface gage or recorder. We found that it is often difficult to obtain very accurate surface-pressure readings because of surges from the injection pump. Nevertheless, surface pressures are useful in many tests for on-the-spot analysis, while the test is in progress. Final test analysis, however, should be based on down-hole pressure data.

Data analysis. The pressures at the start of the test (at q = 0) and at the end of each injection-rate step are plotted against injection rates as in Fig. 1. Shown are down-hole pressures corrected to the surface elevation of the well and pressures recorded at the surface. The difference in the two pressures is mainly due to friction losses in the pipes.

When the data show that it takes a smaller pressure increment for a unit-rate change, we generally infer that fracturing has taken place. Thus, the data of Fig. 1 indicate that Well

Figs. 1-5

Step-rate tests on old and new floods



No. 1 fractured at about 1,300 psi surface pressure.

Sometimes two breaks are indicated in the pressure-vs-rate plots. Each break could represent a separate fracture. For instance, data for Well No. 2 (Fig. 2) indicate a first fracture at a surface pressure of 1,050 psi and a second and more-severe fracturing condition at 1,900 psi.

Occasionally, pressure-vs-rate plots do not form a straight line but form a curve with a distinctive upward curvature near the origin as shown in Fig. 3. The best explanation for this is non-D'Arcy flow downstream from the pressure-measuring device. This implies that there is probably a sizable pressure drop across the perforations or other orifice-like obstructions. An added resistance is created that is proportional to the square of the injection rate. Thus, we observed we could not interpret the step-rate data for Well No. 3 from a standard pressure-vs-rate (q) plot but could do so from a plot of pressure vs. $q + Dq^2$ (A method for determining D is given in the appendix). Data in Fig. 3 indicate that the fracturing pressure was about 1,300 psi in Well No. 3.

In some pressure-depleted reservoirs, initial pressures are lower than hydrostatic head. Such a situation occured during the tests illustrated in Figs. 4 and 5. Down-hole rates at the end of the early steps were somewhat smaller in these tests than rates measured at the surface because of rising fluid levels in the wells. Appropriate corrections for this condition had to be made before the data could be analyzed.

Complementary techniques. Pressure-falloff tests are generally a good source of information on permeability capacity, probable presence of fractures, skin and nearness to faults or barriers.[4] An excellent opportunity generally exists for conducting this type of test while the test well is being shut in before step-rate testing. If the skin calculated from such a test is definitely negative, we can infer that we probably have a fracture. One way to find out whether the fracture is natural or induced is to reduce the injection pressure for some time, say 1 month, and then run another pressure-falloff test. If the skin is closer to zero in the second test, we can conclude that an induced fracture tended to close.

Permeability capacity and skin (before fracturing) can also be evaluated directly from step-rate test data using a multiple-rate flow-test analysis technique.[3,4] A prerequisite to this technique is great care to keep rates constant in each step and to obtain accurate data. Use of the technique is illustrated in the appendix.

Step-rate tests and pressure-falloff tests give virtually no information about fluid-injection distribution. For diagnosing the formation characteristics near injection wells, in a vertical dimension, injectivity-profile tests are needed. These tests are very useful and popular. Results obtained from them can beneficially supplement results obtained from step-rate and pressure-falloff tests. Especially helpful for this purpose are radioactive tracer injection and/or temperature decay surveys (Absolute temperature profile while injecting, followed by absolute temperature profiles after shutin of injection).

Typical data. Typical pressure-vs-rate plots are shown in Figs. 1-5. The remarkable feature brought out by the last two figures is that the fracturing pressure was near hydrostatic head for most of the wells tested in the pressure-depleted reservoirs B and C. It was even slightly below the hydrostatic head in one well (No. 6, Fig. 5).

To place the data presented so far into perspective, a plot of fracturing gradients vs. shut-in formation pressure/depth ratios was prepared for wells from six formations. The resulting graph (Fig. 6) covers a wide range of prior injection histories, lithology, depths, geographic distribution (five states), geologic ages (Mississippian to Pliocene), and shut-in formation pressure/depth ratios.

Note that fracturing gradients ranged from 0.43 psi/ft to 0.93 psi/ft with the higher gradients generally occurring at the higher shut-in formation pressure/depth ratios. This trend of increasing fracturing gradients with shut-in formation pressure is in agreement with observations reported in several literature references.[5-8] This trend is especially well illustrated in Fig. 6 by the data for reservoir D (solid circles denote data taken in the first month of the flood and open circles denote data taken in the same wells 6 months later). These data indicate that fracturing pressures should be reevaluated periodically.

Vertical arrows in Fig. 6 connect first fracturing indications with second fracturing indications during the same test in the same well. (Details for Well No. 2 are shown in Fig. 2 and for Well Nos. 5, 6, and 8 in Fig. 5.) A preferred interpretation for this is that a first fracture occurred in comparatively hard, brittle rock and a second fracture in softer and more plastic rock.

The dashed lines shown in Fig. 6 show a comparison with a prevalent fracturing theory[6,7] (explained in the appendix). This presentation does not exclude the possibility that a refinement of this theory or some other theory would result in a better fit of the curves and data points.

Numbers on the dashed lines in Fig. 6 are Poisson's ratios. It has been speculated in the literature[8] that data points coinciding with relatively high Poisson's ratios (greater than 0.35) might be indicative of fracture extension through plastic cap-rock shales. This view is unconfirmed, however, at this time, because injectivity profiles, particularly temperature-decay surveys, were not made at the time (or close to the time) when the step-rate tests associated with high Poisson's ratios were made.

Will test damage formation? A study of field records for injection Wells Nos. 1-8 (Figs. 1-5) showed that earlier injection pressures exceeded the maximum pressure used during the step-rate tests. The theory of rock mechanics indicates that fractures once opened will tend to close again when the injection pressure is reduced below the fracturing pressure. What is happening is that the net effect of the overburden becomes stronger than the force that tends to keep an unpropped, induced fracture open. This is the mechanism that apparently occurred before step-rate testing in Wells Nos. 1-8.

No damage can conceivably be caused by step-rate tests in old waterfloods as long as the injection pressure during the tests does not exceed injection pressures used earlier during the waterflood history and as long as high-quality injection water is used. In a new waterflood, a typical well should be selected for a step-rate test. In this well, one should use only low and moderate injection rates until a fracturing pressure is definitely established. Later tests should be designed so that they do not greatly

exceed this pressure for any appreciable length of time (more than a few hours).

Acknowledgments

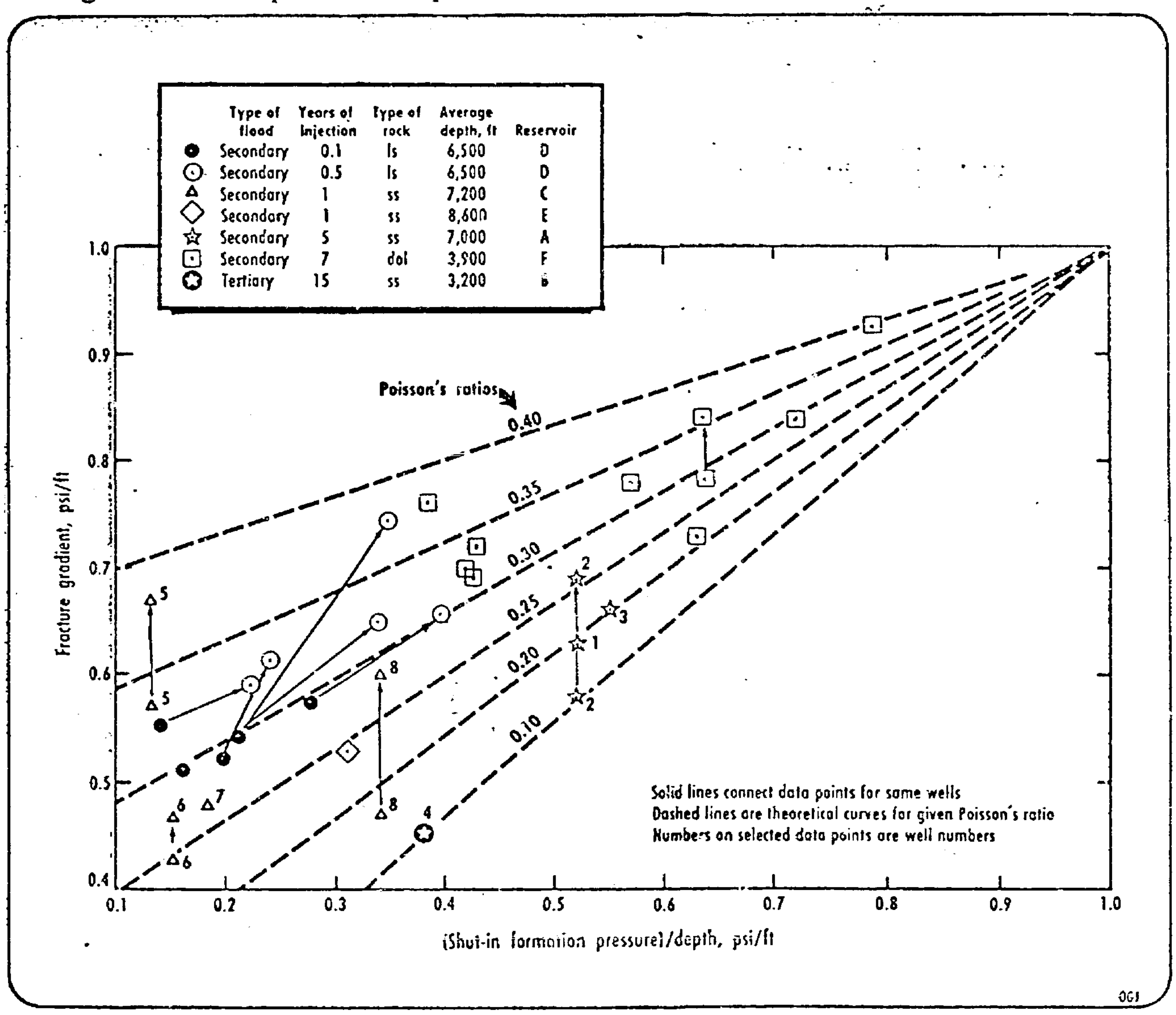
I am indebted to H. C. Walther for guidance and constructive criticisms, to H. A. Wahl for valuable suggestions, and to R. C. Cooper, Wayland Edwards, Dell Conley, and R. A. Strode for assistance in data collection and analysis.

Nomenclature

b' = Odeh intercept
B = Constant, psi/(b/d)^2
B_W = Water formation volume factor, RB/st-tk bbl
c = Total compressibility, psi^{-1}.
C = Constant, (b/d)/psi
D = Non-D'Arcy flow constant, (b/d)$^{-1}$
D' = Another non-D'Arcy flow constant related to D as explained in equation 5, (b/d)$^{-1}$
h = Net effective pay, ft
K_{air} = Absolute permeability to air, md
k_{rw} = Relative permeability to water
k_w = Effective permeability to water, md
m' = Odeh slope
n = Step number in step-rate test
p = Pressure during step-rate test at time t, psi
p_e = Shut-in formation pressure, psi
P_f = Fracturing pressure related to same elevation as p_e, psi
p_i = True initial pressure during step-rate test, defined by intercept of p vs. q plot when q = o, psi
p_W = Bottom-hole pressure in well, psi
Δp = Difference in pressures, psi
Δp_f = Friction loss through perforations or slots, psi
q = Injection rate, b/d
r_e = Outer radius of pressure influence, ft
r_W = Well-bore radius, ft
r_{We} = Effective well-bore radius, ft
s = Skin factor, dimensionless
s' = Apparent skin factor, dimensionless
S = Overburden pressure, psi
t = Time since start of test, hr.
t_n = Time at end of step n of step-rate test, hr
Z = Depth, ft
Φ = Porosity, fraction
μ_W = Water viscosity, cp
ν = Poisson's ratio, dimensionless

Fig. 6

Frac gradients vs. pressure-depth ratio



References

1. Yuster, S. T., and Calhoun, J. C., Jr., "Pressure Parting," Prod. Monthly, V. 9, No. 4: 16-26, February 1945.
2. Grandone, P., and Holleyman, J. B., "Injectivity Tests for Waterflooding Mid-Continent Oil Sands," World Oil, pp. 152-4, 6, 8, December 1949.
3. Odeh, A. S., and Jones, L. G., "Pressure Drawdown Analysis, Variable-Rate Case," Jour. Pet. Tech., pp. 960-964, August 1965.
4. Matthews, C. S., and Russell, D. G., "Pressure Buildup and Flow Tests in Wells," SPE Monograph, V. 1, 1967.
5. Heck, E. T., "Fractures and Joints," Prod. Monthly, p. 20, February 1955.
6. Hubbert, M. K., and Willis, D. G., "Mechanics of Hydraulic Fracturing," AIME Trans., V. 210: 153-166, 1957.
7. Eaton, B. A., "Fracture Gradient Prediction and Its Application in Oilfield Operations," Jour. Pet. Tech., pp. 1353-1360, October 1969.
8. Felsenthal, M., and Ferrell, H. H., "Fracturing Gradients in Waterfloods of Low-Permeability, Partially Depleted Zones," Jour. Pet. Tech., pp. 727-730, June 1971.

Appendix

PRESENTED here are recommended step-rate test times, non-D'Arcy flow-analysis techniques, and a multiple-rate analysis technique applied to step-rate tests. Also, presented is a brief description of a fracturing theory used in diagnosing step-rate test data.

Recommended time for each injection-rate step

Radius of investigation, $r_{inv} = \sqrt{0.00105 k_w t/\phi \mu_w c}$ (1)

This radius should be about 10 ft or larger to investigate formation properties adequately. For assumed typical values of $\phi = 0.2$, $\mu_w = 0.7$ cp, $c = 1.5 \times 10^{-5}$ psi^{-1}, $kr_w = 0.05$ for $K_{air} = 5$ md, and 0.10 for $K_{air} > 5$ md, we obtain.

Table 1

Test design values

Average K_{air}	Recommended minimum time for each step
5 md	60 min
10 md and larger	30 min

Non-D'Arcy flow analysis techniques

In non-D'Arcy radial flow:

$$q = \frac{0.00708 k_w h \Delta p}{\mu_w [\ln(r_e/r_w) + s + Dq]} \quad (2)$$

Where D is the non-D'Arcy flow constant, $(B/D)^{-1}$:

The apparent skin $= s' = s + Dq$ (3)

The s' term can be evaluated through a multiple-rate flow-test analysis technique (described in another part of this appendix) by substituting s' for s in equation 16. Next, s' is plotted vs q for the early steps of the test. D is then determined from this plot with the aid of equation 3. Analyses of s (= s' − Dq) for all steps of the step-rate test follow. The s terms are finally plotted vs injection pressures, and the point at which s becomes greatly more negative is interpreted as the fracturing pressure.

The aforementioned procedure is rather time-consuming. A shortcut approach was, therefore, developed and applied to the data of Well No. 3. This approach gave the same results as the method based on the multiple-rate flow-test analysis technique for this well.

For the derivation of the shortcut formula, Equation 2 was rewritten as

$$q + D'q^2 = C\Delta p \quad (4)$$

Where:
$C = 0.00708\, k_w h/\mu_w [\ln(r_e/r_w) + s]$

$$D' = D/[\ln(r_e/r_w) + s] \quad (5)$$

It was assumed here that $\ln(r_e/r_w)$ and C remained virtually constant before fracturing occurred. This is a reasonable assumption as long as q in a given step is much larger than q in the preceding step. Selecting two such steps (before indicated fracturing) as shown in Fig. 3, we wrote

$$q_1 + D'q_1^2 = C\Delta p_1 \quad (6)$$

$$q_2 + D'q_2^2 = C\Delta p_2 \quad (7)$$

Dividing (6) ÷ (7) gave:

$$D' = (q_2\Delta p_1 - q_1\Delta p_2)/(q_1^2\Delta p_2 - q_2^2\Delta p_1) \quad (8)$$

It should be emphasized that D' and D carry the same units, $(b/d)^{-1}$, but are not identical. They are related as shown in Equation 5. In the shortcut approach, pressure is finally plotted vs. $(q+D'q^2)$, as shown in Fig. 3.

In an alternate approach to solving the non-D'Arcy flow problem, we start with this equation:

$$q = \frac{0.00708 k_w h(\Delta p - \Delta p_f)}{\mu_w [\ln(r_e/r_w) + s]} \quad (9)$$

where $\Delta p = p_w - p_e$ and Δp_f is the friction loss which in turn is related to q as follows:

$$\Delta p_f = Bq^2 \quad (10)$$

In Equation 10, B is a function of the water density and the number and diameter of perforations that are open. Defining C as above, we then obtain from 9 and 10 for two rates, q_1 and q_2, before fracturing,

$$q_1 + BCq_1^2 = C\Delta p_1 \quad (11)$$

$$q_2 + BCq_2^2 = C\Delta p_2 \quad (12)$$

It is evident from an analogy to Equations 6 and 7 that BC=D'. It follows that we arrive in effect at the same solution, i.e., Equation 8, regardless of whether we start from Equation 2 or 9.

Multiple-rate flow test analysis

The technique of applying multiple-rate flow-test analysis to step-rate injectivity test data is based on the prin-

Table 2

Step-rate data during early part of test, Well No. 2

t, hr	q, b/d	p, psi	Data point	Step no. n	Odeh sum*	$\Delta p_t / q$
0	0	642	–	–	–	–
0.5	100	720	a	1	−0.301	0.780
1.0	100	730	b	1	0	0.880
1.5	250	856	c	2	−0.110	0.856
2.0	250	874	d	2	0.120	0.928
2.25	750	1,143	e	3	−0.335	0.668
2.50	750	1,182	f	3	−0.112	0.720
3.00	750	1,216	g	3	0.124	0.765

*Oden sum $= [q_1 \log t + (q_2 - q_1) \log (t - t_1) + (q_3 - q_2) \log (t - t_2) + \ldots + (q_n - q_{n-1}) \log (t - t_{n-1})]\, 1/q_n$ (13)

$(p - p_i)/q_n$ (14)

$p_i = 642$ psi

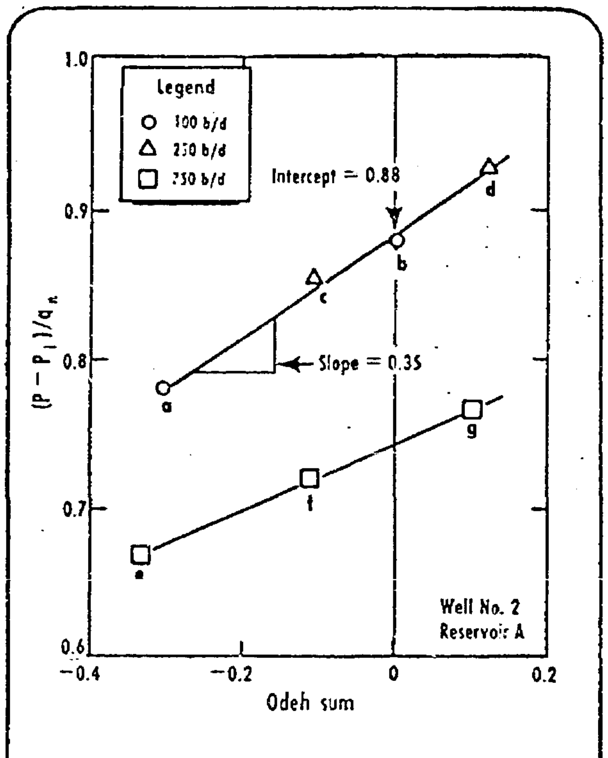
$t_1 = 1.0$ hr; $q_1 = 100$ b/d

$t_2 = 2.0$ hr; $q_2 = 250$ b/d

$t_3 = 3.0$ hr; $q_3 = 750$ b/d

Fig. 7

Odeh method of analysis



Standard step-rate graph as shown in Fig. 2

OGJ

ciple of "superposition." The technique, sometimes called the Odeh method, is well described in the literature for drawdown tests.[3,4] The equations presented in the literature can be used for the analysis of step-rate test data after making a change in sign and a change in symbol notations. Applicable equations and their use are presented in the following paragraphs.

The multiple-rate flow-test analysis technique determines $k_w h$ and skin before fracturing. It is essential that good data are available. Also, the correct initial pressure, p_i, must be known. This is the pressure that represents the intercept of the p vs. q plot when $q = 0$. Note, for instance, that using this criterion gives a lower p_i for Well No. 4 (Fig. 4) than indicated by the first observed pressure.

The method can be applied in theory only to data taken during the early rate steps when radial flow is the predominant flow mechanism in the formation zone under investigation. This approach was used for the data of Well No. 2 (Fig. 2). Data for the end of each of the early steps and for one or more arbitrary points during each of these steps were tabulated as shown in the first three columns of table 2, shown at left.

Sample calculations. For data point a (Step 1):

Odeh sum $= q_1 (\log t)/q_1 = 100 (\log 0.5)/100 = -0.301$

$(p - p_i)/q_1 = (720 - 642)/100 = 0.78$

For data point g (Step 3):

$$\text{Odeh sum} = [q_1 \log t + (q_2 - q_1) \log (t - t_1) + (q_3 - q_2) \log (t - t_2)]/q_3$$

$$= [100 \log 3 + (250 - 100) \log (3 - 1) + (750 - 250) \log (3 - 2)]/750$$

$$= 0.124$$

$(p - p_i)/q_3 = (1{,}216 - 642)/750 = 0.765$

The last two columns of Table 2 were plotted in Fig. 7. From this graph we read slope, $m' = 0.35$, and intercept, $b' = 0.88$. Known also were: $\mu_w = 0.45$ cp, $B_w = 1.0$, $h = 270$ ft (from a radioactive tracer-injectivity survey), $\Phi = 0.186$, $c = 1.5 \times 10^{-5}$ psi^{-1}, and $r_w = 0.25$ ft.

$$k_w h = 162.6 \mu_w B_w / m' \quad (15)$$

$$k_w h = 162.6 \times 0.45 \times 1.0/0.35 = 209 \text{ md ft}$$

$$k_w = 209/270 = 0.77 \text{ md}$$

$$s = 1.151 \left[\frac{b'}{m'} - \log \frac{k_w}{\Phi \mu_w c r_w^2} + 3.23 \right] \quad (16)$$

$$s = 1.151 \left[\frac{0.88}{0.35} - \log \frac{0.77}{0.186 \times 0.45 \times 1.5 \times 10^{-5} \times 0.0625} + 3.23 \right]$$

$$s = -1.4$$

$$r_{wa} = r_w e^{-s} \quad (17)$$

$$r_{wa} = 0.25 e^{1.4} = 1.0 \text{ ft}$$

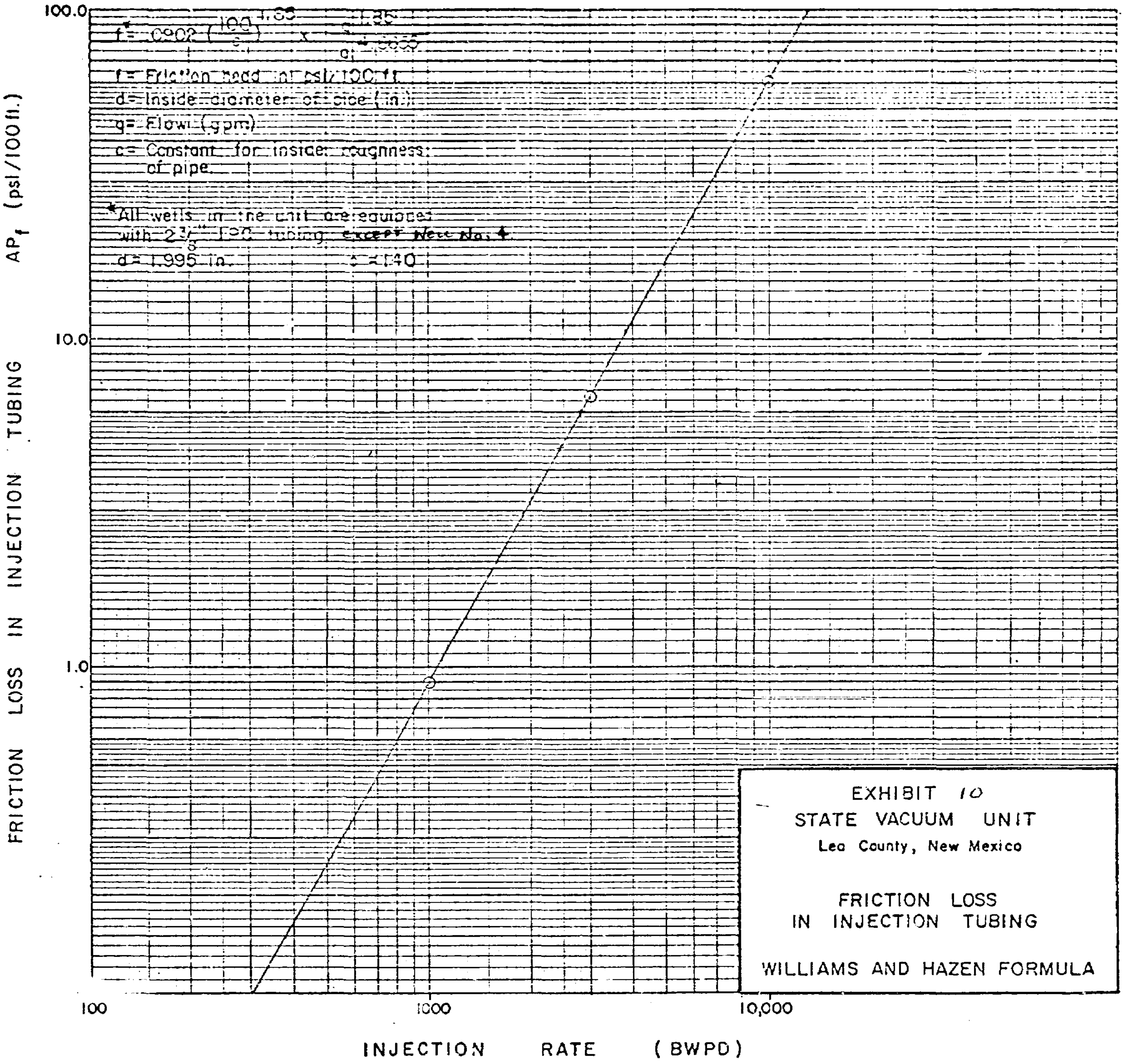
The data plotted in Fig. 7 show that the method broke down after point d was measured. That is, the following data points, e, f, and g, fell no longer on the old line. This was interpreted to indicate that radial flow was no longer the predominant flow regime and that fracturing had occurred.

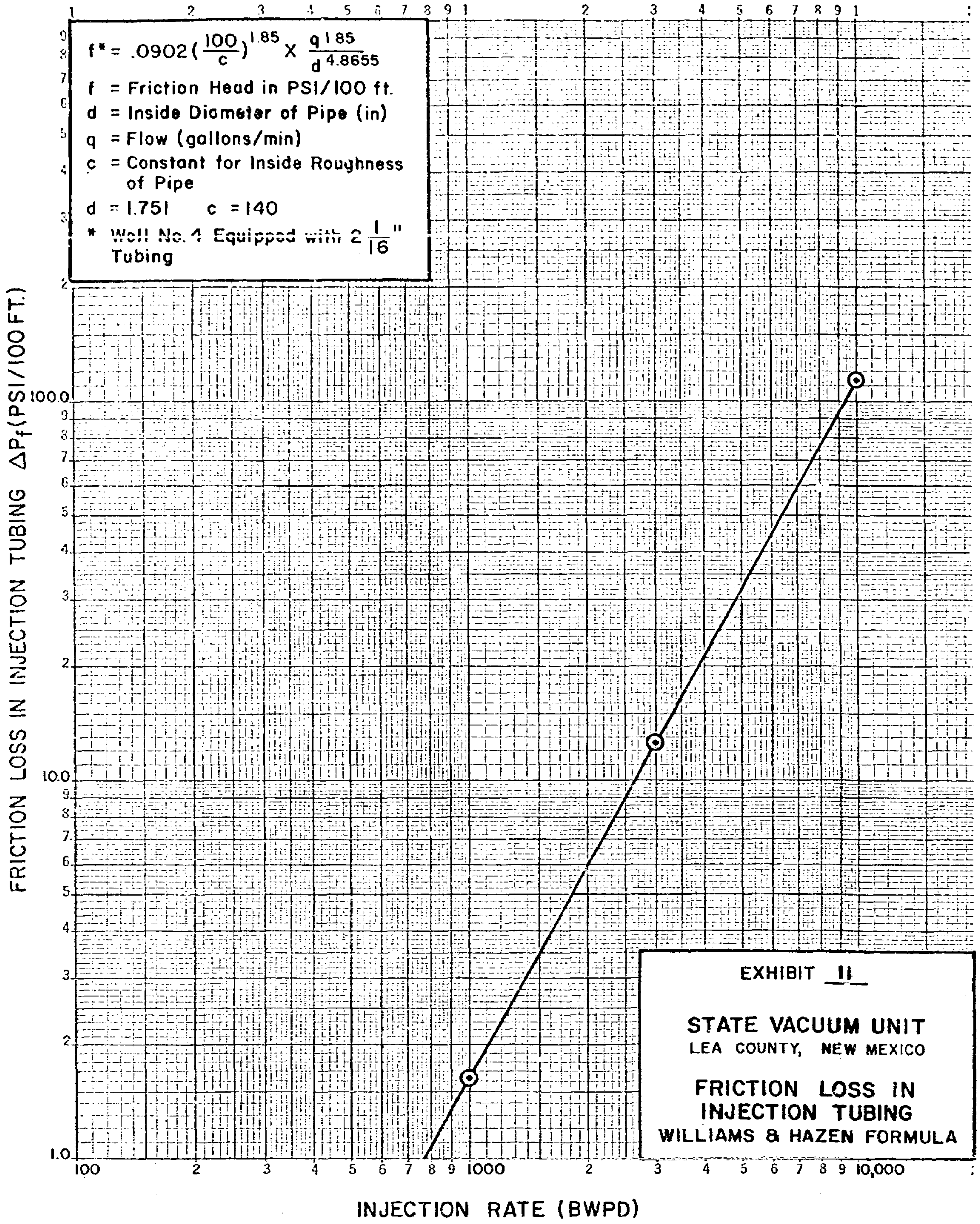
Fracturing theory for diagnosis.

The theory[6,7] used in drawing the dashed lines in Fig. 6 is expressed by the equation:

$$p_f/Z = [(S/Z) - (p_r/Z)]\,[\mu/(1 - \mu)] + p_r/Z \quad (18)$$

The Poisson's ratio, ν is the ratio of maximum lateral deformation to maximum longitudinal deformation observed during compression loading of rock samples. A low ratio is generally associated with dense, brittle rock and a higher ratio with more elastic rock. The overburden pressure gradient, S/Z, used in constructing the theoretical curves of Fig. 6, was 1.0 psi/ft of depth. Other terms are defined in the nomenclature.


100.0
f = Friction head in psi/100 ft.
d = Inside diameter of pipe (in.)
q = Flow (gpm)
c = Constant for inside roughness of pipe
*All wells in the unit are equipped with 2 3/8" IPC
d = 1.995 in.
c = 140
10.0
1.0
100
1000
10,000
FRICTION LOSS IN INJECTION TUBING AP_f (psi/100 ft.)
INJECTION RATE (BWPD)
EXHIBIT 10
STATE VACUUM UNIT
Lea County, New Mexico
FRICTION LOSS
IN INJECTION TUBING
WILLIAMS AND HAZEN FORMULA


f* = .0902 (100/c)^1.85 X q^1.85 / d^4.8655
f = Friction Head in PSI/100 ft.
d = Inside Diameter of Pipe (in)
q = Flow (gallons/min)
c = Constant for Inside Roughness of Pipe
d = 1.751 c = 140
* Well No. 4 Equipped with 2 1/16" Tubing
FRICTION LOSS IN INJECTION TUBING ΔPf (PSI/100 FT.)
INJECTION RATE (BWPD)
100
1000
10,000
1.0
10.0
100.0
EXHIBIT 11
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FRICTION LOSS IN INJECTION TUBING
WILLIAMS & HAZEN FORMULA

AtlanticRichfieldCompany

North American Producing Division
Permian District
Post Office Box 1610
Midland, Texas 79701
Telephone 915 682 8631

22 1978

May 19, 1978

Oil Conservation Division of the
New Mexico Department of
Energy and Minerals
P. O. Box 2088
Santa Fe, New Mexico

File

Attn: Mr. Ramey

Re: Case No. 5762; Order No. R-5295
Atlantic Richfield Company
State Vacuum Unit
Waterflood Project
T-17S, R-34E, Lea County, New Mexico

Dear Mr. Ramey:

In the Order establishing the waterflood project, wellhead injection pressure was limited to 860 psi. Approval of a higher wellhead pressure could be obtained by showing that the increase in pressure would not fracture the confining strata. As operator of the State Vacuum Unit, Atlantic Richfield Company applies for administrative approval of a wellhead injection pressure of 1134 psi. The attached exhibits are offered as evidence that this pressure will not fracture the confining strata.

The exhibits are based on pressure parting tests run on April 24-26, 1978. Exhibit 1 is a map of the unit area showing the seven injection wells which were tested. Insufficient pump capacity on Well No. 9 prevented the use of data from the test. The remaining six wells indicated a range of surface parting pressures from 1234 psi to 2101 psi as shown on Exhibit 2. Necessary equipment and well data is included on Exhibit 3.

The paper "Step-Rate Tests Determine Safe Injection Pressures in Floods" (Exhibit 10) was used as a reference to help determine proper testing procedures and analysis methods. The tests were run by Atlantic Richfield Company using a downhole pressure recorder and a Hallibruton turbine flowmeter. Individual well data and results are shown in Exhibits 4 through 9.

Some injection wells exhibit non-D'Arcy flow characteristics which prevents determination of the parting pressure by the normal rate vs. pressure graphical technique. Two of the wells

tested exhibited this behavior. By using the technique outlined in the reference paper ($q + Dq^2$) parting pressures were determined for the two wells and are included as Exhibits 4A and 5A. Exhibit 11 is a graphical solution of the Williams and Hazen formula for determining the pressure drop due to friction in the injection tubing. Data for the individual wells is listed on Exhibit 2.

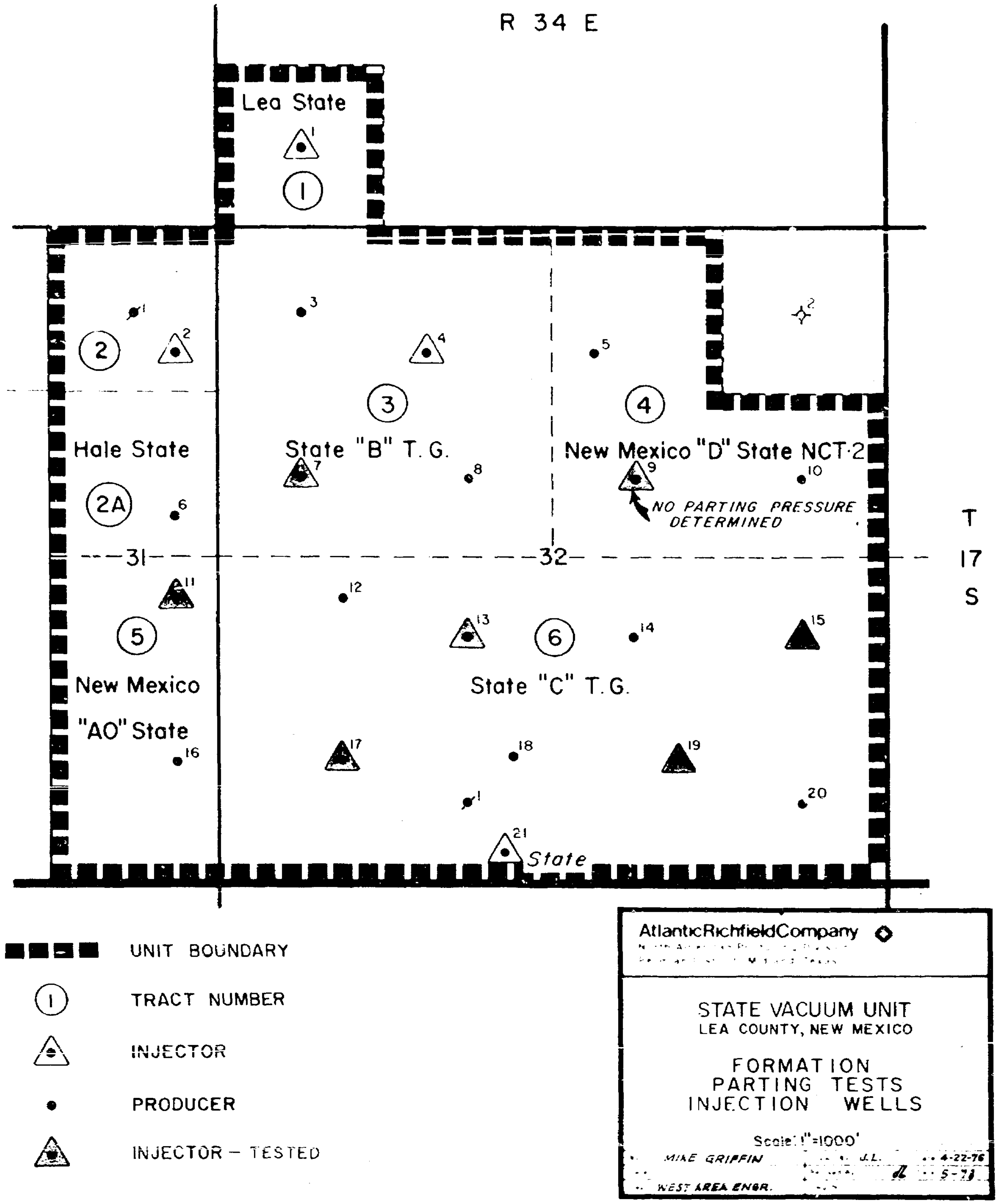
At the current limiting pressure of 860 psi, injection rates in the unit have begun to decline. We feel that an increased wellhead injection pressure is necessary if we are to maintain adequate injection rates to promote the timely production of the secondary reserves in the unit. Our application for administrative approval of a wellhead injection pressure of 1134 psi should insure that we are not fracturing the formation strata but also allow us to increase our current injection rates. We will gladly forward any additional information which may be required and ask for your prompt consideration.

Very truly yours,

J L Tweed

J. L. Tweed

MG/agp


R 34 E
Lea State
Hale State
State "B" T. G.
New Mexico "D" State NCT-2
NO PARTING PRESSURE DETERMINED
T
17
S
31
32
New Mexico
"AO" State
State "C" T. G.
State
2A
UNIT BOUNDARY
TRACT NUMBER
INJECTOR
PRODUCER
INJECTOR – TESTED
AtlanticRichfieldCompany
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION
PARTING TESTS
INJECTION WELLS
Scale: 1"=1000'
MIKE GRIFFIN
WEST AREA ENGR.
4-22-76

STATE VACUUM UNIT

PRESSURE PARTING TESTS

WELL NO.	CUM. INJ. 3/1/78 (MB)	PRESS. BOMB SETTING DEPTH (FT)	HYDROSTATIC[1] HEAD Ph (PSI)	INJ. RATE @ PART. PRESS. (BPD)	PRESS. DROP-FRICTION[2] ΔP_f (PSI/100 FT)	ΔP_f-TOTAL @ SETTING DEPTH (PSI)	BTM. HOLE PTG. PRESS. (PSI)	SURF. PTG.[3] PRESSURE (PSI)	PTG. GRADIENT (PSI/FT)
7	119.5	4671	2022.5	1700	2.34	109.3	3305	1391.8	.707
11	94.7	4693	2032.1	2050	3.32	155.8	3200	1323.7	.682
13	54.1	4660	2017.8	1530	1.91	89.0	4030	2101.0	.865
15	173.5	4636	2007.4	2630	5.20	241.1	3478	1711.7	.750
17	17.5	4721	2044.2	1000	0.86	40.7	3238	1234.5	.686
19	98.1	4692	2031.6	1610	2.12	99.5	3446	1513.5	.734

1. Injection water has specific gravity equal to 1.001; pressure gradient = .433 psi/ft.
2. Taken from Exhibit 11 (Williams and Hazen formula).
3. Surface Parting Pressure = Bottom Hole Parting Pressure - Hydrostatic head + ΔP_f

STATE VACUUM UNIT
Pressure Parting Tests
Injection Well Data

WELL NO.	COMPLETION CASING SIZE (DEPTH)	TUBING SIZE* IN.	DEPTH SET	PERFORATIONS
7	3½" liner (4426-4728)	2-3/8'	4426'	4671-4718'
11	3½" liner (4242-4768)	2-3/8"	4242'	4693-4734'
13	3½" liner (4241-4717)	2-3/8"	4241'	4660-4710'
15	3½" liner (4249-4708)	2-3/8"	4249'	4636-4686'
17	3½" liner (4429-4761)	2-3/8"	4429'	4721-4761'
19	3½" liner (4416-4750)	2-3/8"	4416'	4692-4742'

*All tubing is internally plastic coated.

EXHIBIT 4

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

WELL NUMBER: 7

COUNTY: Lea County, New Mexico

DATE OF TEST: 4/24/78

ELEMENT: 7287

TEST DEPTH: 4671'

TIME/ [redacted] PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:44	0	2448	560
1:00	200	2503	650
1:10	400	2569	725
1:20	600	2649	800
1:30	800	2739	900
1:40	1000	2864	1025
1:50	1200	2972	1125
2:00	1400	3101	1325
2:10	1600	3236	1475
2:20	1800	3358	1725
2:30	2000	3455	1875
2:40	2200	3563	2050
2:50	2400	3649	2200
2:56	3200	3782	2500
3:02	3600	3866	2775

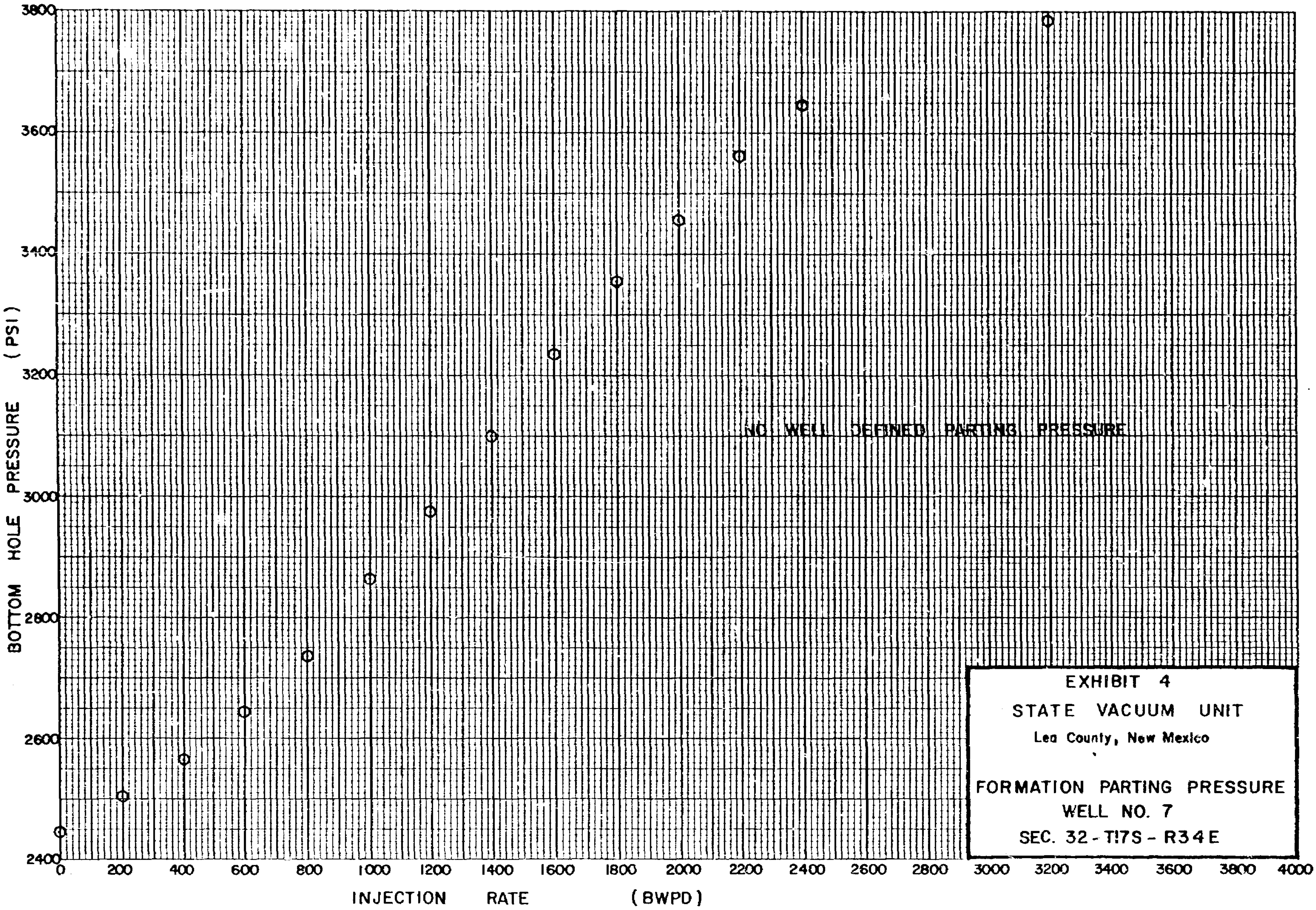


EXHIBIT 4
STATE VACUUM UNIT
Lea County, New Mexico

FORMATION PARTING PRESSURE
WELL NO. 7
SEC. 32 - T17S - R34E

STATE VACUUM UNIT
Formation Parting Pressure
Non D'Arcy Flow Technique
Well No. 7

From Exhibit 10:

$$D = (q_2 \Delta P_1 - q_1 \Delta P_2)/(q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: $q_1 = 200$ BPD; $P_1 = 2503$ psi

$q_2 = 400$ BPD; $P_2 = 2569$ psi

$D = .000555\ B/D^{-1}$

INJECTION RATE (BPD)	BHP @ TEST DEPTH (PSI)	$q + Dq^2$ (BPD)
0	2448	
200	2503	222
400	2569	489
600	2649	800
800	2739	1155
1000	2864	1555
1200	2972	1999
1400	3101	2488
1600	3236	3020
1800	3358	3598
2000	3455	4220
2200	3563	4886
2400	3649	5597
3200	3782	8883
3600	3866	10793

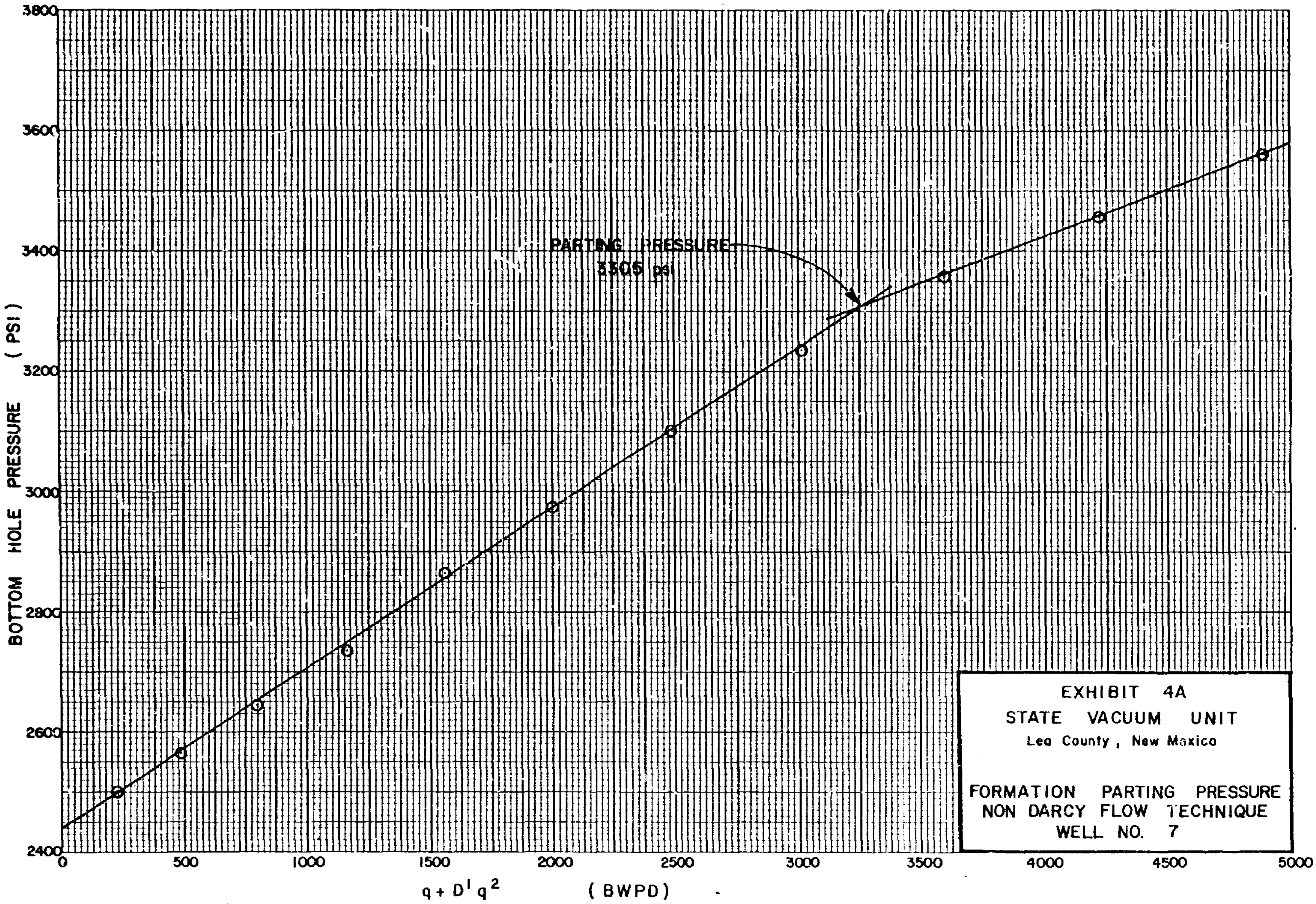


EXHIBIT 4A
STATE VACUUM UNIT
Lea County, New Mexico

FORMATION PARTING PRESSURE
NON DARCY FLOW TECHNIQUE
WELL NO. 7

EXHBIT 5

STEP RATE TEST REPORT

LEASE: STATE-VACUUM

DATE OF TEST: 4/25/78

WELL NUMBER: 11

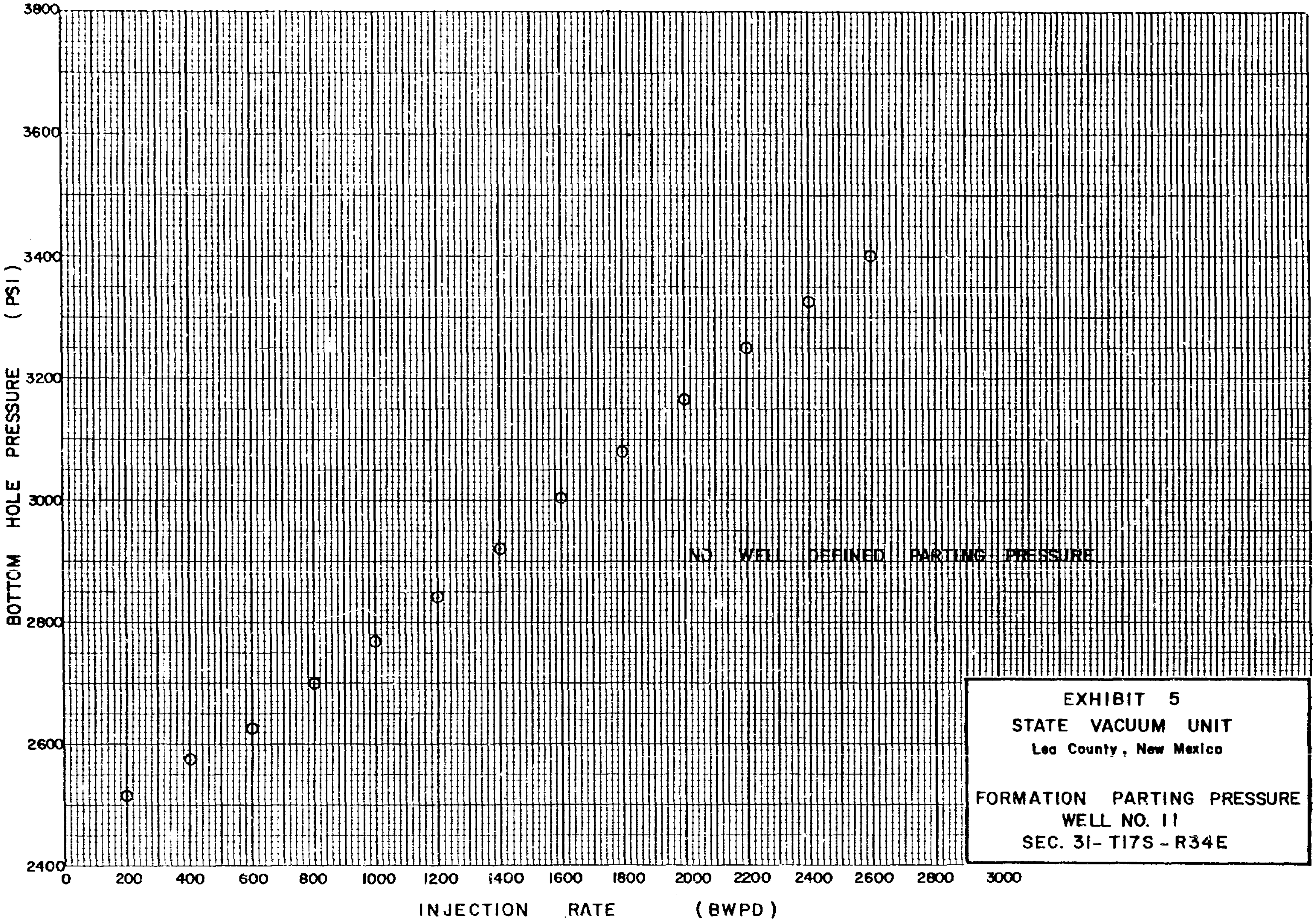
ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4693'

TIME/ AM ~~PM~~	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
8:34	0	2433	
8:50	200	2518	650
9:00	400	2577	700
9:10	600	2624	725
9:20	800	2701	825
9:30	1000	2767	950
9:40	1200	2842	1050
9:50	1400	2922	1175
10:00	1600	3004	1280
10:10	1800	3080	1400
10:20	2000	3166	1410
10:30	2200	3252	1490
10:40	2400	3322	1550
10:50	2600	3402	1640

46 1323



NO WELL DEFINED PARTING PRESSURE
BOTTOM HOLE PRESSURE (PSI)
INJECTION RATE (BWPD)
3800
3600
3400
3200
3000
2800
2600
2400
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
EXHIBIT 5
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 11
SEC. 31- T17S - R34E

STATE VACUUM UNIT
Formation Parting Pressure
Non D'Arcy Flow Technique
Well No. 11

From Exhibit 10:

$$D = (q_2 \Delta P_1 - q_1 \Delta P_2)/(q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: $q_1 = 600$ BPD; $P_1 = 2624$ psi

$q_2 = 800$ BPD; $P_2 = 2701$ psi

$D = .000311$ B/D^{-1}

INJECTION RATE (BPD)	BHP @ TEST DEPTH (PSI)	$q + Dq^2$ (BPD)
0	2433	
200	2518	212
400	2577	450
600	2624	712
800	2701	999
1000	2767	1311
1200	2842	1648
1400	2922	2009
1600	3004	2396
1800	3080	2807
2000	3166	3244
2200	3252	3705
2400	3322	4192
2600	3402	4702

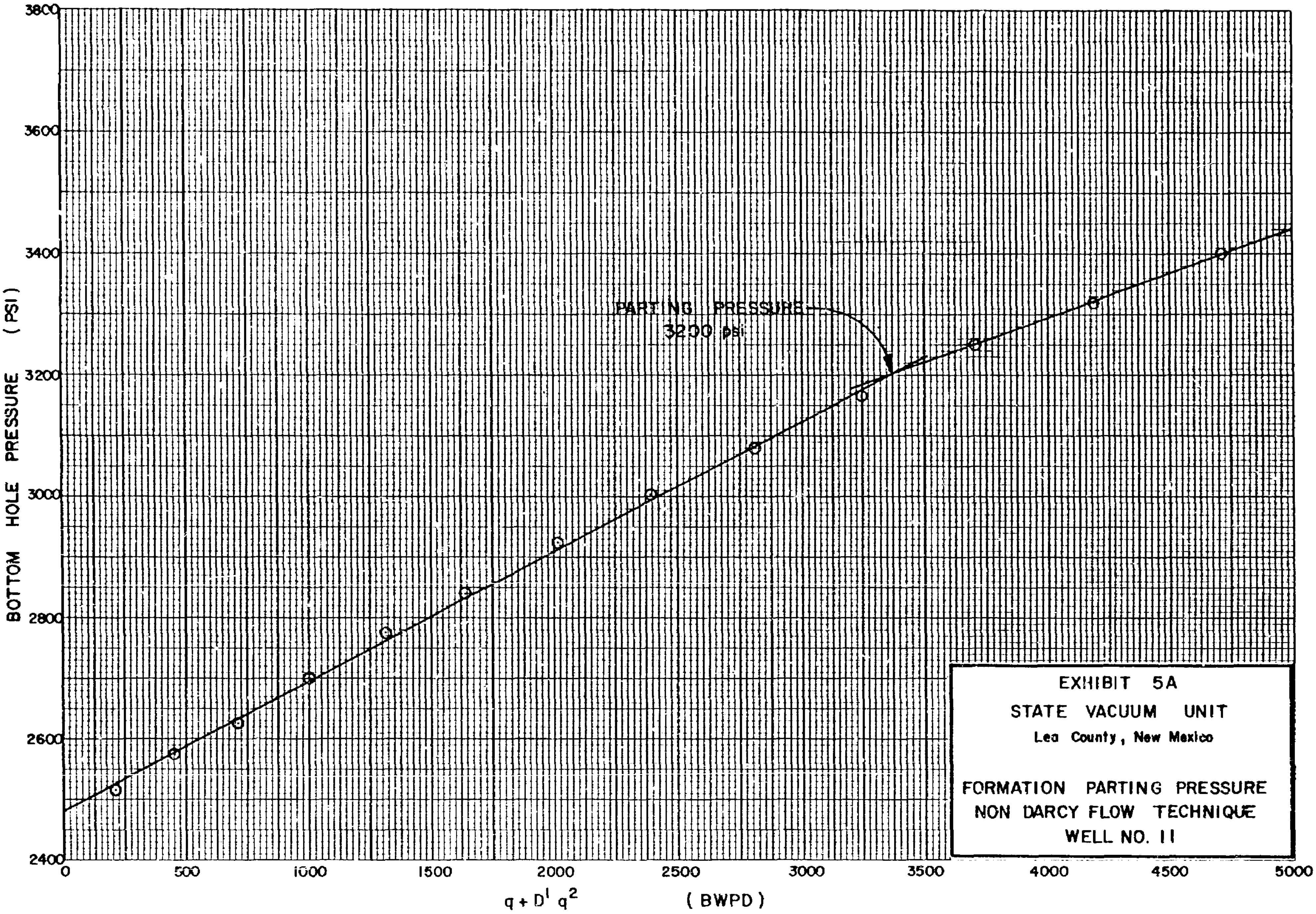

BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
PARTING PRESSURE
3200 psi
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
q + D' q² (BWPD)
EXHIBIT 5A
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
NON DARCY FLOW TECHNIQUE
WELL NO. 11

EXHIBIT 6

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/26/78

WELL NUMBER: 13

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4660'

TIME/ ~~AM~~ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:16	0	2392	540
12:25	200	2551	715
12:35	400	2725	850
12:45	600	2917	1050
12:55	800	3164	1415
1:05	1000	3420	1700
1:15	1200	3662	1990
1:25	1400	3885	2190
1:35	1600	4055	2490
1:45	1800	4169	2580
1:55	2000	4263	2740
2:05	2200	4343	2860

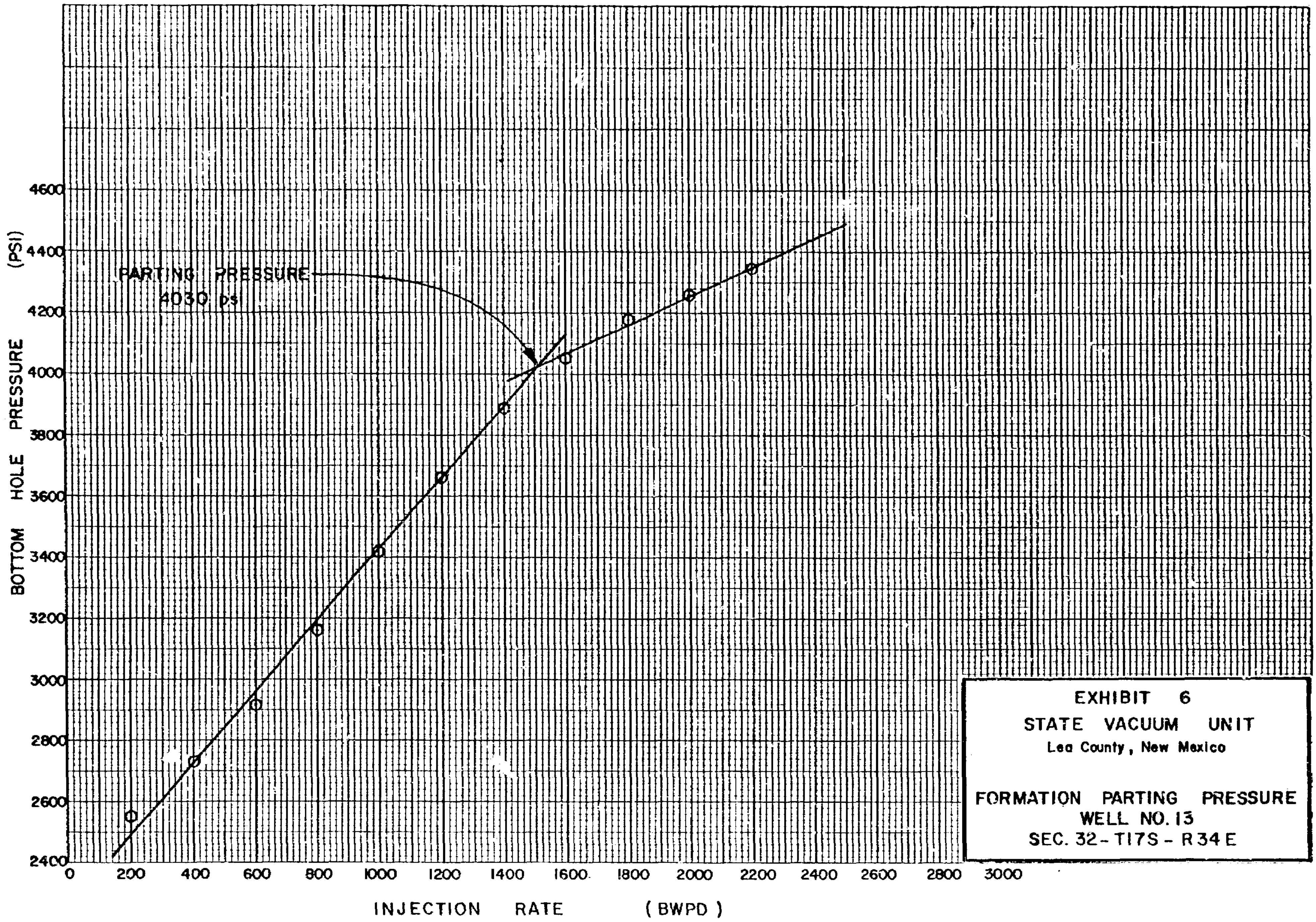


EXHIBIT 6
STATE VACUUM UNIT
Lea County, New Mexico

FORMATION PARTING PRESSURE
WELL NO. 13
SEC. 32 - T17S - R34E

EXHIBIT 7

STEP RATE TEST REPORT

LEASE: STATE-VACUUM

DATE OF TEST: 4/25/78

WELL NUMBER: 15

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4636'

TIME/ ~~AM~~ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
2:45	0	2008	160
2:55	600	2230	350
3:05	1000	2460	625
3:15	1400	2724	925
3:25	1800	3010	1250
3:35	2200	3243	1575
3:45	2600	3420	1840
3:55	3000	3572	2120
4:05	3400	3663	2300
4:15	3800	3772	2500

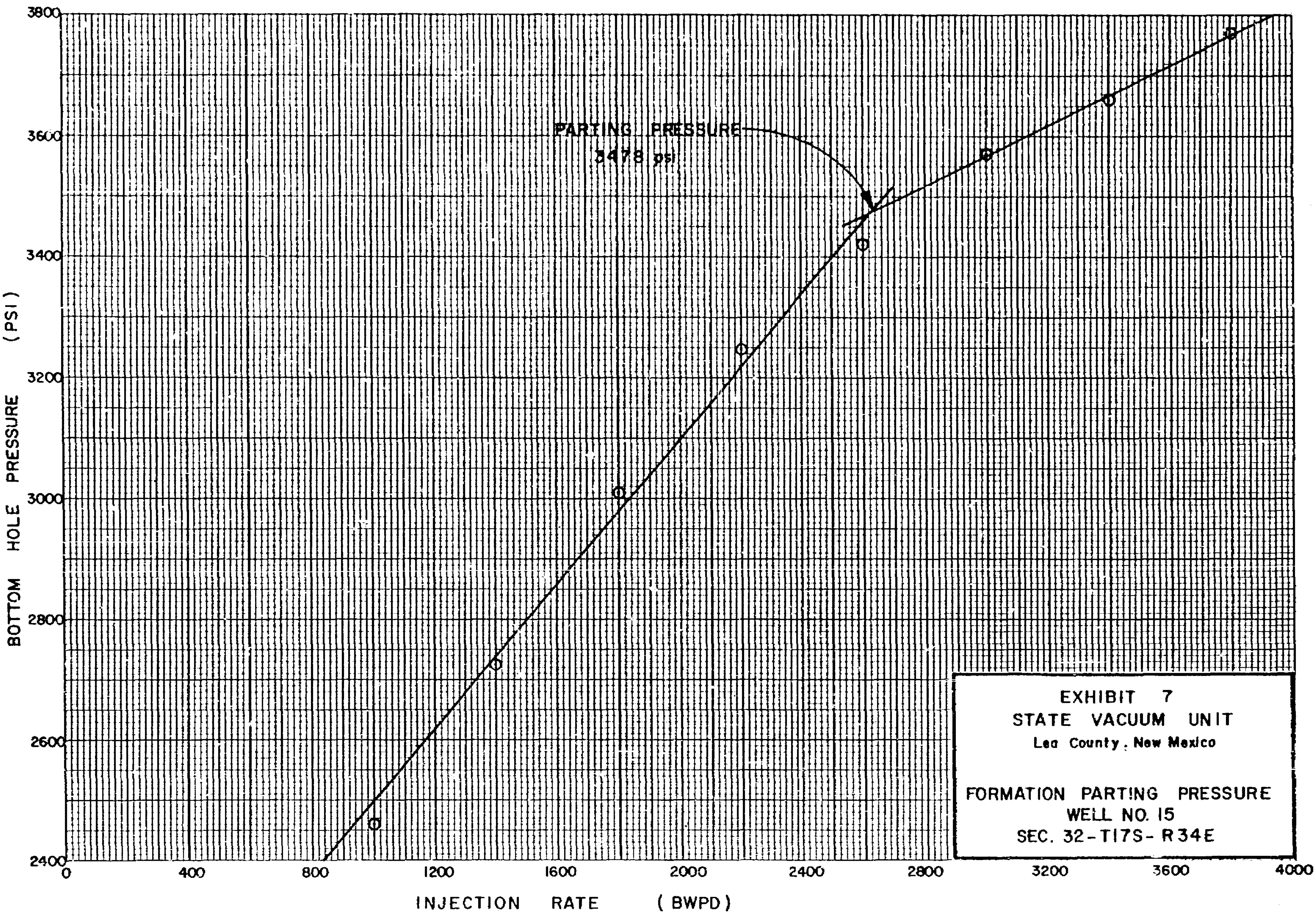

PARTING PRESSURE
3478 psi
BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
INJECTION RATE (BWPD)
EXHIBIT 7
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 15
SEC. 32-T17S-R34E

EXHIBIT 8

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/25/78

WELL NUMBER: 17

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4721'

TIME/ AM PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:50	0	2477	569
12:05	200	2670	780
12:15	400	2854	930
12:25	600	2973	1120
12:35	800	3117	1280
12:45	1000	3239	1445
12:55	1200	3312	1555
1:05	1400	3390	1665
1:15	1600	3462	1785
1:25	1800	3531	1890
1:35	2000	3585	2000

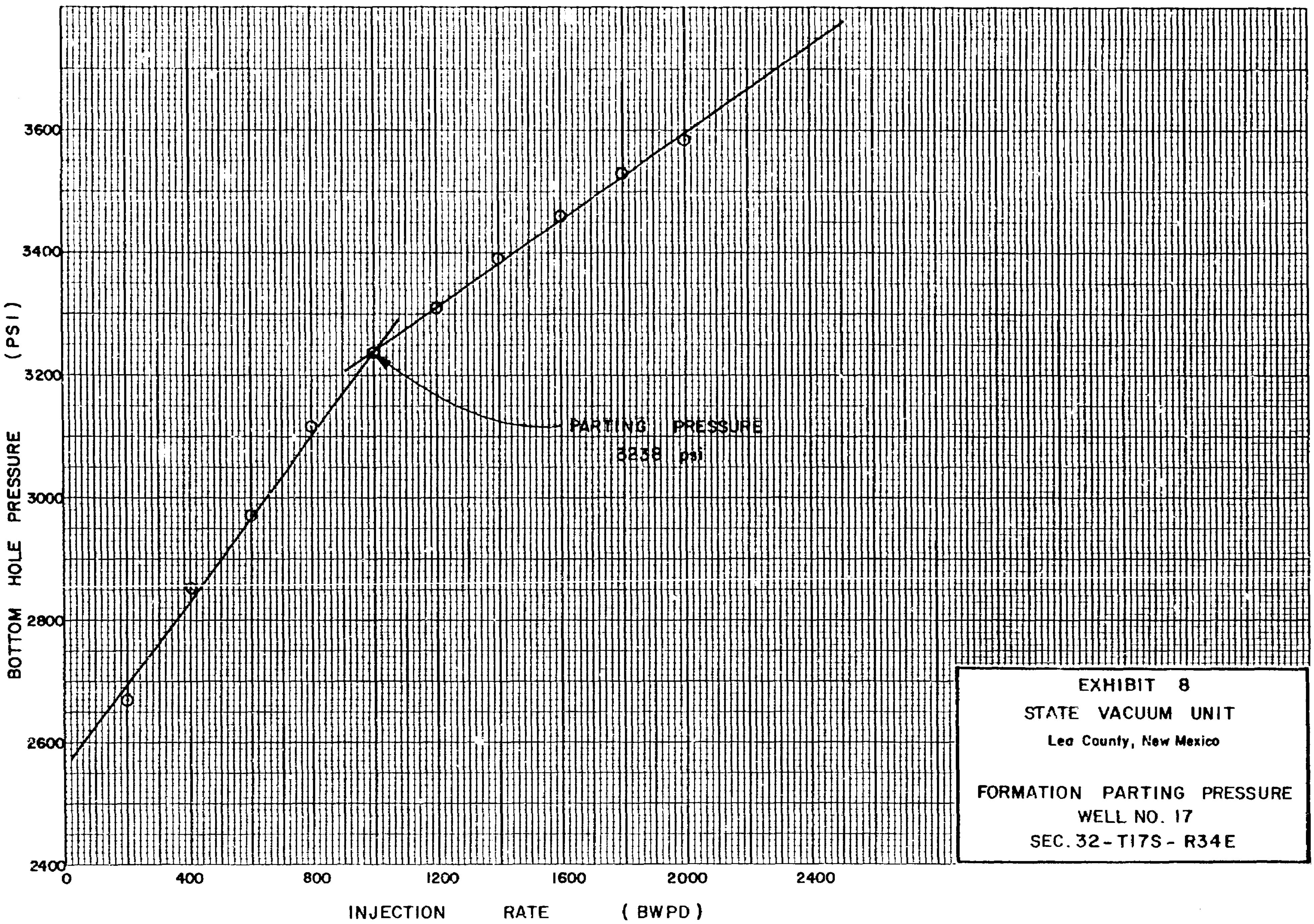

BOTTOM HOLE PRESSURE (PSI)
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
INJECTION RATE (BWPD)
PARTING PRESSURE
3238 psi
EXHIBIT 8
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 17
SEC. 32-T17S-R34E

EXHIBIT 9

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/26/78

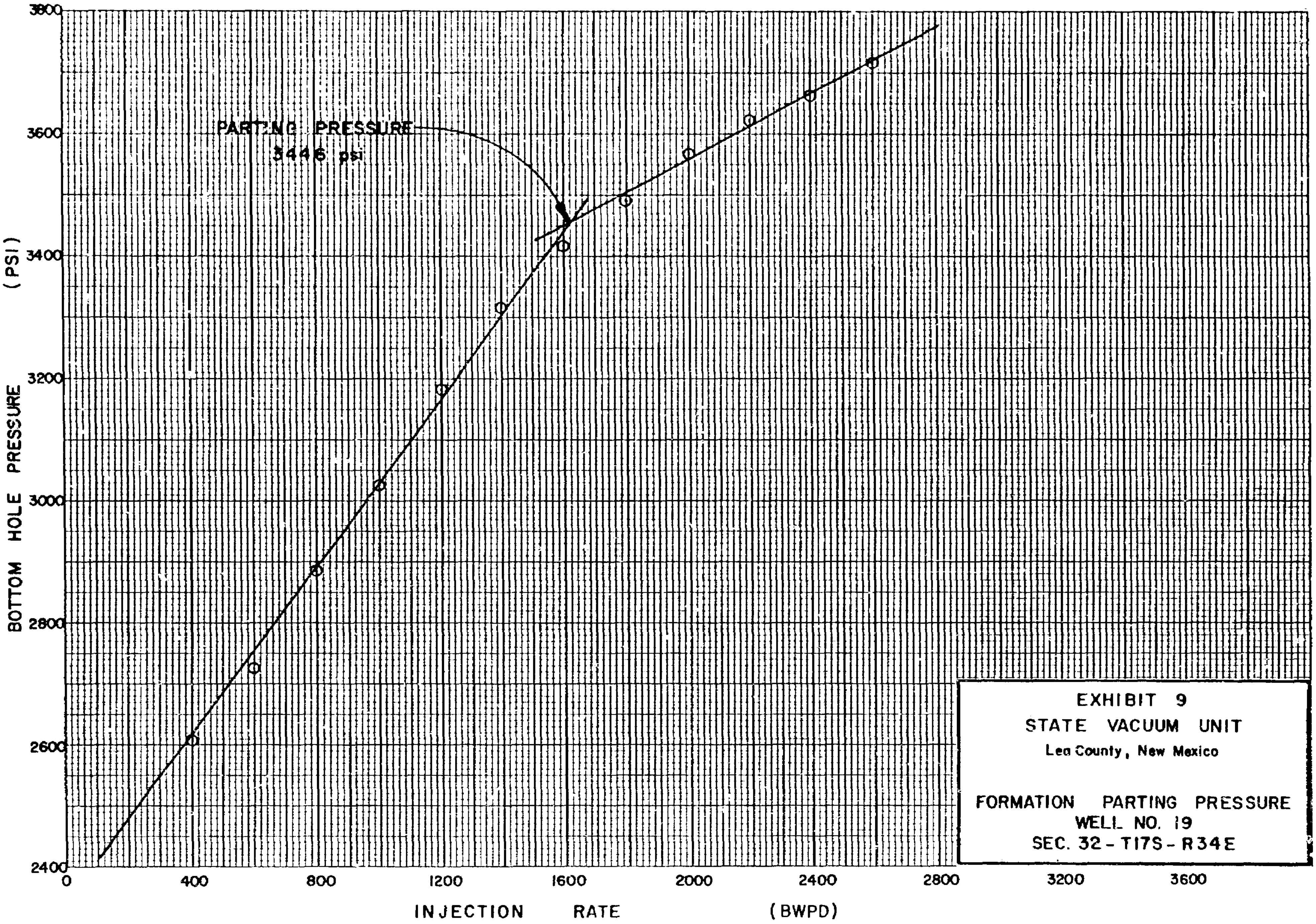
WELL NUMBER: 19

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4692'

TIME/ AM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
9:01	0	2460	500
9:15	200	2336	500
9:25	400	2607	600
9:35	600	2724	750
9:45	800	2887	920
9:55	1000	3027	1080
10:05	1200	3181	1260
10:15	1400	3314	1430
10:25	1600	3415	1600
10:35	1800	3491	1700
10:45	2000	3565	1840
10:55	2200	3622	1940
11:05	2400	3666	2020
11:15	2600	3715	2110



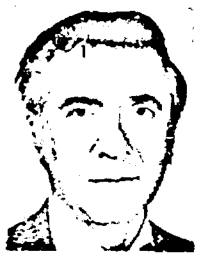
PARTING PRESSURE
3446 psi
BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
2800
3200
3600
INJECTION RATE (BWPD)
EXHIBIT 9
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 19
SEC. 32 - T17S - R34E

EXHIBIT 10

Step-rate tests determine safe injection pressures in floods

The author...

Martin Felsenthal is a senior research engineer with Continental Oil Co. in Ponca City, Oklahoma. He works in the areas of formation evaluation, waterflooding and tertiary recovery. A petroleum engineering graduate from University of California, he also holds an MS from Penn state.



Felsenthal

STEP-RATE injectivity tests can define the maximum safe injection pressures that can be used without fracturing the reservoir rock.

This information is important in waterfloods. It is of critical importance in tertiary-recovery projects where we cannot afford to lose costly injection fluids through uncontrolled induced fractures.

Recently, we tried the step-rate test in a number of projects. Although the test concept is simple, results were conclusive only if proper procedures and equipment were used. From this experience, a recommended procedure has been developed.

This article presents the recommended procedure and shows typical data.

A remarkable point brought out by these data is that formations sometimes fracture near hydrostatic head in pressure-depleted reservoirs.

The procedure. The early literature references [1,2] generally talked about pressure parting rather than fracturing during step-rate injectivity tests. It was pointed out, however, at the outset that the two expressions are synonymous.

The test well should be shut in long enough so that the bottom-hole pressure is near the shut-in formation pressure. The step-rate injectivity test that follows consists of a series of constant-rate injections with rates increasing from low to high in stepwise fashion.

In t i g h t formation ($K_{air} \sim 5$md) each step should last 60 min. Shorter time spans can be used in higher-permeability formations as shown in Table 1 of the appendix. The time-step duration itself is not critical. It only should be reasonably close to the recommended values shown. Also, each step should last exactly as long as the preceding step.

In selecting rates for the test, one possible rule of thumb is to use 5, 10, 20, 40, 60, 80, and 100% of the desired maximum test rate. The above schedule may be varied to suit the conditions of the test. For instance, it may be difficult to control accurately a very low rate in which case, the test may be started at a somewhat higher rate than shown above.

Equipment. Injection rates during the test should be controlled with a constant flow-rate regulator. We have used regulators made by three different companies and obtained useful data. All regulators should be tested before use.

Use of a throttling valve as a flow-rate regulating device is not recommended. Reason is that this valve acts like an orifice. Pressures and rates will thus interact continuously during the transient flow conditions of each rate step. Consequently, as well pressures rise, injection rates will tend to decline.

Flow rates should be measured with a turbine flowmeter and a rate meter such as those made by Halliburton. It is advisable to calibrate this equipment by timing flow into a 5-gal container (b/d = 10,286 ÷ seconds to fill a 5-gal container).

In critically important tests, it is advisable to record rates throughout the test. For this purpose, we have fed a s i g n a l from a rate meter through a dampening circuit to a strip-chart recorder. Use of a rate recorder is desirable but not mandatory.

Our experience has shown that best results were obtained when pressures were measured with a down-hole instrument. For instance, we used

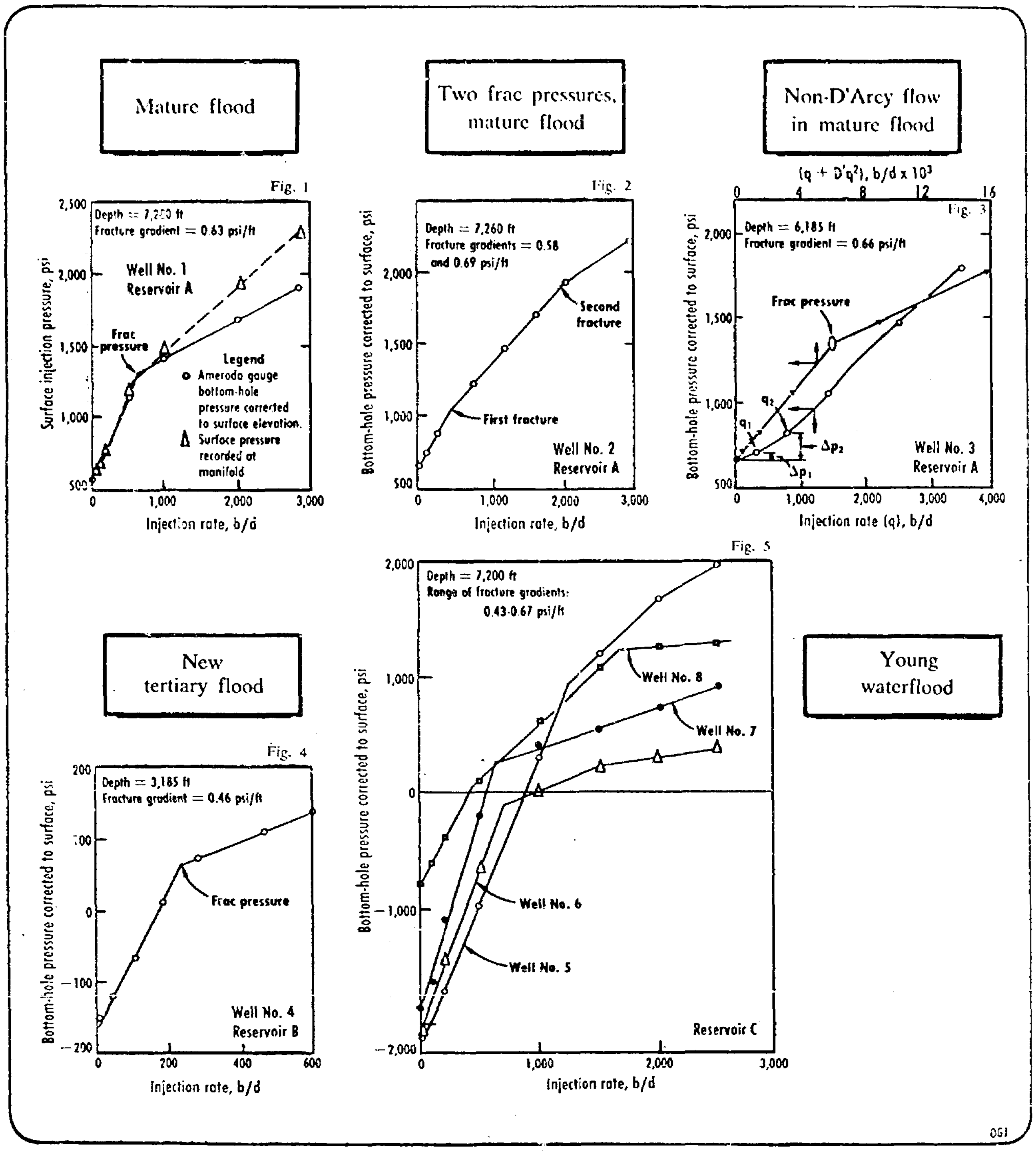
Amerada-type pressure-recording devices in all tests shown in Figs. 1-5. Other down-hole devices may be equally suitable. In addition, it is advisable to observe surface pressures with a surface gage or recorder. We found that it is often difficult to obtain very accurate surface-pressure readings because of surges from the injection pump. Nevertheless, surface pressures are useful in many tests for on-the-spot analysis, while the test is in progress. Final test analysis, however, should be based on down-hole pressure data.

Data analysis. The pressures at the start of the test (at q = O) and at the end of each injection-rate step are plotted against injection rates as in Fig. 1. Shown are down-hole pressures corrected to the surface elevation of the well and pressures recorded at the surface. The difference in the two pressures is mainly due to friction losses in the pipes.

When the data show that it takes a smaller pressure increment for a unit-rate change, we generally infer that fracturing has taken place. Thus, the data of Fig. 1 indicate that Well

Figs. 1-5

Step-rate tests on old and new floods



No. 1 fractured at about 1,300 psi surface pressure.

Sometimes two breaks are indicated in the pressure-vs-rate plots. Each break could represent a separate fracture. For instance, data for Well No. 2 (Fig. 2) indicate a first fracture at a surface pressure of 1,050 psi and a second and more-severe fracturing condition at 1,900 psi.

Occasionally, pressure-vs-rate plots do not form a straight line but form a curve with a distinctive upward curvature near the origin as shown in Fig. 3. The best explanation for this is non-D'Arcy flow downstream from the pressure-measuring device. This implies that there is probably a sizable pressure drop across the perforations or other orifice-like obstructions. An added resistance is created that is proportional to the square of the injection rate. Thus, we observed we could not interpret the step-rate data for Well No. 3 from a standard pressure-vs-rate (q) plot but could do so from a plot of pressure vs. $q + Dq^2$ (A method for determining D is given in the appendix). Data in Fig. 3 indicate that the fracturing pressure was about 1,300 psi in Well No. 3.

In some pressure-depleted reservoirs, initial pressures are lower than hydrostatic head. Such a situation occured during the tests illustrated in Figs. 4 and 5. Down-hole rates at the end of the early steps were somewhat smaller in these tests than rates measured at the surface because of rising fluid levels in the wells. Appropriate corrections for this condition had to be made before the data could be analyzed.

Complementary techniques. Pressure-falloff tests are generally a good source of information on permeability capacity, probable presence of fractures, skin and nearness to faults or barriers.[4] An excellent opportunity generally exists for conducting this type of test while the test well is being shut in before step-rate testing. If the skin calculated from such a test is definitely negative, we can infer that we probably have a fracture. One way to find out whether the fracture is natural or induced is to reduce the injection pressure for some time, say 1 month, and then run another pressure-falloff test. If the skin is closer to zero in the second test, we can conclude that an induced fracture tended to close.

Permeability capacity and skin (before fracturing) can also be evaluated directly from step-rate test data using a multiple-rate flow-test analysis technique.[3,4] A prerequisite to this technique is great care to keep rates constant in each step and to obtain accurate data. Use of the technique is illustrated in the appendix.

Step-rate tests and pressure-falloff tests give virtually no information about fluid-injection distribution. For diagnosing the formation characteristics near injection wells, in a vertical dimension, injectivity-profile tests are needed. These tests are very useful and popular. Results obtained from them can beneficially supplement results obtained from step rate and pressure-falloff tests. Especially helpful for this purpose are radioactive tracer injection and/or temperature decay surveys (Absolute temperature profile while injecting, followed by absolute temperature profiles after shutin of injection).

Typical data. Typical pressure-vs-rate plots are shown in Figs. 1-5. The remarkable feature brought out by the last two figures is that the fracturing pressure was near hydrostatic head for most of the wells tested in the pressure-depleted reservoirs B and C. It was even slightly below the hydrostatic head in one well (No. 6, Fig. 5).

To place the data presented so far into perspective, a plot of fracturing gradients vs. shut-in formation pressure/depth ratios was prepared for wells from six formations. The resulting graph (Fig. 6) covers a wide range of prior injection histories, lithology, depths, geographic distribution (five states), geologic ages (Mississippian to Pliocene), and shut-in formation pressure/depth ratios.

Note that fracturing gradients ranged from 0.43 psi/ft to 0.93 psi/ft with the higher gradients generally occurring at the higher shut-in formation pressure/depth ratios. This trend of increasing fracturing gradients with shut-in formation pressure is in agreement with observations reported in several literature references.[5-8] This trend is especially well illustrated in Fig. 6 by the data for reservoir D (solid circles denote data taken in the first month of the flood and open circles denote data taken in the same wells 6 months later). These data indicate that fracturing pressures should be reevaluated periodically.

Vertical arrows in Fig. 6 connect first fracturing indications with second fracturing indications during the same test in the same well. (Details for Well No. 2 are shown in Fig. 2 and for Well Nos. 5, 6, and 8 in Fig. 5.) A preferred interpretation for this is that a first fracture occurred in comparatively hard, brittle rock and a second fracture in softer and more plastic rock.

The dashed lines shown in Fig. 6 show a comparison with a prevalent fracturing theory[5,7] (explained in the appendix). This presentation does not exclude the possibility that a refinement of this theory or some other theory would result in a better fit of the curves and data points.

Numbers on the dashed lines in Fig. 6 are Poisson's ratios. It has been speculated in the literature[8] that data points coinciding with relatively high Poisson's ratios (greater than 0.35) might be indicative of fracture extension through plastic cap-rock shales. This view is unconfirmed, however, at this time, because injectivity profiles, particularly temperature-decay surveys, were not made at the time (or close to the time) when the step-rate tests associated with high Poisson's ratios were made.

Will test damage formation? A study of field records for injection Wells Nos. 1-8 (Figs. 1-5) showed that earlier injection pressures exceeded the maximum pressure used during the step-rate tests. The theory of rock mechanics indicates that fractures once opened will tend to close again when the injection pressure is reduced below the fracturing pressure. What is happening is that the net effect of the overburden becomes stronger than the force that tends to keep an unpropped, induced fracture open. This is the mechanism that apparently occurred before step-rate testing in Wells Nos. 1-8.

No damage can conceivably be caused by step-rate tests in old waterfloods as long as the injection pressure during the tests does not exceed injection pressures used earlier during the waterflood history and as long as high-quality injection water is used. In a new waterflood, a typical well should be selected for a step-rate test. In this well, one should use only low and moderate injection rates until a fracturing pressure is definitely established. Later tests should be designed so that they do not greatly

exceed this pressure for any appreciable length of time (more than a few hours).

Acknowledgments

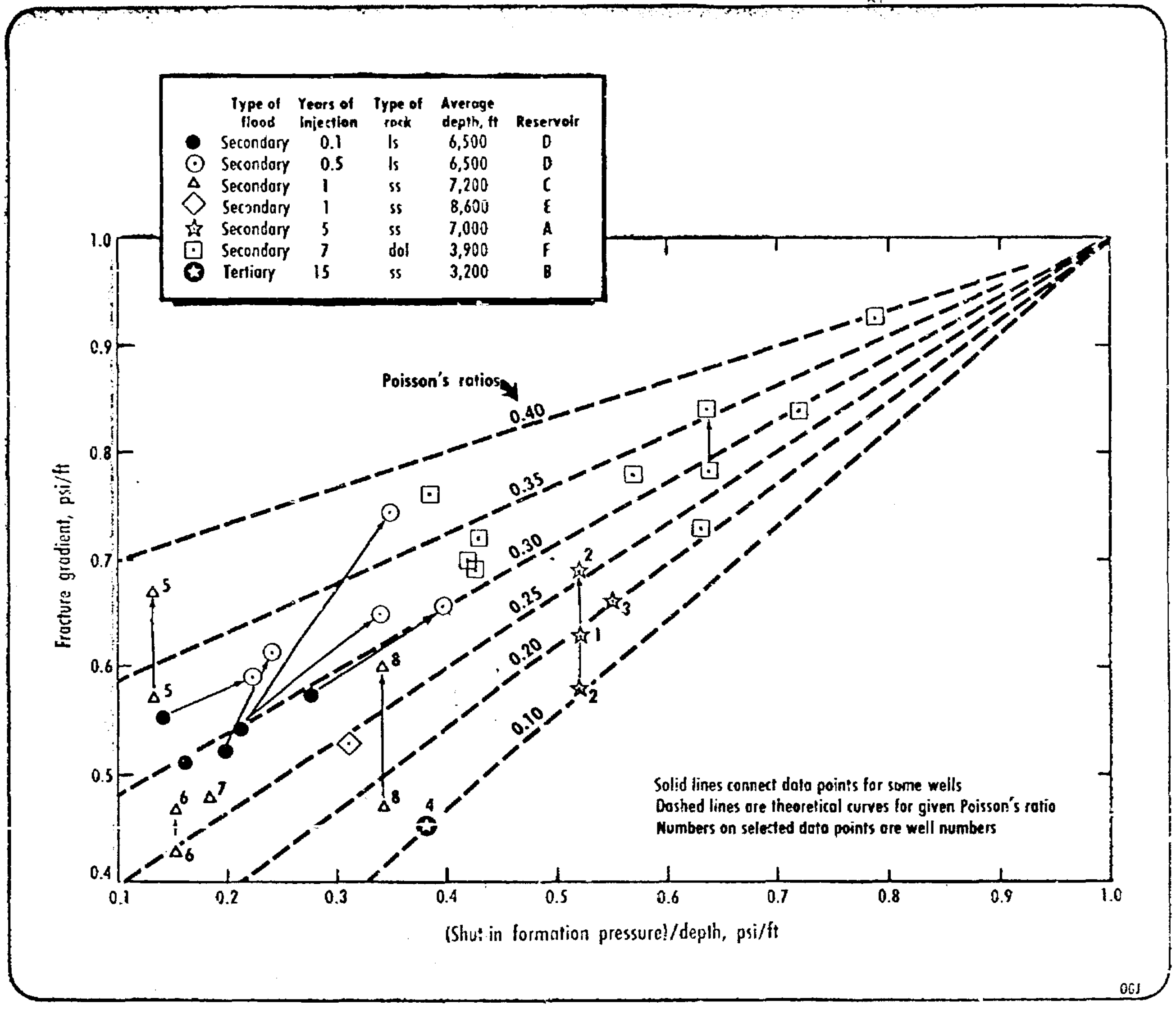
I am indebted to H. C. Walther for guidance and constructive criticisms, to H. A. Wahl for valuable suggestions, and to R. C. Cooper, Wayland Edwards, Dell Conley, and R. A. Strode for assistance in data collection and analysis.

Nomenclature

b' = Odeh intercept
B = Constant, psi/(b/d)^2
B_W = Water formation volume factor, RB/st-tk bbl
c = Total compressibility, psi^{-1}
C = Constant, (b/d)/psi
D = Non-D'Arcy flow constant, (b/d)$^{-1}$
D' = Another non-D'Arcy flow constant related to D as explained in equation 5, (b/d)$^{-1}$
h = Net effective pay, ft
K_{air} = Absolute permeability to air, md
k_{rw} = Relative permeability to water
k_w = Effective permeability to water, md
m' = Odeh slope
n = Step number in step-rate test
p = Pressure during step-rate test at time t, psi
p_e = Shut-in formation pressure, psi
P_f = Fracturing pressure related to same elevation as p_e, psi
p_i = True initial pressure during step-rate test, defined by intercept of p vs. q plot when q = o, psi
p_w = Bottom-hole pressure in well, psi
Δp = Difference in pressures, psi
Δp_f = Friction loss through perforations or slots, psi
q = Injection rate, b/d
r_e = Outer radius of pressure influence, ft
r_w = Well-bore radius, ft
r_{we} = Effective well-bore radius, ft
s = Skin factor, dimensionless
s' = Apparent skin factor, dimensionless
S = Overburden pressure, psi
t = Time since start of test, hr.
t_n = Time at end of step n of step-rate test, hr
Z = Depth, ft
Φ = Porosity, fraction
μ_w = Water viscosity, cp
ν = Poisson's ratio, dimensionless

Fig. 6

Frac gradients vs. pressure-depth ratio



References

1. Yuster, S. T., and Calhoun, J. C., Jr., "Pressure Parting," Prod. Monthly, V. 9, No. 4: 16-26, February 1945.
2. Grandone, P., and Holleyman, J. B., "Injectivity Tests for Waterflooding Mid-Continent Oil Sands," World Oil, pp. 152-4, 6, 8, December 1949.
3. Odeh, A. S., and Jones, L. G., "Pressure Drawdown Analysis, Variable-Rate Case," Jour. Pet. Tech., pp. 960-964, August 1965.
4. Matthews, C. S., and Russell, D. G., "Pressure Buildup and Flow Tests in Wells," SPE Monograph, V. 1, 1967.
5. Heck, E. T., "Fractures and Joints," Prod. Monthly, p. 20, February 1955.
6. Hubbert, M. K., and Willis, D. G., "Mechanics of Hydraulic Fracturing," AIME Trans., V. 210: 153-166, 1957.
7. Eaton, B. A., "Fracture Gradient Prediction and Its Application in Oilfield Operations," Jour. Pet. Tech., pp. 1353-1360, October 1969.
8. Felsenthal, M., and Ferrell, H. H., "Fracturing Gradients in Waterfloods of Low-Permeability, Partially Depleted Zones," Jour. Pet. Tech., pp. 727-730, June 1971.

Appendix

PRESENTED here are recommended step-rate test times, non-D'Arcy flow-analysis techniques, and a multiple-rate analysis technique applied to step-rate tests. Also, presented is a brief description of a fracturing theory used in diagnosing step-rate test data.

Recommended time for each injection-rate step

Radius of investigation, $r_{inv} = \sqrt{0.00105 k_w t / \phi \mu_w c}$ (1)

This radius should be about 10 ft or larger to investigate formation properties adequately. For assumed typical values of $\phi = 0.2$, $\mu_w = 0.7$ cp, $c = 1.5 \times 10^{-5}$ psi^{-1}, $kr_w = 0.05$ for $K_{air} = 5$ md, and 0.10 for $K_{air} > 5$ md, we obtain.

Table 1

Test design values

Average K_{air}	Recommended minimum time for each step
5 md	60 min
10 md and larger	30 min

Non-D'Arcy flow analysis techniques

In non-D'Arcy radial flow:

$$q = \frac{0.00708 k_w h \Delta p}{\mu_w [\ln(r_e/r_w) + s + Dq]} \quad (2)$$

Where D is the non-D'Arcy flow constant, $(B/D)^{-1}$:

$$\text{The apparent skin} = s' = s + Dq \quad (3)$$

The s' term can be evaluated through a multiple-rate flow-test analysis technique (described in another part of this appendix) by substituting s' for s in equation 16. Next, s' is plotted vs q for the early steps of the test. D is then determined from this plot with the aid of equation 3. Analyses of s (= s' − Dq) for all steps of the step-rate test follow. The s terms are finally plotted vs injection pressures, and the point at which s becomes greatly more negative is interpreted as the fracturing pressure.

The aforementioned procedure is rather time-consuming. A shortcut approach was, therefore, developed and applied to the data of Well No. 3. This approach gave the same results as the method based on the multiple-rate flow-test analysis technique for this well.

For the derivation of the shortcut formula, Equation 2 was rewritten as

$$q + D'q^2 = C\Delta p \quad (4)$$

Where:

$C = 0.00708 k_w h / \mu_w [\ln(r_e/r_w) + s]$

$$D' = D / [\ln(r_e/r_w) + s] \quad (5)$$

It was assumed here that $\ln(r_e/r_w)$ and C remained virtually constant before fracturing occurred. This is a reasonable assumption as long as q in a given step is much larger than q in the preceding step. Selecting two such steps (before indicated fracturing) as shown in Fig. 3, we wrote

$$q_1 + D'q_1^2 = C\Delta p_1 \quad (6)$$

$$q_2 + D'q_2^2 = C\Delta p_2 \quad (7)$$

Dividing (6) ÷ (7) gave:

$$D' = (q_2\Delta p_1 - q_1\Delta p_2) / (q_1^2\Delta p_2 - q_2^2\Delta p_1) \quad (8)$$

It should be emphasized that D' and D carry the same units, $(b/d)^{-1}$, but are not identical. They are related as shown in Equation 5. In the shortcut approach, pressure is finally plotted vs. $(q + D'q^2)$, as shown in Fig. 3.

In an alternate approach to solving the non-D'Arcy flow problem, we start with this equation:

$$q = \frac{0.00708 k_w h (\Delta p - \Delta p_f)}{\mu_w [\ln(r_e/r_w) + s]} \quad (9)$$

where $\Delta p = p_w - p_e$ and Δp_f is the friction loss which in turn is related to q as follows:

$$\Delta p_f = Bq^2 \quad (10)$$

In Equation 10, B is a function of the water density and the number and diameter of perforations that are open. Defining C as above, we then obtain from 9 and 10 for two rates, q_1 and q_2, before fracturing,

$$q_1 + BCq_1^2 = C\Delta p_1 \quad (11)$$

$$q_2 + BCq_2^2 = C\Delta p_2 \quad (12)$$

It is evident from an analogy to Equations 6 and 7 that BC=D'. It follows that we arrive in effect at the same solution, i.e., Equation 8, regardless of whether we start from Equation 2 or 9.

Multiple-rate flow test analysis

The technique of applying multiple-rate flow-test analysis to step-rate injectivity test data is based on the prin-

Table 2

Step-rate data during early part of test, Well No. 2

t, hr	q, b/d	p, psi	Data point	Step no. n	Odeh sum*	Δp†/q
0	0	642	–	–	–	–
0.5	100	720	a	1	−0.301	0.780
1.0	100	730	b	1	0	0.880
1.5	250	856	c	2	−0.110	0.856
2.0	250	874	d	2	0.120	0.928
2.25	750	1,143	e	3	−0.335	0.668
2.50	750	1,182	f	3	−0.112	0.720
3.00	750	1,216	g	3	0.124	0.765

*Oden sum $= [q_1 \log t + (q_2 - q_1) \log (t - t_1) + (q_3 - q_2) \log (t - t_2) + \ldots + (q_n - q_{n-1}) \log (t - t_{n-1})]/q_n$ (13)

†$(p - p_i)/q_n$ (14)

$p_i = 642$ psi

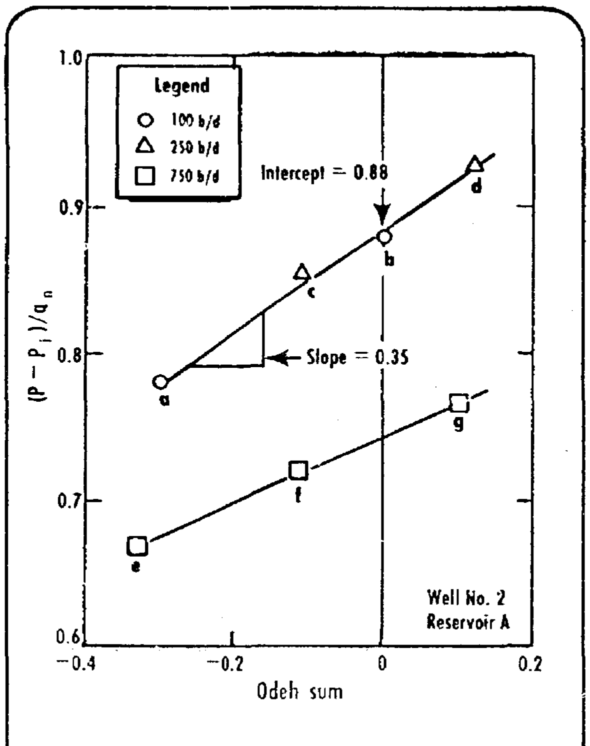
$t_1 = 1.0$ hr, $q_1 = 100$ b/d

$t_2 = 2.0$ hr; $q_2 = 250$ b/d

$t_3 = 3.0$ hr; $q_3 = 750$ b/d

Fig. 7

Odeh method of analysis



Standard step-rate graph as shown in Fig. 2

OGJ

ciple of "superposition." The technique, sometimes called the Odeh method, is well described in the literature for drawdown tests.[3,4] The equations presented in the literature can be used for the analysis of step-rate test data after making a change in sign and a change in symbol notations. Applicable equations and their use are presented in the following paragraphs.

The multiple-rate flow-test analysis technique determines k_wh and skin before fracturing. It is essential that good data are available. Also, the correct initial pressure, p_i, must be known. This is the pressure that represents the intercept of the p vs. q plot when $q = 0$. Note, for instance, that using this criterion gives a lower p_i for Well No. 4 (Fig. 4) than indicated by the first observed pressure.

The method can be applied in theory only to data taken during the early rate steps when radial flow is the predominant flow mechanism in the formation zone under investigation. This approach was used for the data of Well No. 2 (Fig. 2). Data for the end of each of the early steps and for one or more arbitrary points during each of these steps were tabulated as shown in the first three columns of table 2, shown at left.

Sample calculations. For data point a (Step 1):

Odeh sum $= q_1 (\log t)/q_1 = 100 (\log 0.5)/100 = -0.301$

$(p - p_i)/q_1 = (720 - 642)/100 = 0.78$

For data point g (Step 3):

$$\text{Odeh sum} = [q_1 \log t + (q_2 - q_1) \log (t - t_1) + (q_3 - q_2) \log (t - t_2)]/q_3$$

$$= [100 \log 3 + (250 - 100) \log (3 - 1) + (750 - 250) \log (3 - 2)]/750$$

$$= 0.124$$

$(p - p_i)/q_3 = (1{,}216 - 642)/750 = 0.765$

The last two columns of Table 2 were plotted in Fig. 7. From this graph we read slope, $m' = 0.35$, and intercept, $b' = 0.88$. Known also were: $\mu_W = 0.45$ cp, $B_W = 1.0$, $h = 270$ ft (from a radioactive tracer-injectivity survey), $\Phi = 0.186$, $c = 1.5 \times 10^{-5}$ psi^{-1}, and $r_w = 0.25$ ft.

$$k_wh = 162.6 \mu_W B_W / m' \quad (15)$$

$$k_wh = 162.6 \times 0.45 \times 1.0/0.35 = 209 \text{ md ft}$$

$$k_w = 209/270 = 0.77 \text{ md}$$

$$s = 1.151 \left[\frac{b'}{m'} - \log \frac{k_w}{\Phi \mu_W c r_w^2} + 3.23 \right] \quad (16)$$

$$s = 1.151 \left[\frac{0.88}{0.35} - \log \frac{0.77}{0.186 \times 0.45 \times 1.5 \times 10^{-5} \times 0.0625} + 3.23 \right]$$

$s = -1.4$

$$r_{we} = r_w e^{-s} \quad (17)$$

$r_{we} = 0.25 e^{1.4} = 1.0$ ft

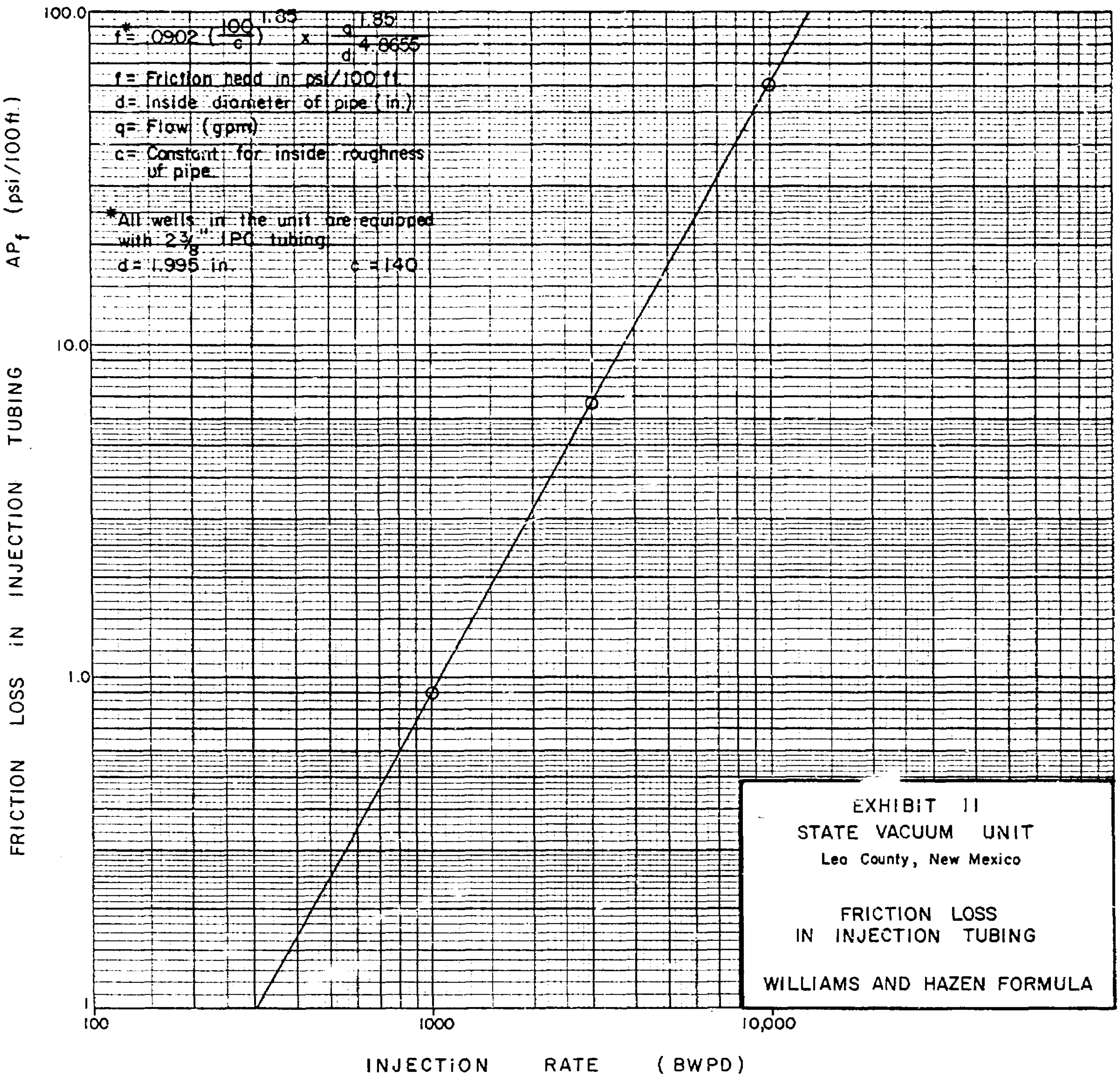
The data plotted in Fig. 7 show that the method broke down after point d was measured. That is, the following data points, e, f, and g, fell no longer on the old line. This was interpreted to indicate that radial flow was no longer the predominant flow regime and that fracturing had occurred.

Fracturing theory for diagnosis.

The theory[6,7] used in drawing the dashed lines in Fig. 6 is expressed by the equation:

$$p_f/Z = [(S/Z) - (p_e/Z)] [\mu/(1 - \mu)] + p_e/Z \quad (18)$$

The Poisson's ratio, ν is the ratio of maximum lateral deformation to maximum longitudinal deformation observed during compression loading of rock samples. A low ratio is generally associated with dense, brittle rock and a higher ratio with more elastic rock. The overburden pressure gradient, S/Z, used in constructing the theoretical curves of Fig. 6, was 1.0 psi/ft of depth. Other terms are defined in the nomenclature.



f* = .0902 (100/c)^1.85 x q^1.85 / d^4.8655
f = Friction head in psi/100 ft.
d = Inside diameter of pipe (in.)
q = Flow (gpm)
c = Constant for inside roughness of pipe
*All wells in the unit are equipped with 2⅜" IPC tubing.
d = 1.995 in.
c = 140
100.0
10.0
1.0
1
100
1000
10,000
FRICTION LOSS IN INJECTION TUBING AP_f (psi/100 ft.)
INJECTION RATE (BWPD)
EXHIBIT 11
STATE VACUUM UNIT
Lea County, New Mexico
FRICTION LOSS IN INJECTION TUBING
WILLIAMS AND HAZEN FORMULA

AtlanticRichfieldCompany
North American Producing Division
Permian District
Post Office Box 1610
Midland, Texas 79701
Telephone 915 682 8631

May 19, 1978

Oil Conservation Division of the
New Mexico Department of
Energy and Minerals
P. O. Box 2088
Santa Fe, New Mexico

Attn: Mr. Ramey

Re: Case No. 5762; Order No. R-5295
Atlantic Richfield Company
State Vacuum Unit
Waterflood Project
T-17S, R-34E, Lea County, New Mexico

Dear Mr. Ramey:

In the Order establishing the waterflood project, wellhead injection pressure was limited to 860 psi. Approval of a higher wellhead pressure could be obtained by showing that the increase in pressure would not fracture the confining strata. As operator of the State Vacuum Unit, Atlantic Richfield Company applies for administrative approval of a wellhead injection pressure of 1134 psi. The attached exhibits are offered as evidence that this pressure will not fracture the confining strata.

The exhibits are based on pressure parting tests run on April 24-26, 1978. Exhibit 1 is a map of the unit area showing the seven injection wells which were tested. Insufficient pump capacity on Well No. 9 prevented the use of data from the test. The remaining six wells indicated a range of surface parting pressures from 1234 psi to 2101 psi as shown on Exhibit 2. Necessary equipment and well data is included on Exhibit 3.

The paper "Step-Rate Tests Determine Safe Injection Pressures in Floods" (Exhibit 10) was used as a reference to help determine proper testing procedures and analysis methods. The tests were run by Atlantic Richfield Company using a downhole pressure recorder and a Hallibruton turbine flowmeter. Individual well data and results are shown in Exhibits 4 through 9.

Some injection wells exhibit non-D'Arcy flow characteristics which prevents determination of the parting pressure by the normal rate vs. pressure graphical technique. Two of the wells

tested exhibited this behavior. By using the technique outlined in the reference paper ($q + Dq^2$) parting pressures were determined for the two wells and are included as Exhibits 4A and 5A. Exhibit 11 is a graphical solution of the Williams and Hazen formula for determining the pressure drop due to friction in the injection tubing. Data for the individual wells is listed on Exhibit 2.

At the current limiting pressure of 860 psi, injection rates in the unit have begun to decline. We feel that an increased wellhead injection pressure is necessary if we are to maintain adequate injection rates to promote the timely production of the secondary reserves in the unit. Our application for administrative approval of a wellhead injection pressure of 1134 psi should insure that we are not fracturing the formation strata but also allow us to increase our current injection rates. We will gladly forward any additional information which may be required and ask for your prompt consideration.

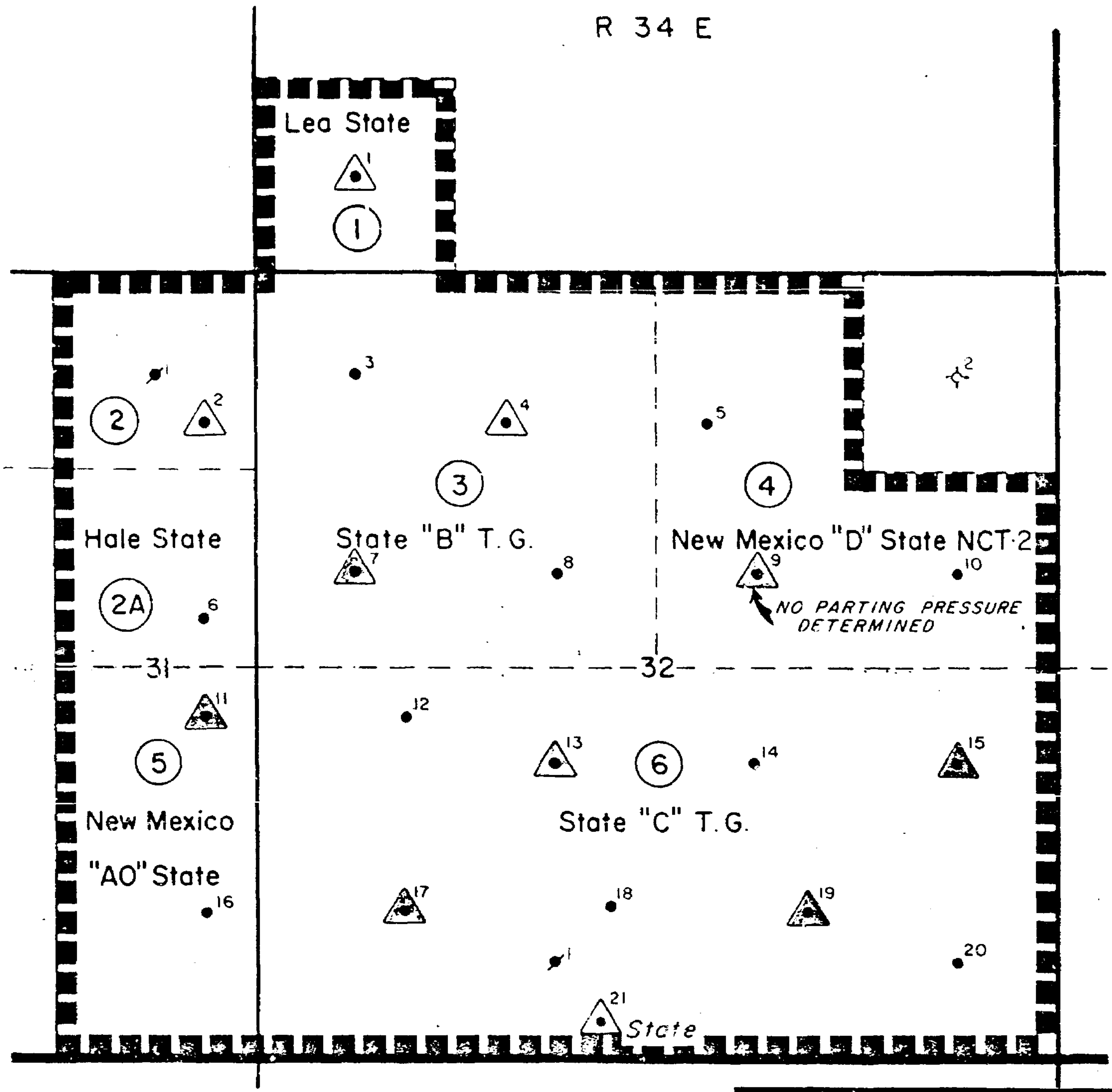
Very truly yours,

J L Tweed

J. L. Tweed

MG/agp

EXHIBIT 1



UNIT BOUNDARY

TRACT NUMBER

INJECTOR

PRODUCER

INJECTOR – TESTED

AtlanticRichfieldCompany

STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO

FORMATION
PARTING TESTS
INJECTION WELLS

Scale: 1"=1000'

MIKE GRIFFIN 4-22-76
WEST AREA ENGR.

STATE VACUUM UNIT

PRESSURE PARTING TESTS

WELL NO.	CUM. INJ. 3/1/78 (MB)	PRESS. BOMB SETTING DEPTH (FT)	HYDROSTATIC[1] HEAD P_h (PSI)	INJ. RATE @ PART. PRESS. (BPD)	PRESS. DROP-FRICTION[2] ΔP_f (PSI/100 FT)	ΔP_f-TOTAL @ SETTING DEPTH (PSI)	BTM. HOLE PTG. PRESS. (PSI)	SURF. PTG.[3] PRESSURE (PSI)	PTG. GRADIENT (PSI/FT)
7	119.5	4671	2022.5	1700	2.34	109.3	3305	1391.8	.707
11	94.7	4693	2032.1	2050	3.32	155.8	3200	1323.7	.682
13	54.1	4660	2017.8	1530	1.91	89.0	4030	2101.0	.865
15	173.5	4636	2007.4	2630	5.20	241.1	3478	1711.7	.750
17	17.5	4721	2044.2	1000	0.86	40.7	3238	1234.5	.686
19	98.1	4692	2031.6	1610	2.12	99.5	3446	1513.5	.734

1. Injection water has specific gravity equal to 1.001; pressure gradient = .433 psi/ft.
2. Taken from Exhibit 11 (Williams and Hazen formula).
3. Surface Parting Pressure = Bottom Hole Parting Pressure - Hydrostatic head + ΔP_f

STATE VACUUM UNIT
Pressure Parting Tests
Injection Well Data

WELL NO.	COMPLETION CASING SIZE (DEPTH)	TUBING SIZE* IN.	DEPTH SET	PERFORATIONS
7	3½" liner (4426-4728)	2-3/8"	4426'	4671-4718'
11	3½" liner (4242-4768)	2-3/8"	4242'	4693-4734'
13	3½" liner (4241-4717)	2-3/8"	4241'	4660-4710'
15	3½" liner (4249-4708)	2-3/8"	4249'	4636-4686'
17	3½" liner (4429-4761)	2-3/8"	4429'	4721-4761'
19	3½" liner (4416-4750)	2-3/8"	4416'	4692-4742'

*All tubing is internally plastic coated.

EXHIBIT 4

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/24/78

WELL NUMBER: 7

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4671'

TIME/ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:44	0	2448	560
1:00	200	2503	650
1:10	400	2569	725
1:20	600	2649	800
1:30	800	2739	900
1:40	1000	2864	1025
1:50	1200	2972	1125
2:00	1400	3101	1325
2:10	1600	3236	1475
2:20	1800	3358	1725
2:30	2000	3455	1875
2:40	2200	3563	2050
2:50	2400	3649	2200
2:56	3200	3782	2500
3:02	3600	3866	2775

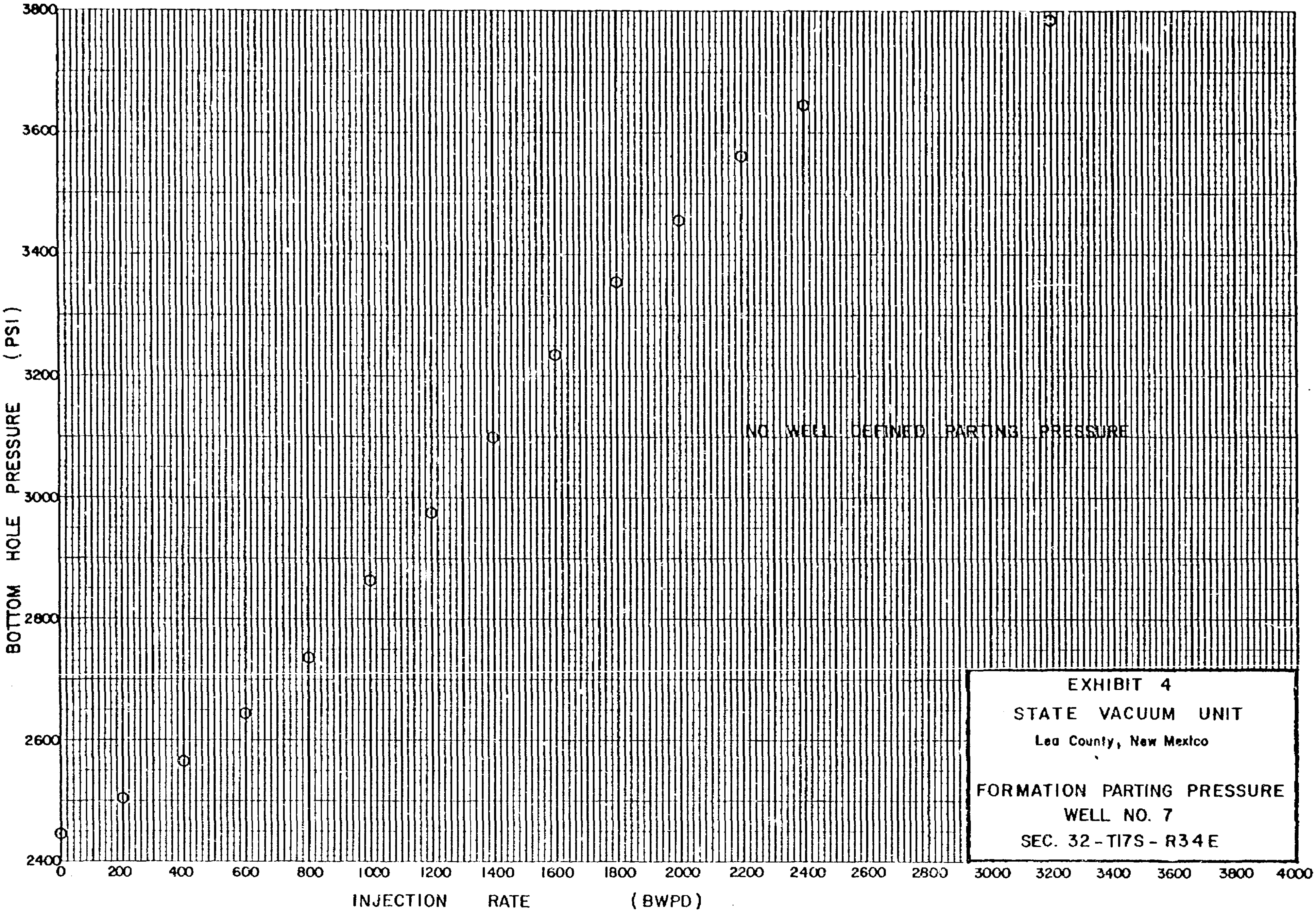


EXHIBIT 4

STATE VACUUM UNIT

Lea County, New Mexico

FORMATION PARTING PRESSURE

WELL NO. 7

SEC. 32 - T17S - R34E

STATE VACUUM UNIT
Formation Parting Pressure
Non D'Arcy Flow Technique
Well No. 7

From Exhibit 10:

$$D = (q_2 \Delta P_1 - q_1 \Delta P_2)/(q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: $q_1 = 200$ BPD; $P_1 = 2503$ psi

$q_2 = 400$ BPD; $P_2 = 2569$ psi

$$D = .000555 \text{ B/D}^{-1}$$

INJECTION RATE (BPD)	BHP @ TEST DEPTH (PSI)	$q + Dq^2$ (BPD)
0	2448	
200	2503	222
400	2569	489
600	2649	800
800	2739	1155
1000	2864	1555
1200	2972	1999
1400	3101	2488
1600	3236	3020
1800	3358	3598
2000	3455	4220
2200	3563	4886
2400	3649	5597
3200	3782	8883
3600	3866	10793

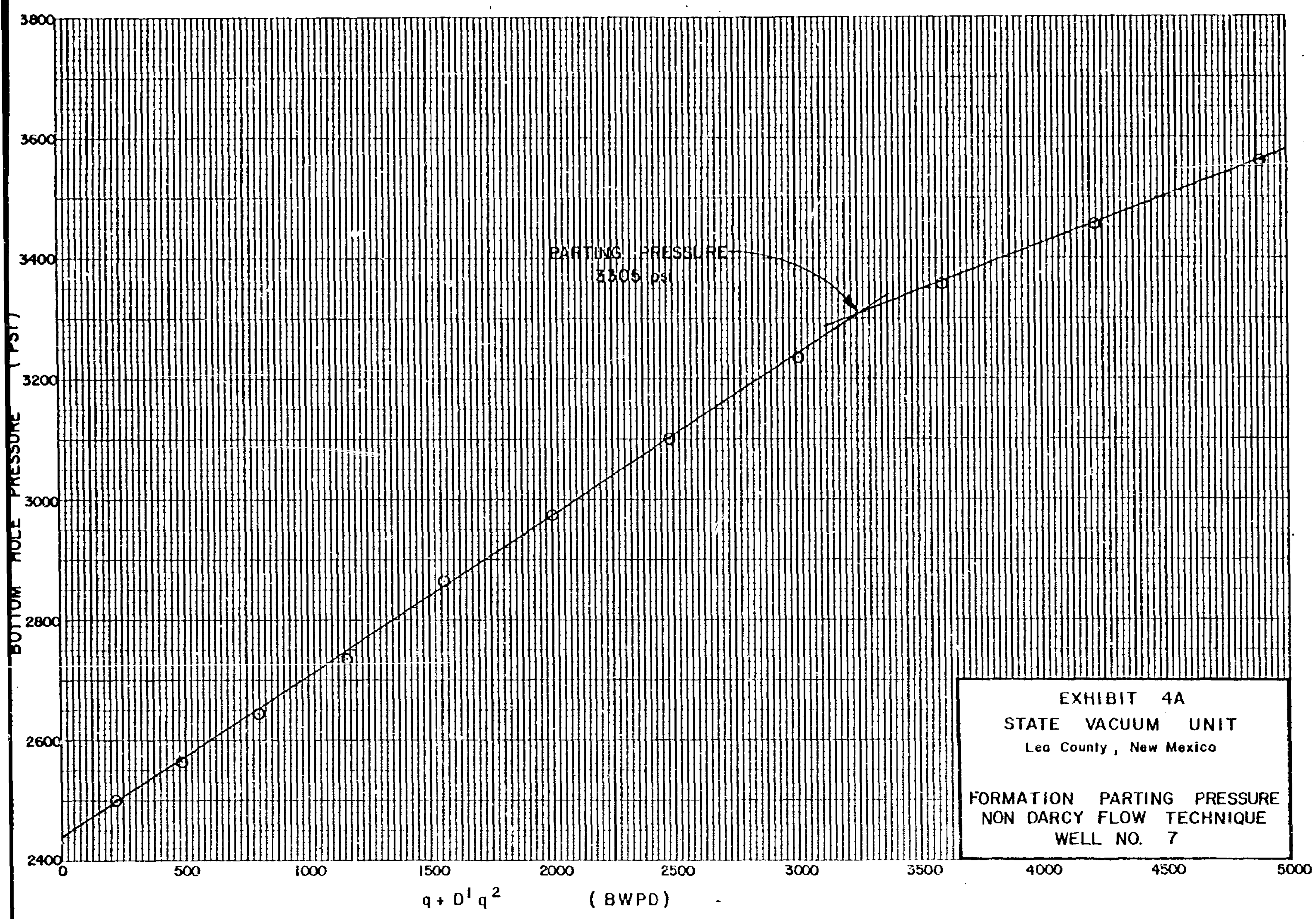

BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
q + D' q²   (BWPD)
PARTING PRESSURE
3305 psi
EXHIBIT 4A
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
NON DARCY FLOW TECHNIQUE
WELL NO. 7

EXHIBIT 5

STEP RATE TEST REPORT

LEASE: STATE-VACUUM

DATE OF TEST: 4/25/78

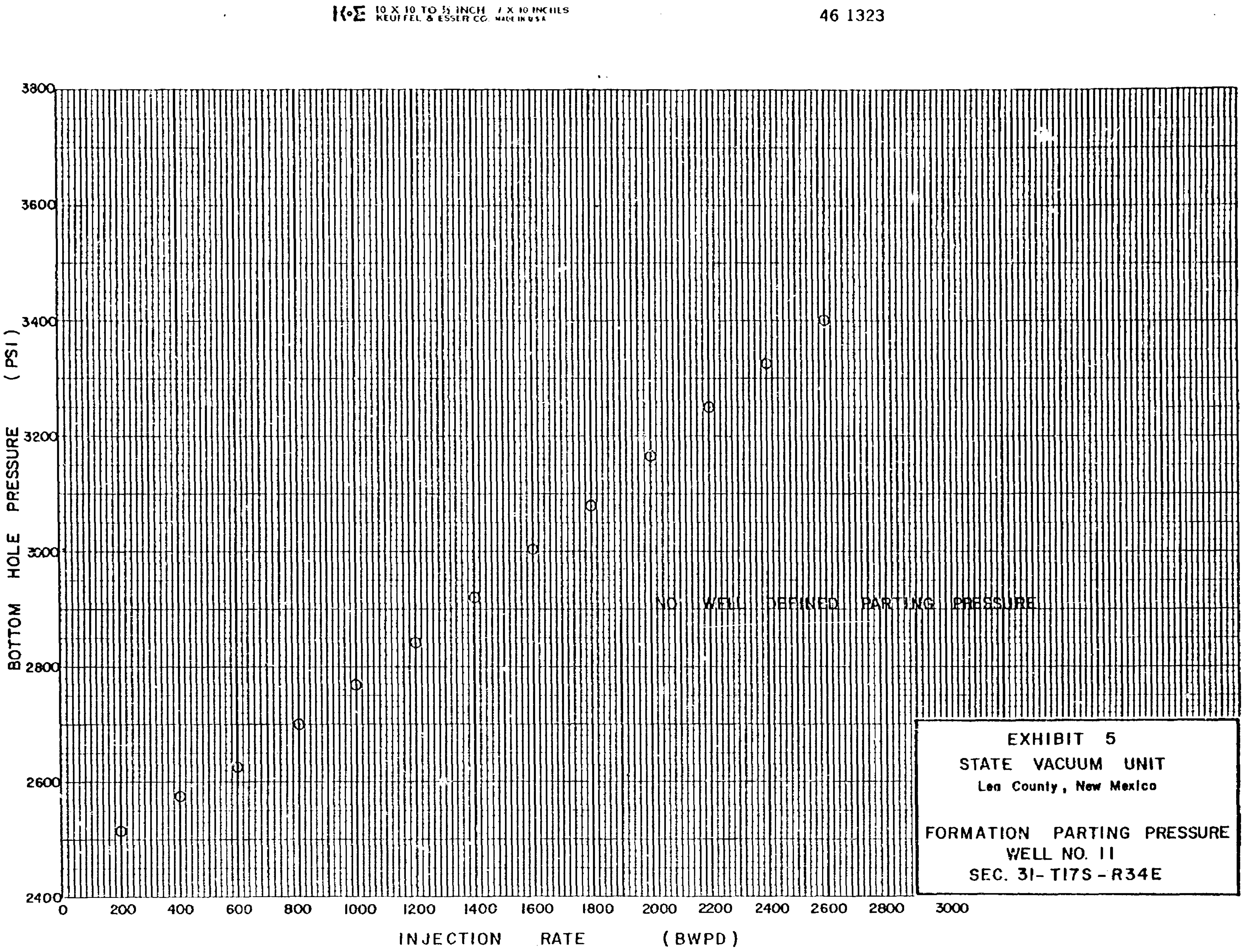
WELL NUMBER: 11

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4693'

TIME/ AM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
8:34	0	2433	
8:50	200	2518	650
9:00	400	2577	700
9:10	600	2624	725
9:20	800	2701	825
9:30	1000	2767	950
9:40	1200	2842	1050
9:50	1400	2922	1175
10:00	1600	3004	1280
10:10	1800	3080	1400
10:20	2000	3166	1410
10:30	2200	3252	1490
10:40	2400	3322	1550
10:50	2600	3402	1640


K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
INJECTION RATE (BWPD)
NO WELL DEFINED PARTING PRESSURE
EXHIBIT 5
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 11
SEC. 31-T17S-R34E

STATE VACUUM UNIT
Formation Parting Pressure
Non D'Arcy Flow Technique
Well No. 11

From Exhibit 10:

$$D = (q_2 \Delta P_1 - q_1 \Delta P_2)/(q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: $q_1 = 600$ BPD; $P_1 = 2624$ psi

$q_2 = 800$ BPD; $P_2 = 2701$ psi

$D = .000311\ B/D^{-1}$

INJECTION RATE (BPD)	BHP @ TEST DEPTH (PSI)	$q + Dq^2$ (BPD)
0	2433	
200	2518	212
400	2577	450
600	2624	712
800	2701	999
1000	2767	1311
1200	2842	1648
1400	2922	2009
1600	3004	2396
1800	3080	2807
2000	3166	3244
2200	3252	3705
2400	3322	4192
2600	3402	4702

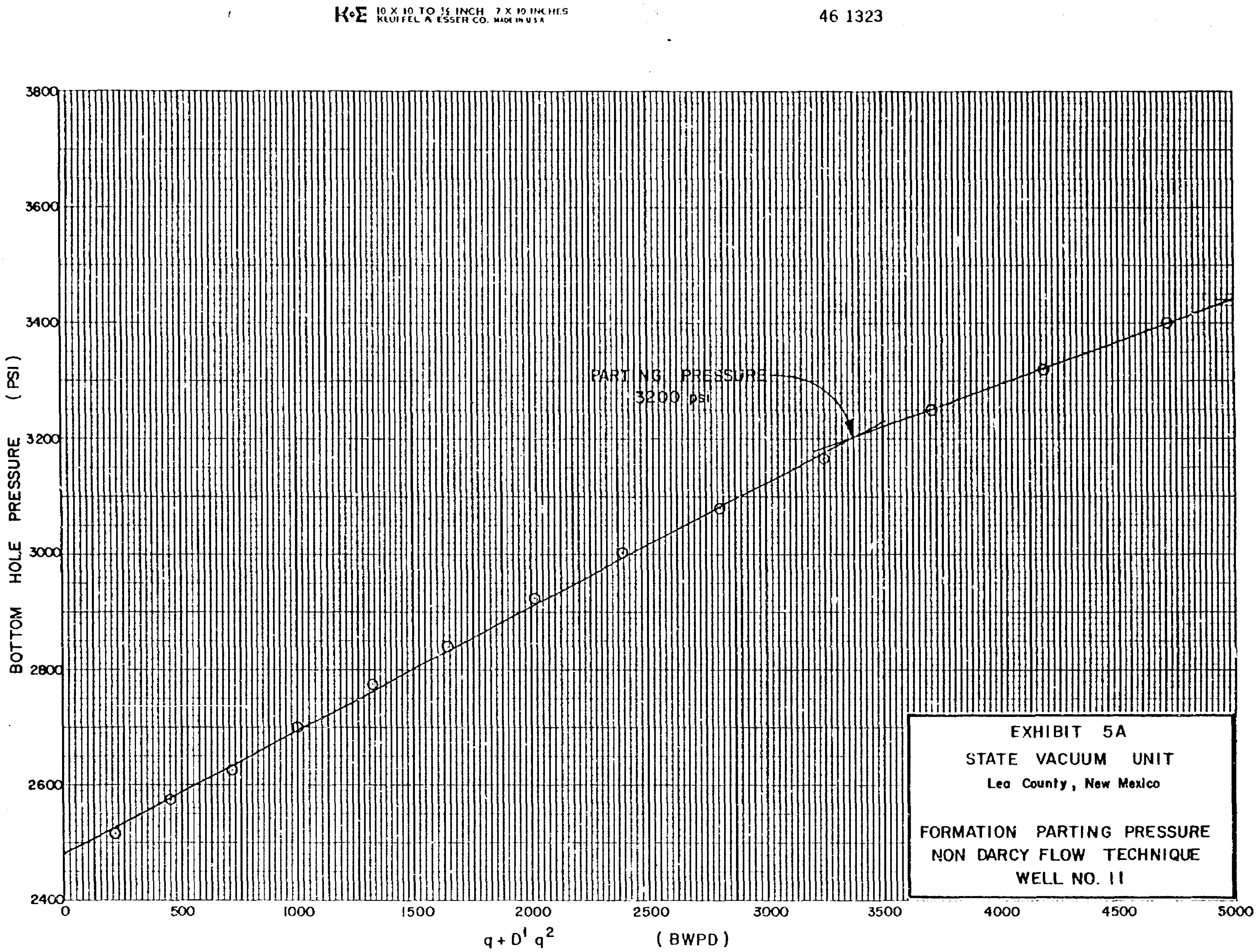


EXHIBIT 5A

STATE VACUUM UNIT

Lea County, New Mexico

FORMATION PARTING PRESSURE

NON DARCY FLOW TECHNIQUE

WELL NO. 11

EXHIBIT 6

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/26/78

WELL NUMBER: 13

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4660'

TIME/ ~~AM~~ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:16	0	2392	540
12:25	200	2551	715
12:35	400	2725	850
12:45	600	2917	1050
12:55	800	3164	1415
1:05	1000	3420	1700
1:15	1200	3662	1990
1:25	1400	3885	2190
1:35	1600	4055	2490
1:45	1800	4169	2580
1:55	2000	4263	2740
2:05	2200	4343	2860

K+E 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1323

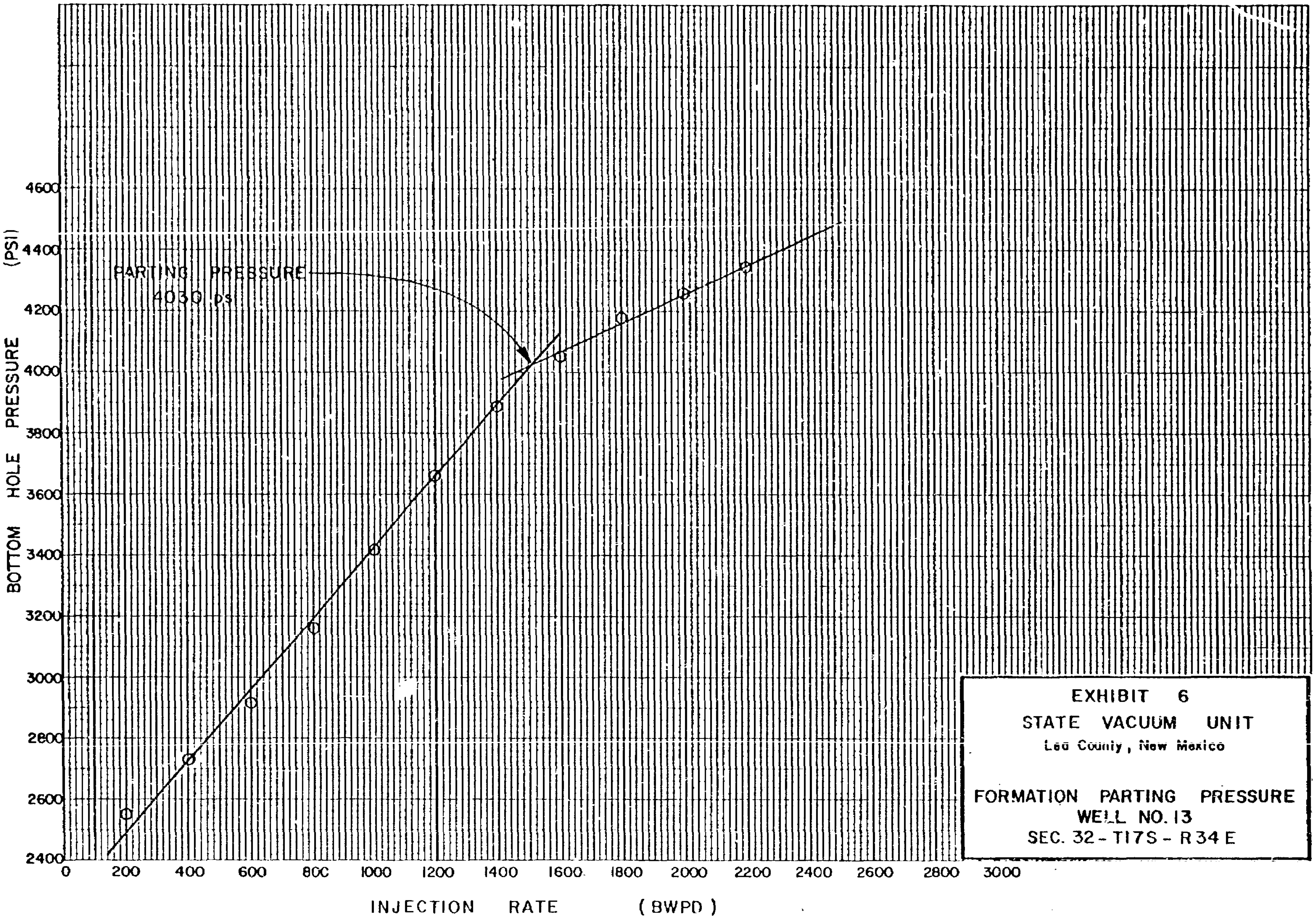


EXHIBIT 7

STEP RATE TEST REPORT

LEASE: STATE-VACUUM

DATE OF TEST: 4/25/78

WELL NUMBER: 15

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4636'

TIME/ ~~AM~~ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
2:45	0	2008	160
2:55	600	2230	350
3:05	1000	2460	625
3:15	1400	2724	925
3:25	1800	3010	1250
3:35	2200	3243	1575
3:45	2600	3420	1840
3:55	3000	3572	2120
4:05	3400	3663	2300
4:15	3800	3772	2500

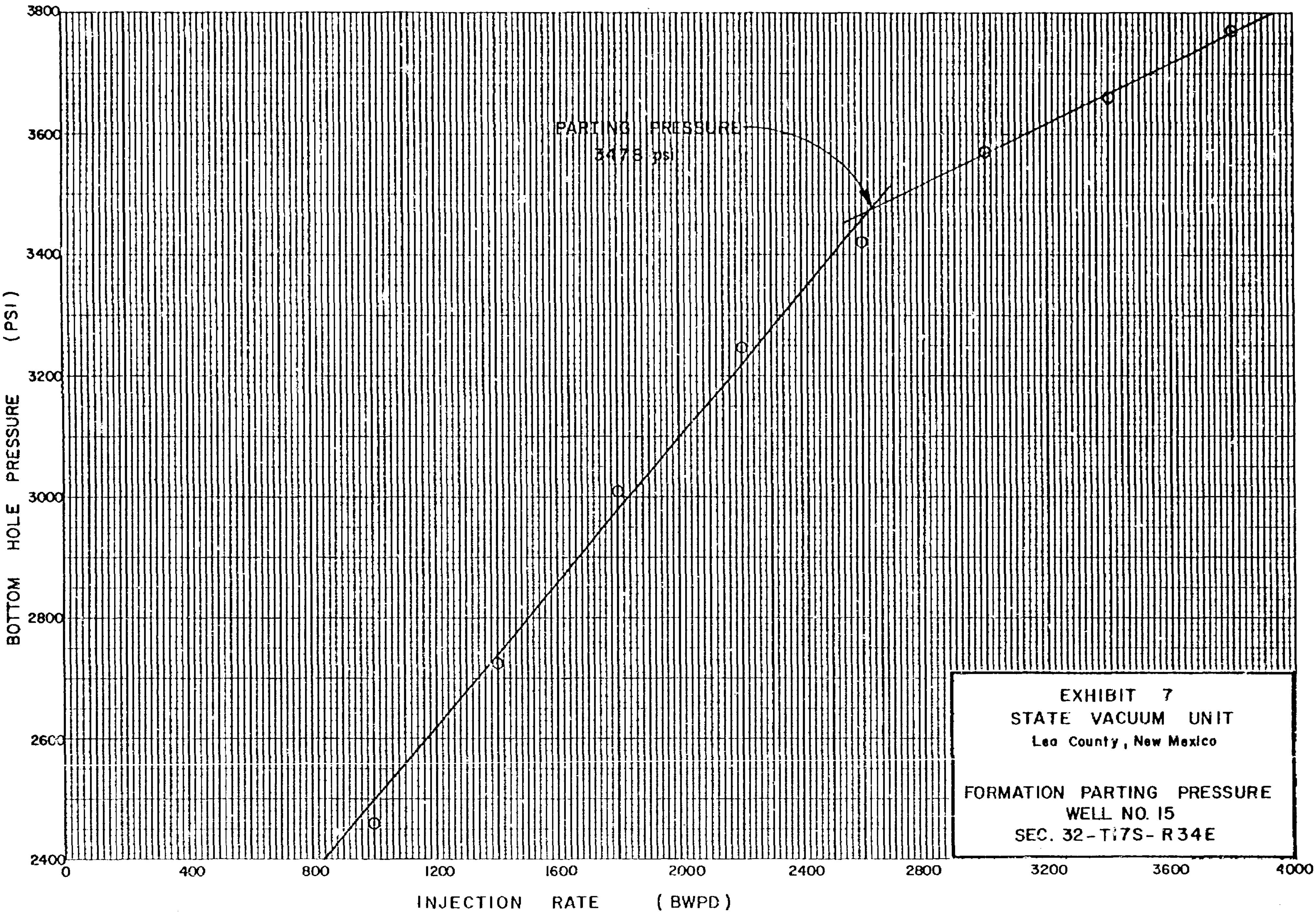


EXHIBIT 7
STATE VACUUM UNIT
Lea County, New Mexico

FORMATION PARTING PRESSURE
WELL NO. 15
SEC. 32-T17S-R34E

EXHIBIT 8

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/25/78

WELL NUMBER: 17

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4721'

TIME/ AM PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:50	0	2477	569
12:05	200	2670	780
12:15	400	2854	930
12:25	600	2973	1120
12:35	800	3117	1280
12:45	1000	3239	1445
12:55	1200	3312	1555
1:05	1400	3390	1665
1:15	1600	3462	1785
1:25	1800	3531	1890
1:35	2000	3585	2000

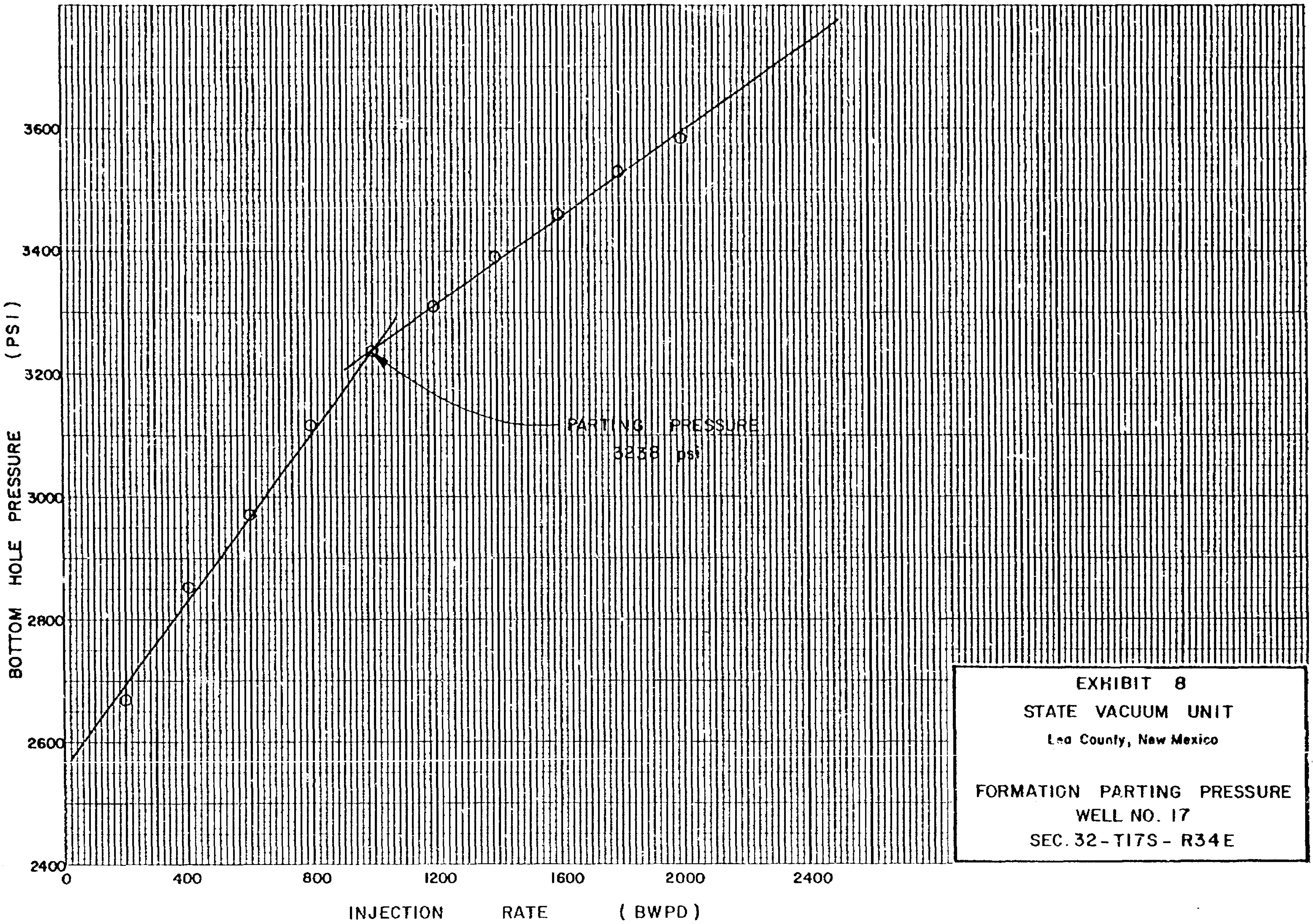

BOTTOM HOLE PRESSURE (PSI)
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
INJECTION RATE (BWPD)
PARTING PRESSURE
3238 psi
EXHIBIT 8
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 17
SEC. 32-T17S-R34E

EXHIBIT 9

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/26/78

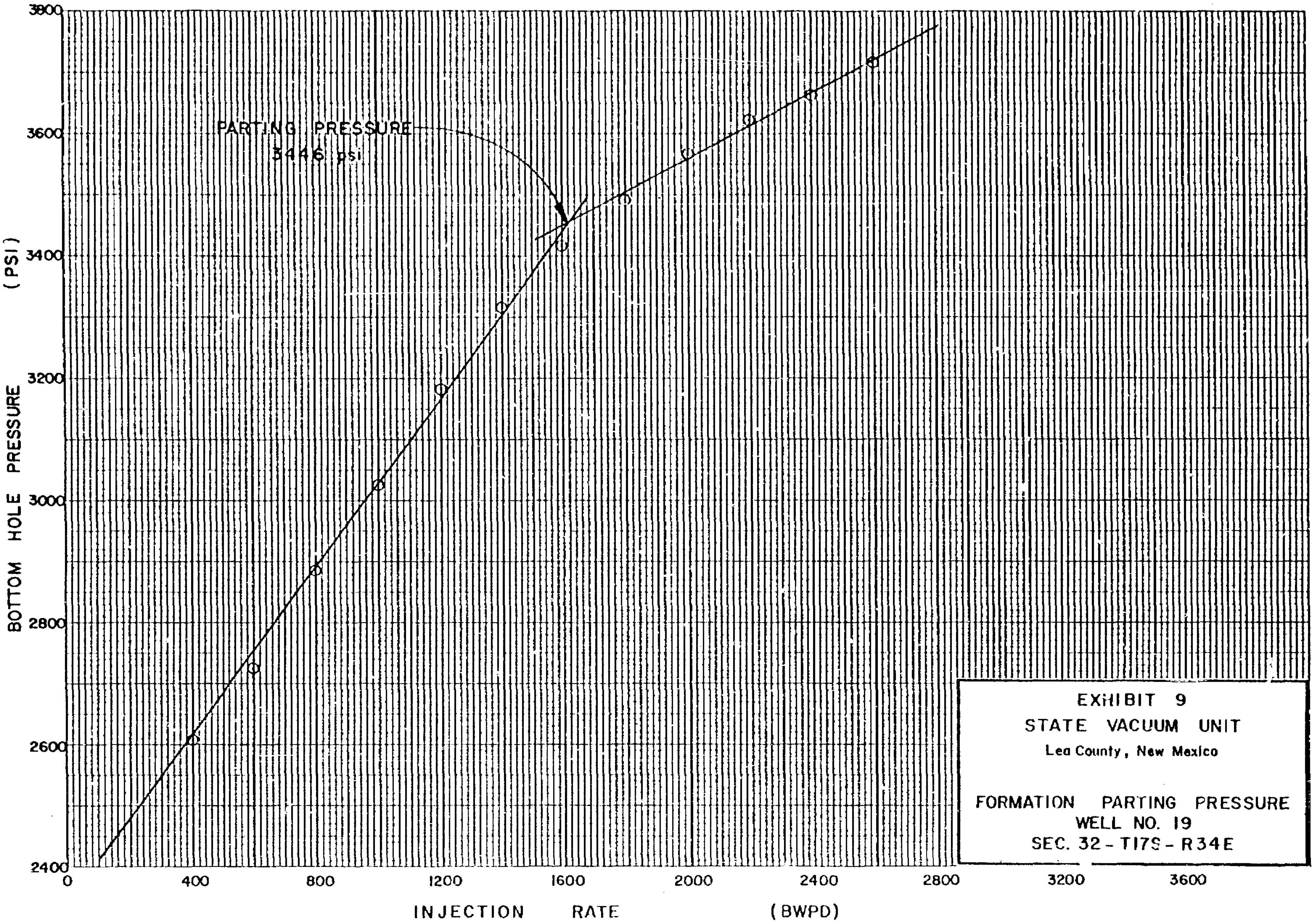
WELL NUMBER: 19

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4692'

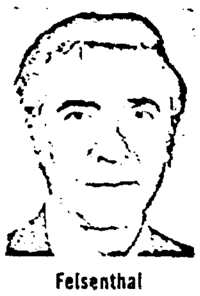
TIME/ AM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
9:01	0	2460	500
9:15	200	2336	500
9:25	400	2607	600
9:35	600	2724	750
9:45	800	2887	920
9:55	1000	3027	1080
10:05	1200	3181	1260
10:15	1400	3314	1430
10:25	1600	3415	1600
10:35	1800	3491	1700
10:45	2000	3565	1840
10:55	2200	3622	1940
11:05	2400	3666	2020
11:15	2600	3715	2110


PARTING PRESSURE
3446 psi
BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
2800
3200
3600
INJECTION RATE (BWPD)
EXHIBIT 9
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 19
SEC. 32 - T17S - R34E

Step-rate tests determine safe injection pressures in floods

The author . . .

Martin Felsenthal is a senior research engineer with Continental Oil Co. in Ponca City, Oklahoma. He works in the areas of formation evaluation, waterflooding and tertiary recovery. A petroleum engineering graduate from University of California, he also holds an MS from Penn state.



Felsenthal

STEP-RATE injectivity tests can define the maximum safe injection pressures that can be used without fracturing the reservoir rock.

This information is important in waterfloods. It is of critical importance in tertiary-recovery projects where we cannot afford to lose costly injection fluids through uncontrolled induced fractures.

Recently, we tried the step-rate test in a number of projects. Although the test concept is simple, results were conclusive only if proper procedures and equipment were used. From this experience, a recommended procedure has been developed.

This article presents the recommended procedure and shows typical data.

A remarkable point brought out by these data is that formations sometimes fracture near hydrostatic head in pressure-depleted reservoirs.

The procedure. The early literature references [1,2] generally talked about pressure parting rather than fracturing during step-rate injectivity tests. It was pointed out, however, at the outset that the two expressions are synonymous.

The test well should be shut in long enough so that the bottom-hole pressure is near the shut-in formation pressure. The step-rate injectivity test that follows consists of a series of constant-rate injections with rates increasing from low to high in stepwise fashion.

In tight formation ($K_{air} \sim 5md$) each step should last 60 min. Shorter time spans can be used in higher-permeability formations as shown in Table 1 of the appendix. The time-step duration itself is not critical. It only should be reasonably close to the recommended values shown. Also, each step should last exactly as long as the preceding step.

In selecting rates for the test, one possible rule of thumb is to use 5, 10, 20, 40, 60, 80, and 100% of the desired maximum test rate. The above schedule may be varied to suit the conditions of the test. For instance, it may be difficult to control accurately a very low rate in which case, the test may be started at a somewhat higher rate than shown above.

Equipment. Injection rates during the test should be controlled with a constant flow-rate regulator. We have used regulators made by three different companies and obtained useful data. All regulators should be tested before use.

Use of a throttling valve as a flow-rate regulating device is not recommended. Reason is that this valve acts like an orifice. Pressures and rates will thus interact continuously during the transient flow conditions of each rate step. Consequently, as well pressures rise, injection rates will tend to decline.

Flow rates should be measured with a turbine flowmeter and a rate meter such as those made by Halliburton. It is advisable to calibrate this equipment by timing flow into a 5-gal container (b/d = 10,286 ÷ seconds to fill a 5-gal container).

In critically important tests, it is advisable to record rates throughout the test. For this purpose, we have fed a signal from a rate meter through a dampening circuit to a strip-chart recorder. Use of a rate recorder is desirable but not mandatory.

Our experience has shown that best results were obtained when pressures were measured with a down-hole instrument. For instance, we used

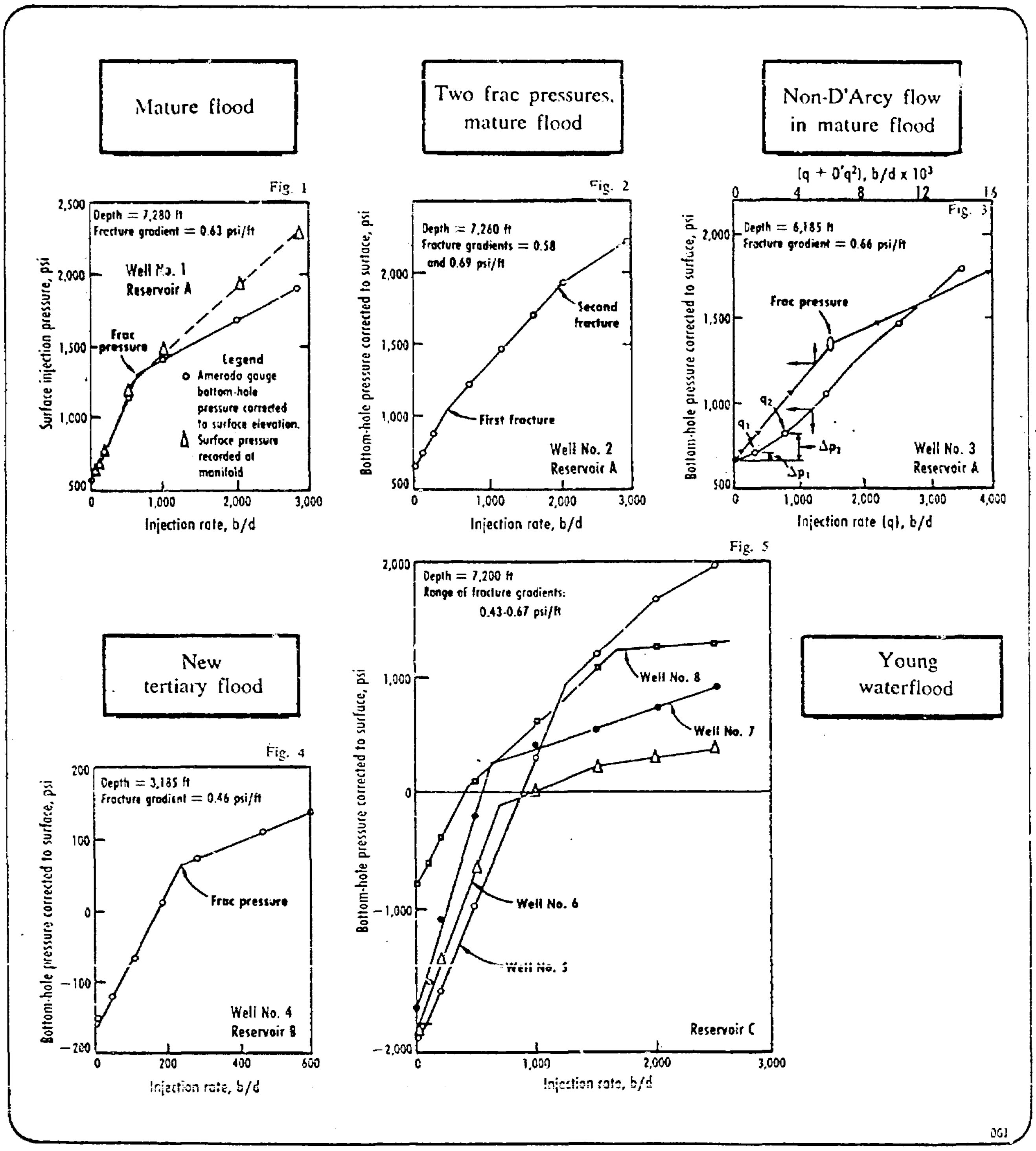
Amerada-type pressure-recording devices in all tests shown in Figs. 1-5. Other down-hole devices may be equally suitable. In addition, it is advisable to observe surface pressures with a surface gage or recorder. We found that it is often difficult to obtain very accurate surface-pressure readings because of surges from the injection pump. Nevertheless, surface pressures are useful in many tests for on-the-spot analysis, while the test is in progress. Final test analysis, however, should be based on down-hole pressure data.

Data analysis. The pressures at the start of the test (at q = 0) and at the end of each injection-rate step are plotted against injection rates as in Fig. 1. Shown are down-hole pressures corrected to the surface elevation of the well and pressures recorded at the surface. The difference in the two pressures is mainly due to friction losses in the pipes.

When the data show that it takes a smaller pressure increment for a unit-rate change, we generally infer that fracturing has taken place. Thus, the data of Fig. 1 indicate that Well

Figs. 1-5

Step-rate tests on old and new floods



No. 1 fractured at about 1,300 psi surface pressure.

Sometimes two breaks are indicated in the pressure-vs-rate plots. Each break could represent a separate fracture. For instance, data for Well No. 2 (Fig. 2) indicate a first fracture at a surface pressure of 1,050 psi and a second and more-severe fracturing condition at 1,900 psi.

Occasionally, pressure-vs-rate plots do not form a straight line but form a curve with a distinctive upward curvature near the origin as shown in Fig. 3. The best explanation for this is non-D'Arcy flow downstream from the pressure-measuring device. This implies that there is probably a sizable pressure drop across the perforations or other orifice-like obstructions. An added resistance is created that is proportional to the square of the injection rate. Thus, we observed we could not interpret the step-rate data for Well No. 3 from a standard pressure-vs-rate (q) plot but could do so from a plot of pressure vs. $q + Dq^2$ (A method for determining D is given in the appendix). Data in Fig. 3 indicate that the fracturing pressure was about 1,300 psi in Well No. 3.

In some pressure-depleted reservoirs, initial pressures are lower than hydrostatic head. Such a situation occured during the tests illustrated in Figs. 4 and 5. Down-hole rates at the end of the early steps were somewhat smaller in these tests than rates measured at the surface because of rising fluid levels in the wells. Appropriate corrections for this condition had to be made before the data could be analyzed.

Complementary techniques. Pressure-falloff tests are generally a good source of information on permeability capacity, probable presence of fractures, skin and nearness to faults or barriers.[4] An excellent opportunity generally exists for conducting this type of test while the test well is being shut in before step-rate testing. If the skin calculated from such a test is definitely negative, we can infer that we probably have a fracture. One way to find out whether the fracture is natural or induced is to reduce the injection pressure for some time, say 1 month, and then run another pressure-falloff test. If the skin is closer to zero in the second test, we can conclude that an induced fracture tended to close.

Permeability capacity and skin (before fracturing) can also be evaluated directly from step-rate test data using a multiple-rate flow-test analysis technique.[3,4] A prerequisite to this technique is great care to keep rates constant in each step and to obtain accurate data. Use of the technique is illustrated in the appendix.

Step-rate tests and pressure-falloff tests give virtually no information about fluid-injection distribution. For diagnosing the formation characteristics near injection wells, in a vertical dimension, injectivity-profile tests are needed. These tests are very useful and popular. Results obtained from them can beneficially supplement results obtained from step-rate and pressure-falloff tests. Especially helpful for this purpose are radioactive tracer injection and/or temperature decay surveys (Absolute temperature profile while injecting, followed by absolute temperature profiles after shutin of injection).

Typical data. Typical pressure-vs-rate plots are shown in Figs. 1-5. The remarkable feature brought out by the last two figures is that the fracturing pressure was near hydrostatic head for most of the wells tested in the pressure-depleted reservoirs B and C. It was even slightly below the hydrostatic head in one well (No. 6, Fig. 5).

To place the data presented so far into perspective, a plot of fracturing gradients vs. shut-in formation pressure/depth ratios was prepared for wells from six formations. The resulting graph (Fig. 6) covers a wide range of prior injection histories, lithology, depths, geographic distribution (five states), geologic ages (Mississippian to Pliocene), and shut-in formation pressure/depth ratios.

Note that fracturing gradients ranged from 0.43 psi/ft to 0.93 psi/ft with the higher gradients generally occurring at the higher shut-in formation pressure/depth ratios. This trend of increasing fracturing gradients with shut-in formation pressure is in agreement with observations reported in several literature references.[5-8] This trend is especially well illustrated in Fig. 6 by the data for reservoir D (solid circles denote data taken in the first month of the flood and open circles denote data taken in the same wells 6 months later). These data indicate that fracturing pressures should be reevaluated periodically.

Vertical arrows in Fig. 6 connect first fracturing indications with second fracturing indications during the same test in the same well. (Details for Well No. 2 are shown in Fig. 2 and for Well Nos. 5, 6, and 8 in Fig. 5.) A preferred interpretation for this is that a first fracture occurred in comparatively hard, brittle rock and a second fracture in softer and more plastic rock.

The dashed lines shown in Fig. 6 show a comparison with a prevalent fracturing theory[6,7] (explained in the appendix). This presentation does not exclude the possibility that a refinement of this theory or some other theory would result in a better fit of the curves and data points.

Numbers on the dashed lines in Fig. 6 are Poisson's ratios. It has been speculated in the literature[8] that data points coinciding with relatively high Poisson's ratios (greater than 0.35) might be indicative of fracture extension through plastic cap-rock shales. This view is unconfirmed, however, at this time, because injectivity profiles, particularly temperature-decay surveys, were not made at the time (or close to the time) when the step-rate tests associated with high Poisson's ratios were made.

Will test damage formation? A study of field records for injection Wells Nos. 1-8 (Figs. 1-5) showed that earlier injection pressures exceeded the maximum pressure used during the step-rate tests. The theory of rock mechanics indicates that fractures once opened will tend to close again when the injection pressure is reduced below the fracturing pressure. What is happening is that the net effect of the overburden becomes stronger than the force that tends to keep an unpropped, induced fracture open. This is the mechanism that apparently occurred before step-rate testing in Wells Nos. 1-8.

No damage can conceivably be caused by step-rate tests in old waterfloods as long as the injection pressure during the tests does not exceed injection pressures used earlier during the waterflood history and as long as high-quality injection water is used. In a new waterflood, a typical well should be selected for a step-rate test. In this well, one should use only low and moderate injection rates until a fracturing pressure is definitely established. Later tests should be designed so that they do not greatly

exceed this pressure for any appreciable length of time (more than a few hours).

Acknowledgments

I am indebted to H. C. Walther for guidance and constructive criticisms, to H. A. Wahl for valuable suggestions, and to R. C. Cooper, Wayland Edwards, Dell Conley, and R. A. Strode for assistance in data collection and analysis.

Nomenclature

b' = Odeh intercept

B = Constant, psi/(b/d)^2

B_W = Water formation volume factor, RB/st-tk bbl

c = Total compressibility, psi^{-1}.

C = Constant, (b/d)/psi

D = Non-D'Arcy flow constant, (b/d)$^{-1}$

D' = Another non-D'Arcy flow constant related to D as explained in equation 5, (b/d)$^{-1}$

h = Net effective pay, ft

K_{air} = Absolute permeability to air, md

k_{rw} = Relative permeability to water

k_w = Effective permeability to water, md

m' = Odeh slope

n = Step number in step-rate test

p = Pressure during step-rate test at time t, psi

p_e = Shut-in formation pressure, psi

P_f = Fracturing pressure related to same elevation as p_e, psi

p_i = True initial pressure during step-rate test, defined by intercept of p vs. q plot when q = o, psi

p_W = Bottom-hole pressure in well, psi

Δp = Difference in pressures, psi

Δp_f = Friction loss through perforations or slots, psi

q = Injection rate, b/d

r_e = Outer radius of pressure influence, ft

r_W = Well-bore radius, ft

r_{We} = Effective well-bore radius, ft

s = Skin factor, dimensionless

s' = Apparent skin factor, dimensionless

S = Overburden pressure, psi

t = Time since start of test, hr.

t_n = Time at end of step n of step-rate test, hr

Z = Depth, ft

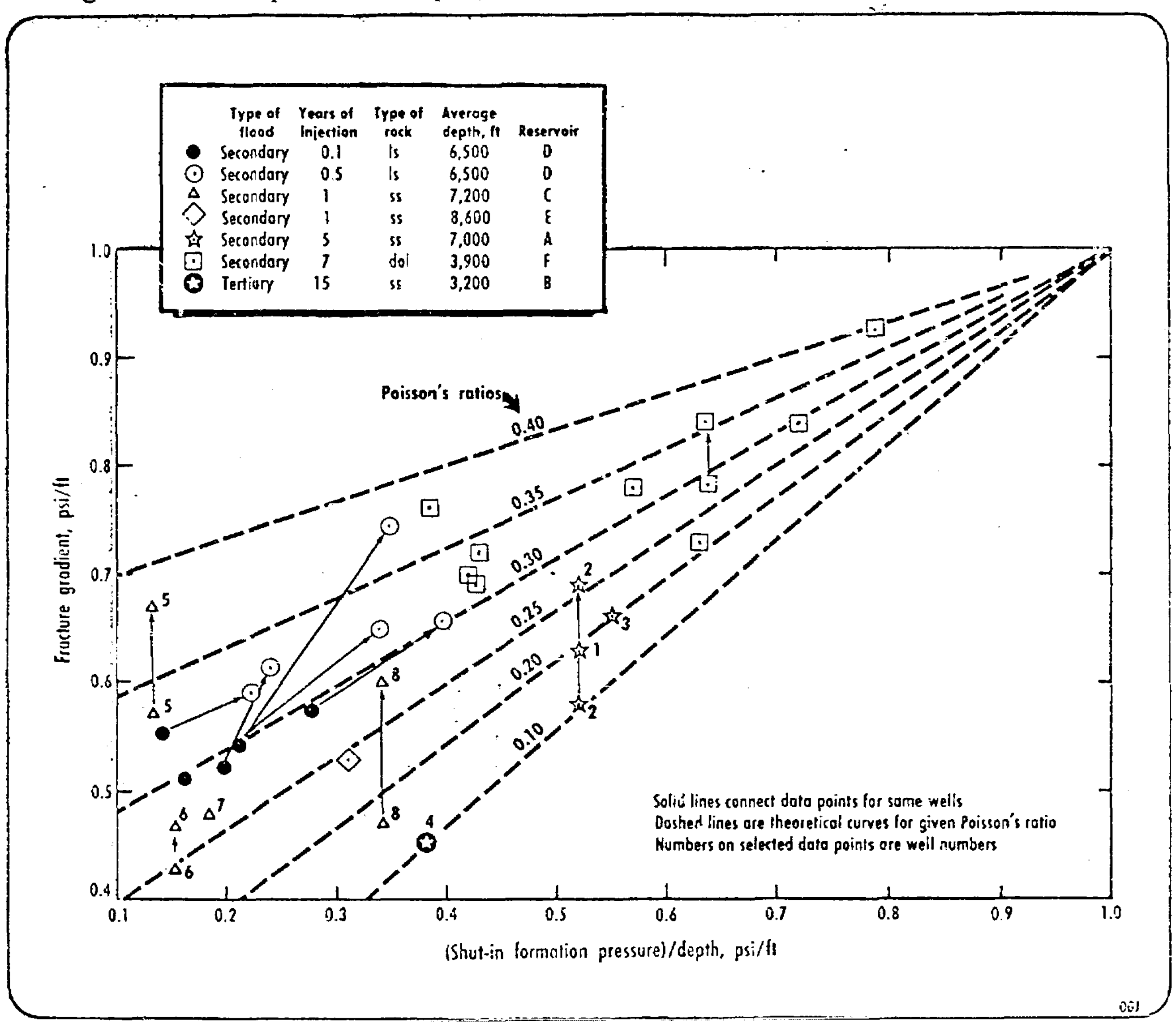
Φ = Porosity, fraction

μ_W = Water viscosity, cp

ν = Poisson's ratio, dimensionless

Fig. 6

Frac gradients vs. pressure-depth ratio



References

1. Yuster, S. T., and Calhoun, J. C., Jr., "Pressure Parting," Prod. Monthly, V. 9, No. 4: 16-26, February 1945.
2. Grandone, P., and Holleyman, J. B., "Injectivity Tests for Waterflooding Mid-Continent Oil Sands," World Oil, pp. 152-4, 6, 8, December 1949.
3. Odeh, A. S., and Jones, L. G., "Pressure Drawdown Analysis, Variable-Rate Case," Jour. Pet. Tech., pp. 960-964, August 1965.
4. Matthews, C. S., and Russell, D. G., "Pressure Buildup and Flow Tests in Wells," SPE Monograph, V. 1, 1967.
5. Heck, E. T., "Fractures and Joints," Prod. Monthly, p. 20, February 1955.
6. Hubbert, M. K., and Willis, D. G., "Mechanics of Hydraulic Fracturing," AIME Trans., V. 210: 153-166, 1957.
7. Eaton, B. A., "Fracture Gradient Prediction and Its Application in Oilfield Operations," Jour. Pet. Tech., pp. 1353-1360, October 1969.
8. Felsenthal, M., and Ferrell, H. H., "Fracturing Gradients in Waterfloods of Low-Permeability, Partially Depleted Zones," Jour. Pet. Tech., pp. 727-730, June 1971.

Appendix

PRESENTED here are recommended step-rate test times, non-D'Arcy flow-analysis techniques, and a multiple-rate analysis technique applied to step-rate tests. Also, presented is a brief description of a fracturing theory used in diagnosing step-rate test data.

Recommended time for each injection-rate step

Radius of investigation, $r_{inv} = \sqrt{0.00105 k_w t/\phi \mu_w c}$ (1)

This radius should be about 10 ft or larger to investigate formation properties adequately. For assumed typical values of $\phi = 0.2$, $\mu_w = 0.7$ cp, $c = 1.5 \times 10^{-5}$ psi^{-1}, $kr_w = 0.05$ for $K_{air} = 5$ md, and 0.10 for $K_{air} > 5$ md, we obtain.

Table 1

Test design values

Average K_{air}	Recommended minimum time for each step
5 md	60 min
10 md and larger	30 min

Non-D'Arcy flow analysis techniques

In non-D'Arcy radial flow:

$$q = \frac{0.00708 k_w h \Delta p}{\mu_w [\ln(r_e/r_w) + s + Dq]} \quad (2)$$

Where D is the non-D'Arcy flow constant, $(B/D)^{-1}$:

The apparent skin $= s' = s + Dq$ (3)

The s' term can be evaluated through a multiple-rate flow-test analysis technique (described in another part of this appendix) by substituting s' for s in equation 16. Next, s' is plotted vs q for the early steps of the test. D is then determined from this plot with the aid of equation 3. Analyses of s (= s' − Dq) for all steps of the step-rate test follow. The s terms are finally plotted vs injection pressures, and the point at which s becomes greatly more negative is interpreted as the fracturing pressure.

The aforementioned procedure is rather time-consuming. A shortcut approach was, therefore, developed and applied to the data of Well No. 3. This approach gave the same results as the method based on the multiple-rate flow-test analysis technique for this well.

For the derivation of the shortcut formula, Equation 2 was rewritten as

$$q + D'q^2 = C\Delta p \quad (4)$$

Where:

$C = 0.00708 k_w h/\mu_w [\ln(r_e/r_w) + s]$

$$D' = D/[\ln(r_e/r_w) + s] \quad (5)$$

It was assumed here that $\ln(r_e/r_w)$ and C remained virtually constant before fracturing occurred. This is a reasonable assumption as long as q in a given step is much larger than q in the preceding step. Selecting two such steps (before indicated fracturing) as shown in Fig. 3, we wrote

$$q_1 + D'q_1^2 = C\Delta p_1 \quad (6)$$

$$q_2 + D'q_2^2 = C\Delta p_2 \quad (7)$$

Dividing (6) ÷ (7) gave:

$$D' = (q_2\Delta p_1 - q_1\Delta p_2)/(q_1^2\Delta p_2 - q_2^2\Delta p_1) \quad (8)$$

It should be emphasized that D' and D carry the same units, $(b/d)^{-1}$, but are not identical. They are related as shown in Equation 5. In the shortcut approach, pressure is finally plotted vs. $(q+D'q^2)$, as shown in Fig. 3.

In an alternate approach to solving the non-D'Arcy flow problem, we start with this equation:

$$q = \frac{0.00708 k_w h(\Delta p - \Delta p_f)}{\mu_w[\ln(r_e/r_w)+s]} \quad (9)$$

where $\Delta p = p_w - p_e$ and Δp_f is the friction loss which in turn is related to q as follows:

$$\Delta p_f = Bq^2 \quad (10)$$

In Equation 10, B is a function of the water density and the number and diameter of perforations that are open. Defining C as above, we then obtain from 9 and 10 for two rates, q_1 and q_2, before fracturing,

$$q_1 + BCq_1^2 = C\Delta p_1 \quad (11)$$

$$q_2 + BCq_2^2 = C\Delta p_2 \quad (12)$$

It is evident from an analogy to Equations 6 and 7 that BC=D'. It follows that we arrive in effect at the same solution, i.e., Equation 8, regardless of whether we start from Equation 2 or 9.

Multiple-rate flow test analysis

The technique of applying multiple-rate flow-test analysis to step-rate injectivity test data is based on the prin-

Table 2

Step-rate data during early part of test, Well No. 2

t, hr	q, b/d	p, psi	Data point	Step no. n	Odeh sum*	$\Delta p\dagger / q$
0	0	642	–	–	–	–
0.5	100	720	a	1	−0.301	0.780
1.0	100	730	b	1	0	0.880
1.5	250	856	c	2	−0.110	0.856
2.0	250	874	d	2	0.120	0.928
2.25	750	1,143	e	3	−0.335	0.668
2.50	750	1,182	f	3	−0.112	0.720
3.00	750	1,216	g	3	0.124	0.765

*Oden sum $= [q_1 \log t + (q_2 - q_1) \log (t - t_1) + (q_3 - q_2) \log (t - t_2) + \ldots + (q_n - q_{n-1}) \log (t - t_{n-1})]\, 1/q_n$ (13)

†$(p - p_i)/q_n$ (14)

$p_i = 642$ psi

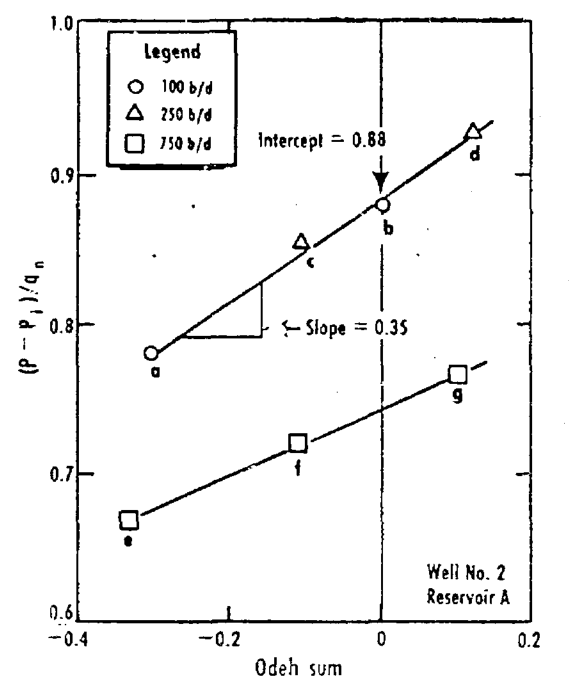
$t_1 = 1.0$ hr; $q_1 = 100$ b/d

$t_2 = 2.0$ hr; $q_2 = 250$ b/d

$t_3 = 3.0$ hr; $q_3 = 750$ b/d

Fig. 7

Odeh method of analysis



Standard step-rate graph as shown in Fig. 2

OGJ

ciple of "superposition." The technique, sometimes called the Odeh method, is well described in the literature for drawdown tests.[3,4] The equations presented in the literature can be used for the analysis of step-rate test data after making a change in sign and a change in symbol notations. Applicable equations and their use are presented in the following paragraphs.

The multiple-rate flow-test analysis technique determines $k_w h$ and skin before fracturing. It is essential that good data are available. Also, the correct initial pressure, p_i, must be known. This is the pressure that represents the intercept of the p vs. q plot when q = 0. Note, for instance, that using this criterion gives a lower p_i for Well No. 4 (Fig. 4) than indicated by the first observed pressure.

The method can be applied in theory only to data taken during the early rate steps when radial flow is the predominant flow mechanism in the formation zone under investigation. This approach was used for the data of Well No. 2 (Fig. 2). Data for the end of each of the early steps and for one or more arbitrary points during each of these steps were tabulated as shown in the first three columns of table 2, shown at left.

Sample calculations. For data point a (Step 1):

Odeh sum $= q_1 (\log t)/q_1 = 100 (\log 0.5)/100 = -0.301$

$(p - p_i)/q_1 = (720 - 642)/100 = 0.78$

For data point g (Step 3):

$$\text{Odeh sum} = [q_1 \log t + (q_2 - q_1) \log (t - t_1) + (q_3 - q_2) \log (t - t_2)]/q_3$$

$$= [100 \log 3 + (250 - 100) \log (3 - 1) + (750 - 250) \log (3 - 2)]/750$$

$$= 0.124$$

$(p - p_i)/q_3 = (1{,}216 - 642)/750 = 0.765$

The last two columns of Table 2 were plotted in Fig. 7. From this graph we read slope, m' = 0.35, and intercept, b' = 0.88. Known also were: $\mu_w = 0.45$ cp, $B_w = 1.0$, h = 270 ft (from a radioactive tracer-injectivity survey), $\Phi = 0.186$, $c = 1.5 \times 10^{-5}$ psi^{-1}, and $r_w = 0.25$ ft.

$$k_w h = 162.6 \mu_w B_w / m' \quad (15)$$

$$k_w h = 162.6 \times 0.45 \times 1.0/0.35 = 209 \text{ md ft}$$

$$k_w = 209/270 = 0.77 \text{ md}$$

$$s = 1.151 \left[\frac{b'}{m'} - \log \frac{k_w}{\Phi \mu_w c r_w^2} + 3.23 \right] \quad (16)$$

$$s = 1.151 \left[\frac{0.88}{0.35} - \log \frac{0.77}{0.186 \times 0.45 \times 1.5 \times 10^{-5} \times 0.0625} + 3.23 \right]$$

$$s = -1.4$$

$$r_{we} = r_w e^{-s} \quad (17)$$

$$r_{we} = 0.25 e^{1.4} = 1.0 \text{ ft}$$

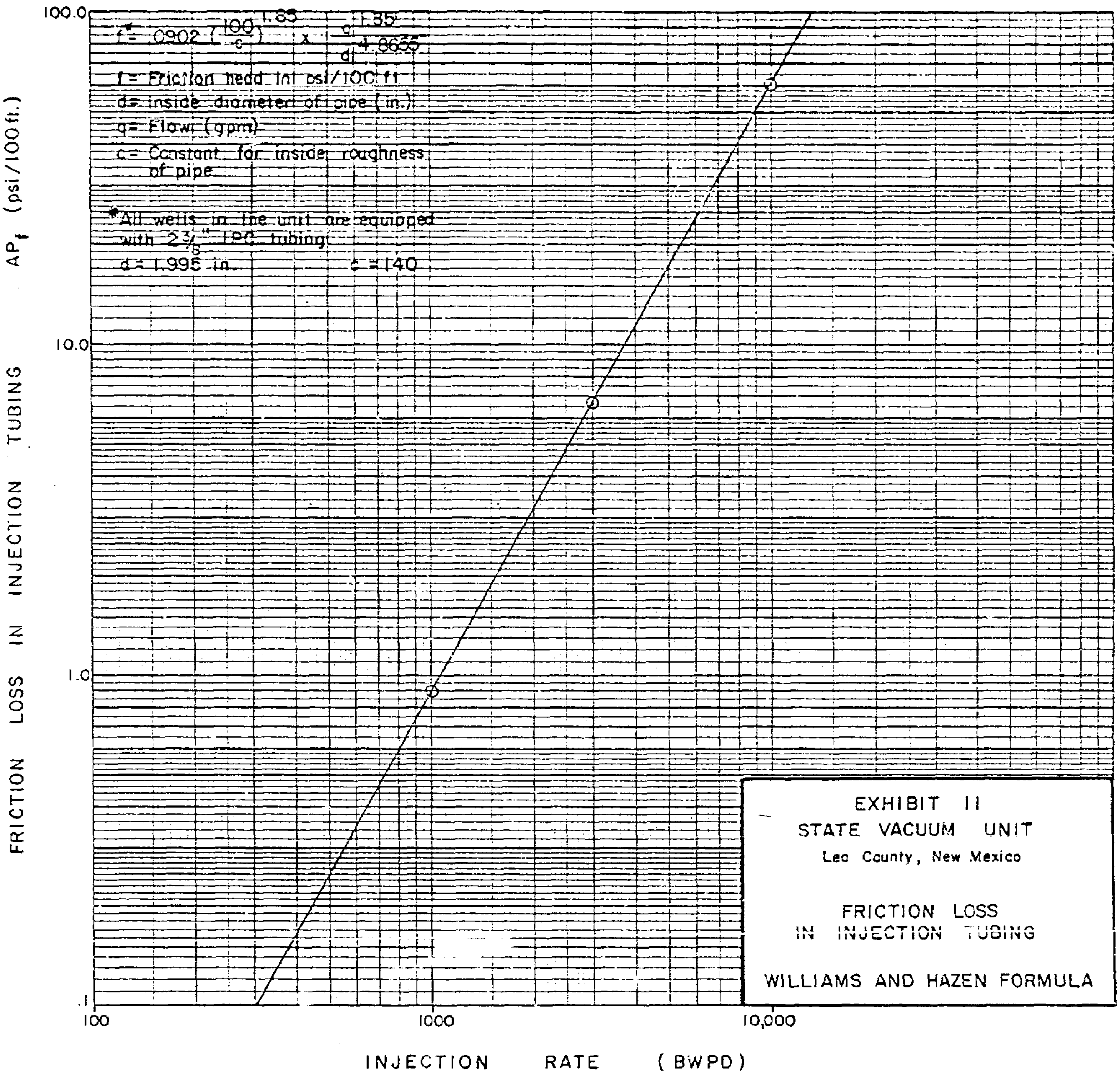
The data plotted in Fig. 7 show that the method broke down after point d was measured. That is, the following data points, e, f, and g, fell no longer on the old line. This was interpreted to indicate that radial flow was no longer the predominant flow regime and that fracturing had occurred.

Fracturing theory for diagnosis.

The theory[6,7] used in drawing the dashed lines in Fig. 6 is expressed by the equation:

$$p_f/Z = [(S/Z) - (p_e/Z)]\, [\mu/(1 - \mu)] + p_e/Z \quad (18)$$

The Poisson's ratio, ν is the ratio of maximum lateral deformation to maximum longitudinal deformation observed during compression loading of rock samples. A low ratio is generally associated with dense, brittle rock and a higher ratio with more elastic rock. The overburden pressure gradient, S/Z, used in constructing the theoretical curves of Fig. 6, was 1.0 psi/ft of depth. Other terms are defined in the nomenclature.



f* = .0902 (100/c)^1.85 x q^1.85 / d^4.8655
f = Friction head in psi/100 ft
d = inside diameter of pipe (in.)
q = Flow (gpm)
c = Constant for inside roughness of pipe
*All wells in the unit are equipped with 2 3/8" IPC tubing
d = 1.995 in.
c = 140
EXHIBIT 11
STATE VACUUM UNIT
Lea County, New Mexico
FRICTION LOSS IN INJECTION TUBING
WILLIAMS AND HAZEN FORMULA
FRICTION LOSS IN INJECTION TUBING AP_f (psi/100 ft.)
100.0
10.0
1.0
.1
100
1000
10,000
INJECTION RATE (BWPD)

Atlan'icRichfieldCompany
North American Producing Division
Permian District
Post Office Box 1610
Midland, Texas 79701
Telephone 915 682 8631

May 19, 1978

Oil Conservation Division of the
New Mexico Department of
Energy and Minerals
P. O. Box 2088
Santa Fe, New Mexico

Attn: Mr. Ramey

Re: Case No. 5762; Order No. R-5295
Atlantic Richfield Company
State Vacuum Unit
Waterflood Project
T-17S, R-34E, Lea County, New Mexico

Dear Mr. Ramey:

In the Order establishing the waterflood project, wellhead injection pressure was limited to 860 psi. Approval of a higher wellhead pressure could be obtained by showing that the increase in pressure would not fracture the confining strata. As operator of the State Vacuum Unit, Atlantic Richfield Company applies for administrative approval of a wellhead injection pressure of 1134 psi. The attached exhibits are offered as evidence that this pressure will not fracture the confining strata.

The exhibits are based on pressure parting tests run on April 24-26, 1978. Exhibit 1 is a map of the unit area showing the seven injection wells which were tested. Insufficient pump capacity on Well No. 9 prevented the use of data from the test. The remaining six wells indicated a range of surface parting pressures from 1234 psi to 2101 psi as shown on Exhibit 2. Necessary equipment and well data is included on Exhibit 3.

The paper "Step-Rate Tests Determine Safe Injection Pressures in Floods" (Exhibit 10) was used as a reference to help determine proper testing procedures and analysis methods. The tests were run by Atlantic Richfield Company using a downhole pressure recorder and a Hallibruton turbine flowmeter. Individual well data and results are shown in Exhibits 4 through 9.

Some injection wells exhibit non-D'Arcy flow characteristics which prevents determination of the parting pressure by the normal rate vs. pressure graphical technique. Two of the wells

tested exhibited this behavior. By using the technique outlined in the reference paper ($q + Dq^2$) parting pressures were determined for the two wells and are included as Exhibits 4A and 5A. Exhibit 11 is a graphical solution of the Williams and Hazen formula for determining the pressure drop due to friction in the injection tubing. Data for the individual wells is listed on Exhibit 2.

At the current limiting pressure of 860 psi, injection rates in the unit have begun to decline. We feel that an increased wellhead injection pressure is necessary if we are to maintain adequate injection rates to promote the timely production of the secondary reserves in the unit. Our application for administrative approval of a wellhead injection pressure of 1134 psi should insure that we are not fracturing the formation strata but also allow us to increase our current injection rates. We will gladly forward any additional information which may be required and ask for your prompt consideration.

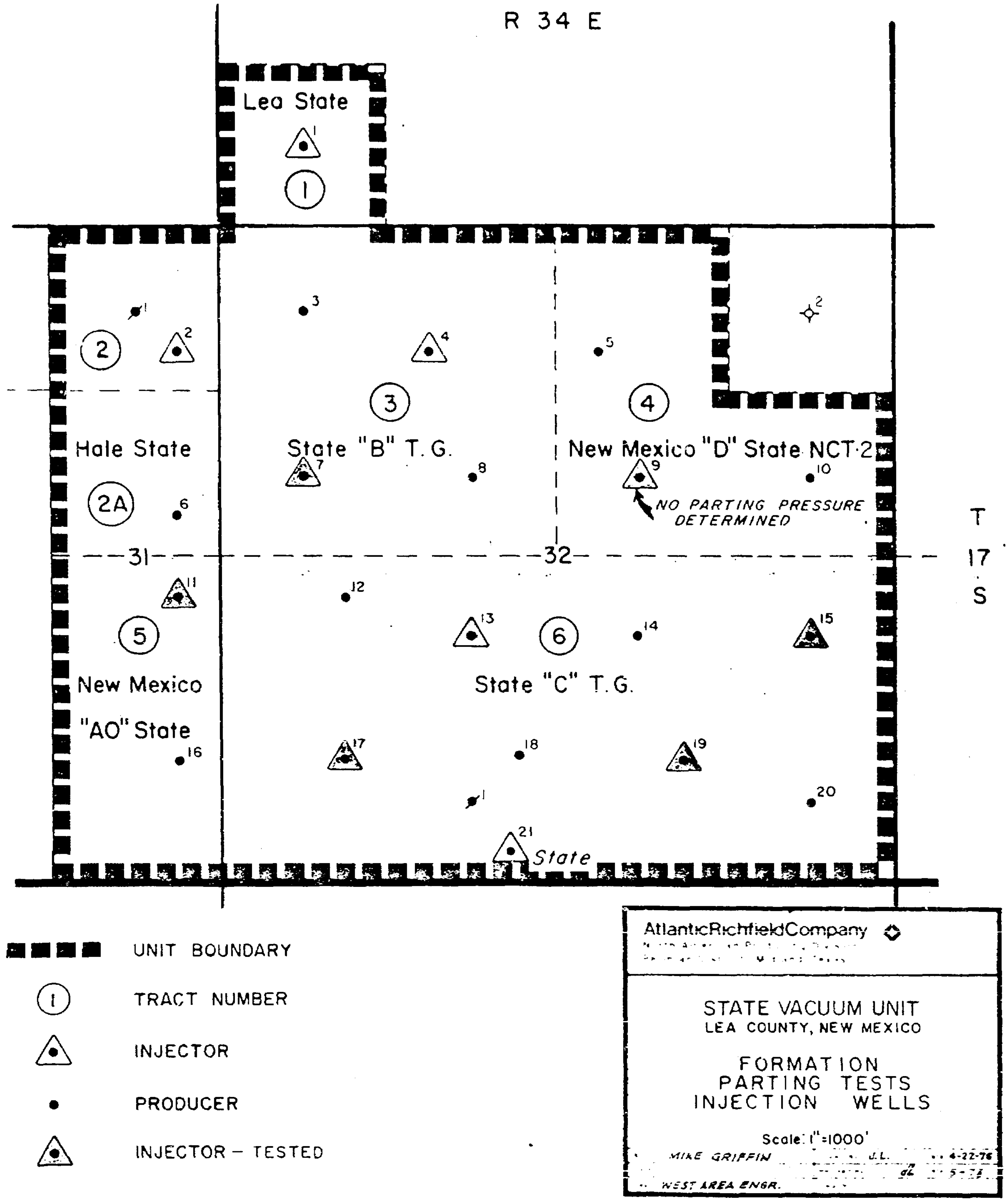
Very truly yours,

J L Tweed

J. L. Tweed

MG/agp

EXHIBIT 1


R 34 E
Lea State
Hale State
State "B" T.G.
New Mexico "D" State NCT-2
NO PARTING PRESSURE DETERMINED
31
32
T
17
S
New Mexico
"AO" State
State "C" T.G.
State
UNIT BOUNDARY
TRACT NUMBER
INJECTOR
PRODUCER
INJECTOR – TESTED
AtlanticRichfieldCompany
STATE VACUUM UNIT
LEA COUNTY, NEW MEXICO
FORMATION
PARTING TESTS
INJECTION WELLS
Scale: 1"=1000'
MIKE GRIFFIN
J.L.
4-22-76
WEST AREA ENGR.

STATE VACUUM UNIT

PRESSURE PARTING TESTS

WELL NO.	CUM. INJ. 3/1/78 (MB)	PRESS. BOMB SETTING DEPTH (FT)	HYDROSTATIC[1] HEAD P_h (PSI)	INJ. RATE @ PART. PRESS. (BPD)	PRESS. DROP-FRICTION[2] ΔP_f (PSI/100 FT)	ΔP_f-TOTAL @ SETTING DEPTH (PSI)	BTM. HOLE PTG. PRESS. (PSI)	SURF. PTG.[3] PRESSURE (PSI)	PTG. GRADIENT (PSI/FT)
7	119.5	4671	2022.5	1700	2.34	109.3	3305	1391.8	.707
11	94.7	4693	2032.1	2050	3.32	155.8	3200	1323.7	.682
13	54.1	4660	2017.8	1530	1.91	89.0	4030	2101.0	.865
15	173.5	4636	2007.4	2630	5.20	241.1	3478	1711.7	.750
17	17.5	4721	2044.2	1000	0.86	40.7	3238	1234.5	.686
19	98.1	4692	2031.6	1610	2.12	99.5	3446	1513.5	.734

1. Injection water has specific gravity equal to 1.001; pressure gradient = .433 psi/ft.
2. Taken from Exhibit 11 (Williams and Hazen formula).
3. Surface Parting Pressure = Bottom Hole Parting Pressure - Hydrostatic head + ΔP_f

EXHIBIT 3

STATE VACUUM UNIT
Pressure Parting Tests
Injection Well Data

WELL NO.	COMPLETION CASING SIZE (DEPTH)	TUBING SIZE* IN.	DEPTH SET	PERFORATIONS
7	3½" liner (4426-4728)	2-3/8"	4426'	4671-4718'
11	3½" liner (4242-4768)	2-3/8"	4242'	4693-4734'
13	3½" liner (4241-4717)	2-3/8"	4241'	4660-4710'
15	3½" liner (4249-4708)	2-3/8"	4249'	4636-4686'
17	3½" liner (4429-4761)	2-3/8"	4429'	4721-4761'
19	3½" liner (4416-4750)	2-3/8"	4416'	4692-4742'

*All tubing is internally plastic coated.

EXHIBIT 4

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/24/78

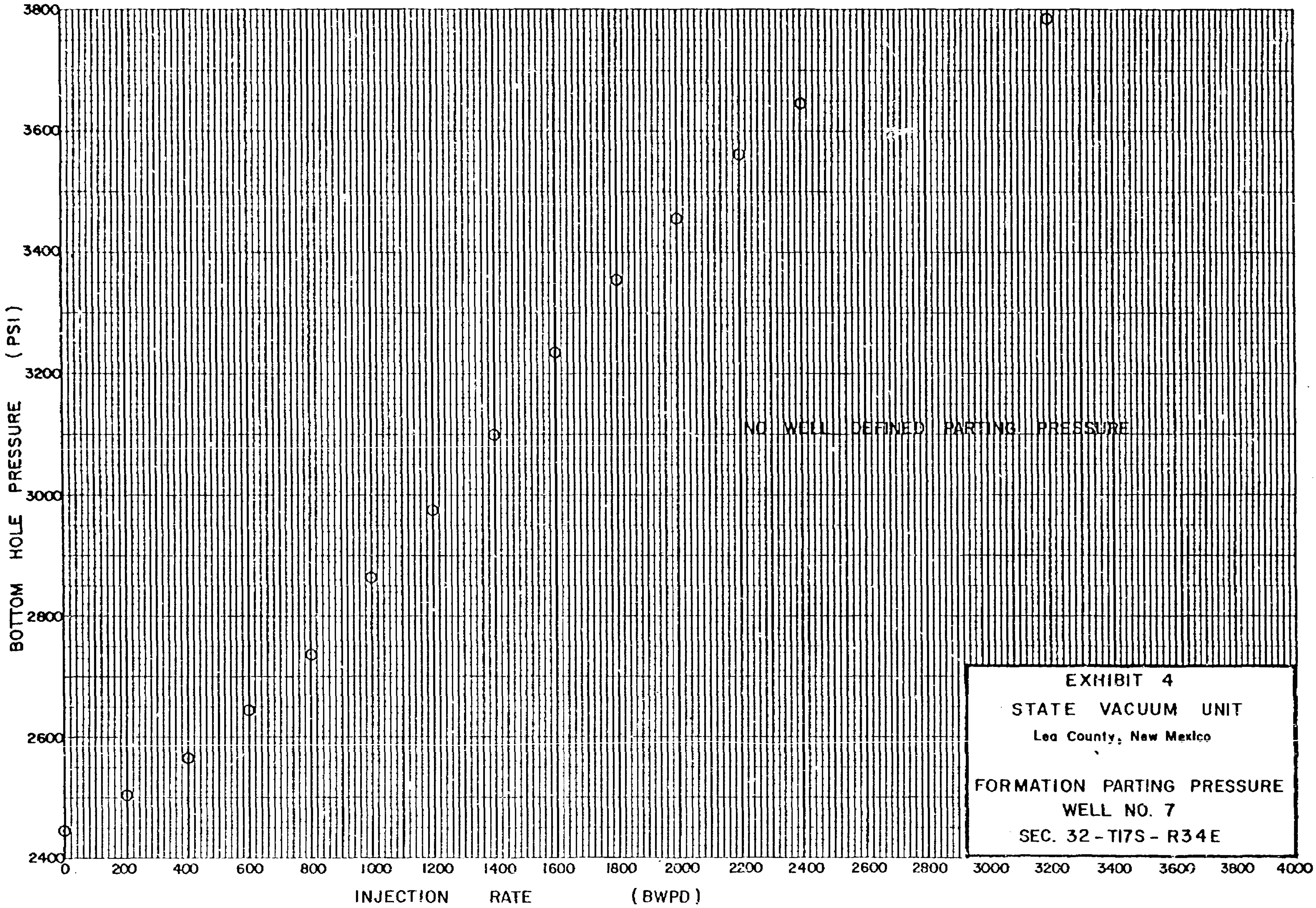
WELL NUMBER: 7

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4671'

TIME/ [redacted] PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:44	0	2448	560
1:00	200	2503	650
1:10	400	2569	725
1:20	600	2649	800
1:30	800	2739	900
1:40	1000	2864	1025
1:50	1200	2972	1125
2:00	1400	3101	1325
2:10	1600	3236	1475
2:20	1800	3358	1725
2:30	2000	3455	1875
2:40	2200	3563	2050
2:50	2400	3649	2200
2:56	3200	3782	2500
3:02	3600	3866	2775



BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
NO WELL DEFINED PARTING PRESSURE
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
INJECTION RATE (BWPD)
EXHIBIT 4
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 7
SEC. 32-T17S-R34E

STATE VACUUM UNIT
Formation Parting Pressure
Non D'Arcy Flow Technique
Well No. 7

From Exhibit 10:

$$D = (q_2 \Delta P_1 - q_1 \Delta P_2)/(q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: q_1 = 200 BPD; P_1 = 2503 psi

q_2 = 400 BPD; P_2 = 2569 psi

$D = .000555\ B/D^{-1}$

INJECTION RATE (BPD)	BHP @ TEST DEPTH (PSI)	$q + Dq^2$ (BPD)
0	2448	
200	2503	222
400	2569	489
600	2649	800
800	2739	1155
1000	2864	1555
1200	2972	1999
1400	3101	2488
1600	3236	3020
1800	3358	3598
2000	3455	4220
2200	3563	4886
2400	3649	5597
3200	3782	8883
3600	3866	10793

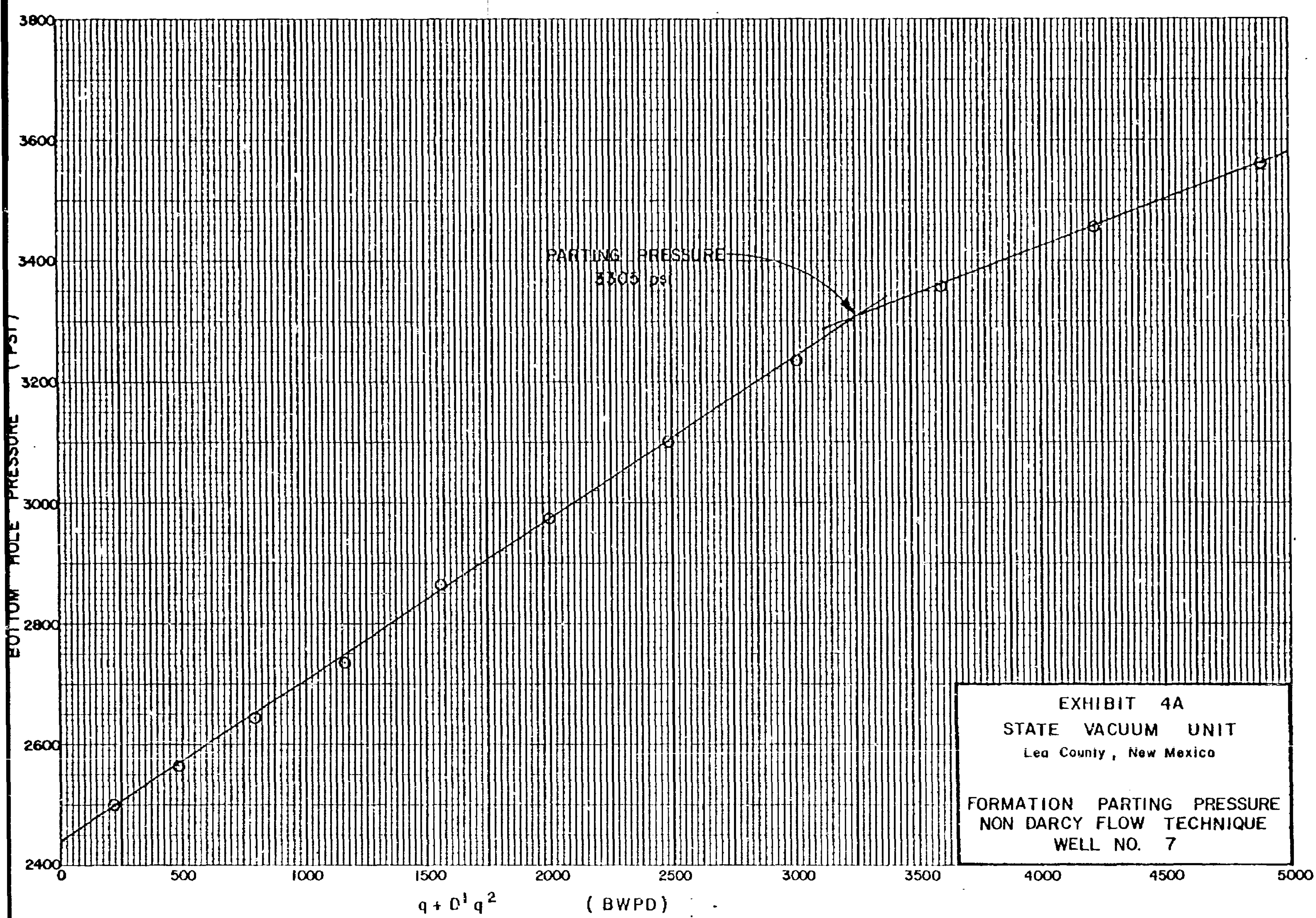

BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
PARTING PRESSURE
3305 psi
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
$q + D^1 q^2$ (BWPD)
EXHIBIT 4A
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
NON DARCY FLOW TECHNIQUE
WELL NO. 7

EXHIBIT 5

STEP RATE TEST REPORT

LEASE: STATE-VACUUM

DATE OF TEST: 4/25/78

WELL NUMBER: 11

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4693'

TIME/ AM ~~PM~~	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
8:34	0	2433	
8:50	200	2518	650
9:00	400	2577	700
9:10	600	2624	725
9:20	800	2701	825
9:30	1000	2767	950
9:40	1200	2842	1050
9:50	1400	2922	1175
10:00	1600	3004	1280
10:10	1800	3080	1400
10:20	2000	3166	1410
10:30	2200	3252	1490
10:40	2400	3322	1550
10:50	2600	3402	1640

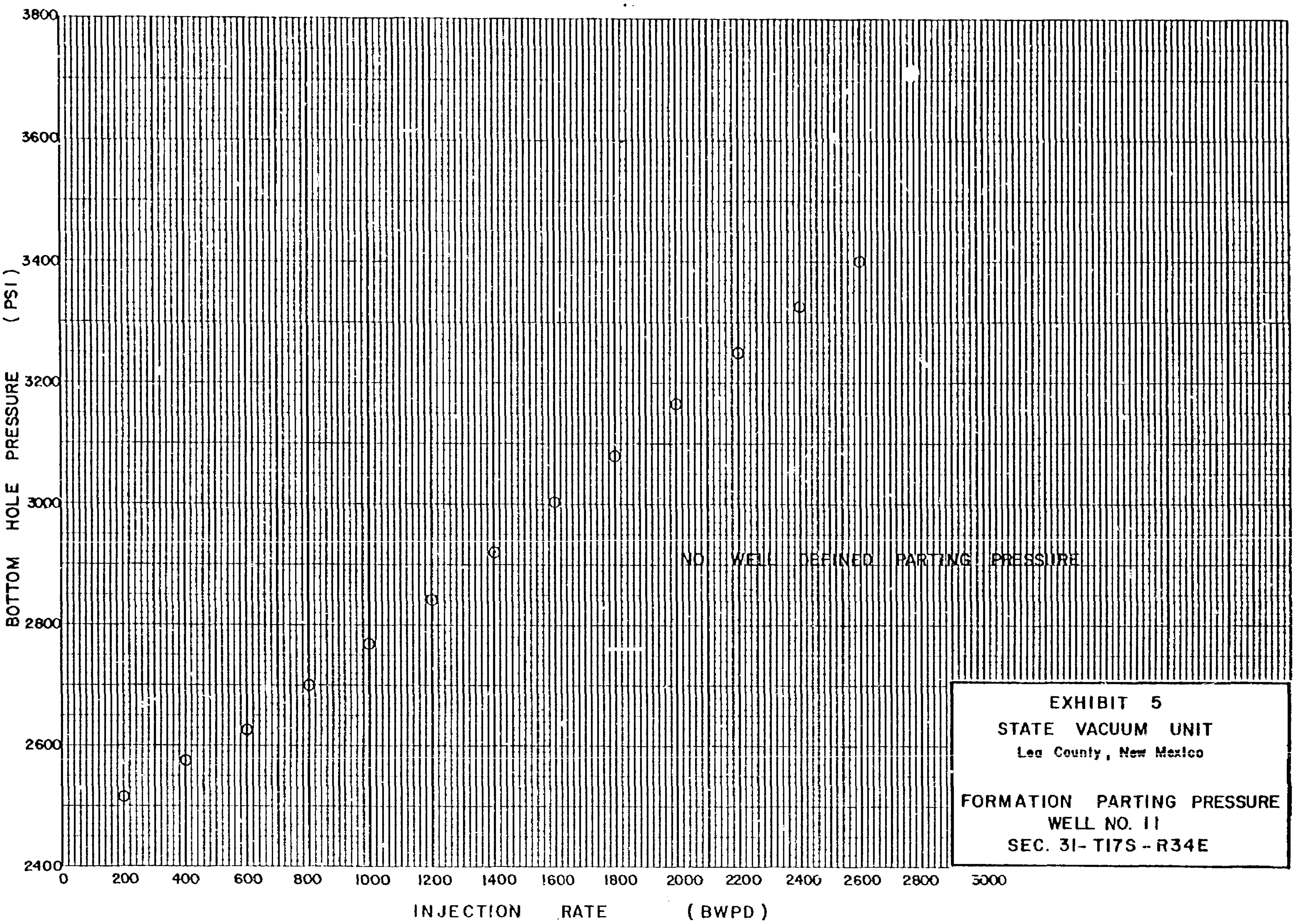


EXHIBIT 5
STATE VACUUM UNIT
Lea County, New Mexico

FORMATION PARTING PRESSURE
WELL NO. 11
SEC. 31-T17S-R34E

STATE VACUUM UNIT
Formation Parting Pressure
Non D'Arcy Flow Technique
Well No. 11

From Exhibit 10:

$$D = (q_2 \Delta P_1 - q_1 \Delta P_2)/(q_1^2 \Delta P_2 - q_2^2 \Delta P_1)$$

Substituting: q_1 = 600 BPD; P_1 = 2624 psi

q_2 = 800 BPD; P_2 = 2701 psi

$D = .000311\ B/D^{-1}$

INJECTION RATE (BPD)	BHP @ TEST DEPTH (PSI)	$q + Dq^2$ (BPD)
0	2433	
200	2518	212
400	2577	450
600	2624	712
800	2701	999
1000	2767	1311
1200	2842	1648
1400	2922	2009
1600	3004	2396
1800	3080	2807
2000	3166	3244
2200	3252	3705
2400	3322	4192
2600	3402	4702

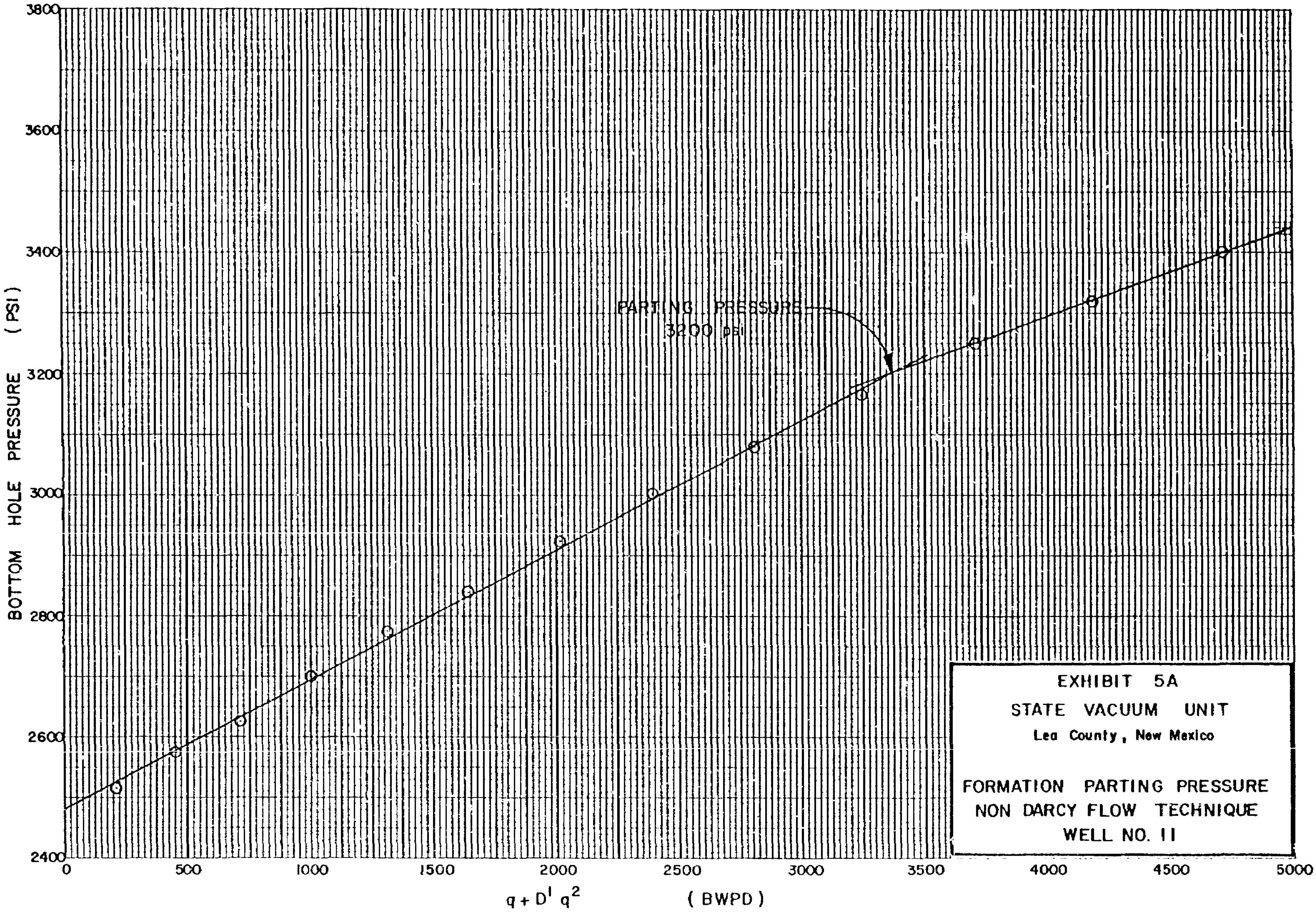


EXHIBIT 5A
STATE VACUUM UNIT
Lea County, New Mexico

FORMATION PARTING PRESSURE
NON DARCY FLOW TECHNIQUE
WELL NO. 11

EXHIBIT 6

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/26/78

WELL NUMBER: 13

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4660'

TIME/ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
12:16	0	2392	540
12:25	200	2551	715
12:35	400	2725	850
12:45	600	2917	1050
12:55	800	3164	1415
1:05	1000	3420	1700
1:15	1200	3662	1990
1:25	1400	3885	2190
1:35	1600	4055	2490
1:45	1800	4169	2580
1:55	2000	4263	2740
2:05	2200	4343	2860

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1323

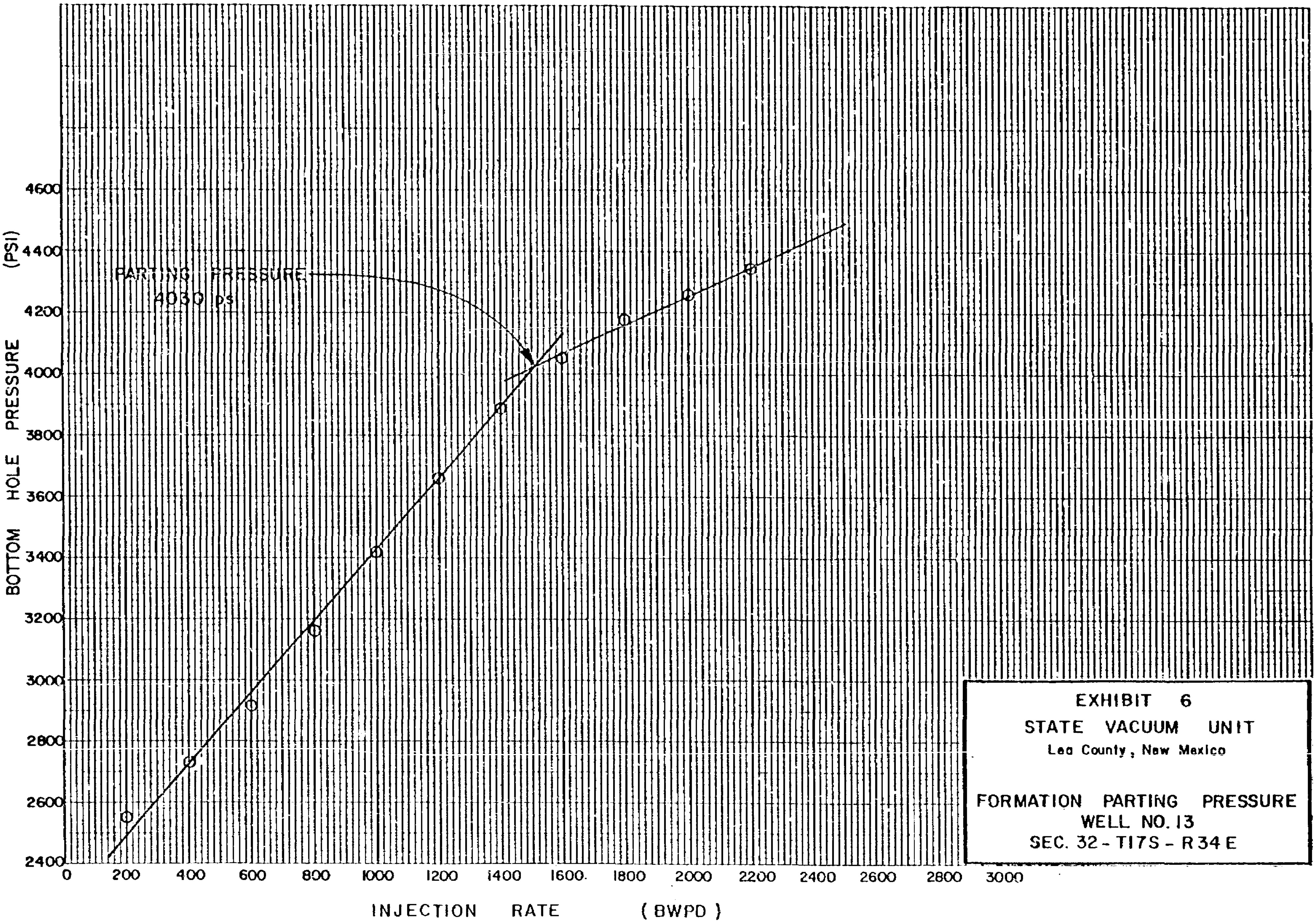


EXHIBIT 7

STEP RATE TEST REPORT

LEASE: STATE-VACUUM

DATE OF TEST: 4/25/78

WELL NUMBER: 15

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4636'

TIME/ ~~AM~~ PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
2:45	0	2008	160
2:55	600	2230	350
3:05	1000	2460	625
3:15	1400	2724	925
3:25	1800	3010	1250
3:35	2200	3243	1575
3:45	2600	3420	1840
3:55	3000	3572	2120
4:05	3400	3663	2300
4:15	3800	3772	2500

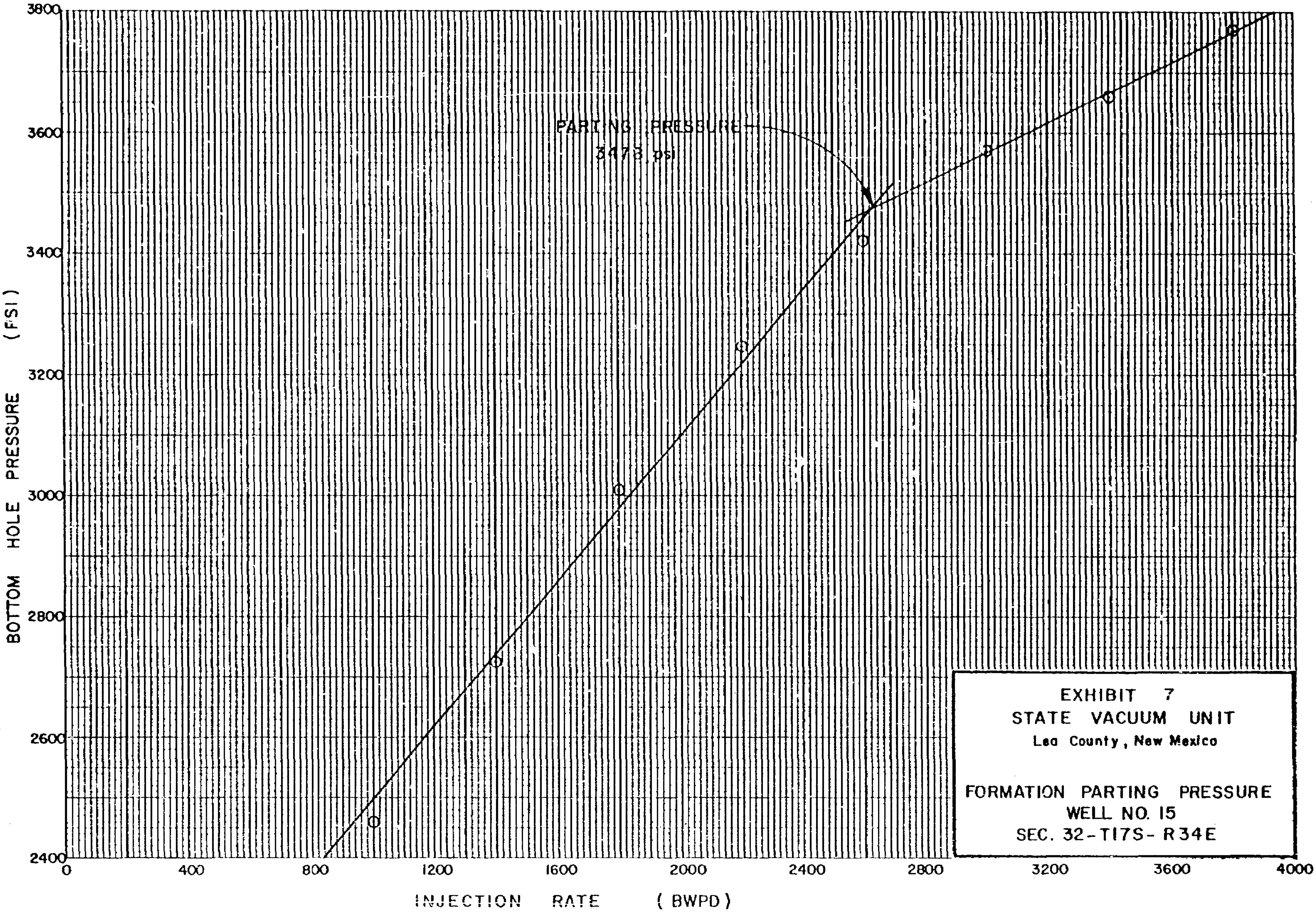

PARTING PRESSURE
3473 psi
BOTTOM HOLE PRESSURE (PSI)
3800
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
INJECTION RATE (BWPD)
EXHIBIT 7
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 15
SEC. 32-T17S-R34E

EXHIBIT 8

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/25/78

WELL NUMBER: 17

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4721'

TIME/ AM PM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
11:50	0	2477	569
12:05	200	2670	780
12:15	400	2854	930
12:25	600	2973	1120
12:35	800	3117	1280
12:45	1000	3239	1445
12:55	1200	3312	1555
1:05	1400	3390	1665
1:15	1600	3462	1785
1:25	1800	3531	1890
1:35	2000	3585	2000

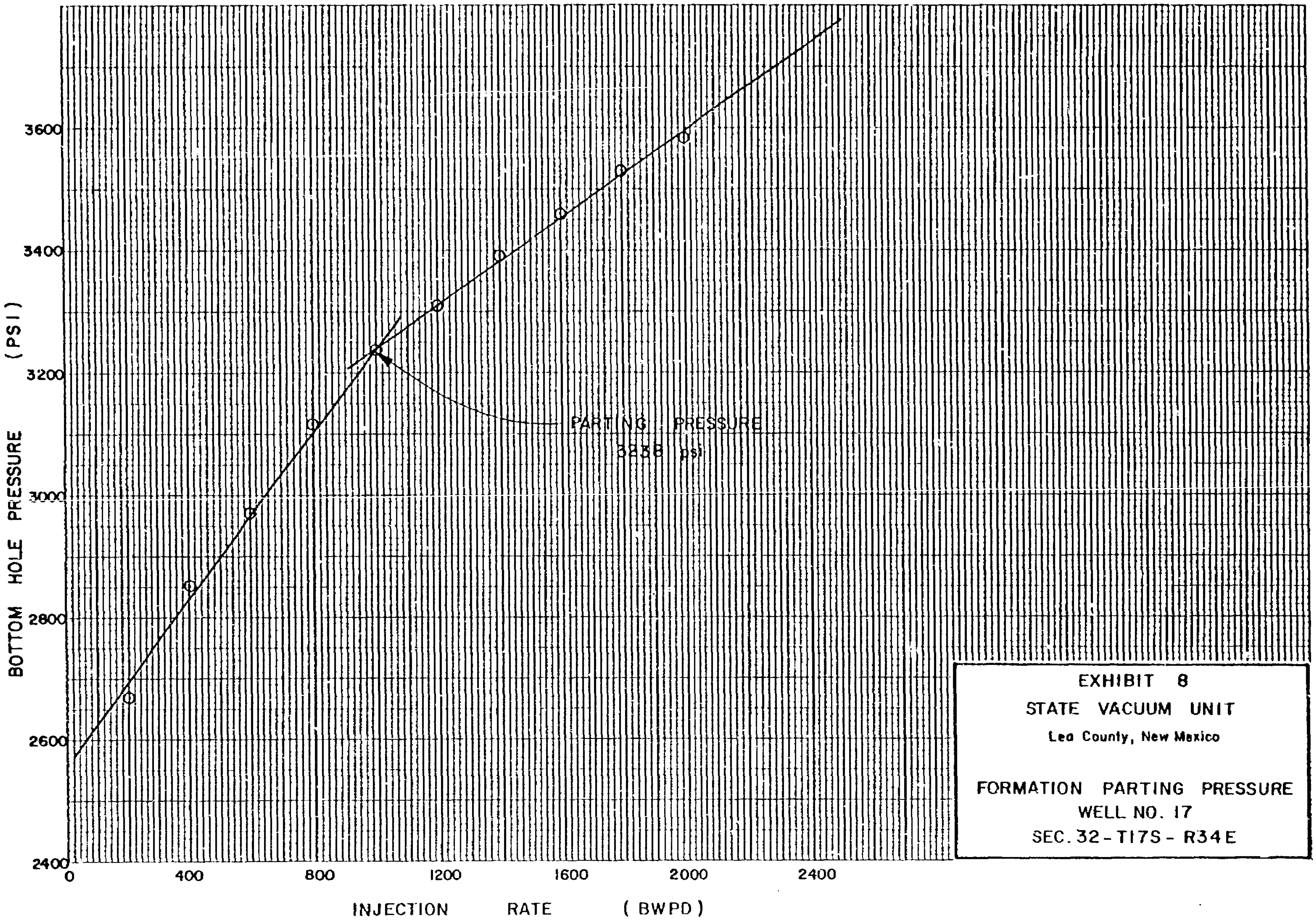

BOTTOM HOLE PRESSURE (PSI)
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
INJECTION RATE (BWPD)
PARTING PRESSURE
3238 psi
EXHIBIT 8
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 17
SEC. 32-T17S-R34E

EXHIBIT 9

STEP RATE TEST REPORT

LEASE: STATE-VACUUM UNIT

DATE OF TEST: 4/26/78

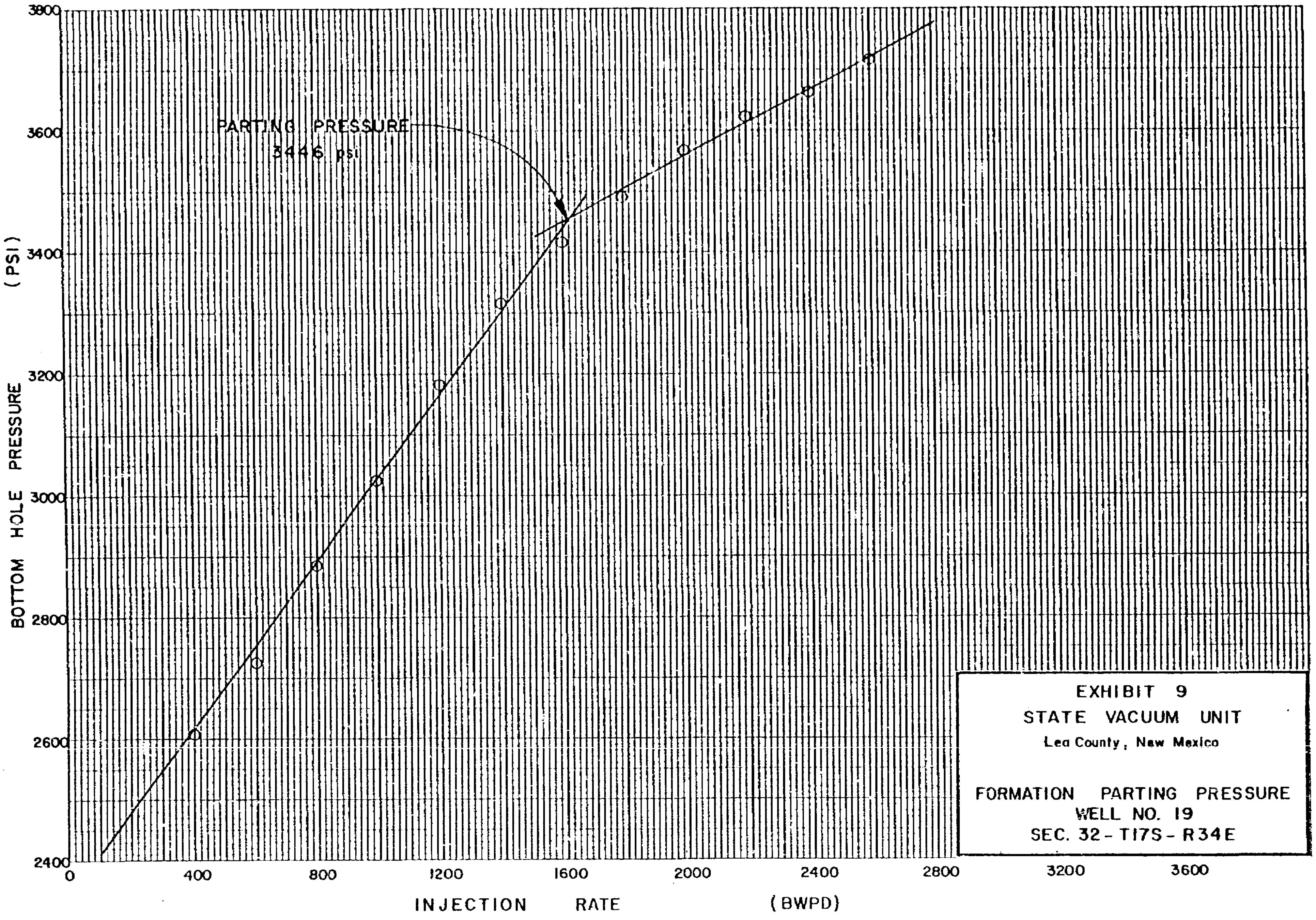
WELL NUMBER: 19

ELEMENT: 7287

COUNTY: Lea County, New Mexico

TEST DEPTH: 4692'

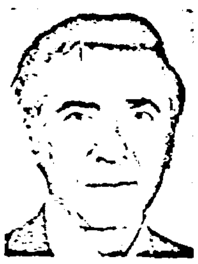
TIME/ AM	APPROX. RATE (BPD)	BHP @ TEST DEPTH (PSI)	SURFACE PRESSURE (PSI)
9:01	0	2460	500
9:15	200	2336	500
9:25	400	2607	600
9:35	600	2724	750
9:45	800	2887	920
9:55	1000	3027	1080
10:05	1200	3181	1260
10:15	1400	3314	1430
10:25	1600	3415	1600
10:35	1800	3491	1700
10:45	2000	3565	1840
10:55	2200	3622	1940
11:05	2400	3666	2020
11:15	2600	3715	2110


PARTING PRESSURE
3446 psi
BOTTOM HOLE PRESSURE (PSI)
INJECTION RATE (BWPD)
3800
3600
3400
3200
3000
2800
2600
2400
0
400
800
1200
1600
2000
2400
2800
3200
3600
EXHIBIT 9
STATE VACUUM UNIT
Lea County, New Mexico
FORMATION PARTING PRESSURE
WELL NO. 19
SEC. 32 - T17S - R34E

Step-rate tests determine safe injection pressures in floods

The author . . .

Martin Felsenthal is a senior research engineer with Continental Oil Co. in Ponca City, Oklahoma. He works in the areas of formation evaluation, waterflooding and tertiary recovery. A petroleum engineering graduate from University of California, he also holds an MS from Penn state.



Felsenthal

STEP-RATE injectivity tests can define the maximum safe injection pressures that can be used without fracturing the reservoir rock.

This information is important in waterfloods. It is of critical importance in tertiary-recovery projects where we cannot afford to lose costly injection fluids through uncontrolled induced fractures.

Recently, we tried the step-rate test in a number of projects. Although the test concept is simple, results were conclusive only if proper procedures and equipment were used. From this experience, a recommended procedure has been developed.

This article presents the recommended procedure and shows typical data.

A remarkable point brought out by these data is that formations sometimes fracture near hydrostatic head in pressure-depleted reservoirs.

The procedure. The early literature references [1,2] generally talked about pressure parting rather than fracturing during step-rate injectivity tests. It was pointed out, however, at the outset that the two expressions are synonymous.

The test well should be shut in long enough so that the bottom-hole pressure is near the shut-in formation pressure. The step-rate injectivity test that follows consists of a series of constant-rate injections with rates increasing from low to high in stepwise fashion.

In tight formation ($K_{air} \sim 5$md) each step should last 60 min. Shorter time spans can be used in higher-permeability formations as shown in Table 1 of the appendix. The time-step duration itself is not critical. It only should be reasonably close to the recommended values shown. Also, each step should last exactly as long as the preceding step.

In selecting rates for the test, one possible rule of thumb is to use 5, 10, 20, 40, 60, 80, and 100% of the desired maximum test rate. The above schedule may be varied to suit the conditions of the test. For instance, it may be difficult to control accurately a very low rate in which case, the test may be started at a somewhat higher rate than shown above.

Equipment. Injection rates during the test should be controlled with a constant flow-rate regulator. We have used regulators made by three different companies and obtained useful data. All regulators should be tested before use.

Use of a throttling valve as a flow-rate regulating device is not recommended. Reason is that this valve acts like an orifice. Pressures and rates will thus interact continuously during the transient flow conditions of each rate step. Consequently, as well pressures rise, injection rates will tend to decline.

Flow rates should be measured with a turbine flowmeter and a rate meter such as those made by Halliburton. It is advisable to calibrate this equipment by timing flow into a 5-gal container (b/d = 10,286 ÷ seconds to fill a 5-gal container).

In critically important tests, it is advisable to record rates throughout the test. For this purpose, we have fed a signal from a rate meter through a dampening circuit to a strip-chart recorder. Use of a rate recorder is desirable but not mandatory.

Our experience has shown that best results were obtained when pressures were measured with a down-hole instrument. For instance, we used

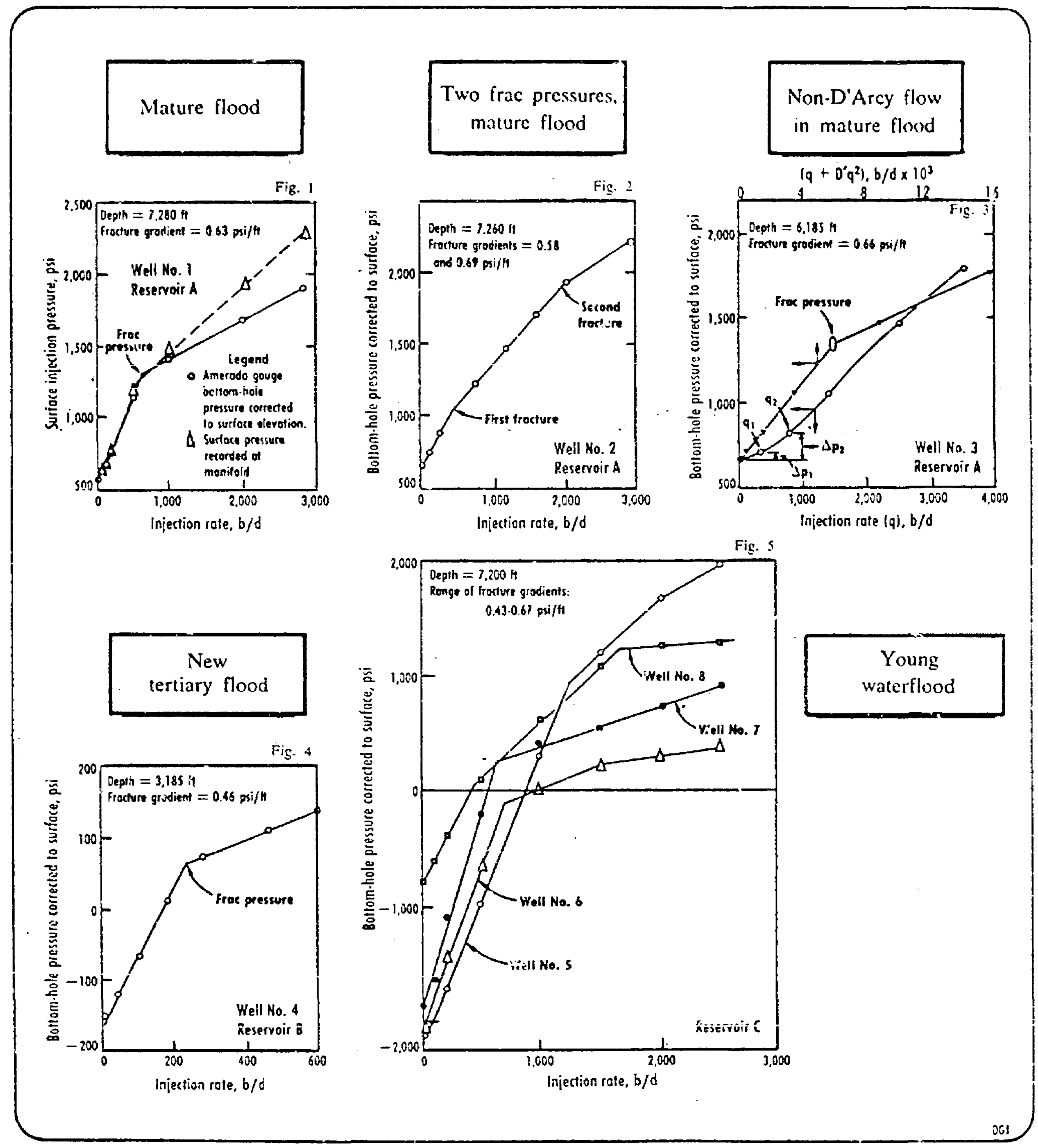
Amerada-type pressure-recording devices in all tests shown in Figs. 1-5. Other down-hole devices may be equally suitable. In addition, it is advisable to observe surface pressures with a surface gage or recorder. We found that it is often difficult to obtain very accurate surface-pressure readings because of surges from the injection pump. Nevertheless, surface pressures are useful in many tests for on-the-spot analysis, while the test is in progress. Final test analysis, however, should be based on down-hole pressure data.

Data analysis. The pressures at the start of the test (at q = 0) and at the end of each injection-rate step are plotted against injection rates as in Fig. 1. Shown are down-hole pressures corrected to the surface elevation of the well and pressures recorded at the surface. The difference in the two pressures is mainly due to friction losses in the pipes.

When the data show that it takes a smaller pressure increment for a unit-rate change, we generally infer that fracturing has taken place. Thus, the data of Fig. 1 indicate that Well

Figs. 1-5

Step-rate tests on old and new floods



No. 1 fractured at about 1,300 psi surface pressure.

Sometimes two breaks are indicated in the pressure-vs-rate plots. Each break could represent a separate fracture. For instance, data for Well No. 2 (Fig. 2) indicate a first fracture at a surface pressure of 1,050 psi and a second and more-severe fracturing condition at 1,900 psi.

Occasionally, pressure-vs-rate plots do not form a straight line but form a curve with a distinctive upward curvature near the origin as shown in Fig. 3. The best explanation for this is non-D'Arcy flow downstream from the pressure-measuring device. This implies that there is probably a sizable pressure drop across the perforations or other orifice-like obstructions. An added resistance is created that is proportional to the square of the injection rate. Thus, we observed we could not interpret the step-rate data for Well No. 3 from a standard pressure-vs-rate (q) plot but could do so from a plot of pressure vs. $q + Dq^2$ (A method for determining D is given in the appendix). Data in Fig. 3 indicate that the fracturing pressure was about 1,300 psi in Well No. 3.

In some pressure-depleted reservoirs, initial pressures are lower than hydrostatic head. Such a situation occured during the tests illustrated in Figs. 4 and 5. Down-hole rates at the end of the early steps were somewhat smaller in these tests than rates measured at the surface because of rising fluid levels in the wells. Appropriate corrections for this condition had to be made before the data could be analyzed.

Complementary techniques. Pressure-falloff tests are generally a good source of information on permeability capacity, probable presence of fractures, skin and nearness to faults or barriers.[4] An excellent opportunity generally exists for conducting this type of test while the test well is being shut in before step-rate testing. If the skin calculated from such a test is definitely negative, we can infer that we probably have a fracture. One way to find out whether the fracture is natural or induced is to reduce the injection pressure for some time, say 1 month, and then run another pressure-falloff test. If the skin is closer to zero in the second test, we can conclude that an induced fracture tended to close.

Permeability capacity and skin (before fracturing) can also be evaluated directly from step-rate test data using a multiple-rate flow-test analysis technique.[1,4] A prerequisite to this technique is great care to keep rates constant in each step and to obtain accurate data. Use of the technique is illustrated in the appendix.

Step-rate tests and pressure-falloff tests give virtually no information about fluid-injection distribution. For diagnosing the formation characteristics near injection wells, in a vertical dimension, injectivity-profile tests are needed. These tests are very useful and popular. Results obtained from them can beneficially supplement results obtained from step-rate and pressure-falloff tests. Especially helpful for this purpose are radioactive tracer injection and/or temperature decay surveys (Absolute temperature profile while injecting, followed by absolute temperature profiles after shut-in of injection).

Typical data. Typical pressure-vs-rate plots are shown in Figs. 1-5. The remarkable feature brought out by the last two figures is that the fracturing pressure was near hydrostatic head for most of the wells tested in the pressure-depleted reservoirs B and C. It was even slightly below the hydrostatic head in one well (No. 6, Fig. 5).

To place the data presented so far into perspective, a plot of fracturing gradients vs. shut-in formation pressure/depth ratios was prepared for wells from six formations. The resulting graph (Fig. 6) covers a wide range of prior injection histories, lithology, depths, geographic distribution (five states), geologic ages (Mississippian to Pliocene), and shut-in formation pressure/depth ratios.

Note that fracturing gradients ranged from 0.43 psi/ft to 0.93 psi/ft with the higher gradients generally occurring at the higher shut-in formation pressure/depth ratios. This trend of increasing fracturing gradients with shut-in formation pressure is in agreement with observations reported in several literature references.[5,6] This trend is especially well illustrated in Fig. 6 by the data for reservoir D (solid circles denote data taken in the first month of the flood and open circles denote data taken in the same wells 6 months later). These data indicate that fracturing pressures should be reevaluated periodically.

Vertical arrows in Fig. 6 connect first fracturing indications with second fracturing indications during the same test in the same well. (Details for Well No. 2 are shown in Fig. 2 and for Well Nos. 5, 6, and 8 in Fig. 5.) A preferred interpretation for this is that a first fracture occurred in comparatively hard, brittle rock and a second fracture in softer and more plastic rock.

The dashed lines shown in Fig. 6 show a comparison with a prevalent fracturing theory[6,7] (explained in the appendix). This presentation does not exclude the possibility that a refinement of this theory or some other theory would result in a better fit of the curves and data points.

Numbers on the dashed lines in Fig. 6 are Poisson's ratios. It has been speculated in the literature[8] that data points coinciding with relatively high Poisson's ratios (greater than 0.35) might be indicative of fracture extension through plastic cap-rock shales. This view is unconfirmed, however, at this time, because injectivity profiles, particularly temperature-decay surveys, were not made at the time (or close to the time) when the step-rate tests associated with high Poisson's ratios were made.

Will test damage formation? A study of field records for injection Wells Nos. 1-8 (Figs. 1-5) showed that earlier injection pressures exceeded the maximum pressure used during the step-rate tests. The theory of rock mechanics indicates that fractures once opened will tend to close again when the injection pressure is reduced below the fracturing pressure. What is happening is that the net effect of the overburden becomes stronger than the force that tends to keep an unpropped, induced fracture open. This is the mechanism that apparently occurred before step-rate testing in Wells Nos. 1-8.

No damage can conceivably be caused by step-rate tests in old waterfloods as long as the injection pressure during the tests does not exceed injection pressures used earlier during the waterflood history and as long as high-quality injection water is used. In a new waterflood, a typical well should be selected for a step-rate test. In this well, one should use only low and moderate injection rates until a fracturing pressure is definitely established. Later tests should be designed so that they do not greatly

exceed this pressure for any appreciable length of time (more than a few hours).

Acknowledgments

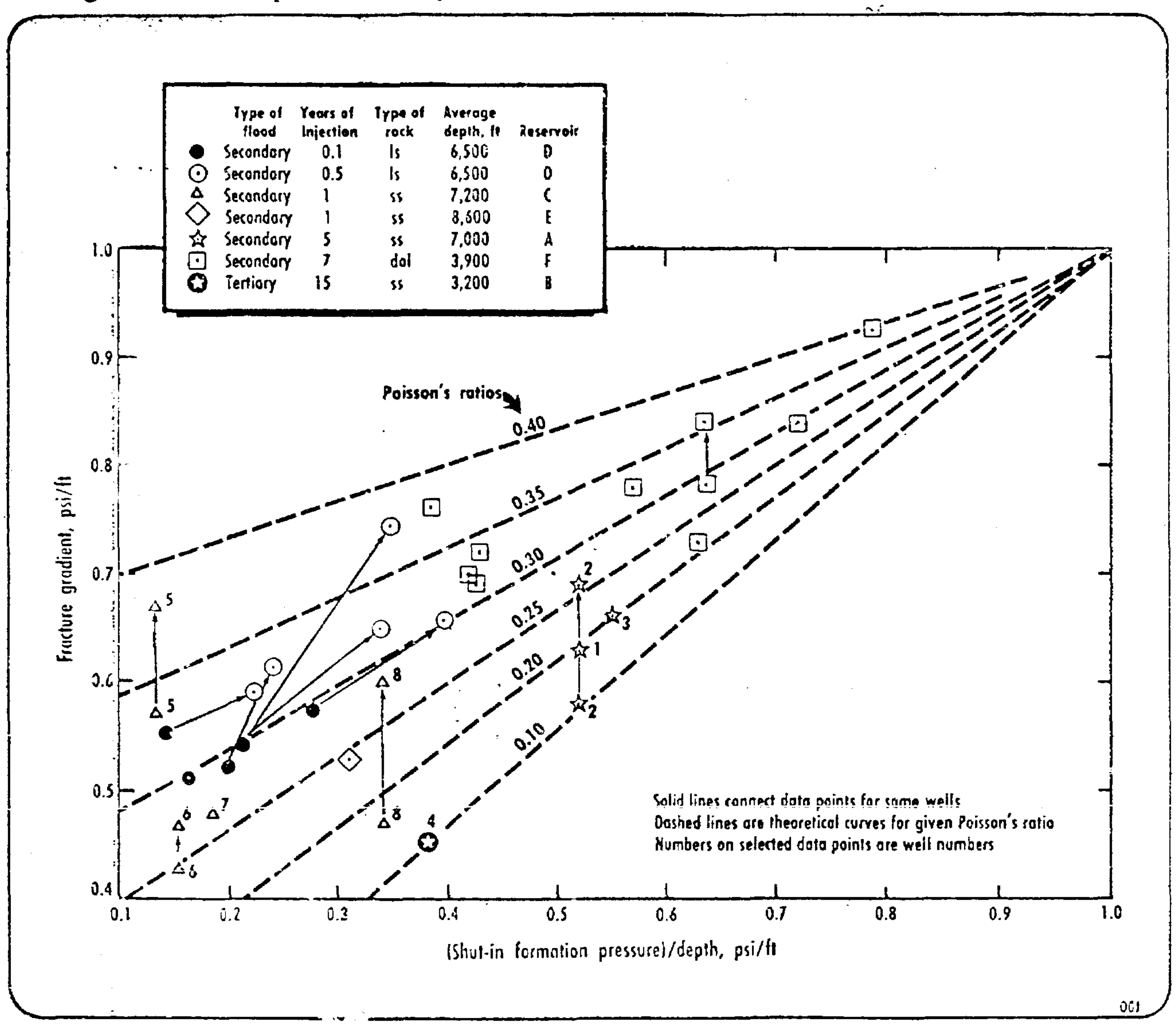
I am indebted to H. C. Walther for guidance and constructive criticisms, to H. A. Wahl for valuable suggestions, and to R. C. Cooper, Wayland Edwards, Dell Conley, and R. A. Strode for assistance in data collection and analysis.

Nomenclature

b' = Odeh intercept
B = Constant, psi/(b/d)^2
B_W = Water formation volume factor, RB/st-tk bbl
c = Total compressibility, psi^{-1}
C = Constant, (b/d)/psi
D = Non-D'Arcy flow constant, (b/d)$^{-1}$
D' = Another non-D'Arcy flow constant related to D as explained in equation 5, (b/d)$^{-1}$
h = Net effective pay, ft
K_{air} = Absolute permeability to air, md
k_{rw} = Relative permeability to water
k_w = Effective permeability to water, md
m' = Odeh slope
n = Step number in step-rate test
p = Pressure during step-rate test at time t, psi
p_e = Shut-in formation pressure, psi
P_f = Fracturing pressure related to same elevation as p_e, psi
p_i = True initial pressure during step-rate test, defined by intercept of p vs. q plot when q = o, psi
p_w = Bottom-hole pressure in well, psi
Δp = Difference in pressures, psi
Δp_f = Friction loss through perforations or slots, psi
q = Injection rate, b/d
r_e = Outer radius of pressure influence, ft
r_w = Well-bore radius, ft
r_{wa} = Effective well-bore radius, ft
s = Skin factor, dimensionless
s' = Apparent skin factor, dimensionless
S = Overburden pressure, psi
t = Time since start of test, hr.
t_n = Time at end of step n of step-rate test, hr
Z = Depth, ft
Φ = Porosity, fraction
μ_w = Water viscosity, cp
ν = Poisson's ratio, dimensionless

Fig. 6

Frac gradients vs. pressure-depth ratio



References

1. Yuster, S. T., and Calhoun, J. C., Jr., "Pressure Parting," Prod. Monthly, V. 9, No. 4: 16-26, February 1945.

2. Grandone, P., and Holleyman, J. B., "Injectivity Tests for Waterflooding Mid-Continent Oil Sands," World Oil, pp. 152-4, 6, 8, December 1949.

3. Odeh, A. S., and Jones, L. G., "Pressure Drawdown Analysis, Variable-Rate Case," Jour. Pet. Tech., pp. 960-964, August 1965.

4. Matthews, C. S., and Russell, D. G., "Pressure Buildup and Flow Tests in Wells," SPE Monograph, V. 1, 1967.

5. Heck, E. T., "Fractures and Joints," Prod. Monthly, p. 20, February 1955.

6. Hubbert, M. K., and Willis, D. G., "Mechanics of Hydraulic Fracturing," AIME Trans., V. 210: 153-166, 1957.

7. Eaton, B. A., "Fracture Gradient Prediction and Its Application in Oilfield Operations," Jour. Pet. Tech., pp. 1353-1360, October 1969.

8. Felsenthal, M., and Ferrell, H. H., "Fracturing Gradients in Waterfloods of Low-Permeability, Partially Depleted Zones," Jour. Pet. Tech., pp. 727-730, June 1971.

Appendix

PRESENTED here are recommended step-rate test times, non-D'Arcy flow-analysis techniques, and a multiple-rate analysis technique applied to step-rate tests. Also, presented is a brief description of a fracturing theory used in diagnosing step-rate test data.

Recommended time for each injection-rate step

Radius of investigation, $r_{inv} = \sqrt{0.00105 k_w t/\phi \mu_w c}$ (1)

This radius should be about 10 ft or larger to investigate formation properties adequately. For assumed typical values of $\phi = 0.2$, $\mu_w = 0.7$ cp, $c = 1.5 \times 10^{-5}$ psi^{-1}, $kr_w = 0.05$ for $K_{air} = 5$ md, and 0.10 for $K_{air} > 5$ md, we obtain.

Table 1

Test design values

Average K_{air}	Recommended minimum time for each step
5 md	60 min
10 md and larger	30 min

Non-D'Arcy flow analysis techniques

In non-D'Arcy radial flow:

$$q = \frac{0.00708 k_w h \Delta p}{\mu_w [\ln(r_e/r_w) + s + Dq]} \quad (2)$$

Where D is the non-D'Arcy flow constant, $(B/D)^{-1}$:

$$\text{The apparent skin} = s' = s + Dq \quad (3)$$

The s' term can be evaluated through a multiple-rate flow-test analysis technique (described in another part of this appendix) by substituting s' for s in equation 16. Next, s' is plotted vs q for the early steps of the test. D is then determined from this plot with the aid of equation 3. Analyses of s (= s' − Dq) for all steps of the step-rate test follow. The s terms are finally plotted vs injection pressures, and the point at which s becomes greatly more negative is interpreted as the fracturing pressure.

The aforementioned procedure is rather time-consuming. A shortcut approach was, therefore, developed and applied to the data of Well No. 3. This approach gave the same results as the method based on the multiple-rate flow-test analysis technique for this well.

For the derivation of the shortcut formula, Equation 2 was rewritten as

$$q + D'q^2 = C\Delta p \quad (4)$$

Where:
$C = 0.00708\, k_w h/\mu_w [\ln(r_e/r_w) + s]$

$$D' = D/[\ln(r_e/r_w) + s] \quad (5)$$

It was assumed here that $\ln(r_e/r_w)$ and C remained virtually constant before fracturing occurred. This is a reasonable assumption as long as q in a given step is much larger than q in the preceding step. Selecting two such steps (before indicated fracturing) as shown in Fig. 3, we wrote

$$q_1 + D'q_1^2 = C\Delta p_1 \quad (6)$$

$$q_2 + D'q_2^2 = C\Delta p_2 \quad (7)$$

Dividing (6) ÷ (7) gave:

$$D' = (q_2\Delta p_1 - q_1\Delta p_2)/(q_1^2\Delta p_2 - q_2^2\Delta p_1) \quad (8)$$

It should be emphasized that D' and D carry the same units, $(b/d)^{-1}$, but are not identical. They are related as shown in Equation 5. In the shortcut approach, pressure is finally plotted vs. $(q+D'q^2)$, as shown in Fig. 3.

In an alternate approach to solving the non-D'Arcy flow problem, we start with this equation:

$$q = \frac{0.00708 k_w h(\Delta p - \Delta p_f)}{\mu_w [\ln(r_e/r_w) + s]} \quad (9)$$

where $\Delta p = p_w - p_e$ and Δp_f is the friction loss which in turn is related to q as follows:

$$\Delta p_f = Bq^2 \quad (10)$$

In Equation 10, B is a function of the water density and the number and diameter of perforations that are open. Defining C as above, we then obtain from 9 and 10 for two rates, q_1 and q_2, before fracturing,

$$q_1 + BCq_1^2 = C\Delta p_1 \quad (11)$$

$$q_2 + BCq_2^2 = C\Delta p_2 \quad (12)$$

It is evident from an analogy to Equations 6 and 7 that BC=D'. It follows that we arrive in effect at the same solution, i.e., Equation 8, regardless of whether we start from Equation 2 or 9.

Multiple-rate flow test analysis

The technique of applying multiple-rate flow-test analysis to step-rate injectivity test data is based on the prin-

Table 2

Step-rate data during early part of test, Well No. 2

t, hr	q, b/d	p, psi	Data point	Step no. n	Odeh sum*	$\Delta p/q$ †
0	0	642	–	–	–	–
0.5	100	720	a	1	−0.301	0.780
1.0	100	730	b	1	0	0.880
1.5	250	856	c	2	−0.110	0.856
2.0	250	874	d	2	0.120	0.928
2.25	750	1,143	e	3	−0.335	0.668
2.50	750	1,182	f	3	−0.112	0.720
3.00	750	1,216	g	3	0.124	0.765

*Oden sum $= [q_1 \log t + (q_2 - q_1)\log(t - t_1) + (q_3 - q_2)\log(t - t_2) + \ldots + (q_n - q_{n-1})\log(t - t_{n-1})]/q_n$ (13)

†$(p - p_i)/q_n$ (14)

$p_i = 642$ psi

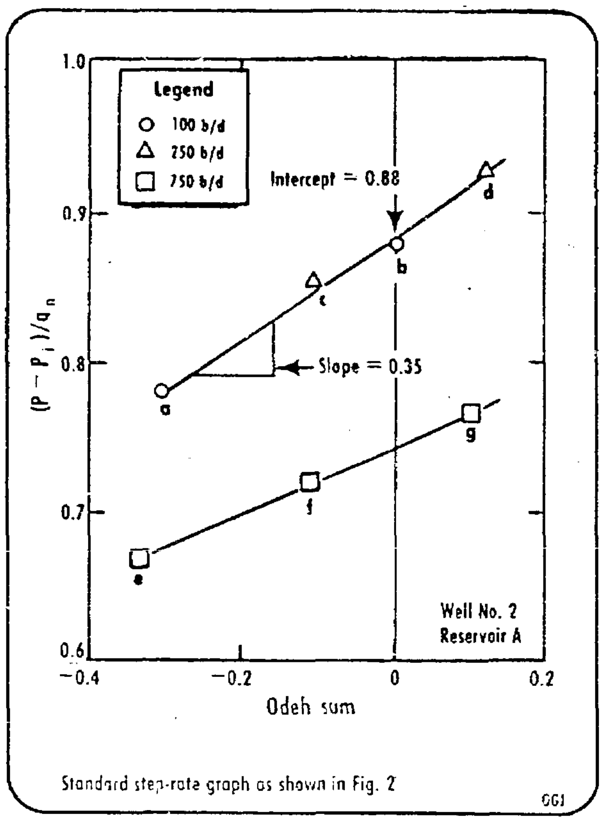
$t_1 = 1.0$ hr; $q_1 = 100$ b/d

$t_2 = 2.0$ hr; $q_2 = 250$ b/d

$t_3 = 3.0$ hr; $q_3 = 750$ b/d

Fig. 7

Odeh method of analysis



Standard step-rate graph as shown in Fig. 2

OGJ

ciple of "superposition." The technique, sometimes called the Odeh method, is well described in the literature for drawdown tests.[3,4] The equations presented in the literature can be used for the analysis of step-rate test data after making a change in sign and a change in symbol notations. Applicable equations and their use are presented in the following paragraphs.

The multiple-rate flow-test analysis technique determines $k_w h$ and skin before fracturing. It is essential that good data are available. Also, the correct initial pressure, p_i, must be known. This is the pressure that represents the intercept of the p vs. q plot when $q = 0$. Note, for instance, that using this criterion gives a lower p_i for Well No. 4 (Fig. 4) than indicated by the first observed pressure.

The method can be applied in theory only to data taken during the early rate steps when radial flow is the predominant flow mechanism in the formation zone under investigation. This approach was used for the data of Well No. 2 (Fig. 2). Data for the end of each of the early steps and for one or more arbitrary points during each of these steps were tabulated as shown in the first three columns of table 2, shown at left.

Sample calculations. For data point a (Step 1):

Odeh sum $= q_1 (\log t)/q_1 = 100 (\log 0.5)/100 = -0.301$

$(p - p_i)/q_1 = (720 - 642)/100 = 0.78$

For data point g (Step 3):

$$\text{Odeh sum} = [q_1 \log t + (q_2 - q_1)\log(t - t_1) + (q_3 - q_2)\log(t - t_2)]/q_3$$
$$= [100 \log 3 + (250 - 100)\log(3 - 1) + (750 - 250)\log(3 - 2)]/750$$
$$= 0.124$$

$(p - p_i)/q_3 = (1{,}216 - 642)/750 = 0.765$

The last two columns of Table 2 were plotted in Fig. 7. From this graph we read slope, $m' = 0.35$, and intercept, $b' = 0.88$. Known also were: $\mu_w = 0.45$ cp, $B_w = 1.0$, $h = 270$ ft (from a radioactive tracer-injectivity survey), $\Phi = 0.186$, $c = 1.5 \times 10^{-5}$ psi^{-1}, and $r_w = 0.25$ ft.

$$k_w h = 162.6 \mu_w B_w / m' \quad (15)$$
$$k_w h = 162.6 \times 0.45 \times 1.0/0.35 = 209 \text{ md ft}$$
$$k_w = 209/270 = 0.77 \text{ md}$$

$$s = 1.151 \left[\frac{b'}{m'} - \log \frac{k_w}{\Phi \mu_w c r_w^2} + 3.23 \right] \quad (16)$$

$$s = 1.151 \left[\frac{0.88}{0.35} - \log \frac{0.77}{0.186 \times 0.45 \times 1.5 \times 10^{-5} \times 0.0625} + 3.23 \right]$$

$s = -1.4$

$$r_{wp} = r_w e^{-s} \quad (17)$$

$r_{wp} = 0.25 e^{1.4} = 1.0$ ft

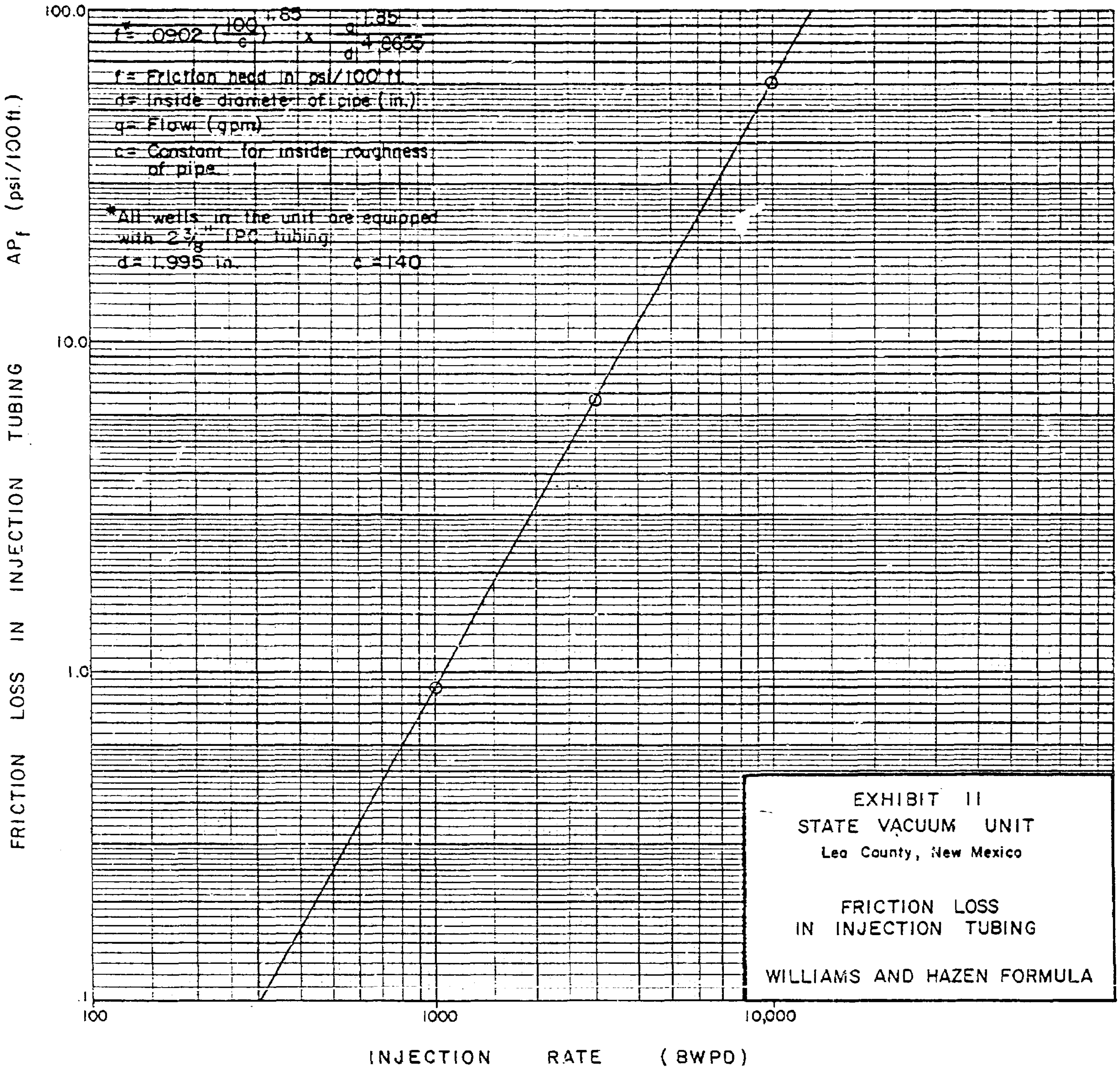
The data plotted in Fig. 7 show that the method broke down after point d was measured. That is, the following data points, e, f, and g, fell no longer on the old line. This was interpreted to indicate that radial flow was no longer the predominant flow regime and that fracturing had occurred.

Fracturing theory for diagnosis.

The theory [6,7] used in drawing the dashed lines in Fig. 6 is expressed by the equation:

$$p_f/Z = [(S/Z) - (p_r/Z)]\,[\mu/(1 - \mu)] + p_r/Z \quad (18)$$

The Poisson's ratio, ν is the ratio of maximum lateral deformation to maximum longitudinal deformation observed during compression loading of rock samples. A low ratio is generally associated with dense, brittle rock and a higher ratio with more elastic rock. The overburden pressure gradient, S/Z, used in constructing the theoretical curves of Fig. 6, was 1.0 psi/ft of depth. Other terms are defined in the nomenclature.



f* = .0902 (100/c)^1.85 x q^1.85 / d^4.8655
f = Friction head in psi/100 ft.
d = Inside diameter of pipe (in.)
q = Flow (gpm)
c = Constant for inside roughness of pipe
*All wells in the unit are equipped with 2 3/8" IPC tubing
d = 1.995 in.
c = 140
100.0
10.0
1.0
.1
100
1000
10,000
FRICTION LOSS IN INJECTION TUBING AP_f (psi/100 ft.)
INJECTION RATE (BWPD)
EXHIBIT II
STATE VACUUM UNIT
Lea County, New Mexico
FRICTION LOSS
IN INJECTION TUBING
WILLIAMS AND HAZEN FORMULA

AtlanticRichfieldCompany

North American Producing Division
New Mexico-Arizona District
P.O. Box 1710
Hobbs, New Mexico 88240
Telephone 505 393 7163

June 10, 1977

New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Attn: Mr. J. D. Ramey

Re: Commencement of water injection into the injection wells in the Atlantic Richfield State Vacuum Unit Waterflood in Sections 29, 31 & 32, T-17-S, R-34-E Lea County, New Mexico

File

Dear Sir:

On June 6, 1977, Atlantic Richfield commenced injecting water into the injection wells in the Atlantic Richfield State Vacuum Unit Waterflood. Permission was granted for this waterflood project on the 12th day of October, 1976, Case Number 5762, Order Number R-5295.

If further information is needed, please advise.

Yours very truly,

L. C. Hudry

L. C. Hudry

LCH:rm

cc: New Mexico Oil Conservation Commission
Hobbs, New Mexico
Attn: Mr. J. Sexton

Mr. Jerry Tweed-Midland

OIL CONSERVATION COMMISSION
P. O. BOX 2088
SANTA FE, NEW MEXICO 87501

January 24, 1977

COPY

Atlantic Richfield Company
P. O. Box 1610
Midland, Texas 79701

Re: Emergency Holding Pits
State Vacuum Unit
Vacuum G-SA Pool
Lea County, New Mexico

Attn: Mr. D. G. Chancey

Gentlemen:

Reference is made to your letter dated November 3, 1976, wherein you requested a permit to construct a nylon-reinforced neoprene lined emergency holding pit at the tank battery and automatic custody transfer system installed on your State Vacuum Unit, Vacuum Grayburg-San Andres Pool, Lea County, New Mexico.

Atlantic Richfield Company is hereby authorized to construct and utilize the above described pit as proposed subject to the following provisions:

(1) The automatic custody transfer system's available storage capacity above the normal high working level of the surge tank shall be maintained at at least 750 barrels. (This is in accordance with the provisions of ACT Permit No. I-574.)

(2) The oil overflow lines to the pit shall not be connected to the surge tank until the pump (Item 222 on Drawing No. E-P-429) has been installed and is operative.

(3) The 3-inch line labeled "Future Inlet" on Drawing No. E-P-429 shall not be connected without prior approval from this office.

(4) No deliberate flow of oil into the pit shall be permitted.

(5) At any time an emergency situation occurs, causing oil to overflow into the emergency holding pit, the Hobbs District Office of the Commission shall be immediately notified. All oil shall be removed from the pit within 12 hours after the LACT resumes pipe line shipments.

It is the Commission's belief that the system as proposed, if operated in accordance with the above provisions, is in the best interest of conservation and will prevent waste. Further, that if proper attention and maintenance is given the system, and if immediate evacuation of the pit is made after use, that it will be environmentally beneficial.

The Commission reserves the right to rescind this approval if it appears that excessive or negligent use is being made of the pit.

Very truly yours,

JOE D. RAMEY
Director

JDR/DSN/fd

cc: OCC Hobbs (with application)
Case File No. 5762

enc.

AtlanticRichfieldCompany
North American Producing Division
Permian District
Post Office Box 1610
Midland, Texas 79701
Telephone 915 682 8631

November 3, 1976

NOV

Mr. Dan S. Nutter
Chief Geologist
New Mexico Oil Conservation Commission
P. O. Box 2088
Santa Fe, New Mexico 87501

Case File 5762

Dear Mr. Nutter:

Atlantic Richfield Company, as operator of the State Vacuum Unit, requests a permit to construct one nylon reinforced neoprene lined emergency holding pit at the consolidated battery site of the State Vacuum Unit. This pit will be located at approximately the center of the west half (W/2) of Section 32, T-17S, R-34E, Lea County, New Mexico.

Three sets of drawings showing the details, location, and capacities of the proposed lined pit are attached to and made a part of this application. The drawing is entitled E-P-429, Emergency Holding Pit, Water Injection Plant and Central Tank Battery, State Vacuum Unit Waterflood.

A brief description of how the emergency holding pit will be utilized in our operations is set out below.

The lined pit will be kept empty to insure sufficient capacity for emergency overflow from three 500-barrel LACT surge tanks and two 500-barrel water tanks. All tanks and treating vessel drains will also be connected to this lined pit. As soon as any system malfunction has been corrected, the pit will be emptied by pumping the water to the produced water tank for injection and the oil back through the oil treating system for sale to the pipeline by the LACT unit. Any basic sediment or non-pipeline oil that might enter the pit will be sold to a reclaiming company so that the pit can be kept empty for emergency use.

The oil surge tanks areequipped with an overflow line to the proposed lined pit so that in the event of a malfunction of the LACT or the oil treating vessels, oil will be flowed to the lined pit instead of onto the battery site which would create a serious fire hazard, a safety hazard to the operating personnel, a major clean-up operation, and would cause the waste of New Mexico's natural resources.

The water tanks are equipped with an overflow line to the proposed lined pit so that in the event of a malfunction of the oil treating vessels or a malfunction of the supply water tank's high level shut-down valve, the fluid will flow to the lined pit instead of onto the plant site, causing pollution and necessitating a major clean-up operation.

The nylon reinforced neoprene lines will be purchased from Misco Supply Company, Wichita, Kansas. Atlantic Richfield has used many of these liners in Kansas, Oklahoma, and in the Empire Abo Unit in New Mexico with success. This liner was recommended by Atlantic Richfield's Research Center Chemical Engineering section after tests were made to determine its resistance to saturated hydrocarbon fluids and chemical and acid wastes. Copies of Misco's specifications for the nylon reinforced neoprene liner are attached.

As operators of the Unit, we hope we do not have to use the emergency holding pit but we do feel that the installation of the pit will be environmentally beneficial and in the best interest of conservation and the prevention of waste.

If any additional information is required by the Commission we will furnish it to you.

Very truly yours,

D. G. Chancey

D. G. Chancey

DGC/agp

MISCO BUILDING • WICHITA, KANSAS 67202 • PHONE (316) 265-6641

MISCO SUPPLY CO.
Division of MISCO INDUSTRIES, Inc.
FORMERLY MOUNTAIN IRON & SUPPLY COMPANY

SPECIFICATIONS FOR NYLON REINFORCED NEOPRENE

	MN-21
Total weight, oz./sq.yd.	16.0
Gauge, inches	.021
Kind of coating	Neoprene
Coating distribution	50/50
Base fabric: fiber	Nylon
weight, oz./sq.yd.	5.1
count	22 x 22
denier	840
Grab tensile, lbs./in.	450 x 375
Mullen burst, lbs./sq.in.	825
Hydrostatic, lbs./sq.in.	750
Tongue tear, lbs.	40 x 40
Adhesion of coating, lbs./in.	20
Low Temp. Res., 1/8 in. mandrel	-40°F[2]
30° flame time, seconds	15[2]
Abrasion Res., Taber, cycles	300[2]
Abrasion Res., duPont Scrub, cycles	2500[2]

OIL CONSERVATION COMMISSION

STATE OF NEW MEXICO
P. O. BOX 2088 · SANTA FE
87501

DIRECTOR
JOE D. RAMEY

LAND COMMISSIONER
PHIL R. LUCERO

STATE GEOLOGIST
EMERY C. ARNOLD

October 13, 1976

Mr. Clarence Hinkle
Hinkle, Bondurant, Cox
& Eaton
Attorneys at Law
Post Office Box 10
Roswell, New Mexico 88201

Re: CASE NO. 5762
ORDER NO. R-5295

Applicant:

Atlantic Richfield Company

Dear Sir:

Enclosed herewith are two copies of the above-referenced Commission order recently entered in the subject case.

Yours very truly,

JOE D. RAMEY
Director

JDR/fd

Copy of order also sent to:

Hobbs OCC x
Artesia OCC x
Aztec OCC ______

Other ______

BEFORE THE
NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
September 15, 1976

EXAMINER HEARING

IN THE MATTER OF:	
Application of Atlantic Richfield Co. for a unit agreement, Lea County, New Mexico.	CASE 5761
Application of Atlantic Richfield Co. for a waterflood project, Lea County, New Mexico.	CASE 5762

BEFORE: Richard L. Stamets, Examiner

TRANSCRIPT OF HEARING

APPEARANCES

For the New Mexico Oil Conservation Commission:
William F. Carr, Esq.
Legal Counsel for the Commission
State Land Office Building
Santa Fe, New Mexico

For the Applicant:
Clarence E. Hinkle, Esq.
HINKLE, BONDURANT, COX & EATON
Attorneys at Law
Hinkle Building
Roswell, New Mexico

I N D E X

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EXHIBIT INDEX

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Applicant's Exhibit Three, Structure Map	7	15
Applicant's Exhibit Four, Cross Section	8	15
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Applicant's Exhibits Six through Fifteen, Schematic Drawings - Injection Wells	8	15
Applicant's Exhibit Sixteen, Schematic Draw.	9	15
Applicant's Exhibits Seventeen through Twenty-six, Schematic Drawings - Producing Wells	10	15

EXHIBIT INDEX CONTINUED

	Offered	Admitted
Applicant's Exhibits Twenty-seven and Twenty-eight, Schematic Drawings - Plugged and Abandoned Wells	10	15
Applicant's Exhibits Twenty-nine through Sixty-six, Schematic Drawings - Wells within one-half mile	12	15
Applicant's Exhibit Number Sixty-seven, Plat	14	15

MR. STAMETS: We will call next Case 5761.

MR. CARR: Case 5761, application of Atlantic Richfield Company for a unit agreement, Lea County, New Mexico.

MR. HINKLE: Mr. Examiner, Clarence Hinkle, Hinkle, Bondurant, Cox and Eaton, appearing on behalf of Atlantic Richfield Company. We have two witnesses we would like to have sworn.

(THEREUPON, the witnesses were duly sworn.)

MR. HINKLE: Mr. Examiner, we have a lot of exhibits, sixty-seven of them, in fact, but most of them are diagrammatic sketches of the injection wells and producing wells so the testimony will be in respect to those. They are all under these folders.

MR. STAMETS: I presume what you would like to do then is consolidate this case and the next case?

MR. HINKLE: Yes, sir, I would.

MR. STAMETS: Let me call that next case then. Case 5762 being the application of Atlantic Richfield Company for a waterflood project, Lea County, New Mexico.

For purposes of the record, Cases 5761 and 5762 will be consolidated.

JOHN KNEPLER

called as a witness, having been first duly sworn, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. HINKLE:

Q State your name, residence and by whom you are employed?

A My name is John Knepler, I live in Midland, Texas and I'm employed by Atlantic Richfield Company.

Q What is your position with Atlantic Richfield?

A I'm an Operations Engineer.

Q Petroleum engineer?

A Yes, sir.

Q Have you previously testified before the Commission?

A No, I have not.

Q State briefly your educational background and your experience as a petroleum engineer?

A I graduated from the Missouri School of Mines with a B.S. in petroleum engineering in 1967 and I received a M.S. in petroleum engineering from Stanford University in 1968. I have worked for Atlantic Richfield as an Operations Engineer for eight years. I'm a Registered Professional Engineer in the State of Louisiana and I've worked in the Permain Basin for three-and-a-half years.

Q Are you familiar with Atlantic Richfield's operations in New Mexico and in particular in this Vacuum area?

A Yes, sir.

Q Have you made a study of the Vacuum Pool and all of the wells that have been drilled in the area?

A. Yes, sir.

MR. HINKLE: Are his qualifications sufficient?

MR. STAMETS: They are.

Q (Mr. Hinkle continuing.) What is Atlantic Richfield seeking to accomplish by this application?

A. Approval for --

Q There are two applications.

A. Approval for unitization and to waterflood the State Vacuum Unit.

Q Have you prepared or has there been prepared under your direction certain exhibits for introduction in this case?

A. Yes, sir.

Q These are the exhibits that have been marked One through Sixty-seven, I believe?

A. Yes, they are.

Q Refer to Exhibit One and explain what this is and what it shows?

A. This exhibit shows the outlines of the proposed unit area and all wells that have been drilled on the unit area and wells within two or more miles surrounding the same and the formations which they are producing from.

This exhibit also shows the outlines of the West Vacuum Unit which is contiguous to the proposed unit on the east and southeast. Also it shows the outline of the EK Queen

Unit which lies to the southwest of the proposed unit.

Exhibit Number One also shows the ownership of all of the leasehold interests within the unit area and in the surrounding area.

The proposed injection wells within the unit are shown by triangles and the additional injection well which is to be drilled is shown near the south boundary of Section 32.

Q Refer to Exhibit Two and explain that?

A Exhibit Number Two is a plat showing the outlines of the unit area which is the same as Exhibit A attached to the unit agreement, copies of which have been filed with the application for approval of the unit agreement.

Q Are all of the lands State lands?

A Yes, they are.

Q How many acres are involved?

A Eight hundred, approximately.

Q Now, refer to Exhibit Three and explain what this is?

A Exhibit Three is a structural map contoured on top of the Grayburg-San Andres formation with a twenty-foot contour interval, which is to be unitized. The Grayburg-San Andres formation as defined by the unit is the seven-hundred-and-seventeen-foot interval, the top of which is shown on the Lane Wells Radioactivity Log dated January 30th, 1948 at a subsurface depth of forty-one hundred and ninety-four feet in the Cole and Darden Phillips State B No. 1-X Well located six-hundred-and-sixty feet from the south line and six-hundred-and-sixty feet from the west line of Section 29, Township 17 South, Range 34 East, Lea County.

Q What does Exhibit Three show in effect?

A. It shows that the proposed unitized formation has continuity and is substantially uniform over the entire unit area.

Q Refer to Exhibit Four and explain this?

A. Exhibit Four is a north-south cross section across the unit, utilizing logs of the unit wells and showing the Grayburg-San Andres interval we propose to waterflood.

Q Is the waterflood interval rather uniform throughout the area?

A. Yes, sir, this exhibit and the next one indicate that the unitized formation has continuity and is substantially uniform over the entire area.

Q The next exhibit is Five and it is an east and west cross section showing the same thing?

A. That is correct.

Q Now, refer to Exhibits Six through Fifteen and explain what these are and what they show?

A. Exhibits Six through Fifteen are schematic drawings of ten of the eleven injection wells which are to be utilized in the unit. These ten wells, Six through Fifteen, are wells

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that are to be converted to injection. Each of these drawings show all casing strings, including diameters and setting depths, quantities used and tops of cement, open-hole intervals as well as tubing strings, including diameters and setting depths and location of packers.

Logs of each well to be converted to injection were filed with the hearing application.

Q. In your opinion will the completion of these wells in the manner shown by these exhibits confine injection water to the unitized formation?

A. Yes, sir, they will.

Q. Do you intend to use plastic-coated tubing in connection with each injection well?

A. Yes, we do.

Q. Refer to Sixteen and state what that is.

A. This is a schematic drawing of the State Vacuum Unit Well No. 21 which is to be drilled and completed as an injection well on the south edge of the unit.

Q. What would be the location of that well?

A. Approximately three, thirty from the south line and twenty-three, ten from the west line of Section 32, 17 South, 34 East.

Q. In this connection have you given all of the offset owners notice of the application?

A. Yes, we have.

Q. Have you had any objections?

A. No, we haven't, all of our offset owners are also partners in the proposed unit.

Q. Now, refer to Exhibits Seventeen through Twenty-Six and explain what these are.

A. These are schematic drawings of the producing wells in the unit. Each of these drawings show all casing strings, including diameters and setting depths, quantities used and tops of cement, open-hole intervals and tubing strings, including diameters.

Q. Did you find any particular problem in connection with any of these wells as far as waterflood is concerned?

A. No, sir, I did not.

Q. Now, refer to Exhibits Twenty-seven and Twenty-eight.

A. These are schematic drawings of two plugged and abandoned wells within the unit area. Each of these drawings shows all casing strings left in the well, including diameters and setting depths, quantities and tops of cement, sizes and locations of cement plugs placed in the wells and the plugging date as completely as I was able to determine.

Q. Why did you include these two wells?

A. Atlantic Richfield is aware of the waterflow problems that have developed in the Vacuum Field and we are participating in the Vacuum Waterflow Committee.

Wellbore diagrams and Bradenhead surveys have been

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submitted to the Commission on all wells within the proposed unit and no waterflow problems were found in any of these wells.

We have submitted schematic diagrams on all wells within the unit area. All of these diagrams on active wells indicate open-hole completions in the Grayburg-San Andres interval with at least six-hundred-and-seventy-five feet of cement above the casing shoe.

The schematic drawing of the proposed injection well to be drilled indicates that we will circulate cement to the surface on the production casing.

The schematic diagram of the two plugged and abandoned wells within the unit area indicate that these wells were properly plugged and should not be a source of water migration out of the waterflood zone.

We intend to run periodic injection surveys and step rate tests on our injection wells to monitor waterflood performance and maximize all producing rate and ultimate recoveries. we will run the first set of the pressure parting tests within sixty to a hundred-and-twenty days after injection starts, if the injection wells have pressure on them. If these wells are still taking water on a vacuum at that time we will be unable to run these tests and it would be unnecessary to do so. We plan to keep our injection pressures below the formation parting pressure as indicated by these step rate tests. This formation parting pressure will continue to increase as reservoir pressure increases with the waterflood operation. However, we do not at any time plan to exceed a formation base injection pressure in excess of one psi per foot. In addition, we will equip the wellhead of each well within the unit area in such a manner so that periodic Bradenhead monitoring can be done.

Q Now, refer to Exhibits Twenty-nine through Sixty-six and explain what these are.

A. Exhibits Twenty-nine through Sixty-six are schematic drawings of all wells producing, injection or plugged and abandoned within one-half-mile of the unit boundary. Each of these drawings show all casing strings, including the diameters and setting depths, quantities used and tops of cement, open-hole intervals and tubing strings, including diameters, as completely as I was able to determine from the Commission records.

Q Why did you include these wells?

A. We wanted to be as certain as possible that there were no problems to be anticipated with waterflows around our proposed unit. There were schematic drawings and Bradenhead surveys made on all wells in the field in accordance with the Waterflow Committee recommendations and there were no problems appeared on any of these wells and we wanted the record to reflect that they were, in our opinion, safe and should not present any problem to our waterflood.

Q This was simply because they have had the waterflow problem in the Vacuum area?

A. In some parts of the field there have been problems.

MR. STAMETS: While we are right on this subject, do you know of your own knowledge, if any of the wells offsetting your proposed waterflood had pressure on the Bradenhead?

A. Well, the criteria that was determined by the Committee as a problem well would be a well that would flow water under a certain -- had a certain pressure on it and would flow water when the valve was open. Now, if a well actually had pressure and it was just a puff of gas that would blow off immediately this was not considered significant and I do not know well-by-well if any of these had that problem but I do know that none of them had a waterflow within the criteria established by that Committee.

MR. STAMETS: Thank you.

Q (Mr. Hinkle continuing.) Have you made an estimate of the additional oil you expect to recover by reason of the waterflood?

A. Yes, we expect to recover approximately one million, seven hundred thousand barrels of secondary oil that would otherwise be unrecoverable without waterflooding the unit area.

Q In your opinion, would it be helpful and advisable if the order approving the waterflood project provides for administrative approval of any changes which might prove necessary as far as the location of the injection wells are concerned?

A. Yes.

Q. Are you requesting a project allowable?

A. Yes, we would like to have the benefit of a project allowable as provided in Rule 701 of the Commission so that the allowable assigned for the wells may be equal to the ability of the wells to produce and so that they would not be subject to the depth bracket allowable for the pool nor the market demand percentage factor.

Q. What quanitity of water do you anticipate you will inject initially?

A. Approximately fifty-five hundred barrels a day into the eleven wells beginning about January 1st, 1977.

Q. What is going to be the source of your water?

A. The City of Carlsbad ity water supply system which obtains water from the Ogallala formation in Lea County.

Q. Do you also contemplate injecting produced water?

A. Yes, we do as it becomes available.

Q. Have all of the wells in the proposed unit reached an advanced stage of production and are classed as stripper wells?

A. Yes, Exhibit Sixty-seven is a plat of the unit area and shows the proposed injection and producing wells and the average daily oil and water production for each well during

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May of 1976.

Q In your opinion will approval of this application be in the interest of conservation, prevention of waste and protect correlative rights?

A. Yes, it will.

MR. HINKLE: We would like to offer Exhibits One through Sixty-seven.

MR. STAMETS: Exhibits One through Sixty-seven will be admitted.

(THEREUPON, Applicant's Exhibits One through Sixty-seven were admitted into evidence.)

MR. HINKLE: That's all the direct we have.

CROSS EXAMINATION

BY MR. STAMETS:

Q Going back to Exhibit Number Twenty-seven.

A. Yes, sir.

Q The well here, located six, sixty north and east of Section 31 has been plugged with a series of five-sack plugs, it appears. Do you think this is adequate by today's standards?

A. Well, certainly if we were going to plug this well today we would probably put more than that amount of cement in the well. However, this is the information which I was able to find after diligent search of our records and the lease owner on whose lease this well is located and the only source of any data from this old well was the Commission's records and the five sacks might or could be sufficient in the proper location. On the note here in the middle of the diagram there is a plug at the base of the salt with no description as to what size it was and also the five-and-a-half casing, the records indicate that it was probably pulled but not definitely. It could possibly be in the well. So certainly with this cement with the casing in the well would be much better than if this amount of cement was used in essentially an open-hole interval of a dry hole that had been drilled with no casing left in the well at all.

Q Nonetheless, this is not the type of plugging program you would recommend today?

A No, sir.

Q Is there a possibility that Atlantic might have to go in this well and re-plug it to assure that water is not going to escape through it?

A Well, there is certainly a possibility. We do intend to monitor all of the wells, including these plugged wells.

Q How would you propose to monitor this well?

A Since this well is cemented about the only thing we could do would be to maybe, and I have not physically been on the site to look at it, we could possibly get into the surface casing and weld a valve on there to see if there was any pressure

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on it and continue to monitor that but if a problem develops and when the problem develops, it would just depend on what the problem was and we would begin a search to try to determine the source and correct the problem, yes, sir.

Q. Now, did I understand you to say that you had checked the Bradenhead on every well within the project area, every well that has one?

A. There has been submitted and it is in the Commission files a sketch and a pressure survey on all wells in this field and I have looked at the records on these wells. I have not personally been out to the wells, especially if they weren't on our lease but this Committee flagged all wells in which there was any problem that exceeded their criteria and this was with people with the Commission staff in the Committee and with their guidance and none of the wells in this area, including the wells that I have shown all of these sketches on, had any problem that was considered significant.

Q. Will the Bradenheads be periodically tested in this area during the course of your flood?

A. Yes, within the unit area. As I said we intend to equip the wellheads so that we can periodically check the pressure on them. Now, as far as those outside the unit area, that would be dependent upon what Commission rules are eventually issued for this field where a problem has been found.

Q Right. I was concerned primarily with the unit area in this case.

A. Yes, indeed, we will monitor those.

Q And you have reviewed the well construction on all of the wells in the unit area and you are fairly confident that they are in good shape?

A. Yes, very much so.

Q Now, you indicated that you planned to limit pressures to one psi per foot. The recent Commission orders have limited pressure generally to seven-tenths of a pound.

A. Well, I said that first and foremost we will limit the pressure to what the step rate tests indicate we should limit it to but under no circumstances would we go over one psi. We fully anticipate that we will limit it to much less than that by those step rate tests and other monitoring techniques which we intend to employ.

Q Now, these step rate tests would be commenced, what, sixty to a hundred-and-twenty days after you get some pressure built up?

A. Well, I said within sixty to a hundred-and-twenty days after injection starts, depending upon if the wells had pressure on them and I think the way you have stated it would probably be more concise that once the wells get enough pressure on them to enable us to run the tests we will run them and we anticipate that it would be something like sixty to a hundred-

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and-twenty days.

Q If you were initially limited to seven-tenths of a pound per foot formula you would not have any problems with that lease as the flood began?

A I don't see that we would, we anticipate that the wells will take water on a vacuum for awhile and then the pressure would gradually increase as we increased the pressure in the reservoir, now, at which time we ran step rate tests which indicated we would not be parting the formation in a pressure in excess of that seven-tenths, we would probably come back to the Commission with that evidence and request that we be allowed to go up to what the step rate test indicated would be a safe operating pressure.

Q Do you plan to run a synergetic log on the well to be drilled in here? This is a log which can be utilized to calculate the parting pressure of the formations in the area.

A I'm not familiar with that log.

Q It might be something to look into when this well is drilled and I know that Schlumberger out of the Hobbs office has run them because I have seen a couple of them.

A It sounds like a new application of some existing logging techniques.

Q It is.

A Which probably we will be running those logs anyway and it wouldn't be any problem to incorporate that calculation from the data.

Q I would encourage you to work with our District Supervisor in Hobbs on this particular problem and if it is run, the Commission would like to have a copy. Would you be agreeable to submitting copies of parting pressure tests as they are run?

A. Yes, sir.

Q And I presume the annulus on all of these wells would be loaded, gauged or left open or some other method to test those?

A. It will be loaded with a treated water to prevent corrosion and hooked up for pressure monitoring.

MR. HINKLE: One other question.

REDIRECT EXAMINATION

BY MR. HINKLE:

Q Does Atlantic Richfield own the leases upon which the two dry holes are located, shown by Exhibits Twenty-seven and Twenty-eight?

A. We own the lease where one of them is located.

Q Which one is that?

A. Well No. 28 is located on Atlantic Richfield's lease in the south half of Section 32.

Q Were these wells plugged and abandoned by Atlantic Richfield?

A. No, sir, they were plugged and abandoned a long time

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before we acquired the lease.

Q By other owners?

A. By other owners, yes.

MR. HINKLE: That's all.

MR. STAMETS: Are there any other questions of this witness? He may be excused.

(THEREUPON, the witness was excused.)

MR. HINKLE: We have one other witness.

THOMAS R. BARR

called as a witness, having been first duly sworn, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. HINKLE:

Q State your name, your residence and by whom you are employed?

A. Thomas R. Barr, I live in Midland, Texas and I'm employed by Atlantic Richfield.

Q What is your position with Atlantic Richfield?

A. Landman.

Q Have you had considerable experience as a Landman?

A. Yes, sir, I have been employed here in the Permian Basin and New Mexico area for about a year-and-a-half and I have had another additional year in other parts of the country.

Q. Are you familiar with the application which Atlantic Richfield has made for the pool of the unit agreement in this case?

A. Yes, sir, I am.

Q. Have you been handling the matter as far as obtaining approval of the unit by the working interest owners?

A. Yes, sir, I have.

Q. Has there been filed with the application in this case, three copies of the unit agreement?

A. Yes, sir.

Q. Has this form been approved by the Commissioner of Public Lands?

A. Yes, sir, it has.

Q. Is this substantially the same form as has heretofore been approved and used where State lands are involved or where a waterflood project is contemplated?

A. Yes, sir, it is.

Q. Is Atlantic Richfield designated as operator in the unit agreement?

A. Yes, sir.

Q. I believe that the previous witness testified as to the formation which is being unitized, there is only the one formation being unitized by the unit?

A. Yes, sir.

Q. Does the unit agreement specifically provide for the primary purpose of the unit and what is that?

A. Secondary recovery, sir.

Q. Does the unit agreement contain a participating formula?

A. Yes, sir, Section 13 which begins on page twelve provides that the respective tracts shown on Exhibit B attached to the unit are to participate in accordance with the percentages as set forth in Exhibits C-One, C-Two during Phase One and Phase Two of the waterflood.

Q. Have you contacted all of the working interest owners and invited them to join the unit?

A. Yes, sir.

Q. What is the present status?

A. We currently have signed joinders from all parties with the exception of Texaco. Texaco has by phone stated that they will join but it has not been formally approved through their organization and shortly we expect their signed joinder as well.

Q. So you contemplate one hundred percent joinder?

A. Yes, sir.

Q. And all of these parties have approved the participating formula?

A. Yes, sir.

MR. HINKLE: That's all we have of this witness.

CROSS EXAMINATION

BY MR. STAMETS:

Q What percent do you have signed up on this unit at this time?

A. It depends on the basis of Phase one or Phase Two. If it is on the basis of Phase One we have approximately fifty percent sign up. Texaco owns currently in Phase one fifty point six, eight percent.

Q. Do you anticipate a hundred percent sign up?

A. Hopefully within two weeks, yes, sir.

MR. STAMETS: Any other questions of the witness? He may be excused.

(THEREUPON, the witness was excused.)

MR. STAMETS: Anything further in this case?

MR. HINKLE: That's all.

MR. STAMETS: The case will be taken under advisement.

REPORTER'S CERTIFICATE

I, SIDNEY F. MORRISH, a Certified Shorthand Reporter, do hereby certify that the foregoing and attached Transcript of Hearing before the New Mexico Oil Conservation Commission was reported by me, and the same is a true and correct record of the said proceedings to the best of my knowledge, skill and ability.

Sidney F. Morrish, C.S.R.

I do hereby certify that the foregoing is a complete record of the proceedings in the Examiner hearing of Case No 5261-5962 heard by me on 9-15, 1976.

Richard L. Stamets, Examiner
New Mexico Oil Conservation Commission

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CASE 5758: Application of Global Survey, Inc. for a unit agreement, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks approval for the Global Survey Unit Area comprising 4,781 acres, more or less, of State and Federal lands in Township 25 South, Ranges 26 and 27 East, Eddy County, New Mexico.

CASE 5759: Application of Universal Resources Corporation for compulsory pooling, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks an order pooling all mineral interests in the Pennsylvanian formation underlying the S/2 of Section 36, Township 17 South, Range 26 East, Eddy County, New Mexico, to be dedicated to a well to be drilled 660 feet from the South line and 1980 feet from the West line of said Section 36. Also to be considered will be the cost of drilling and completing said well and the allocation of the cost thereof, as well as actual operating costs and charges for supervision. Also to be considered will be the designation of applicant as operator of the well and a charge for risk involved in drilling said well.

CASE 5760: Application of Morris R. Antweil for compulsory pooling, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks an order pooling all mineral interests in the Pennsylvanian formation underlying the S/2 of Section 33, Township 21 South, Range 26 East, Avalon Field Extension, Eddy County, New Mexico. Also to be considered will be the cost of drilling and completing said well and the allocation of the cost thereof, as well as actual operating costs and charges for supervision. Also to be considered will be the designation of applicant as operator of the well and a charge for risk involved in drilling said well.

CASE 5761: Application of Atlantic Richfield Company for a unit agreement, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval for the State Vacuum Unit Area comprising 800 acres, more or less, of State lands in Sections 29, 31, and 32, Township 17 South, Range 34 East, Lea County, New Mexico.

CASE 5762: Application of Atlantic Richfield Company for a waterflood project, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to institute a waterflood project on its State Vacuum Unit Area, Vacuum Pool, Lea County, New Mexico, by the injection of water into the Grayburg-San Andres formation through 11 injection wells located in Unit M of Section 29, Units A and I of Section 31, and Units C, E, G, I, K, M, N, and O of Section 32, all in Township 17 South, Range 34 East.

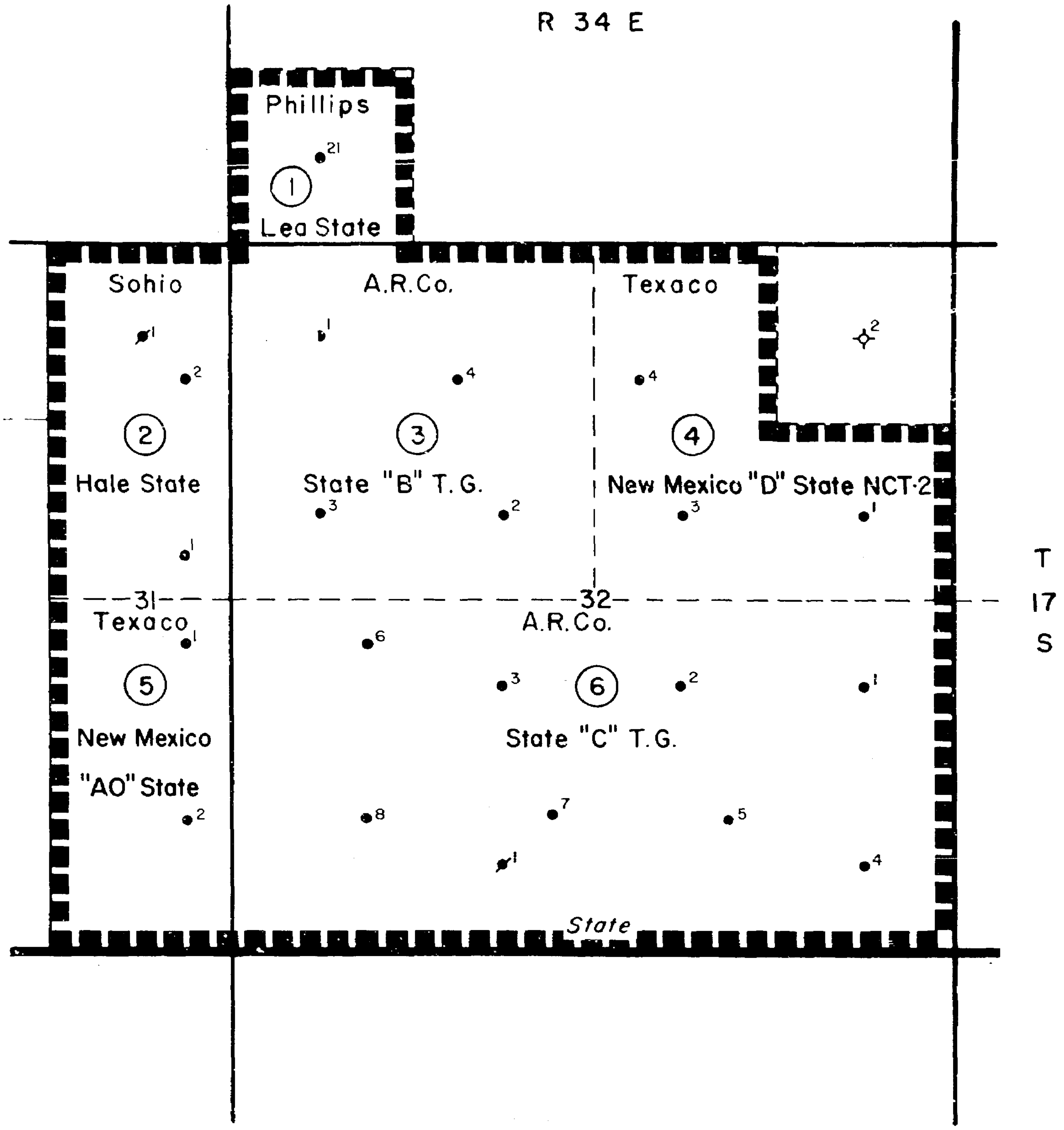
CASE 5763: Application of Roger C. Hanks for the amendment of Order No. R-4691-A, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks the amendment of Order No. R-4691-A, which order promulgated special pool rules for the North Dagger Draw-Upper Pennsylvanian Pool, Eddy County, New Mexico. Applicant seeks the establishment of a special depth bracket allowable for said pool of 350 barrels per day.

CASE 5767: Application of American Quasar Petroleum Co. of New Mexico for a unit agreement, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval for the Brininstool Unit Area comprising 5,743 acres, more or less, of State and Federal lands in Township 23 South, Range 33 East, Lea County, New Mexico.

CASE 5746: In the matter of the hearing called by the Oil Conservation Commission on its own motion to permit Conley and Associates, Inc., the Travelers Indemnity Company, and all other interested parties to appear and show cause why the following wells in Harding County, New Mexico, should not be plugged and abandoned in accordance with a Commission-approved plugging program:

Township 15 North, Range 33 East:
Arthur Cain Well No. 3 located in Unit N of Section 4; Arthur Cain Well No. 2 located in Unit K of Section 10; and State Well No. 1 located in Unit D of Section 21;

Township 16 North, Range 33 East:
State Well No. 1-X located in Unit M of Section 27.



LEGEND

UNIT BOUNDARY

EXHIBIT 2

PROPOSED STATE VACUUM UNIT

TOWNSHIP 17 S, RANGE 34 E

LEA COUNTY, NEW MEXICO

.11 4-22-76

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 1 (Phillips Lea No. 21)
660' FSL & 680' FWL Section 29, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

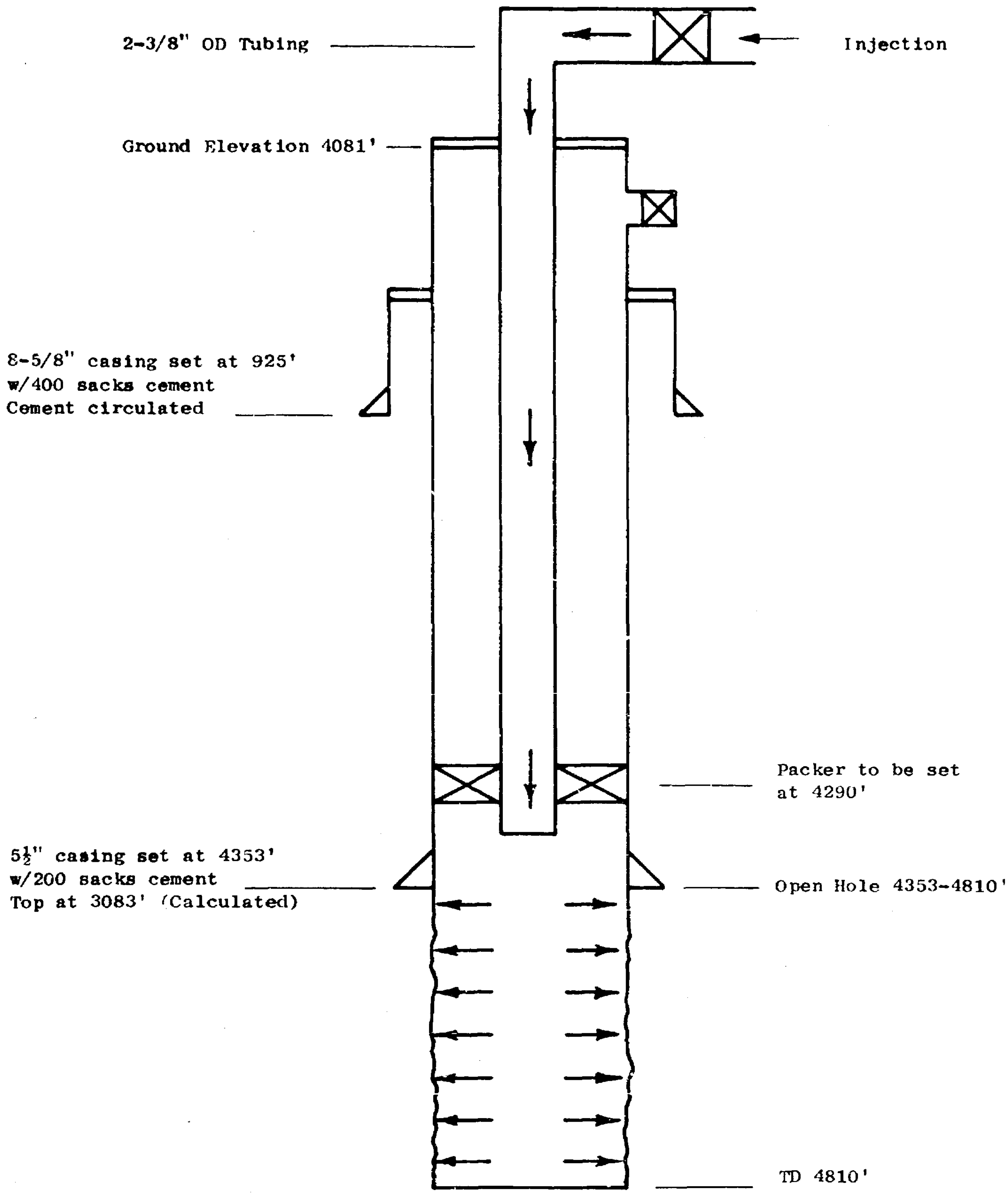


EXHIBIT NO. 6

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 2 (Sohio Hale-State No. 2)
990' FNL & 330' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All Measurements are from KB 2.5' above GL

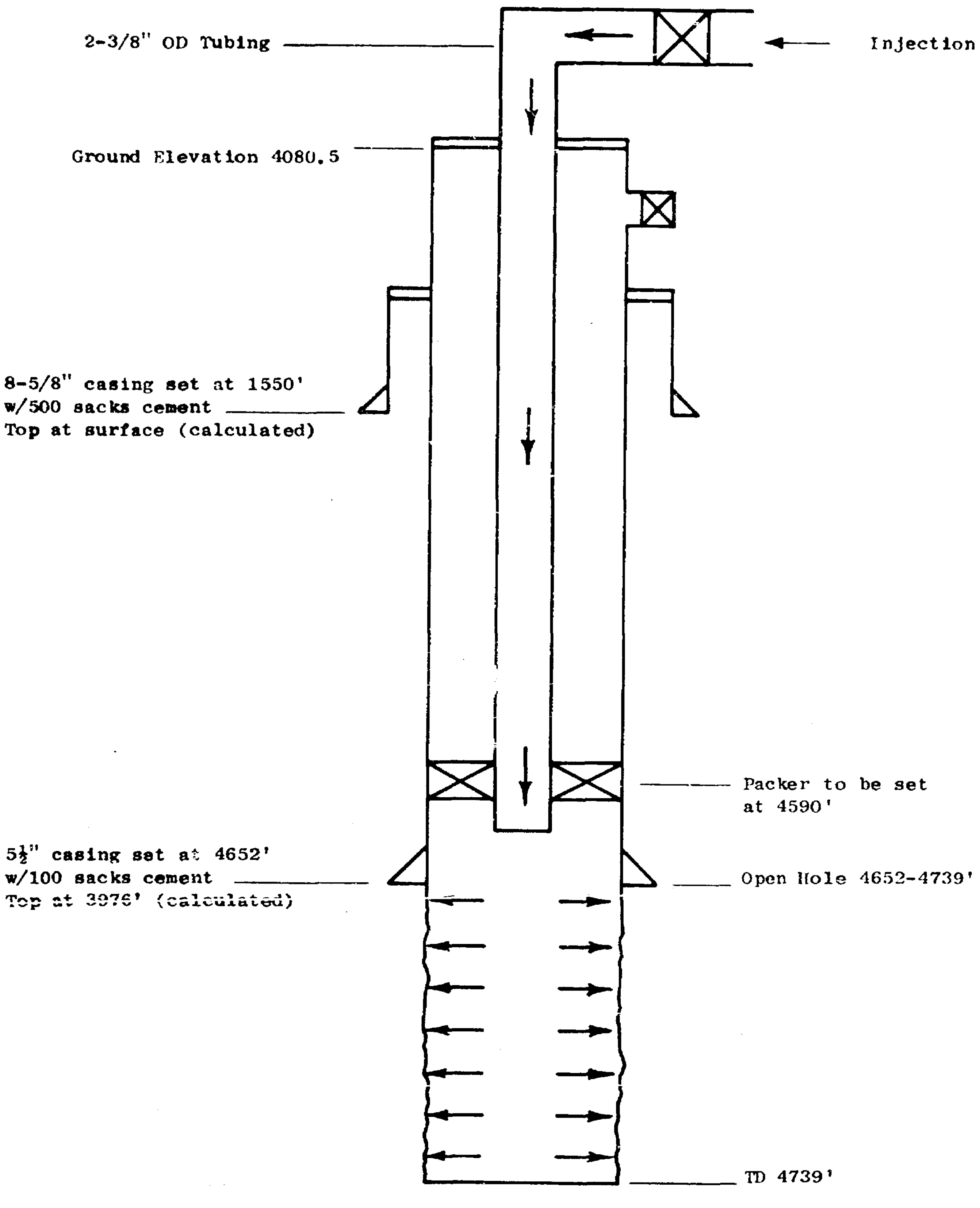


EXHIBIT NO. 7

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 4 (A.R.Co. State "B" TG No. 4)
990' FNL & 1650' FWL Section 32, T-17S R-34E
Lea County, New Mexico

All Measurements are from KB 2' above GL

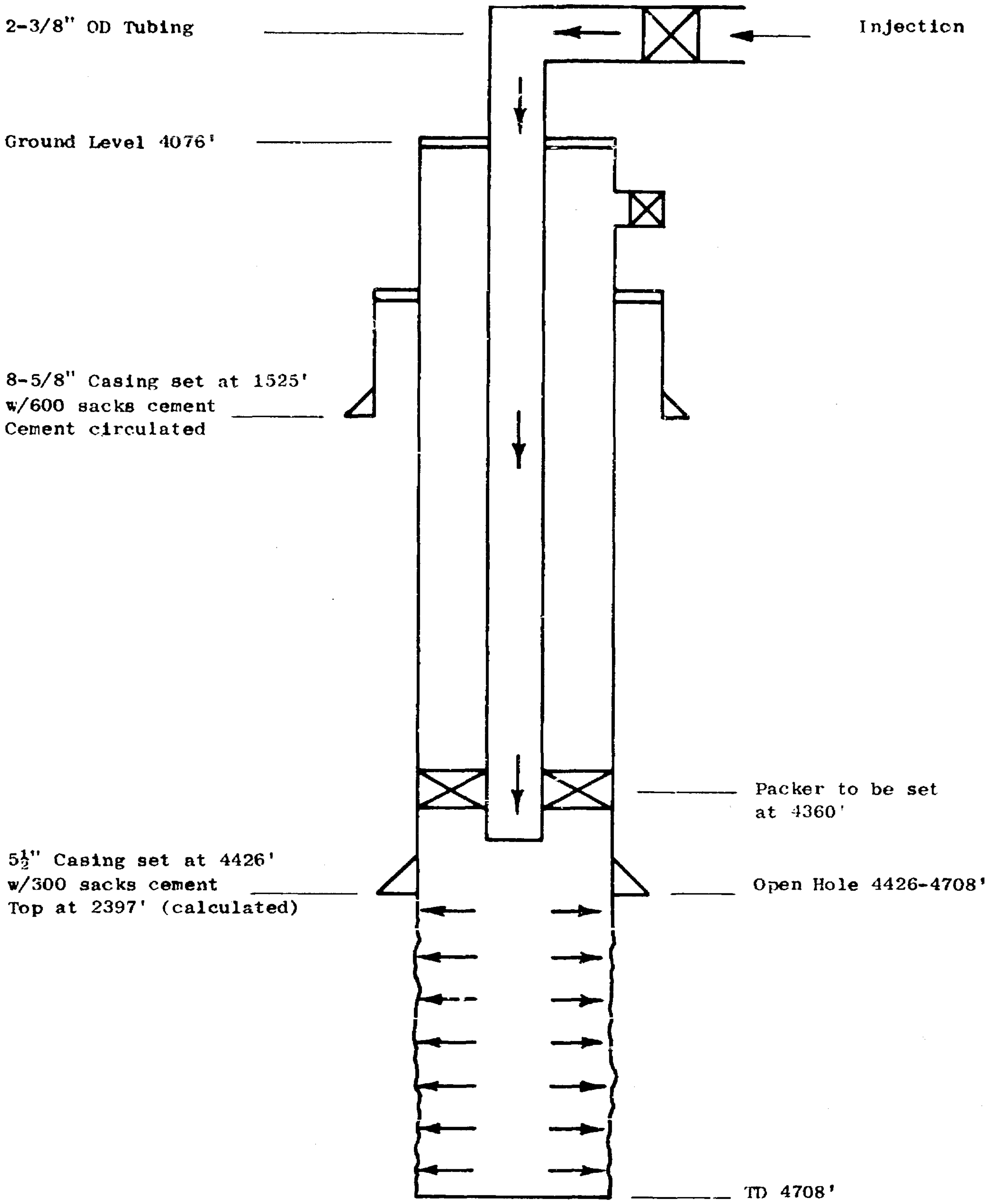


EXHIBIT NO. 8

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 7 (A.R.Co. State "B" TG No. 3)
1980' FNL & 660' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

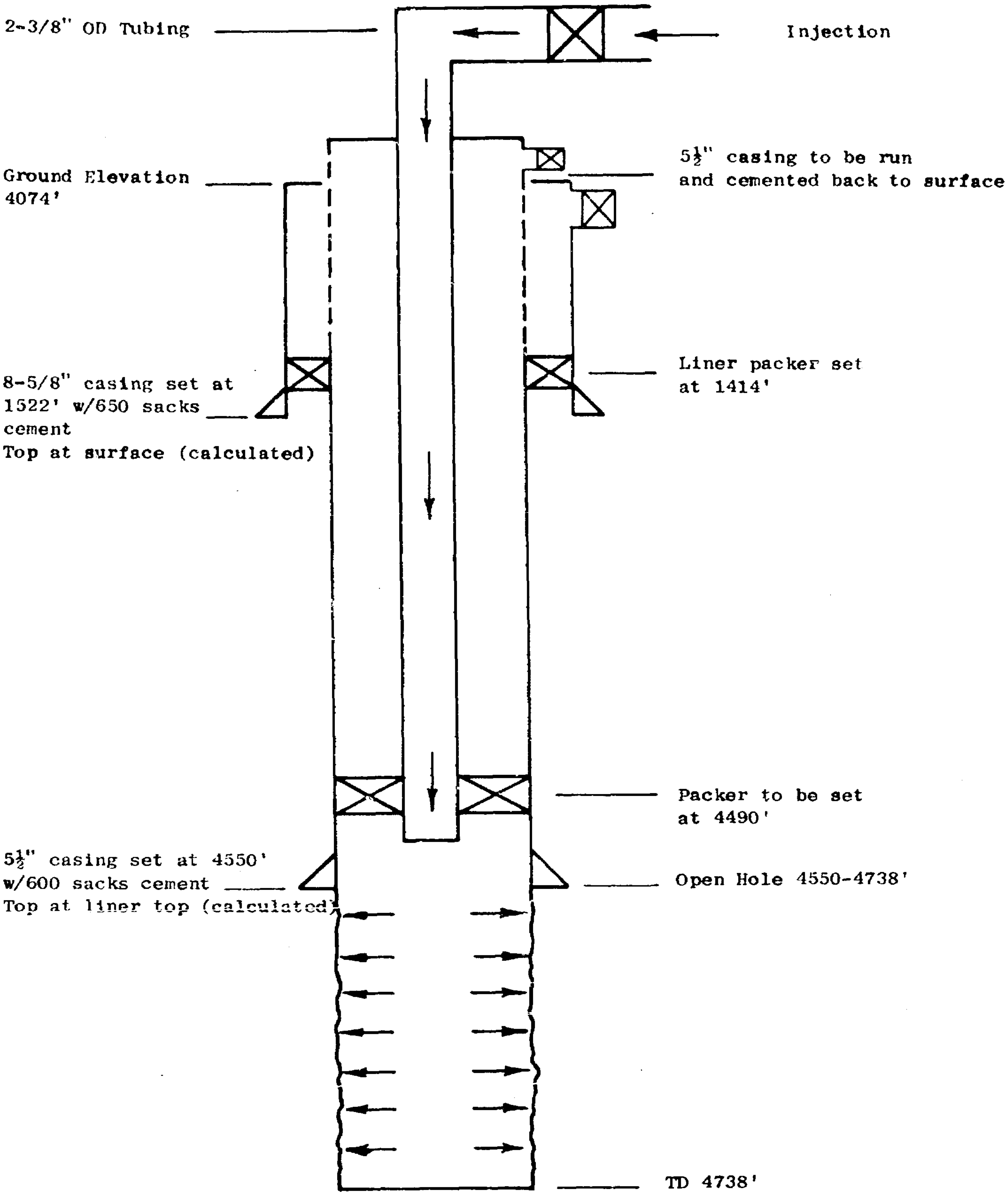


EXHIBIT NO. 9

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 9 (Texaco New Mexico "D" State NCT-2 No. 3)
1980' FNL & 1980' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 9' above GL

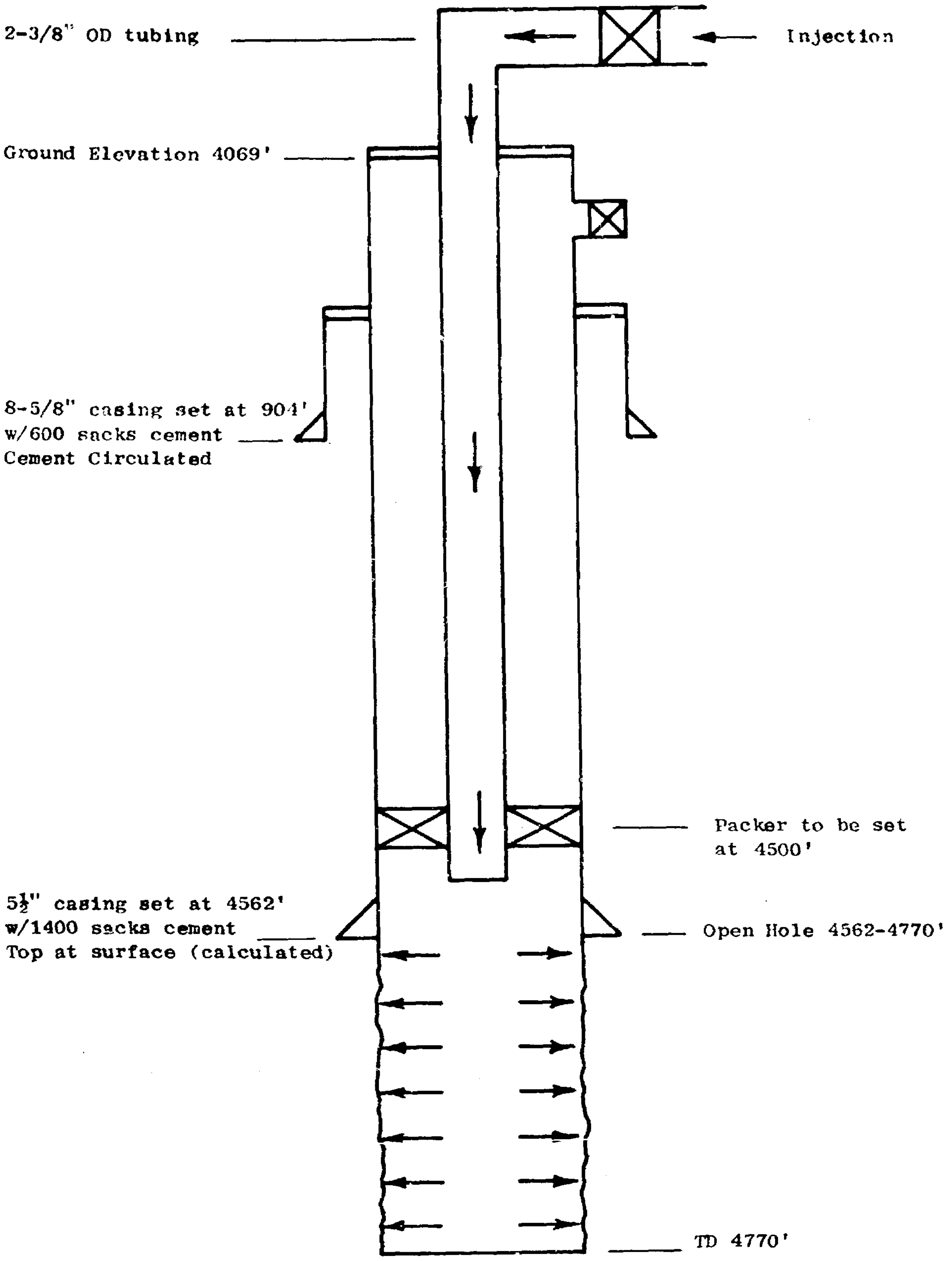


EXHIBIT NO. 10.

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 11 (Texaco New Mexico "AO" State No. 1)
2310' FSL & 330' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

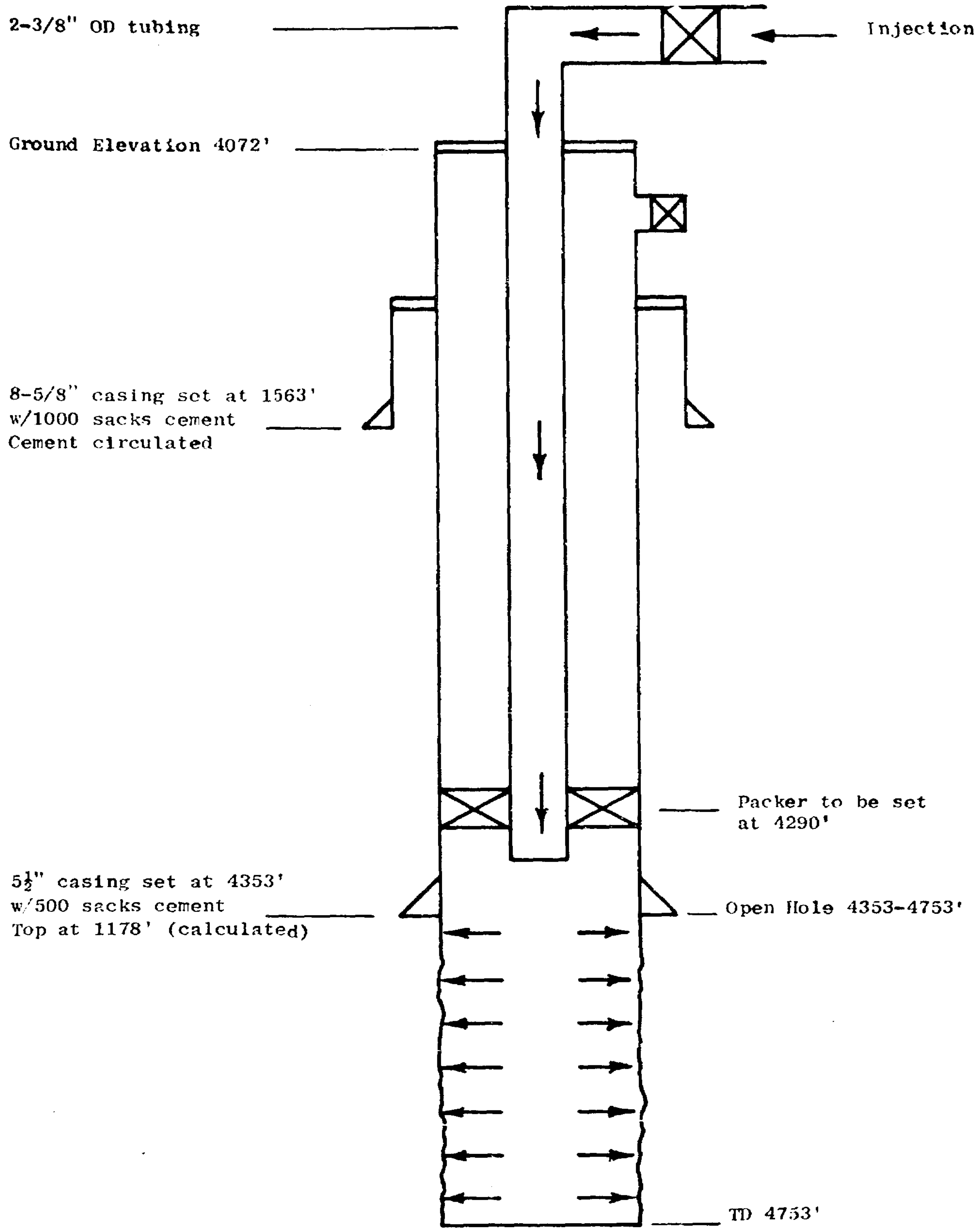


EXHIBIT NO. 11

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 13 (A.R.Co. State "C" TG No. 3)
1980' FSL & 1980' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10.5' above GL

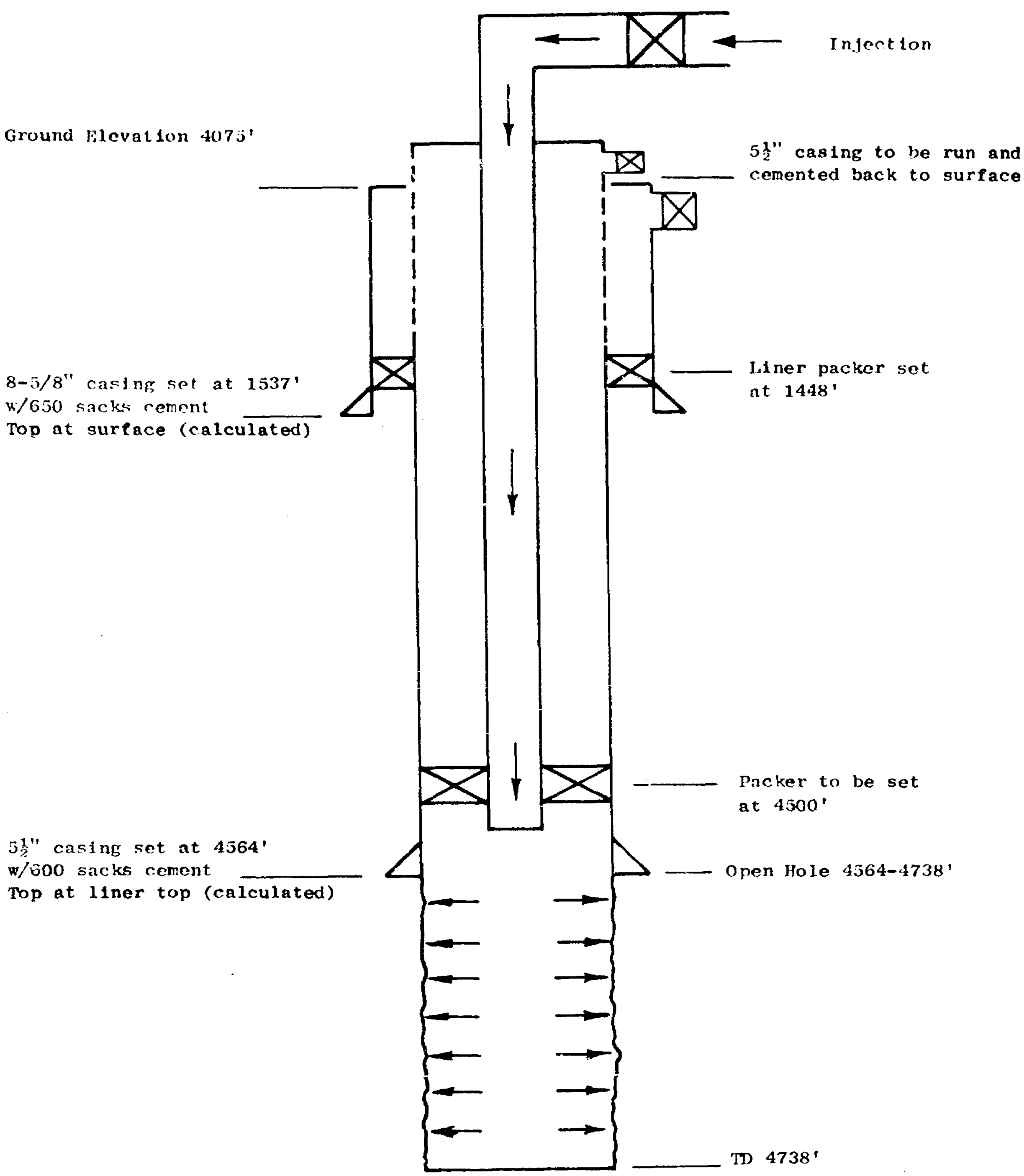


EXHIBIT NO. 12

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 15 (A.R.Co. State "C" TG No. 1)
1980' FSL & 660' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

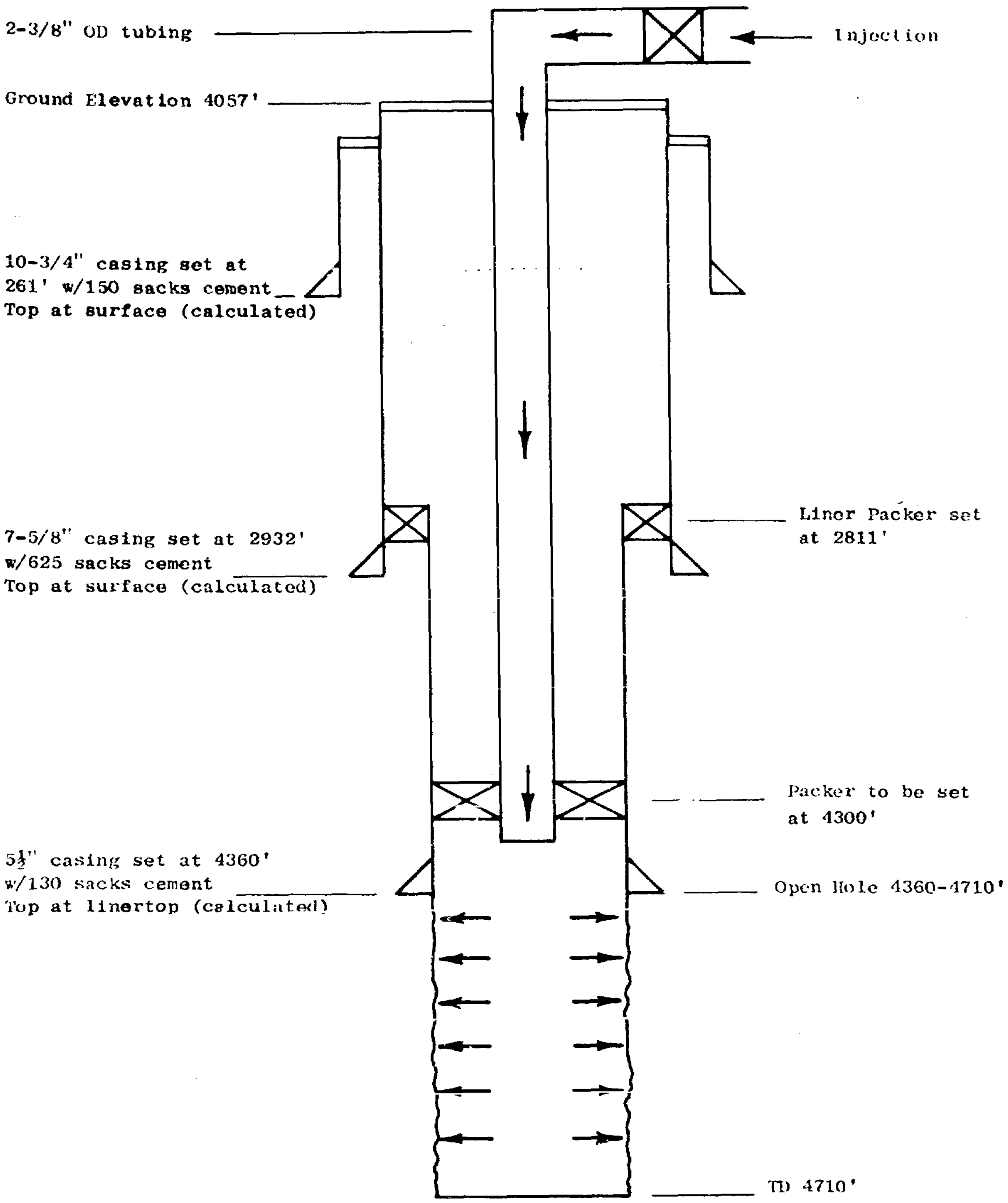


EXHIBIT NO. 13

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 17 (A.R.Co. State "C" TG No. 8)
990' FSL & 990' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 4' above GL

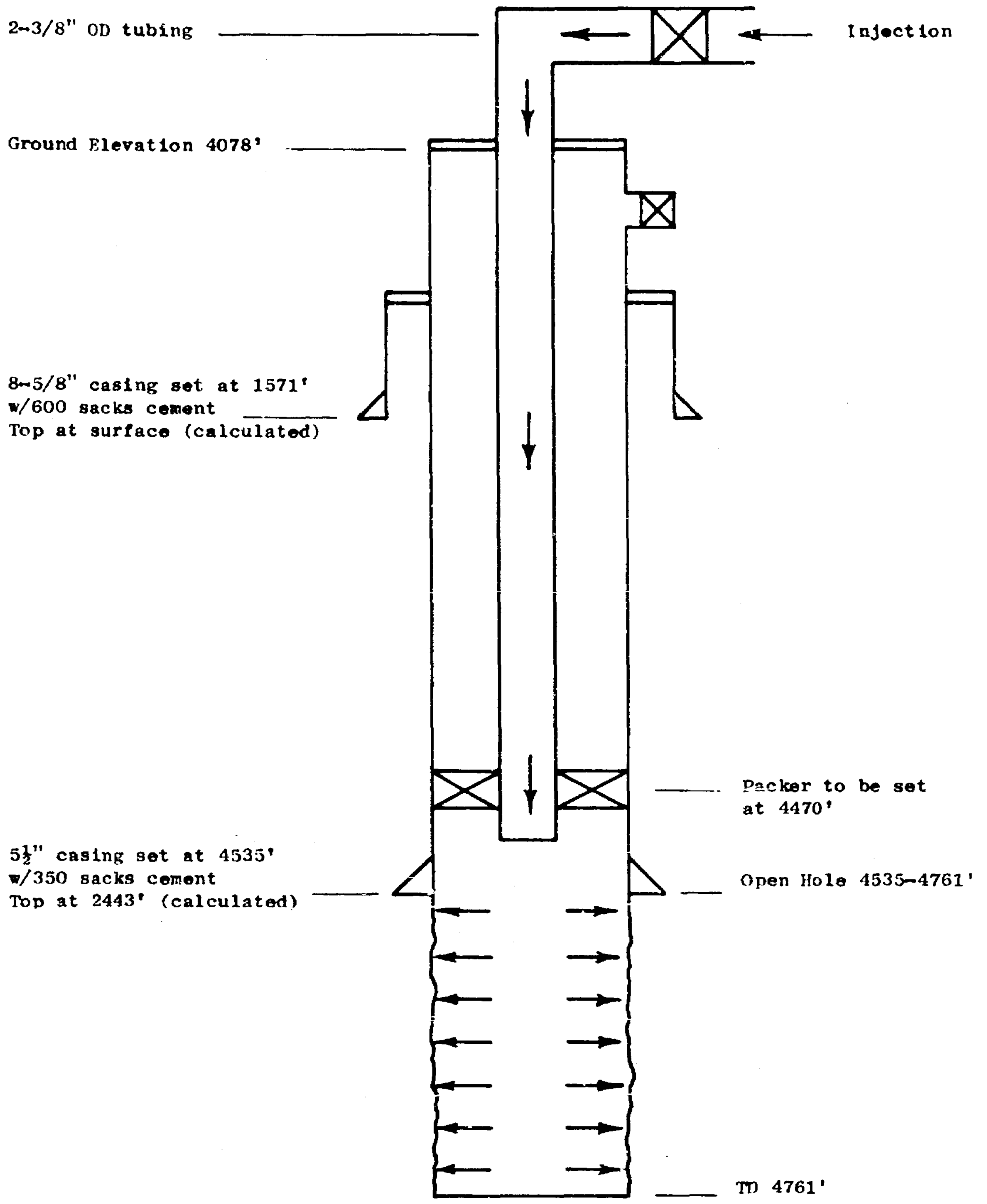


EXHIBIT NO. 14

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 19 (A.R.Co. State "C" TG No. 5)
990' FSL & 1650' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 2' above GL

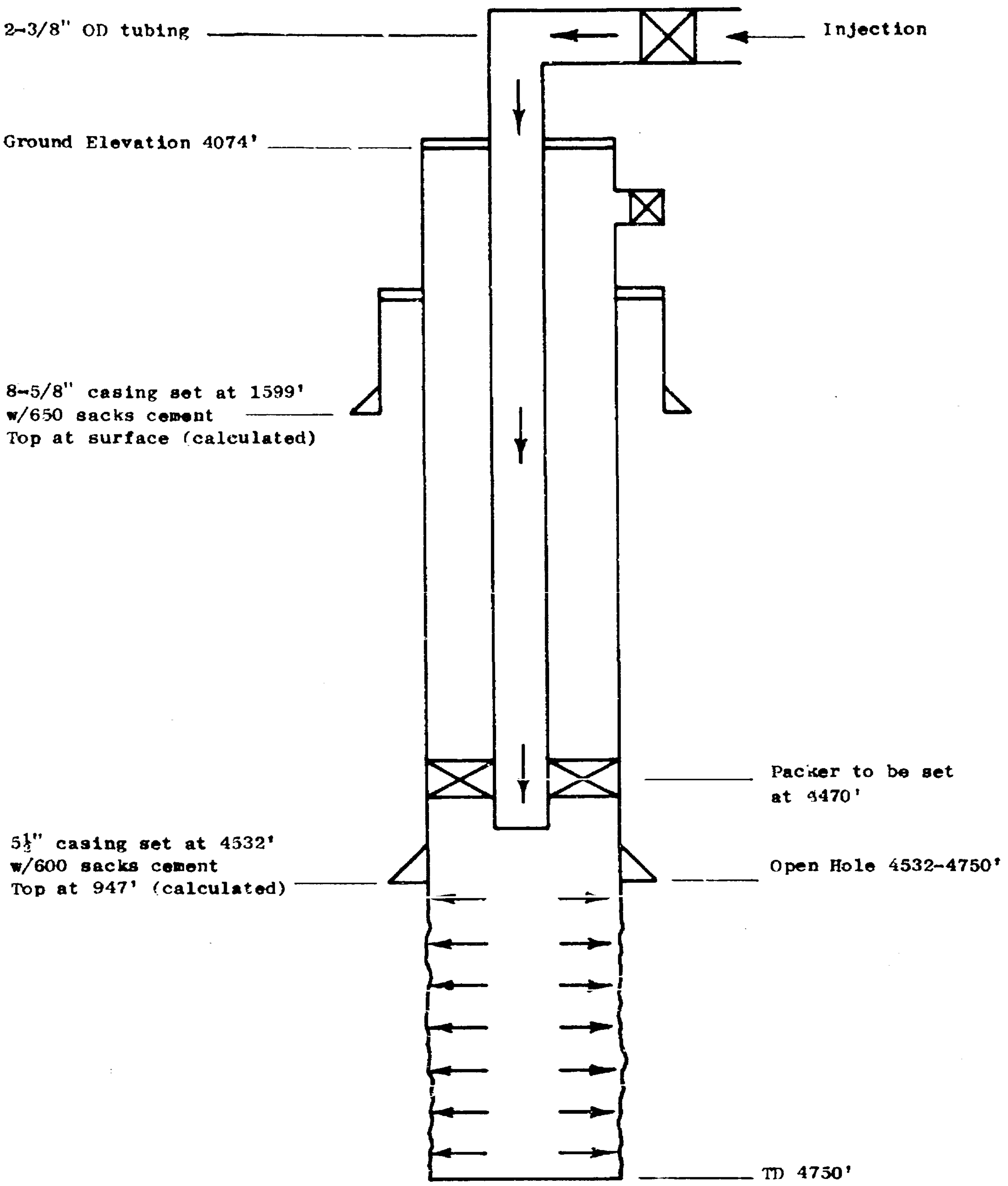


EXHIBIT NO. 15

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT NO. 21
Schematic Drawing of Injection Well
To be drilled approximately 330' FSL & 2310' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

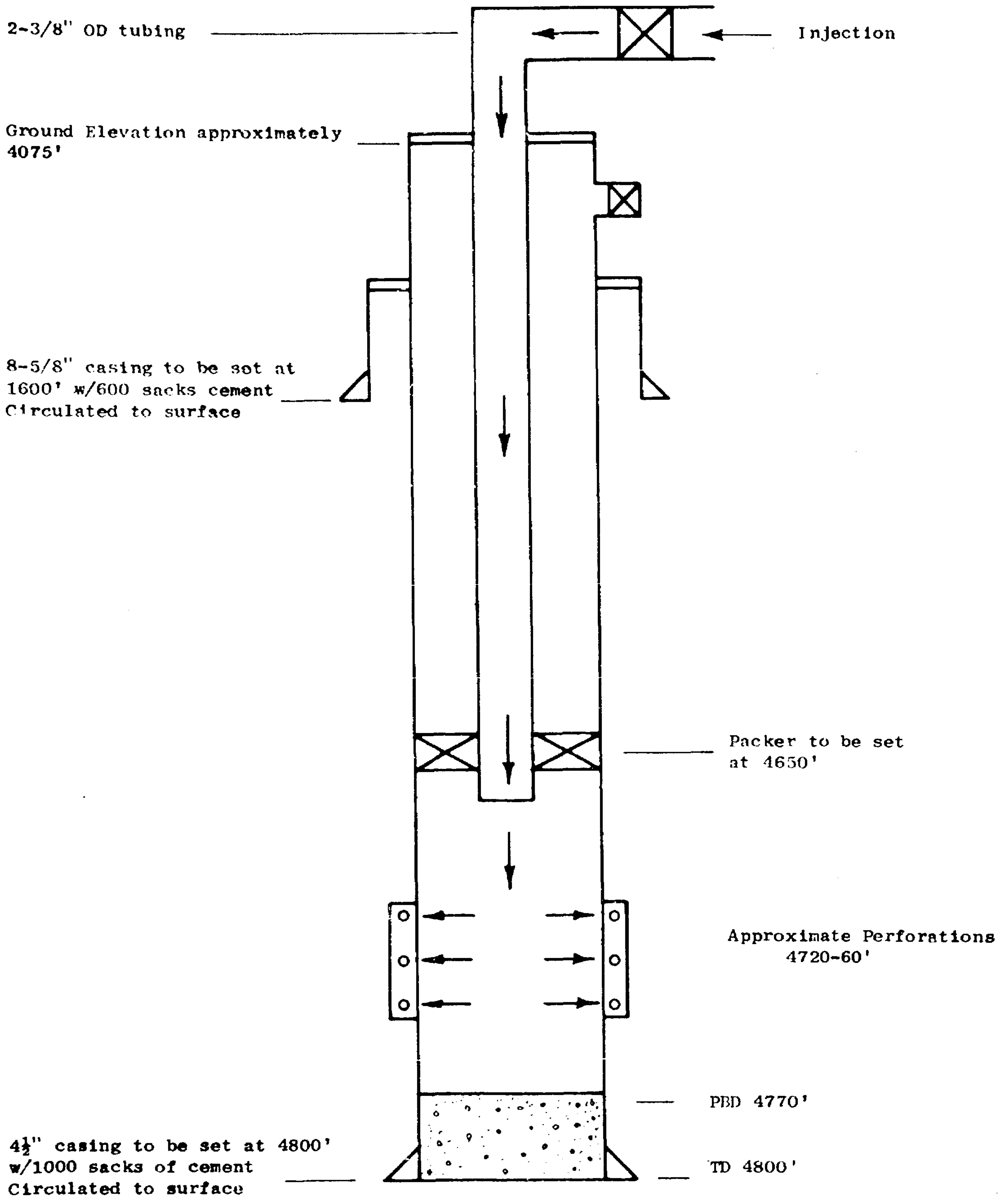
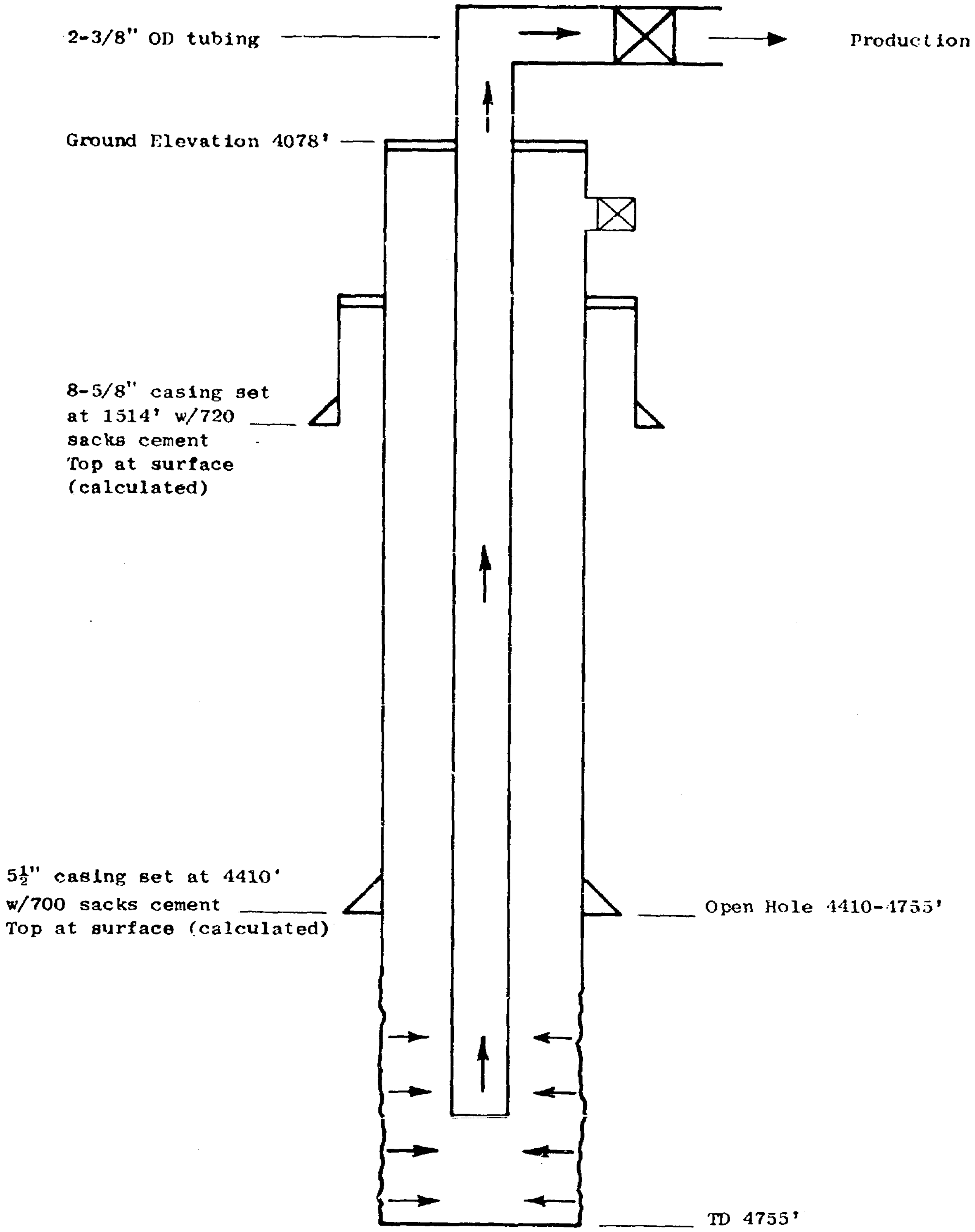


EXHIBIT NO. 16

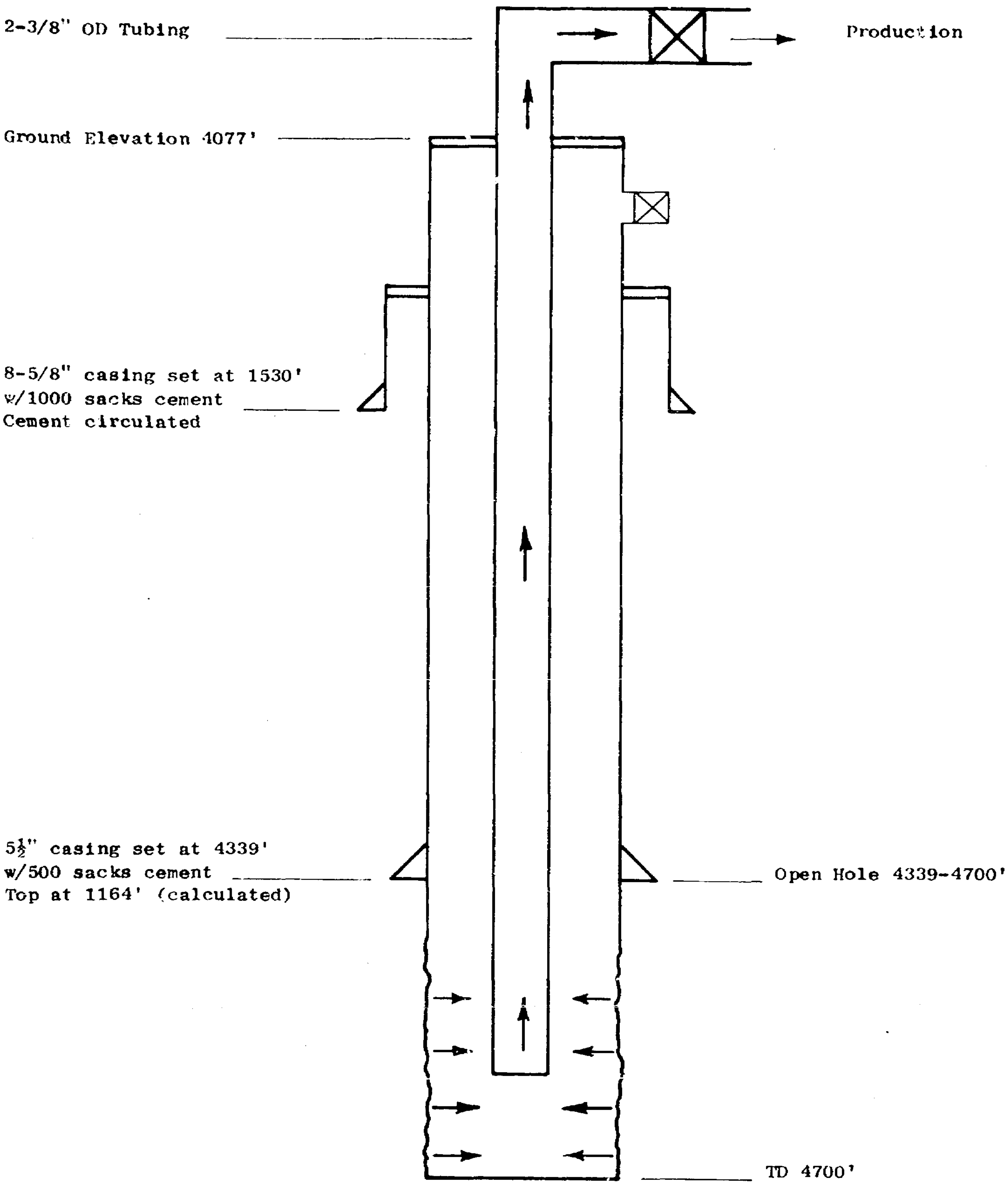
ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 3 (A.R.Co. State "B" TG No. 1)
660' FNL & 660' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All Measurements are from KB 10' above GL



ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 5 (Texaco New Mexico "D" State NCT-2 No. 4)
990' FNL & 2310' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 7.5' above GL



ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 6 (Sohio Hale State No. 1)
2310' FNL & 330' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 3' above GL

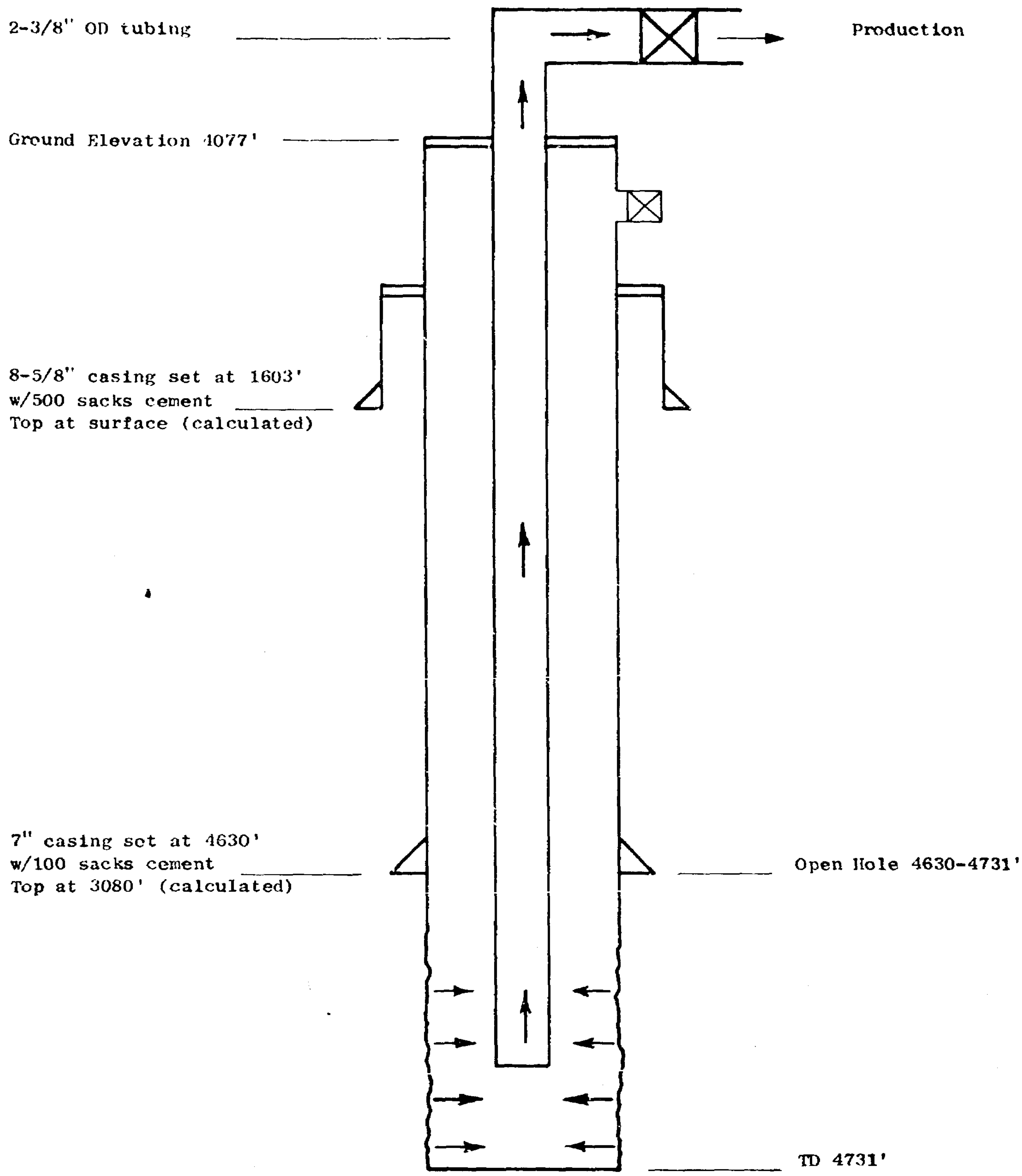


EXHIBIT NO. 19

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 8 (A.R.Co. State "B" TG No. 2)
1980' FNL & 1980' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

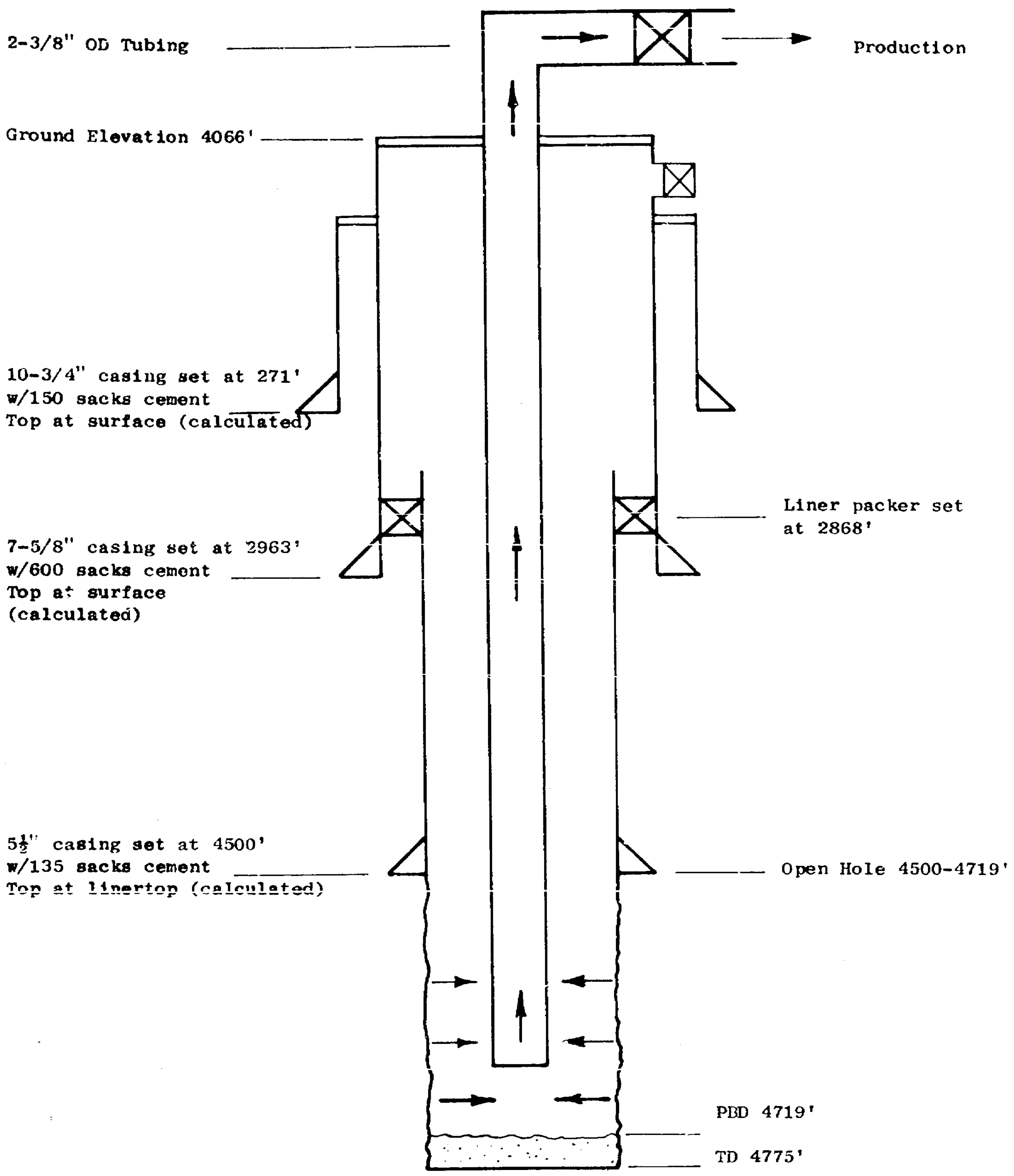


EXHIBIT NO. 20

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 10 (Texaco New Mexico "D" State NCT-2 No. 1)
1980' FNL & 660' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 11.5' above GL

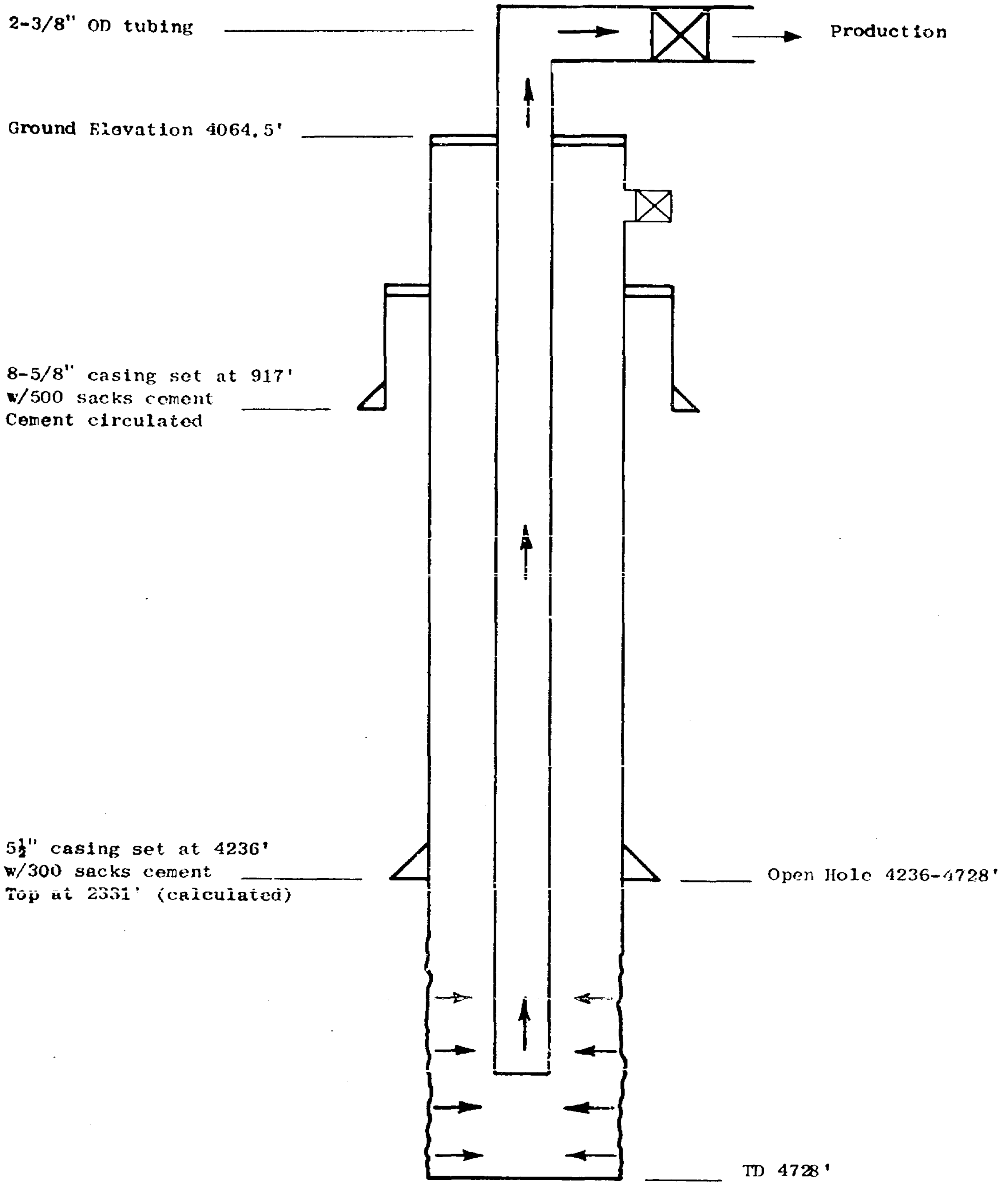
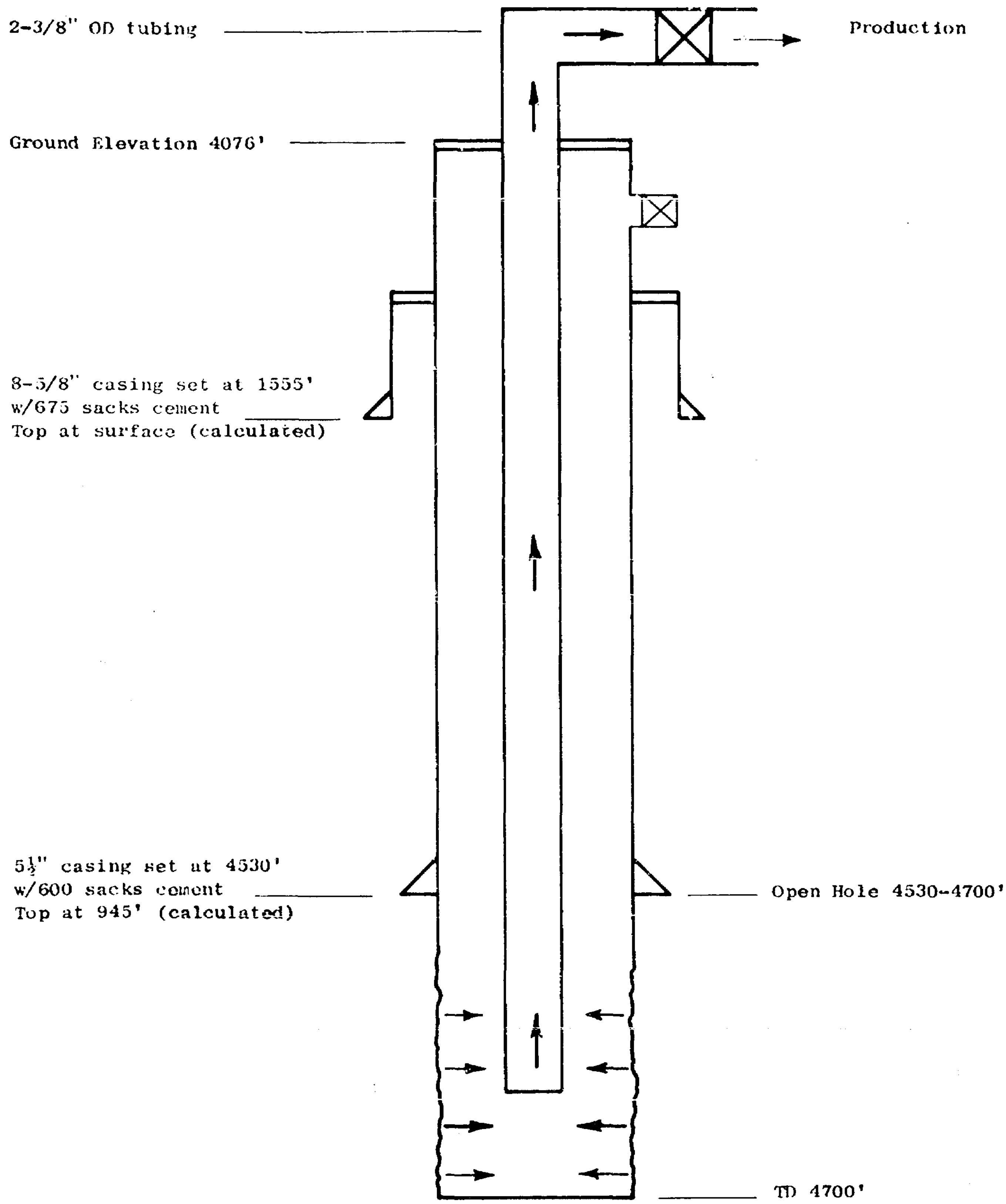


EXHIBIT NO. 21

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 12 (A.R.Co. State "C" TG No. 6)
990' FWL & 2310' FSL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 2' above GL



ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Diagram of Producing Well
Unit Well No. 14 (A.R.Co. State "C" TG No. 2)
1980' FSL & 1980' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

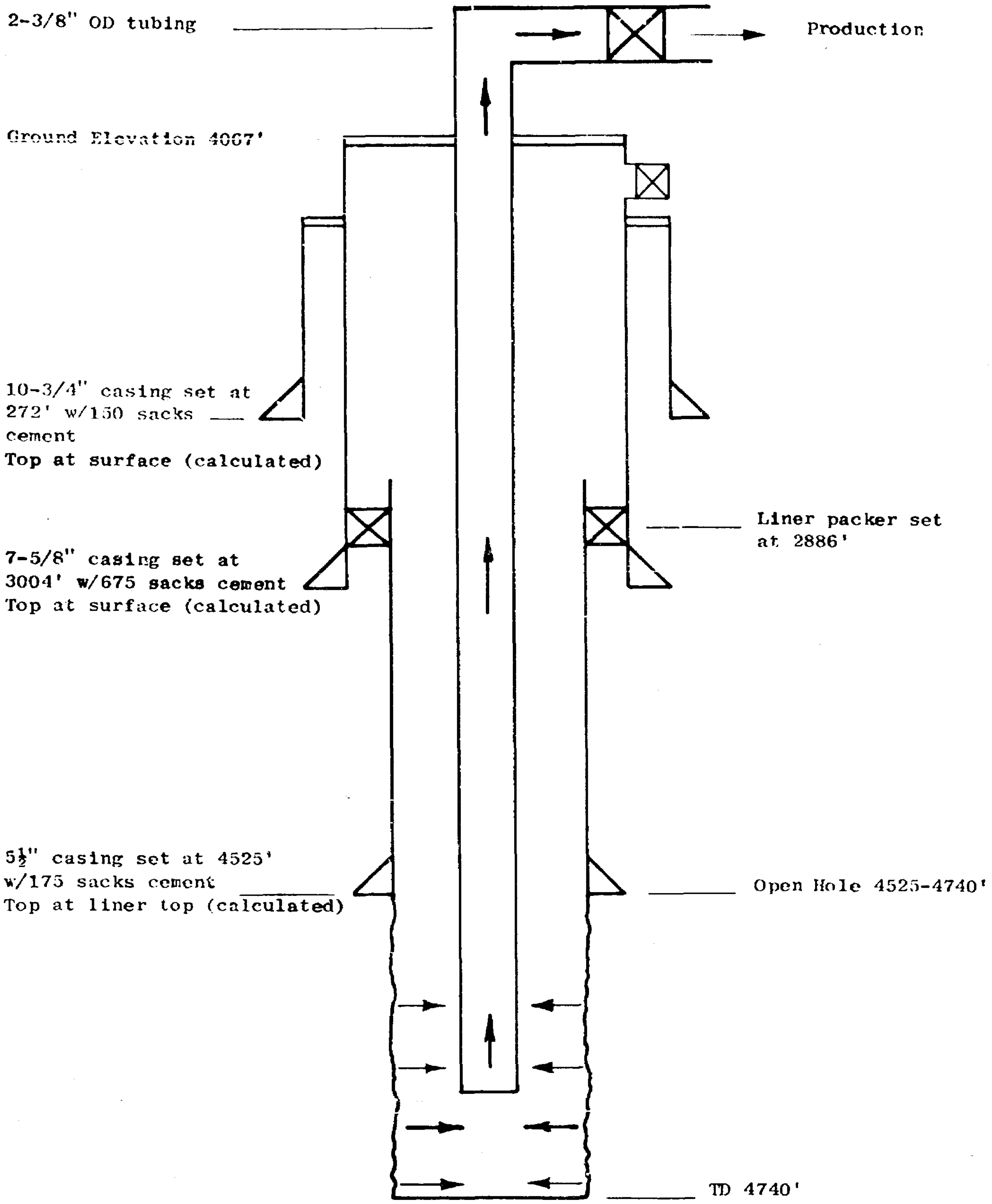


EXHIBIT NO. 23

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 16 (Texaco New Mexico "AO" State No. 2)
990' FSL & 330' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 6' above GL

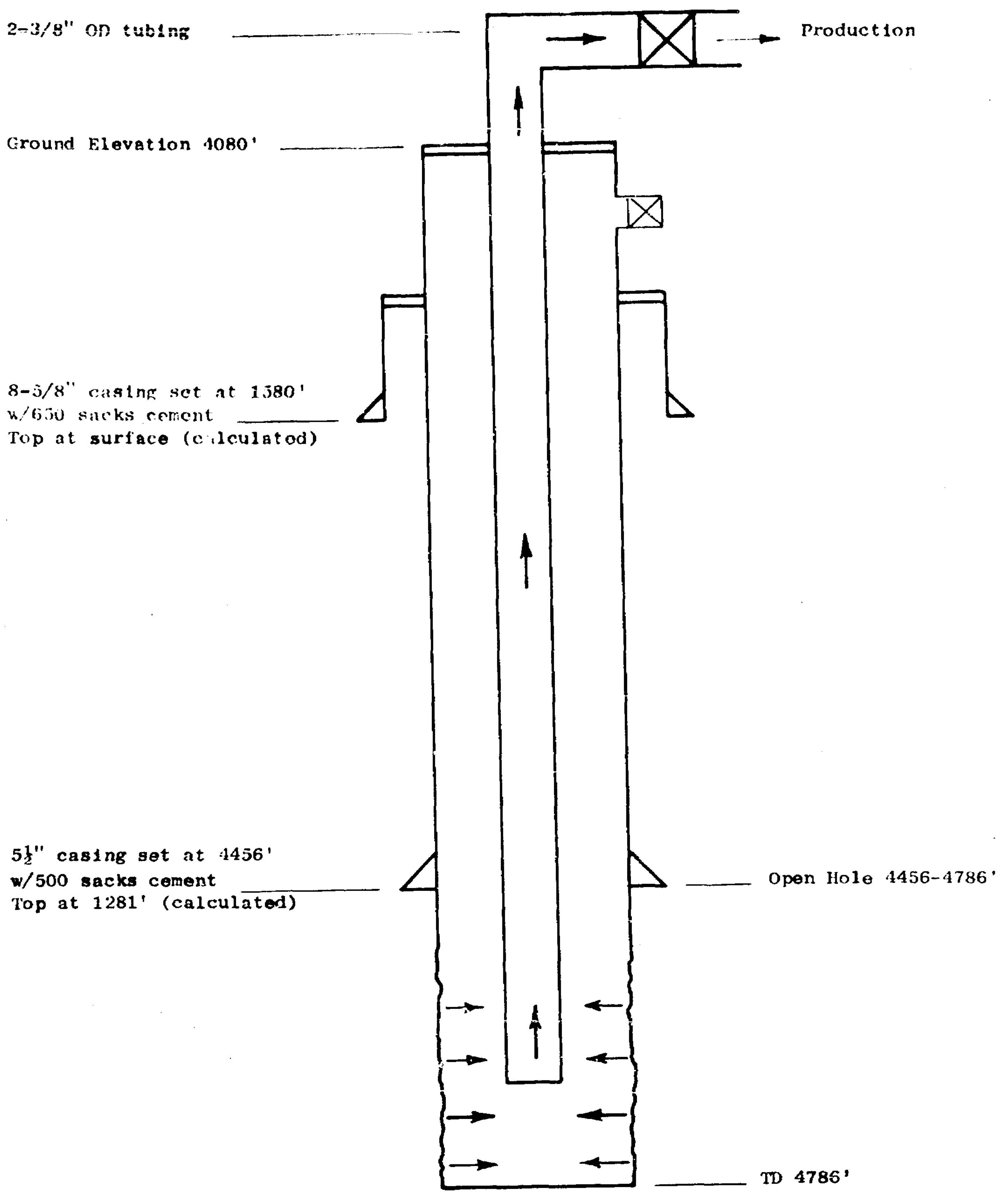
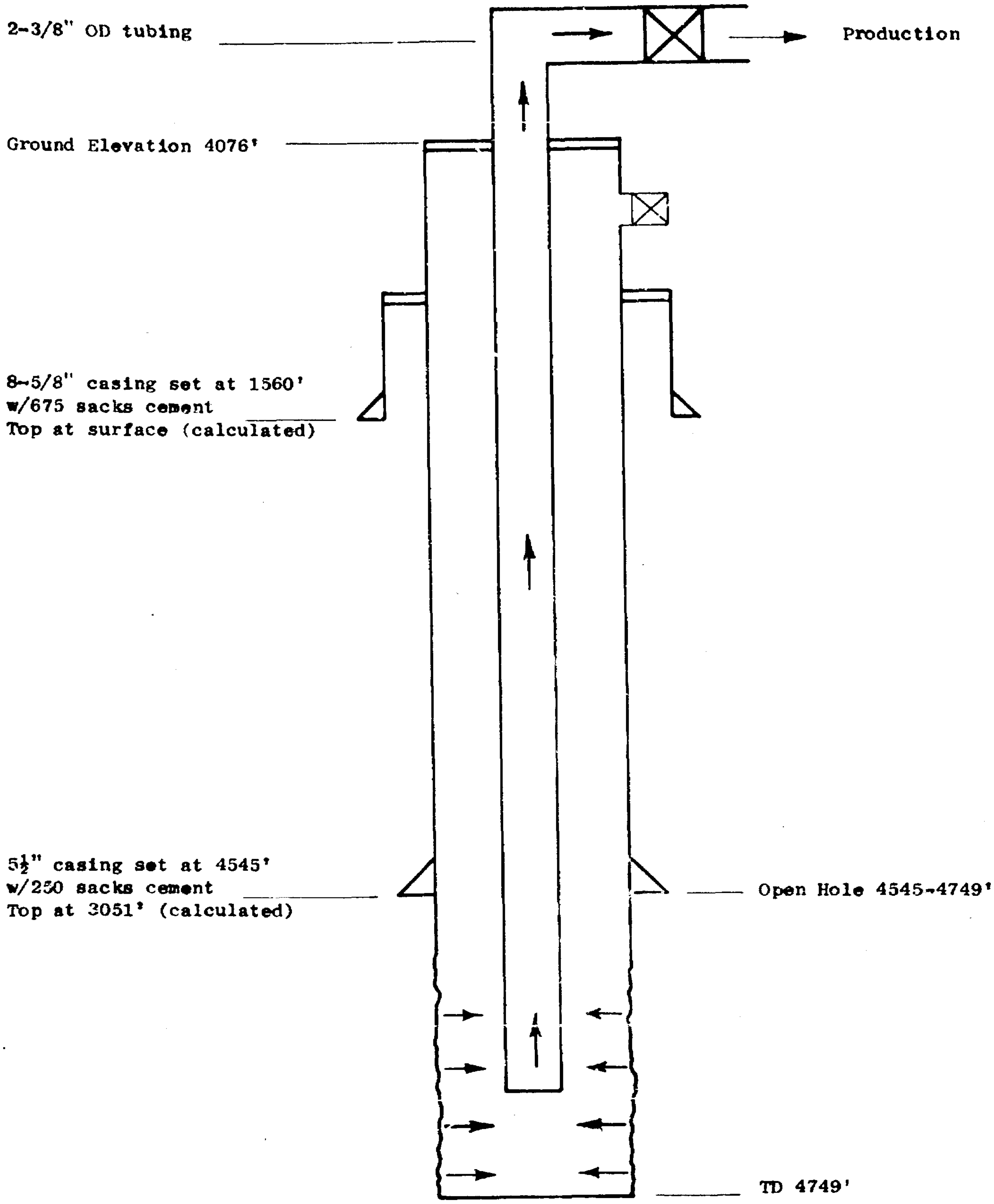


EXHIBIT NO. 24

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 18 (A.R.Co. State "C" TG No. 7)
990' FSL & 2310' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 4' above GL



ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Producing Well
Unit Well No. 20 (A.R.Co. State "C" TG No. 4)
660' FSL & 660' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

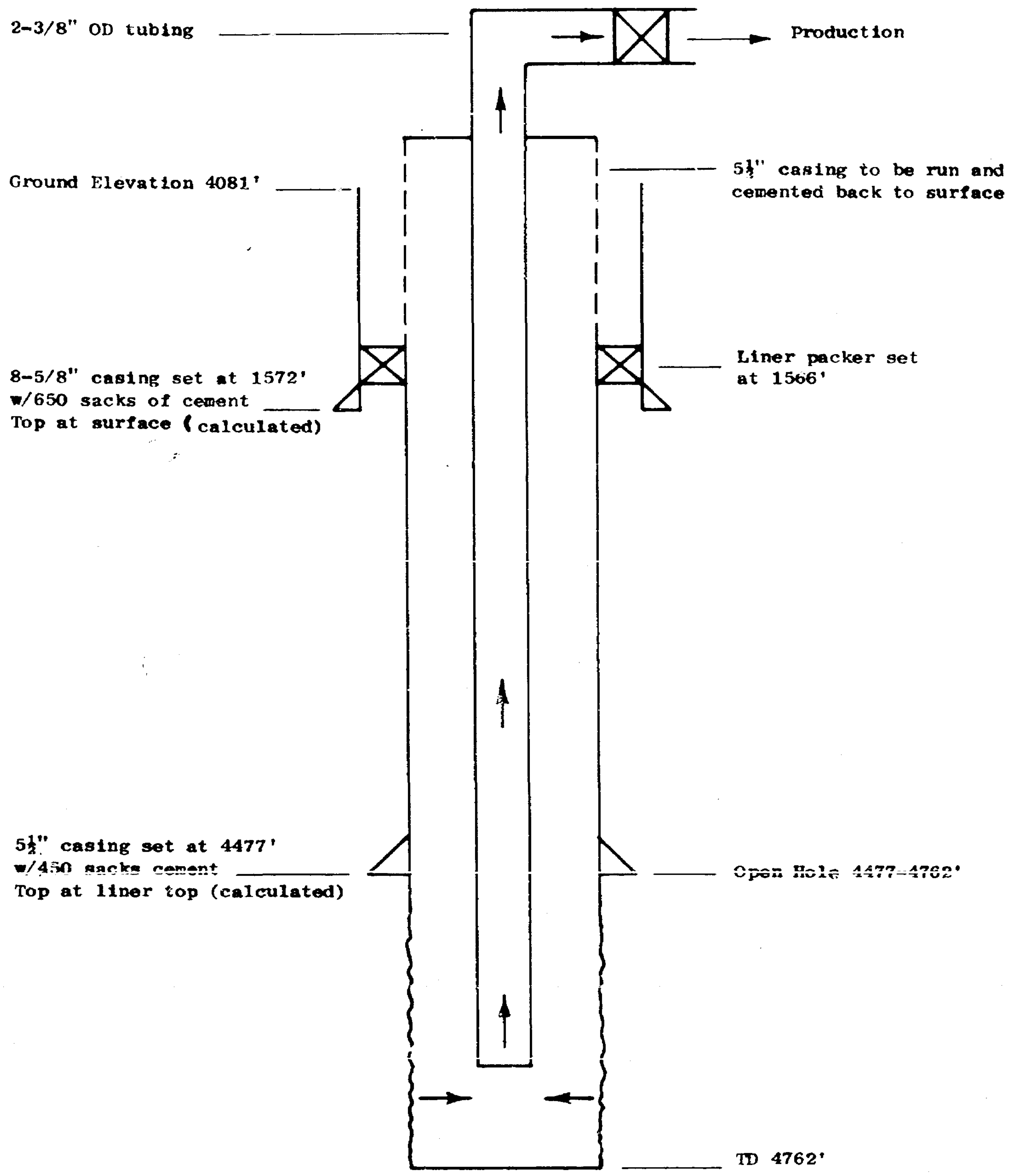
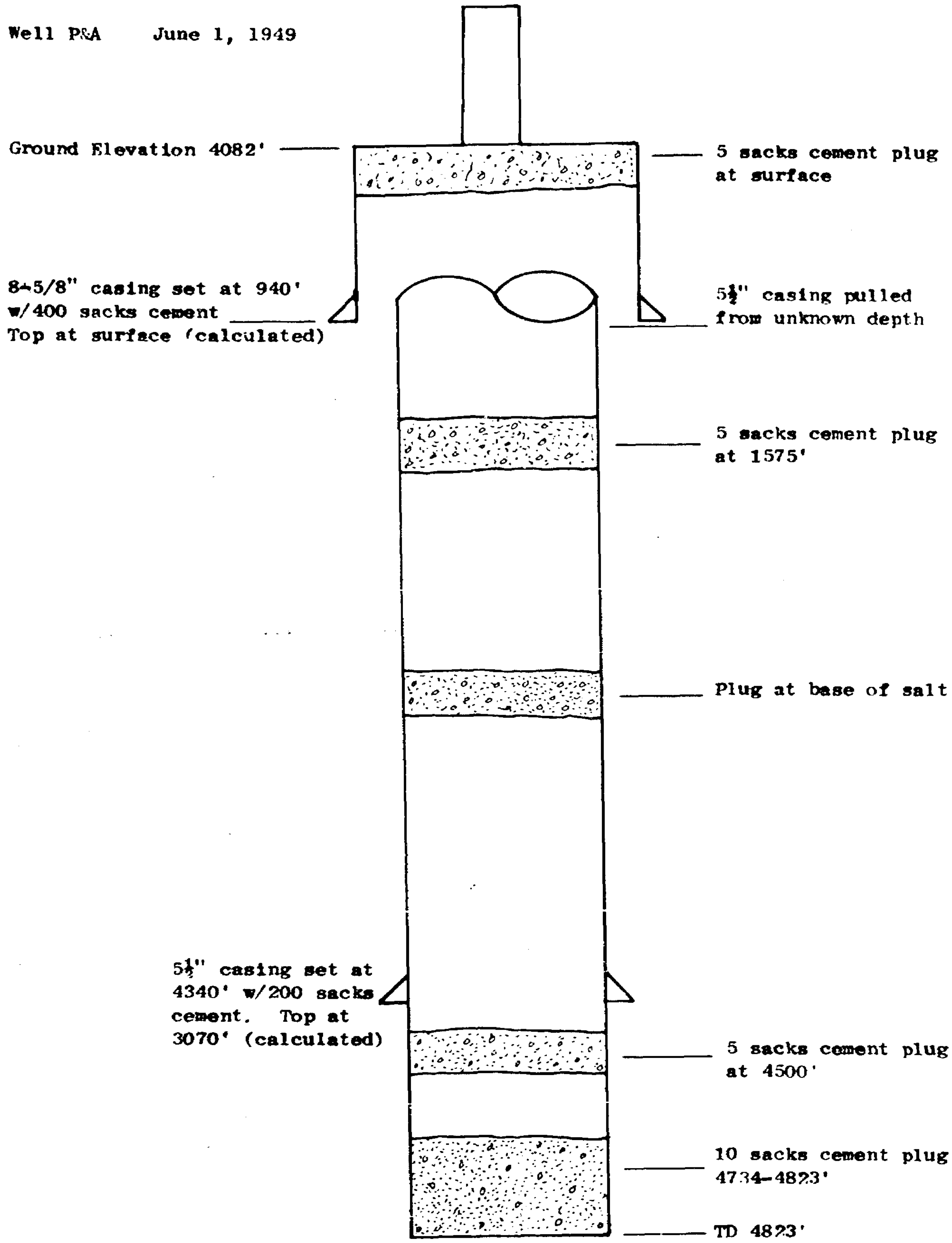


EXHIBIT NO. 26

COLE-DARDEN OIL COMPANY
HALE STATE NO. 1
Schematic Drawing of Plugged and Abandoned Well
660' FNL & 660' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 8' above GL



DEVONIAN OIL COMPANY
STATE NO. 1
Schematic Drawing of Plugged and Abandoned Well
660' FSL & 1980' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 8' (est) above GL

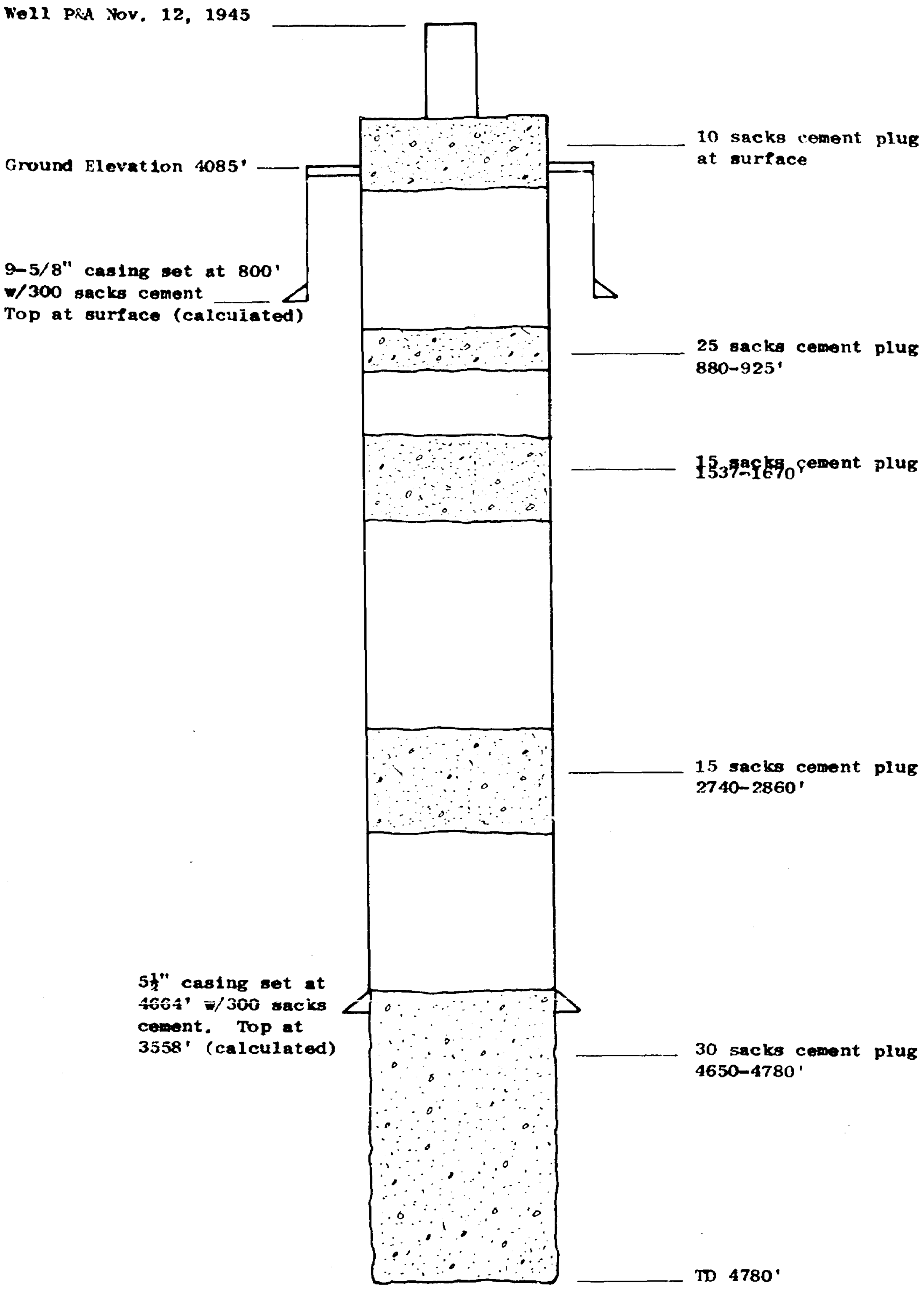


EXHIBIT NO. 28

TEXACO - WEST VACUUM UNIT NO. 4
(BTA - Am. State #3)
Unit K 1980' FS & WL
Section 28, T-17S, R-34E
Lea County, New Mexico

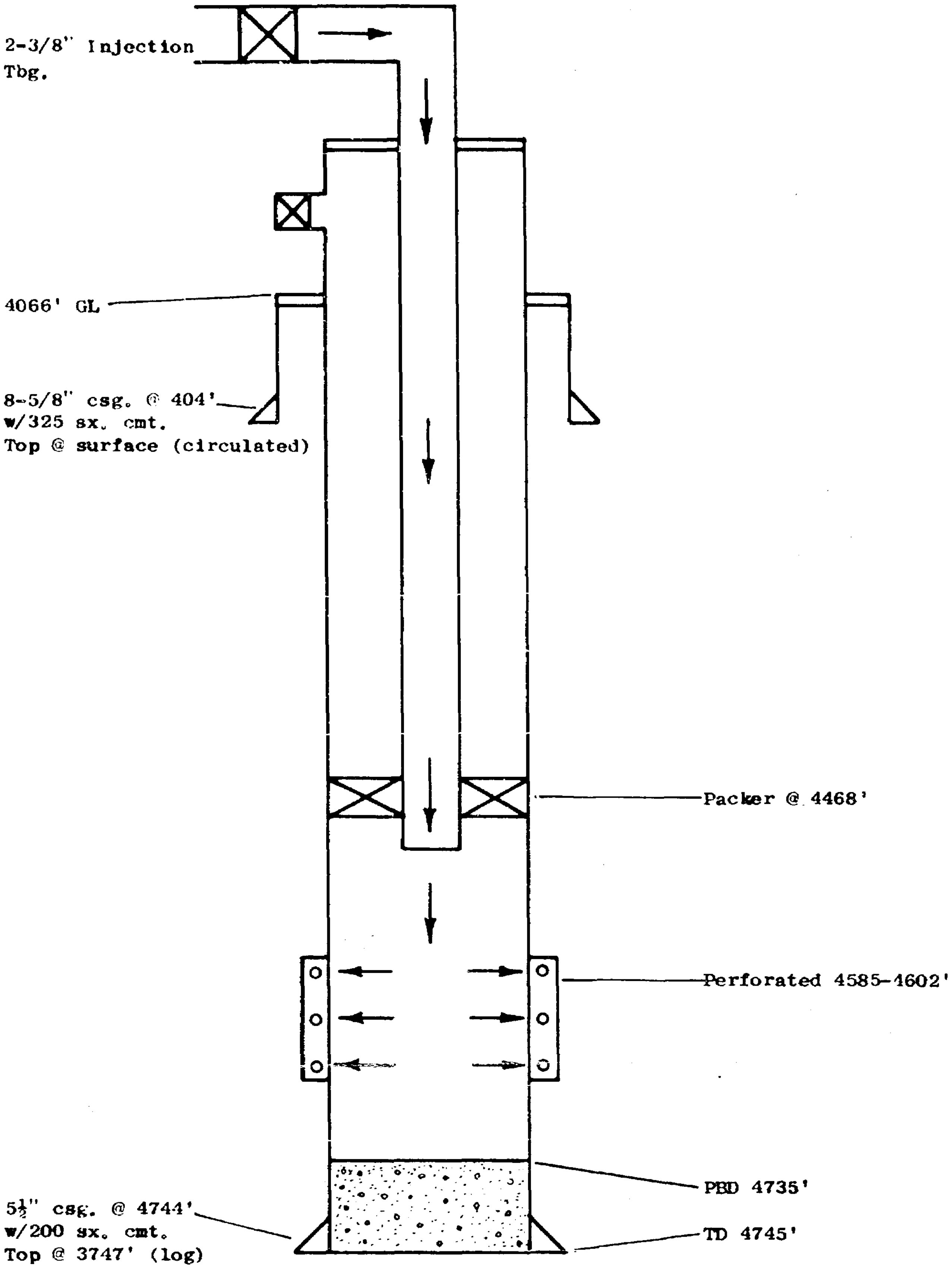


EXHIBIT NO. 29

TEXACO - WEST VACUUM UNIT NO. 3

(BTA Oil Producers - Amstate No. 2)
Unit L 1980' FSL & 660' FWL
Section 28, T-17S, R-34E
Lea County, New Mexico

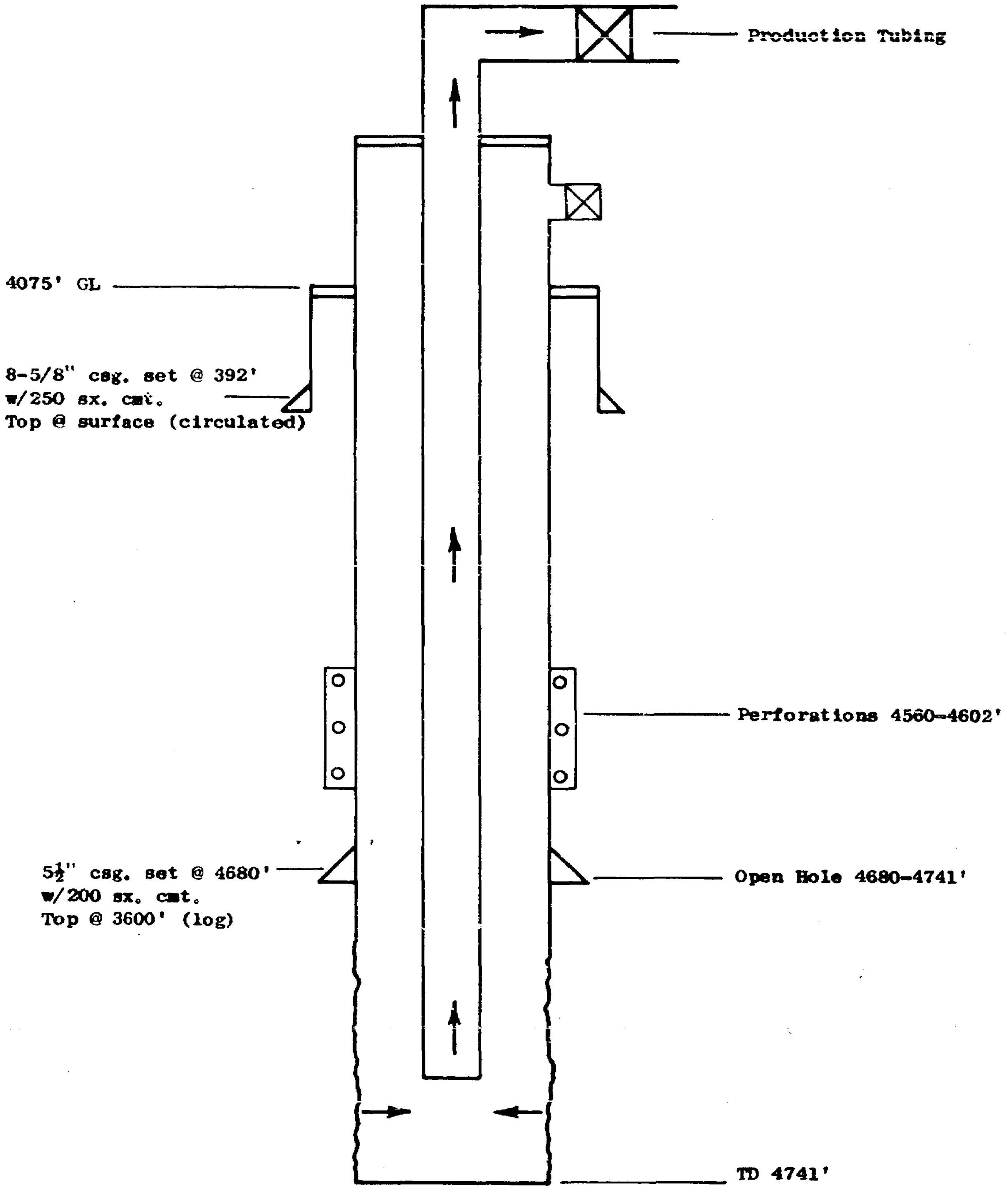


EXHIBIT NO. 30

TEXACO - WEST VACUUM UNIT NO. 5
WIW
(BTA Oil Producers - Amstate #1)
Unit M 660' FS & WL
Section 28, T-17S, R-34E
Lea County, New Mexico

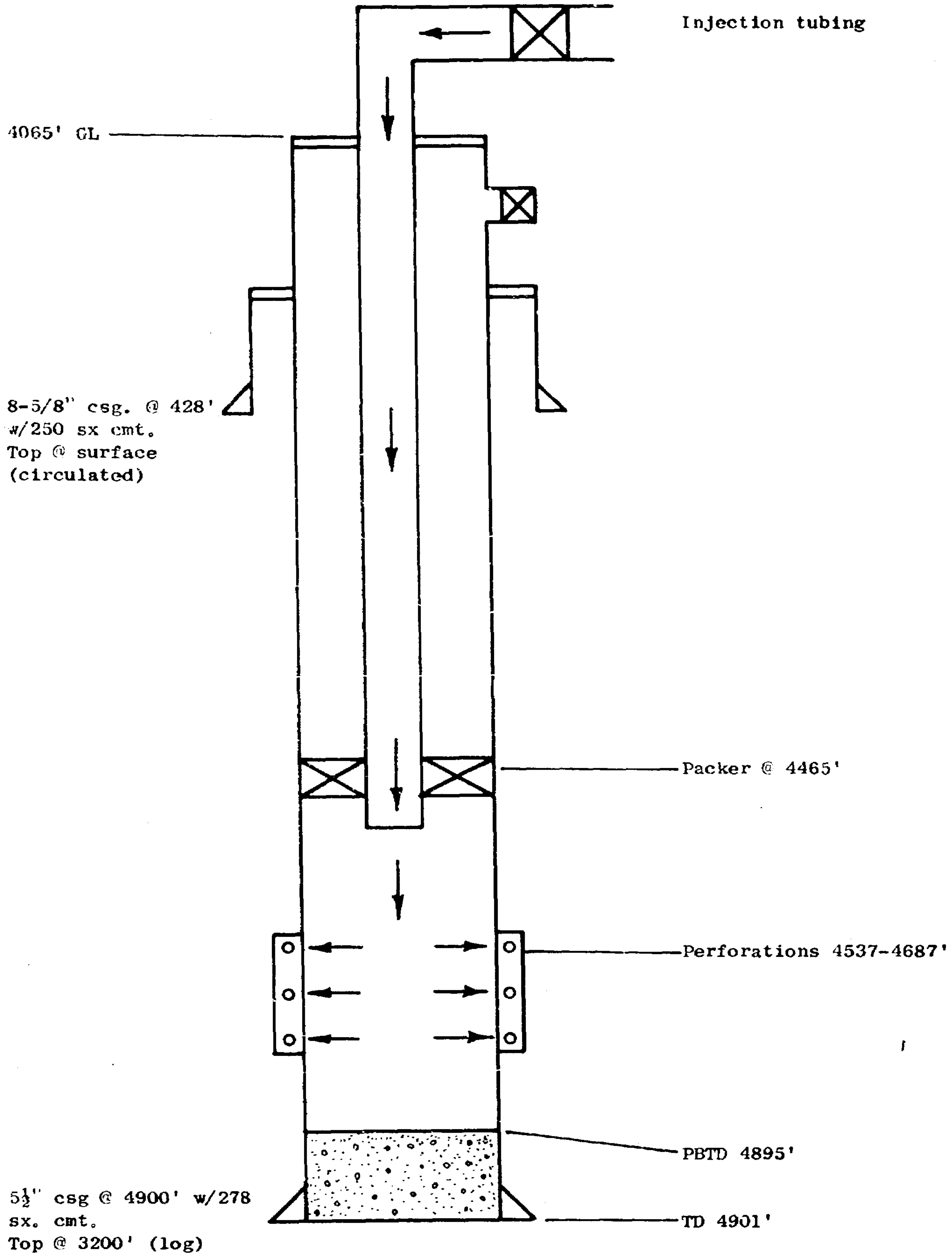


EXHIBIT NO. 31

L. F. OIL COMPANY - AMERADA-STATE #1
Unit N 330' FSL & 2308' FWL
Section 28, T-17S, R-34E
Lea County, New Mexico

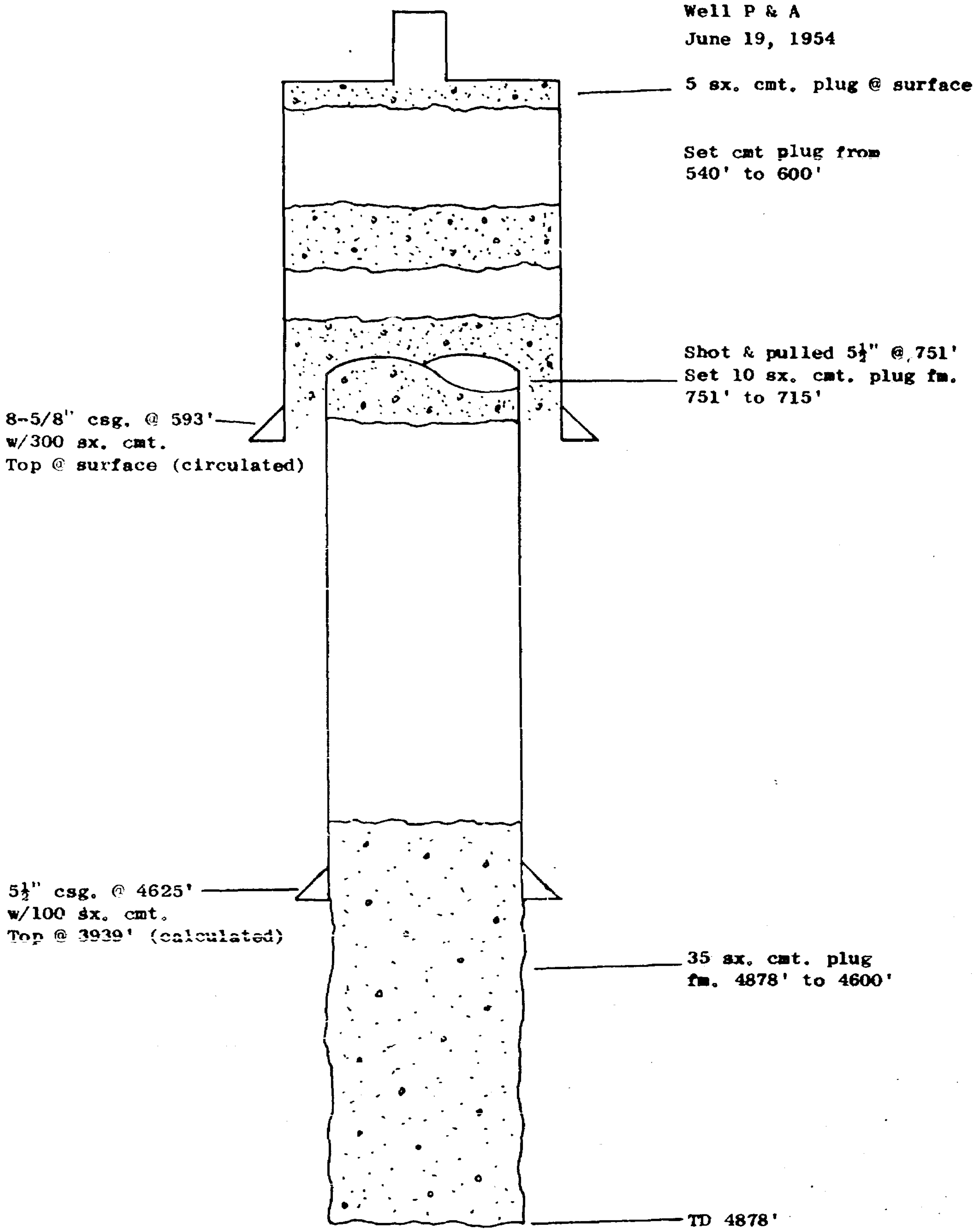


EXHIBIT NO. 32

PHILLIPS - LEA NO. 14
Unit F 1980' FWL & 1880' FNL
Section 29, T-17S, R-34E
Lea County, New Mexico

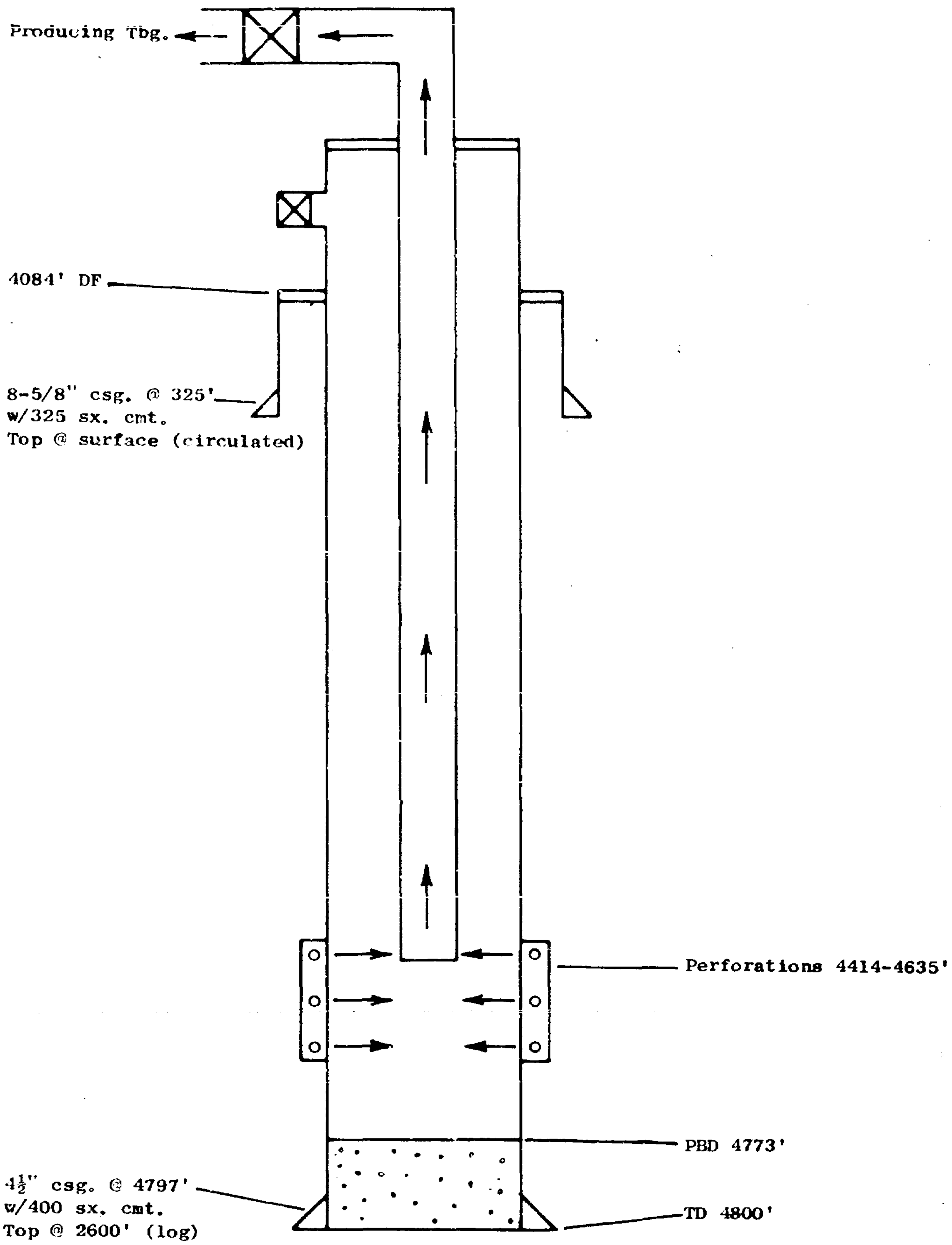


EXHIBIT NO. 33

PHILLIPS - LEA NO. 13
Unit G 1980' FNL & 1650' FEL
Section 29, T-17S, R-34E
Lea County, New Mexico

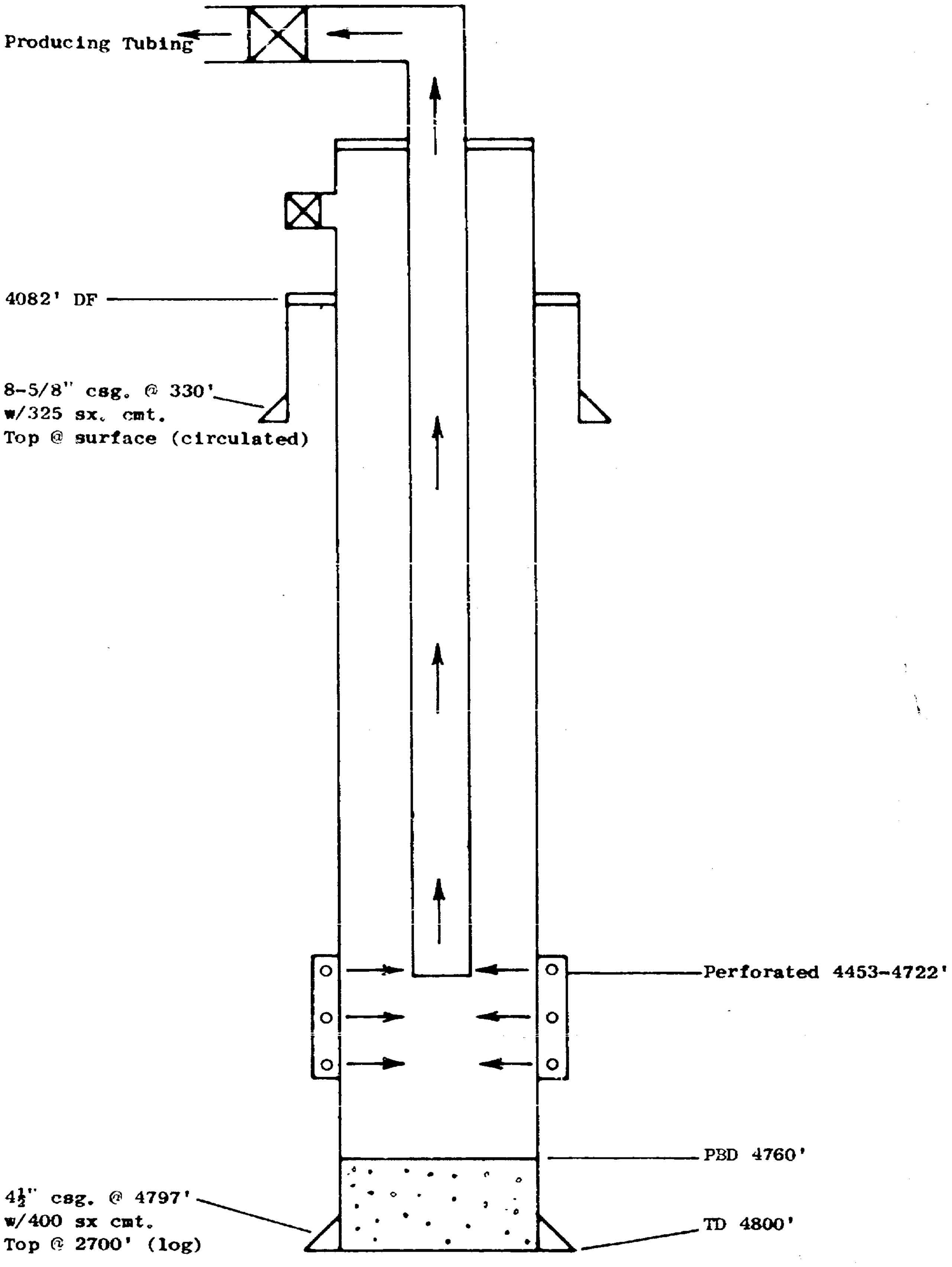


EXHIBIT NO. 34

PHILLIPS - LEA NO. 4
Unit I 660' FEL & 1980' FSL
Section 29, T-17S, R-34E
Lea County, New Mexico

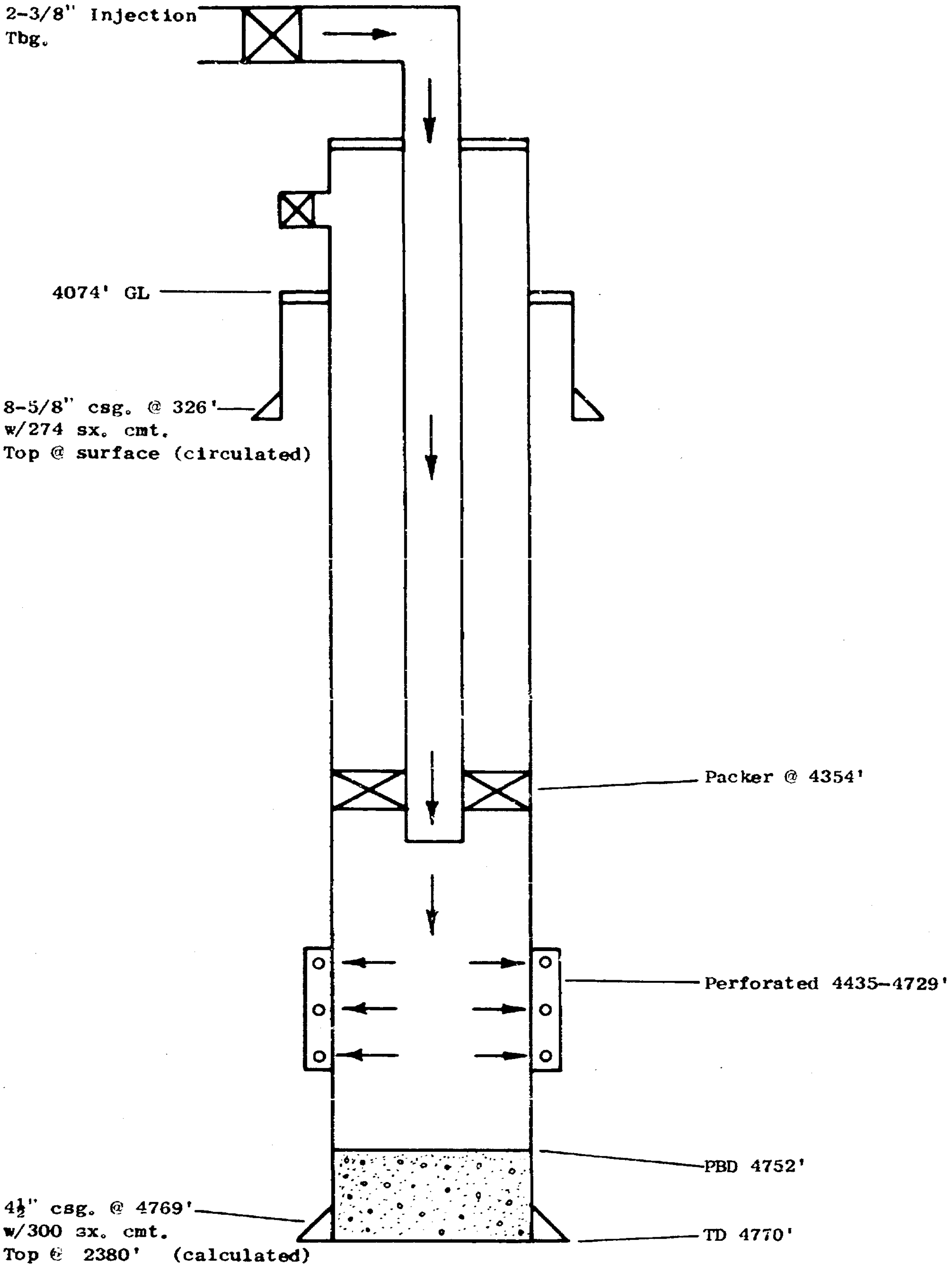


EXHIBIT NO. 35

PHILLIPS PETROLEUM CO. - LEA NO. 11
Unit K 1980' FS & WL
Section 29, T-17S, R-34E
Lea County, New Mexico

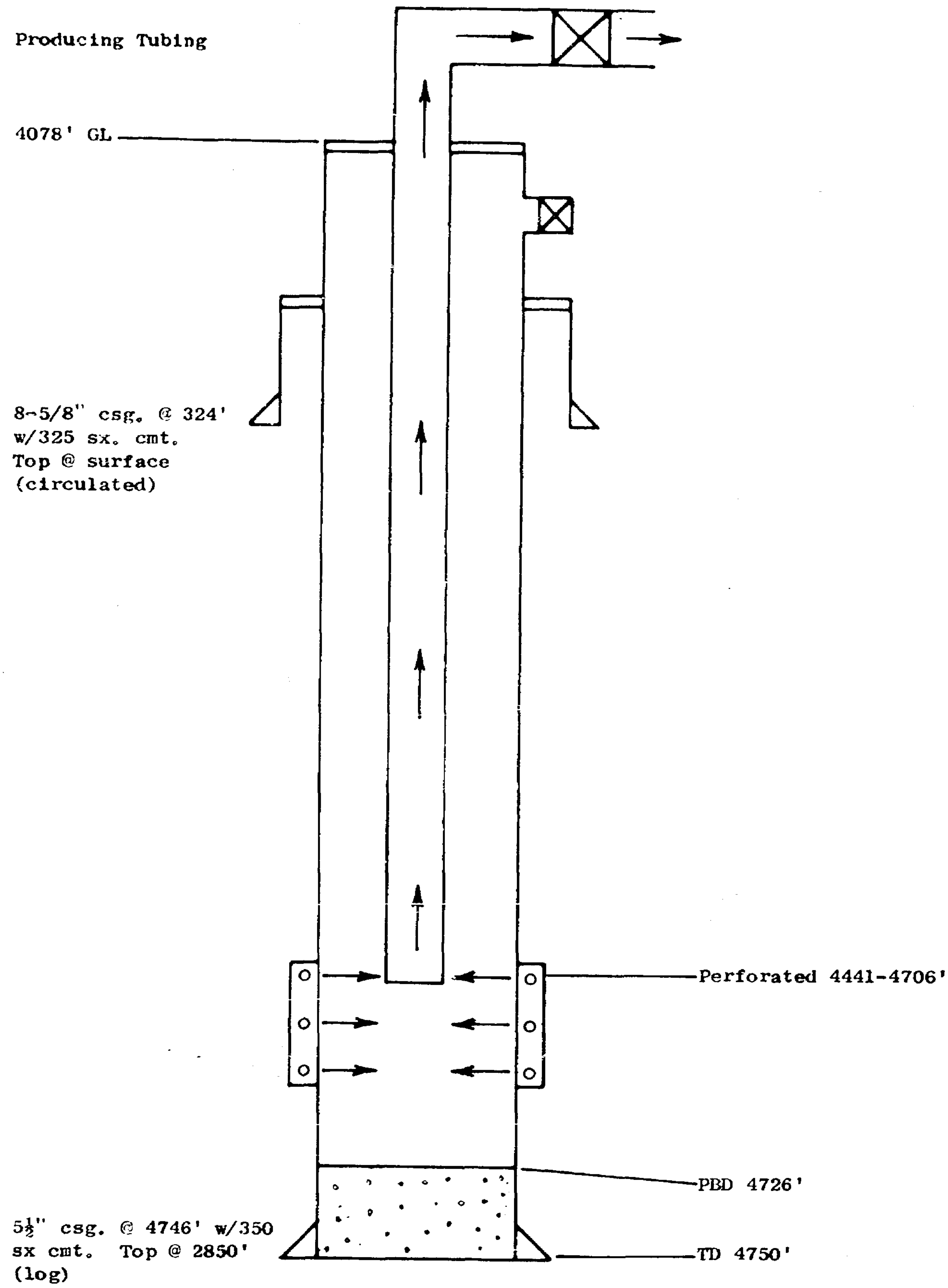


EXHIBIT NO. 36

SOHIO - PHILLIPS LEA NO. 6
Unit K 2310' FS & WL
Section 31, T-17S, R-34E
Lea County, New Mexico

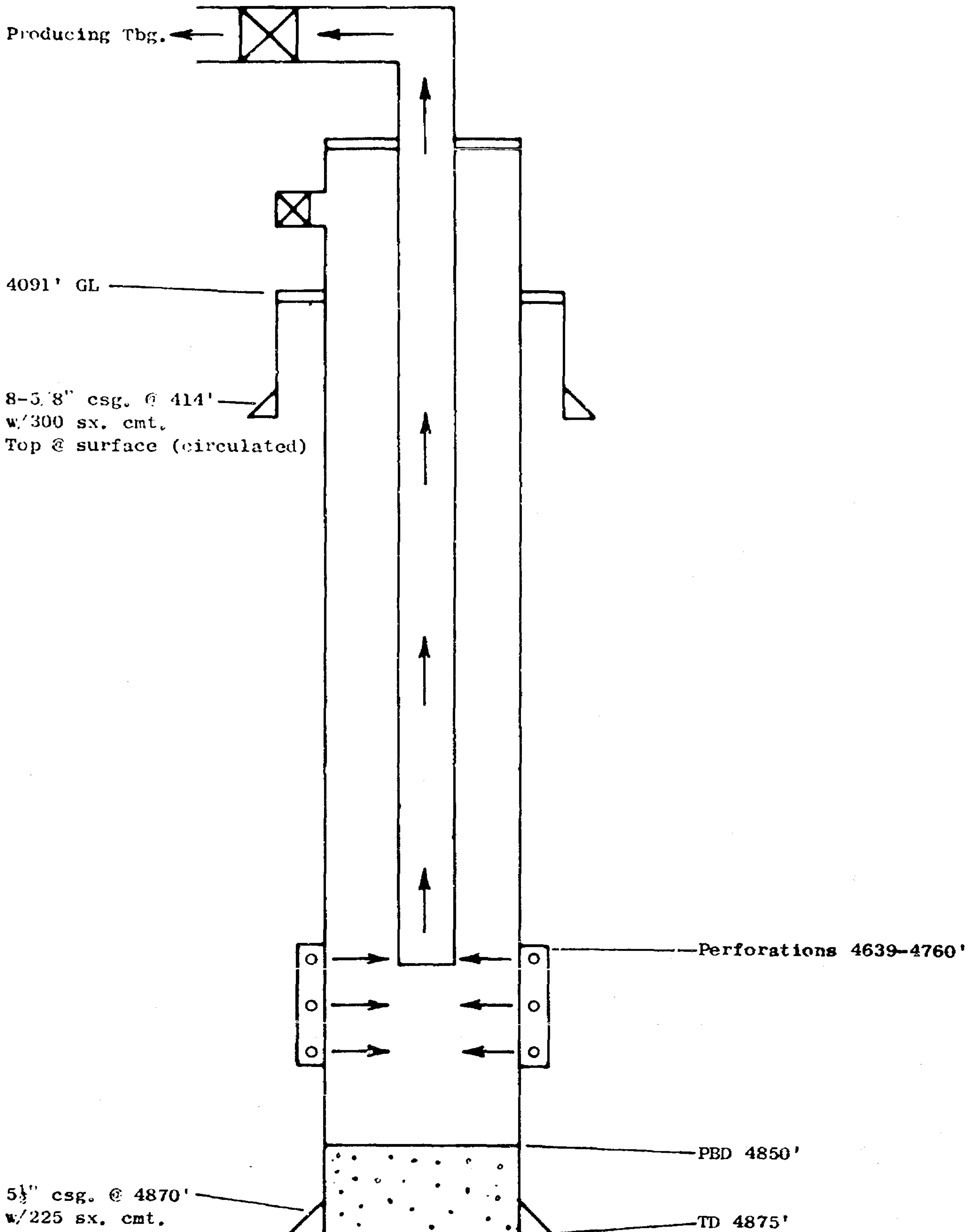


EXHIBIT NO. 37

PHILLIPS PETROLEUM CO. - LEA NO. 5
Unit P 660' FS & EL
Section 29, T-17S, R-34E
Lea County, New Mexico

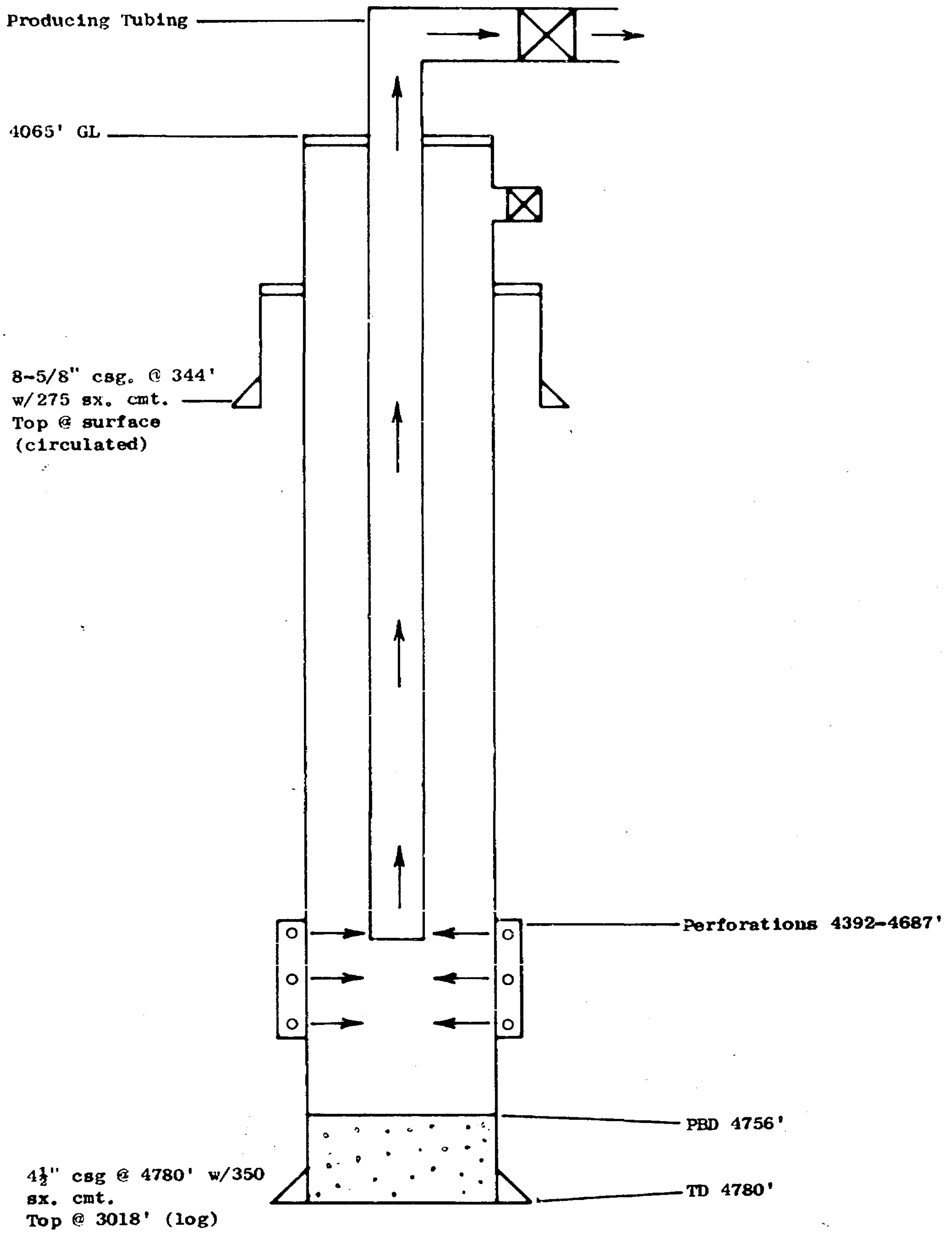


EXHIBIT NO. 38

COLE-DARDEN OIL COMPANY - PHILLIPS STATE A NO. 5
Unit H 1980' FNL & 660' FEL
Section 30, T-17S, R-34E
Lea County, New Mexico

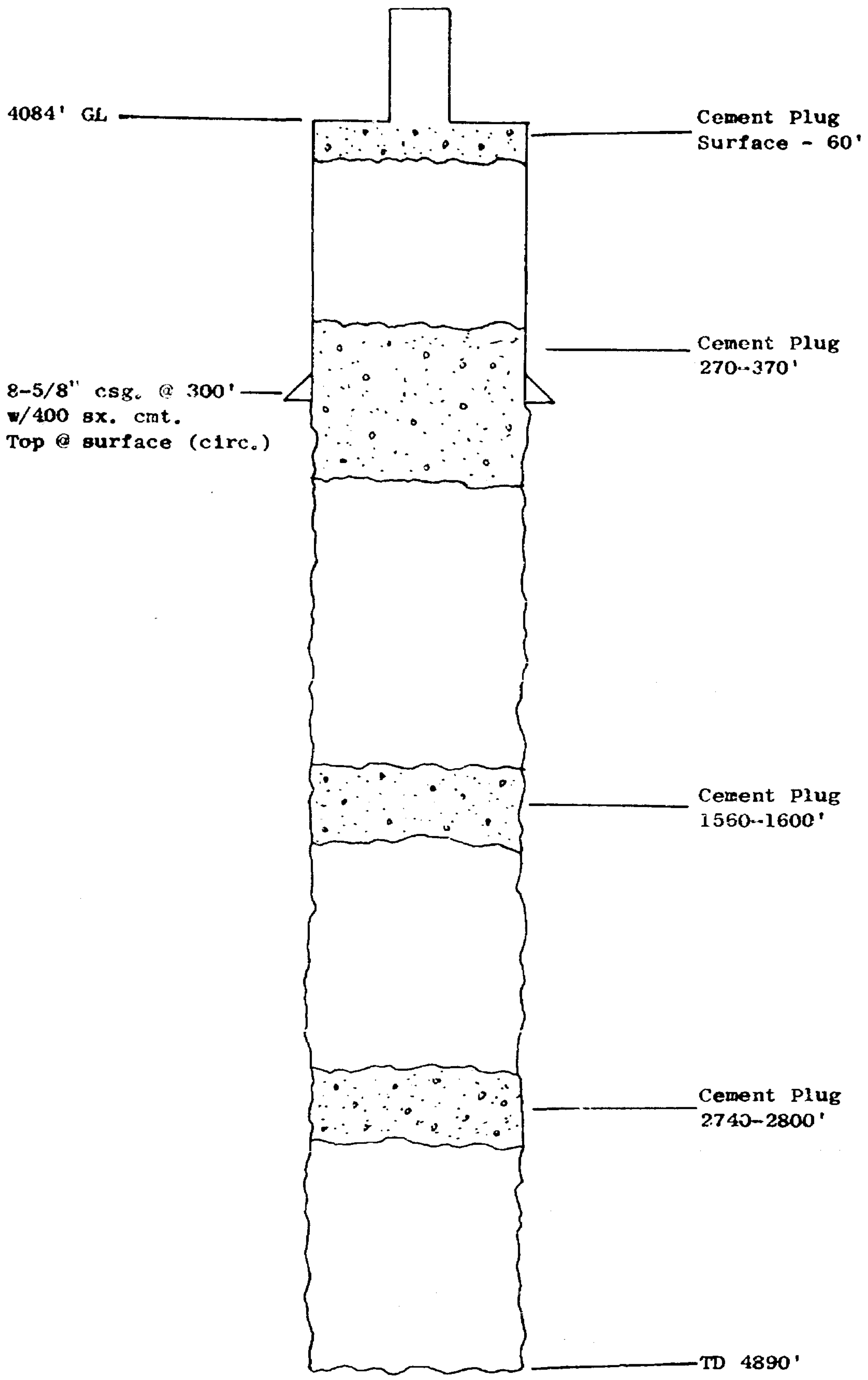


EXHIBIT NO. 39

PHILLIPS PETROLEUM COMPANY - LEA NO. 19
(Cole - Darden Phillips State #2)
Unit I 660' FEL & 1980' FSL
Section 30, T-17S, R-34E
Lea County, New Mexico

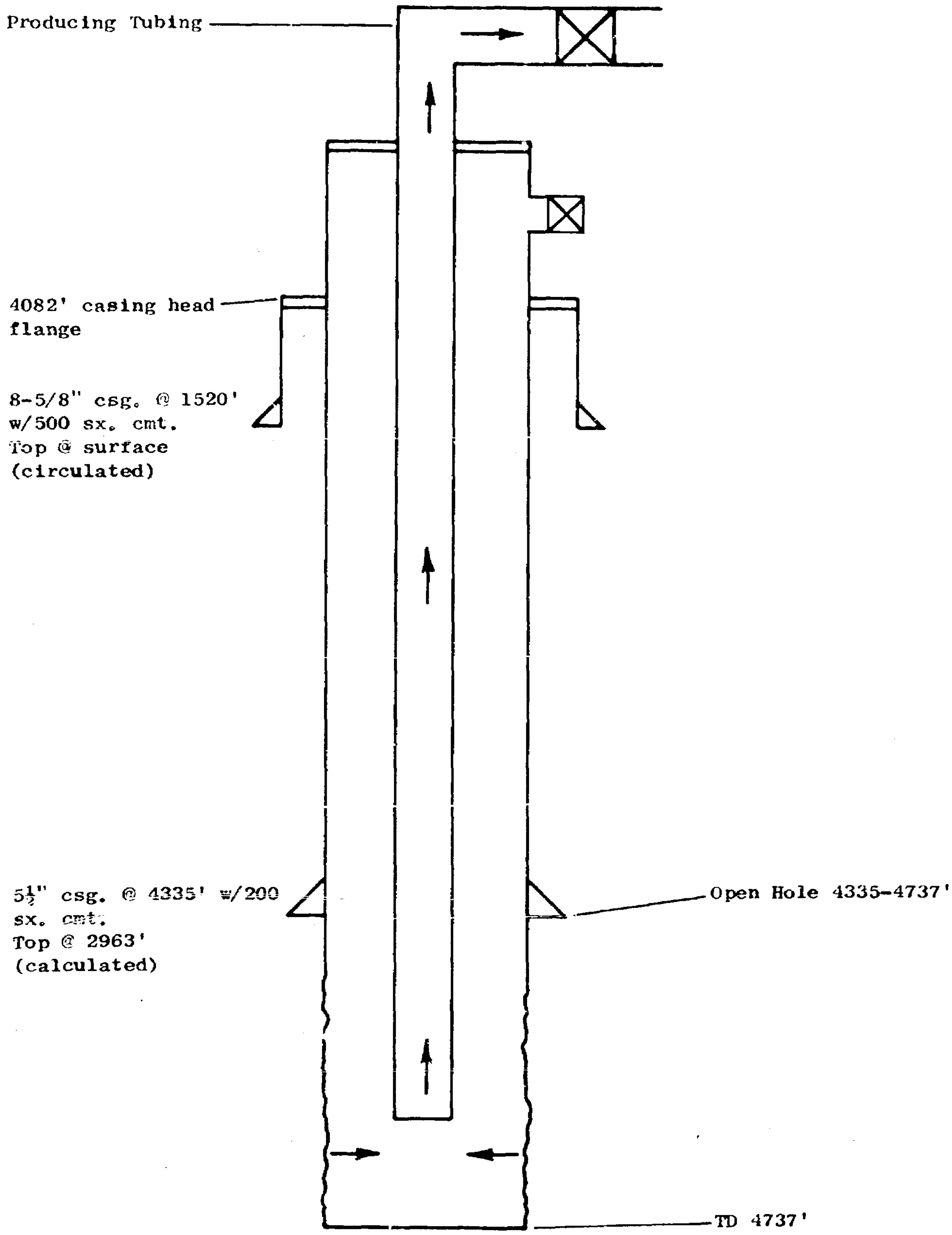


EXHIBIT NO. 40

PHILLIPS - LEA NO. 12
Unit J 1980' FS & EL
Section 29, T-17S, R-34E
Lea County, New Mexico

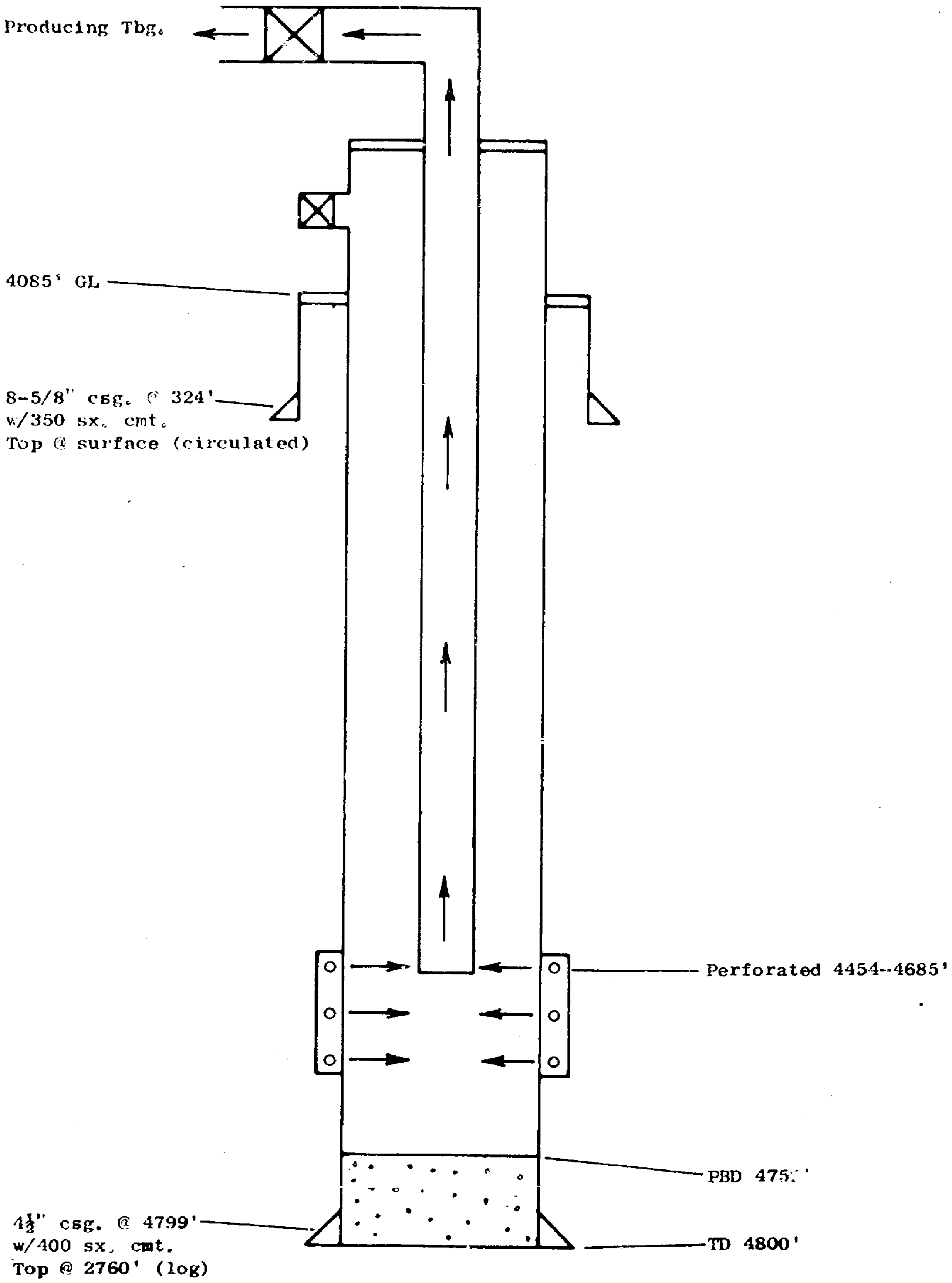


EXHIBIT NO. 41

PHILLIPS PETROLEUM COMPANY - LEA NO. 18

(Cole - Darden Phillips State #1)
Unit P 660' FS & EL
Section 30, T-17S, R-34E
Lea County, New Mexico

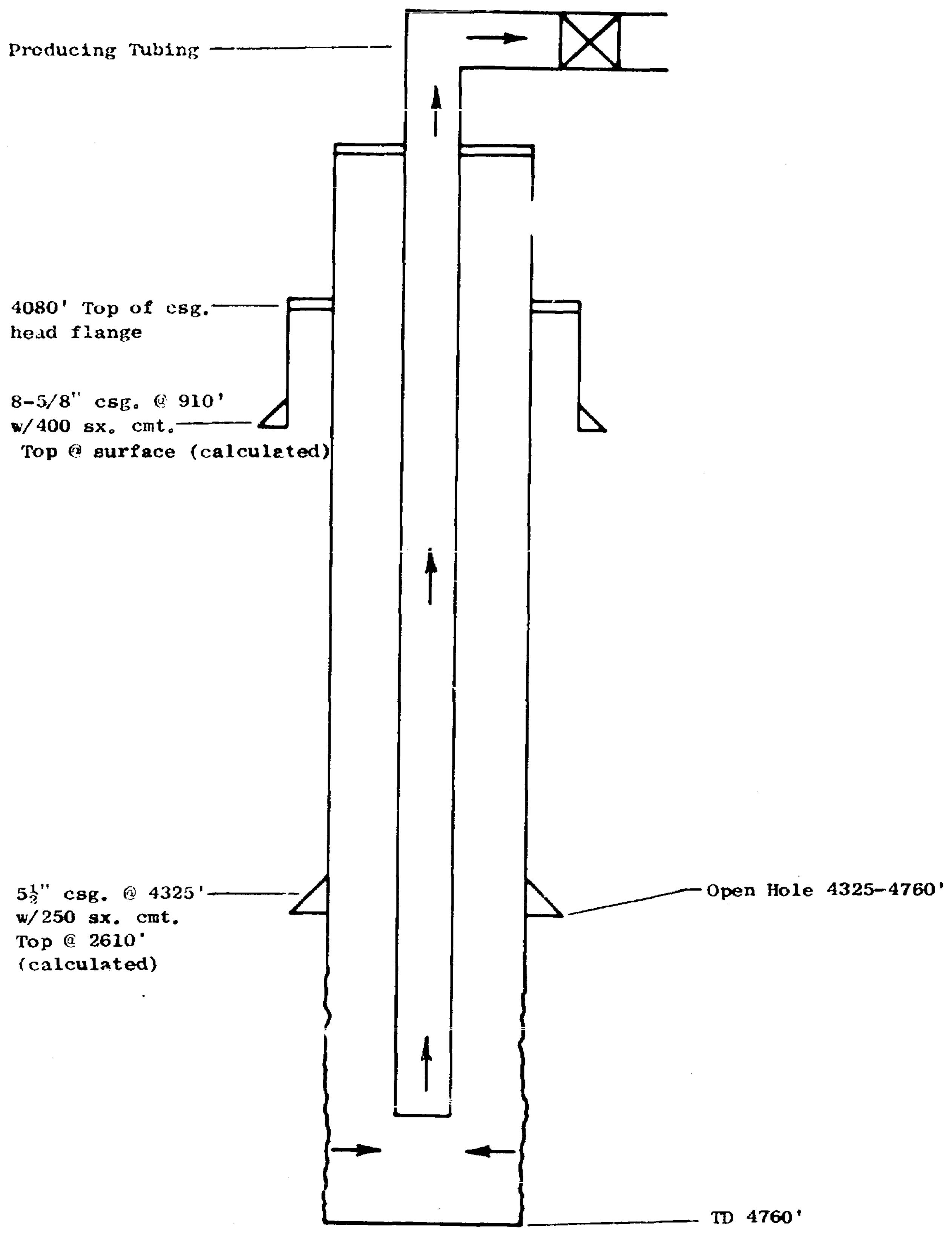


EXHIBIT NO. 42

PHILLIPS NO. 23
Unit P 810' FEL & 510' FSL
Section 30, T-17S, R-34E
Lea County, New Mexico

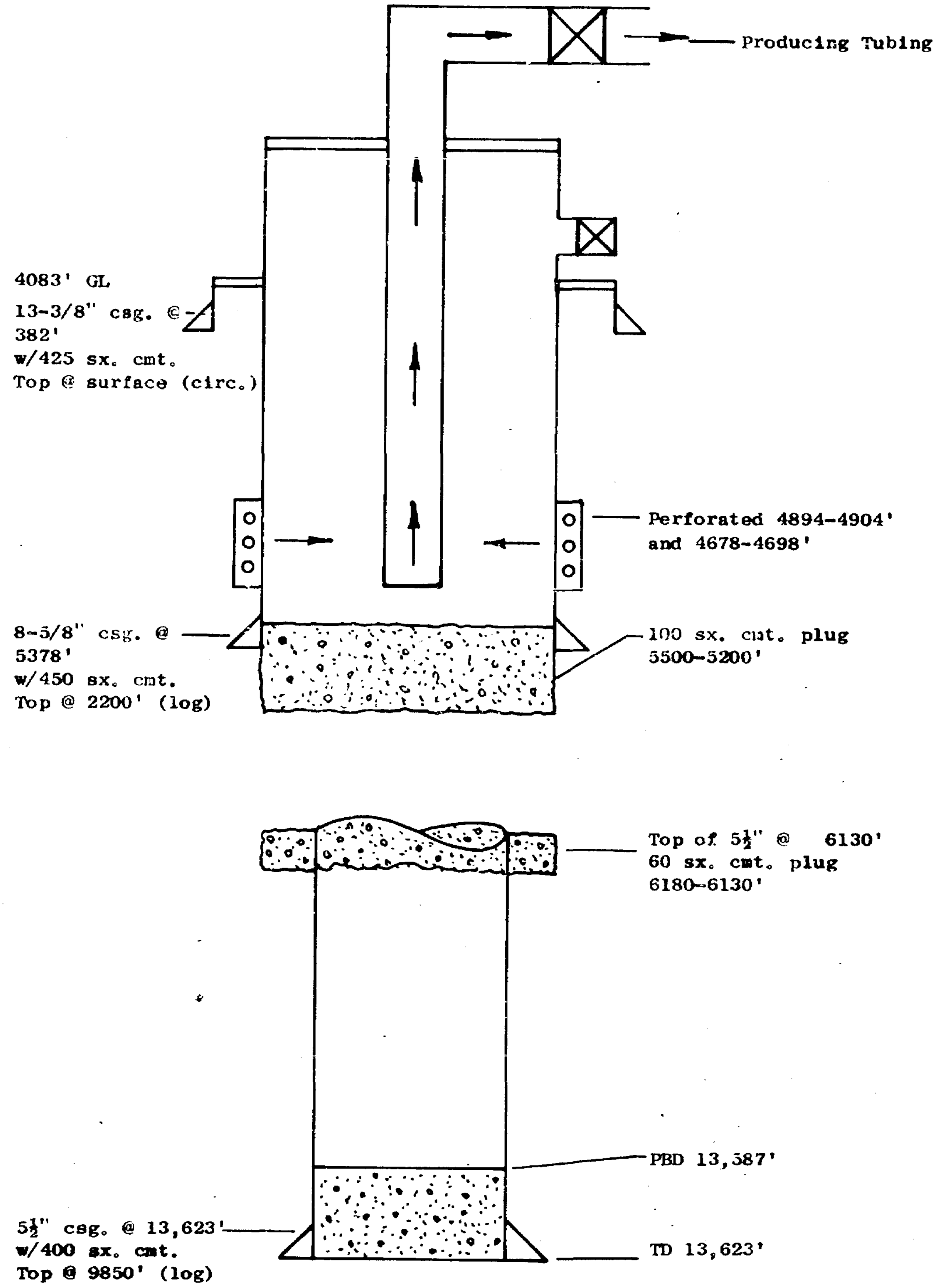


EXHIBIT NO. 43

PHILLIPS - LEA NO. 20
(Cole Darden Oil Company - Phillips State #3)
Unit O 660' FSL & 1980' FEL
Section 30, T-17S, R-34E
Lea County, New Mexico

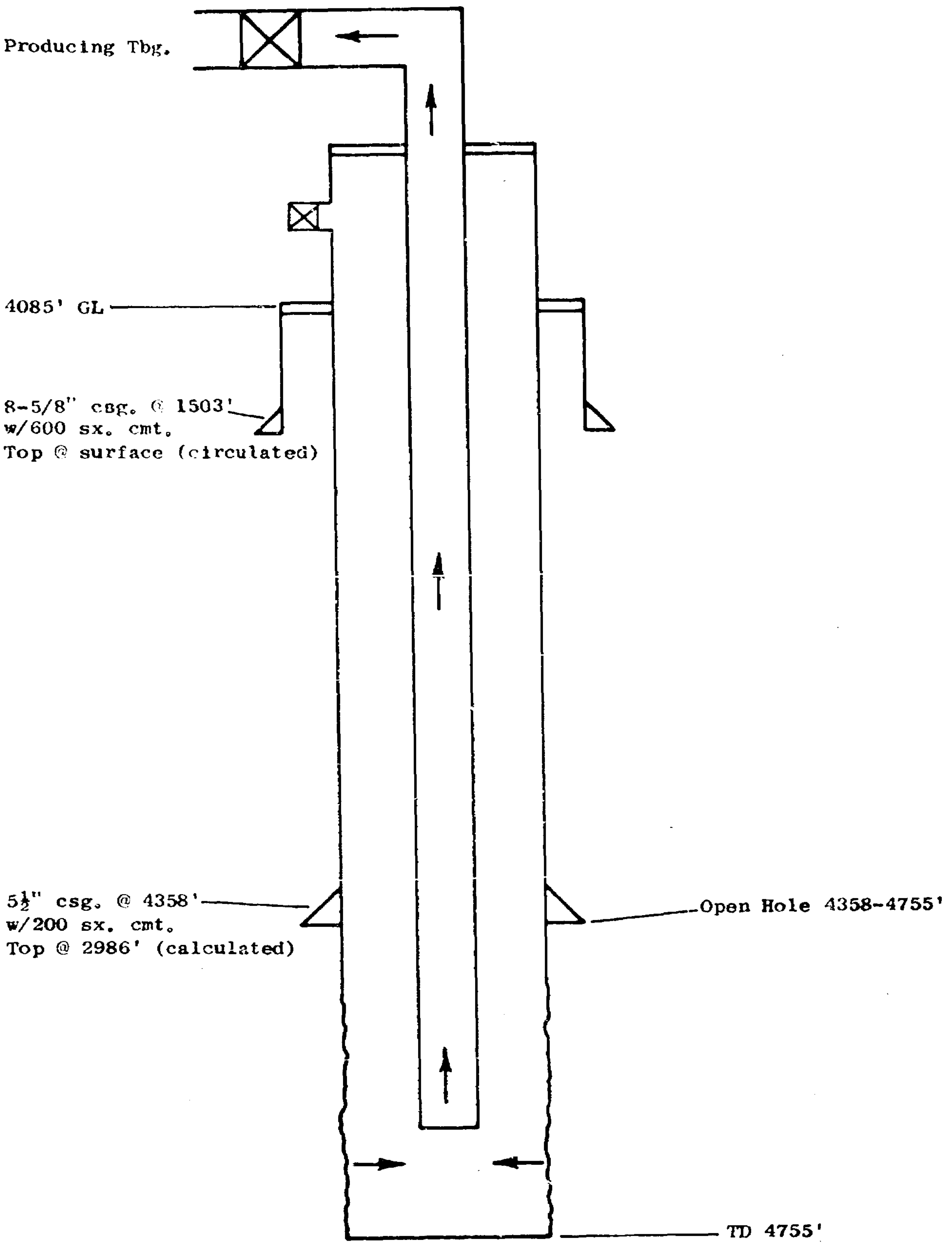


EXHIBIT NO. 44

PHILLIPS PETROLEUM COMPANY - LEA NO. 3
Unit B 660' FNL & 1980' FEL
Section 31, T-17S, R-34E
Lea County, New Mexico

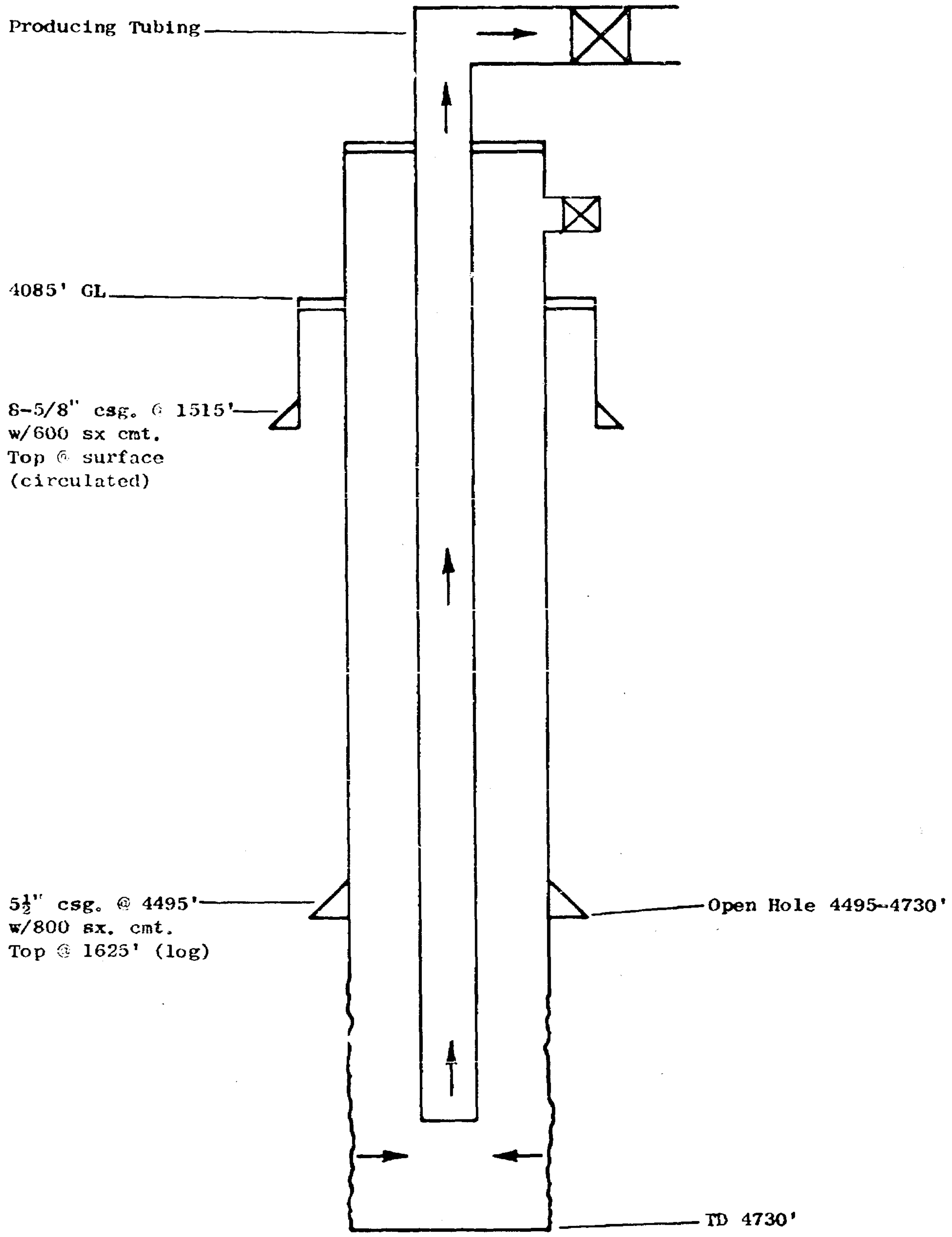


EXHIBIT NO. 45

SOHIO - PHILLIPS LEA NO. 7
Unit C 1980' FWL & 990' FNL
Section 31, T-17S, R-34E
Lea County, New Mexico

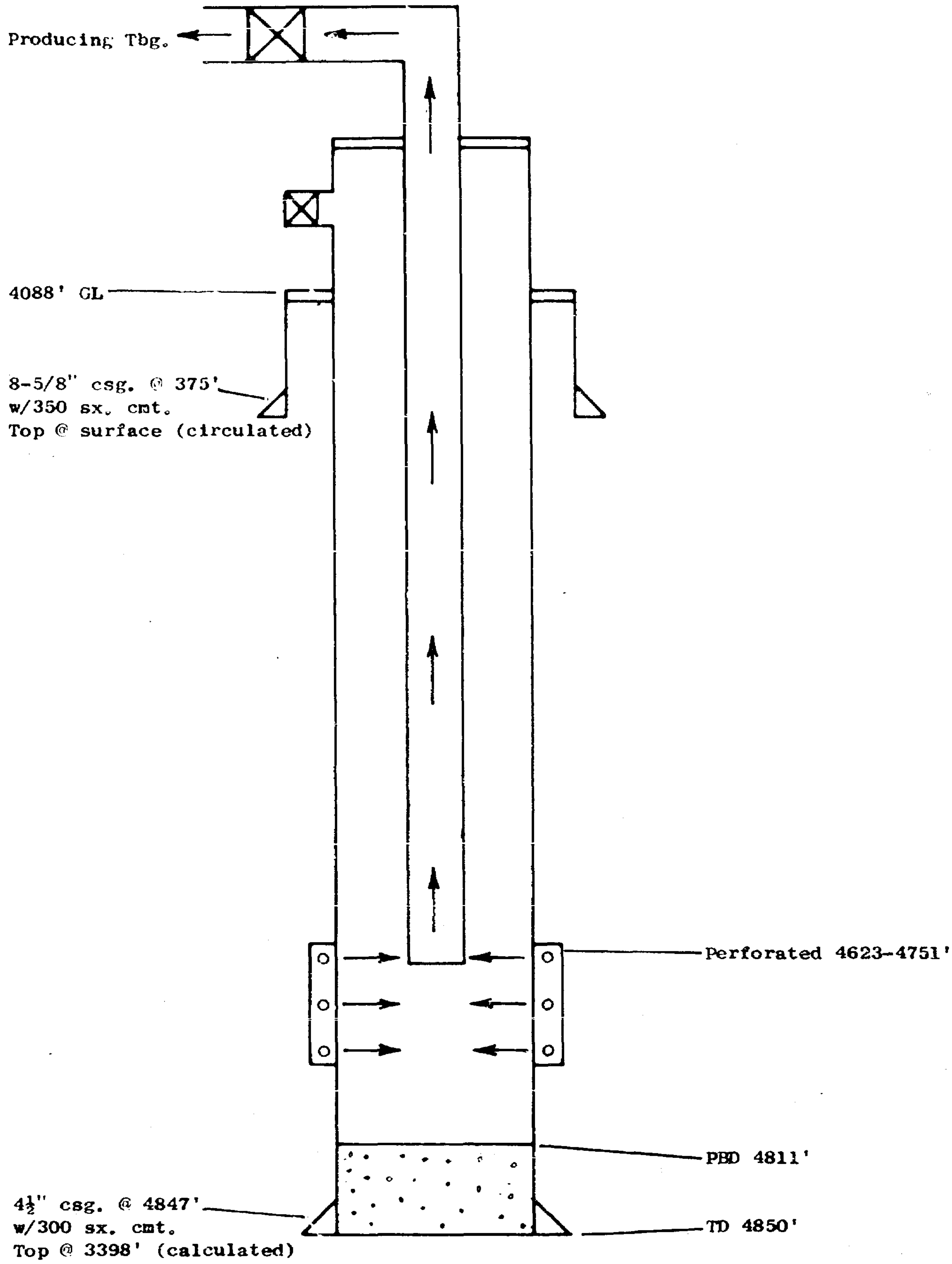


EXHIBIT NO. 46

SOHIO - PHILLIPS LEA NO. 1
(Penrose - Phillips Lea #1)
Unit F 1780' FNL & 1980' FWL
Section 31, T-17S, R-34E
Lea County, New Mexico

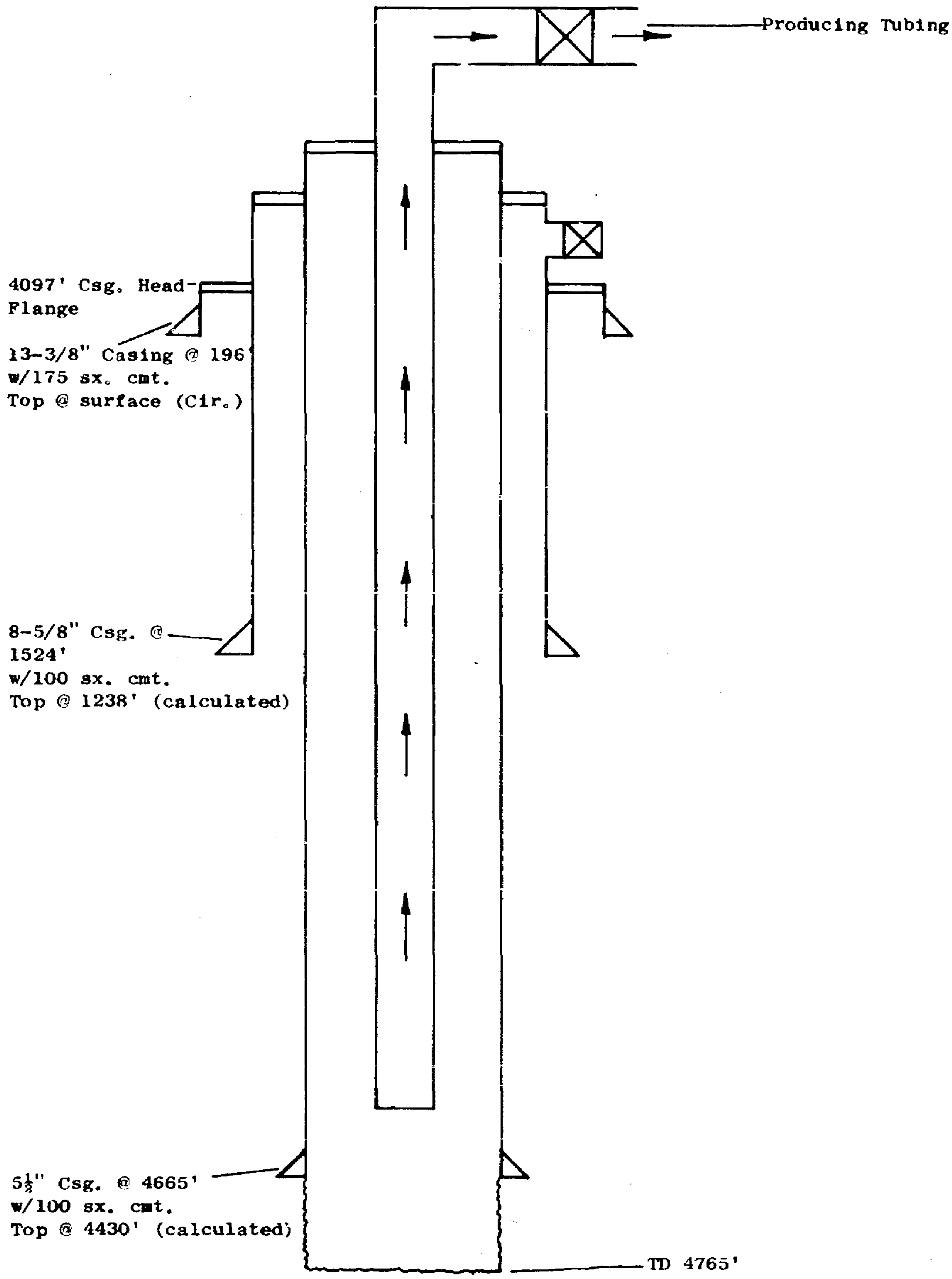


EXHIBIT NO. 47

SOHIO PETROLEUM CO. - PHILLIPS LEA NO. 2
(N. G. Penrose)
Unit G 2310' FNL & 1650' FEL
Section 31, T-17S, R-34E
Lea County, New Mexico

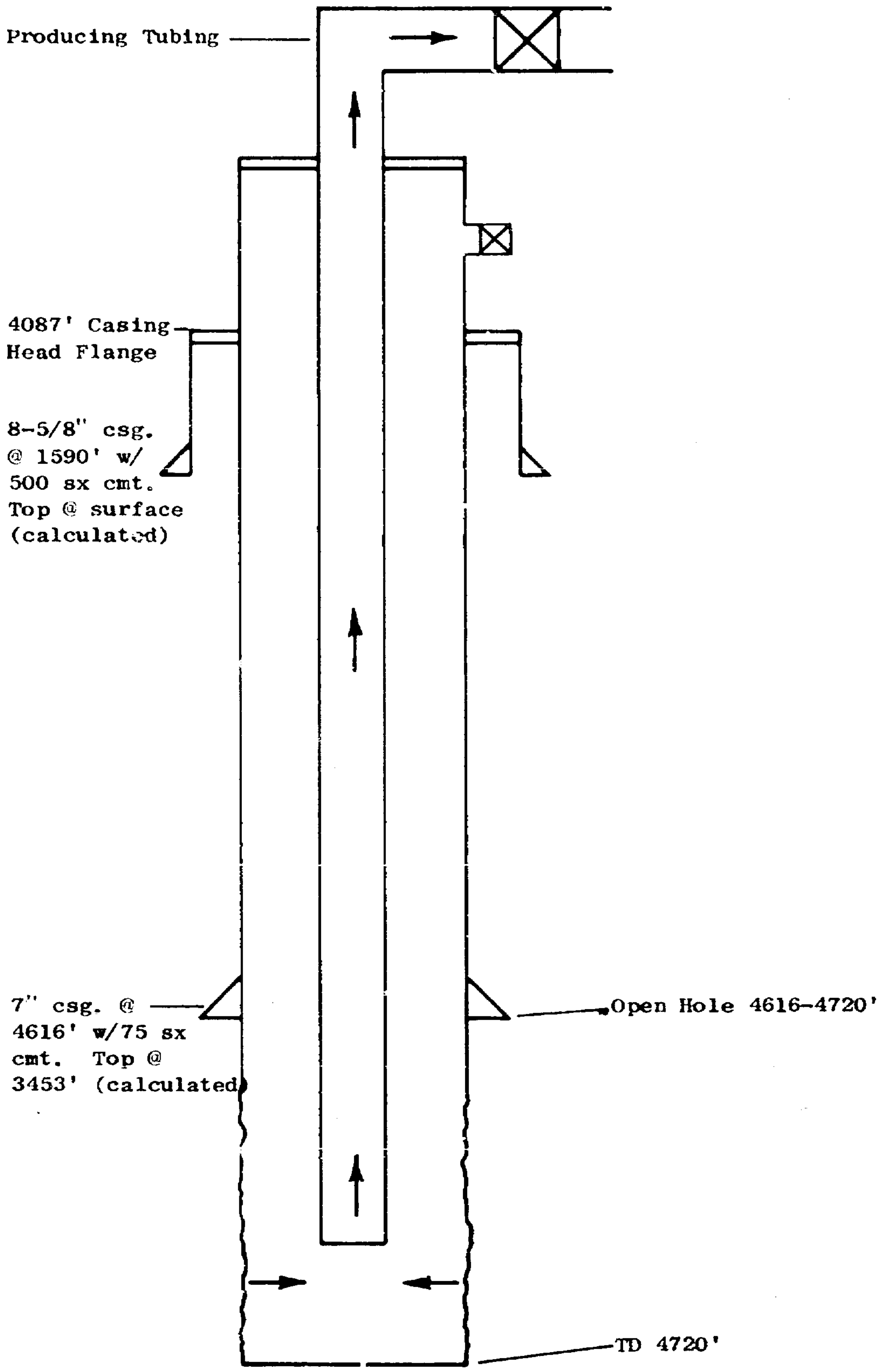
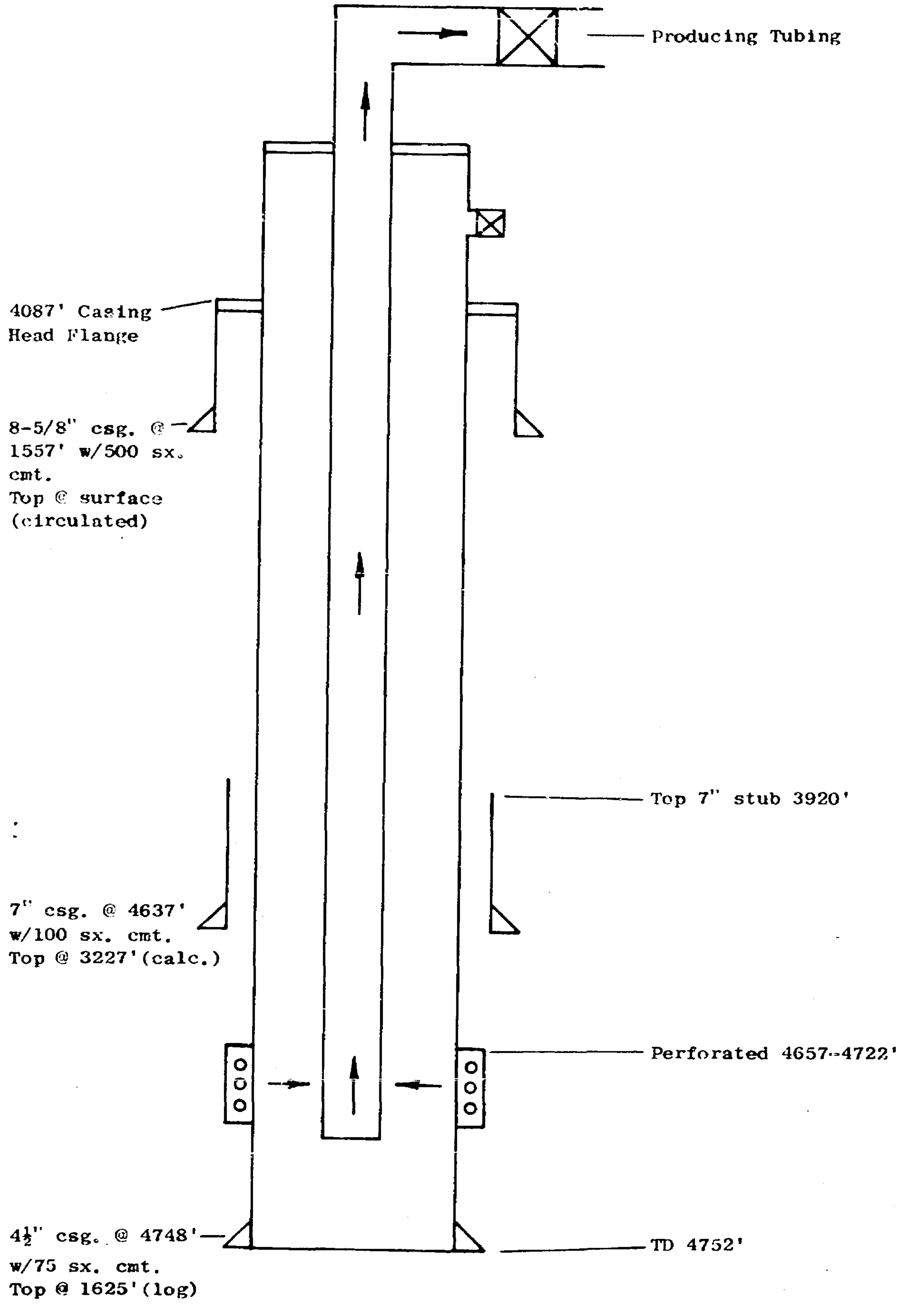


EXHIBIT NO. 48

SOHIO PETROLEUM COMPANY - PHILLIPS LEA NO. 3
(N. G. Penrose)
Unit J 2310' FSL & 1650' FEL
Section 31, T-17S, R-34E
Lea County, New Mexico



Well P & A May 10, 1957 and 3920' of 7" pulled. Well re-entered April 20, 1970 and full string of 4½" run.

EXHIBIT NO. 49

SOHIO - PHILLIPS LEA NO. 6
Unit K 2310' FS & WL
Section 31, T-17S, R-34E
Lea County, New Mexico

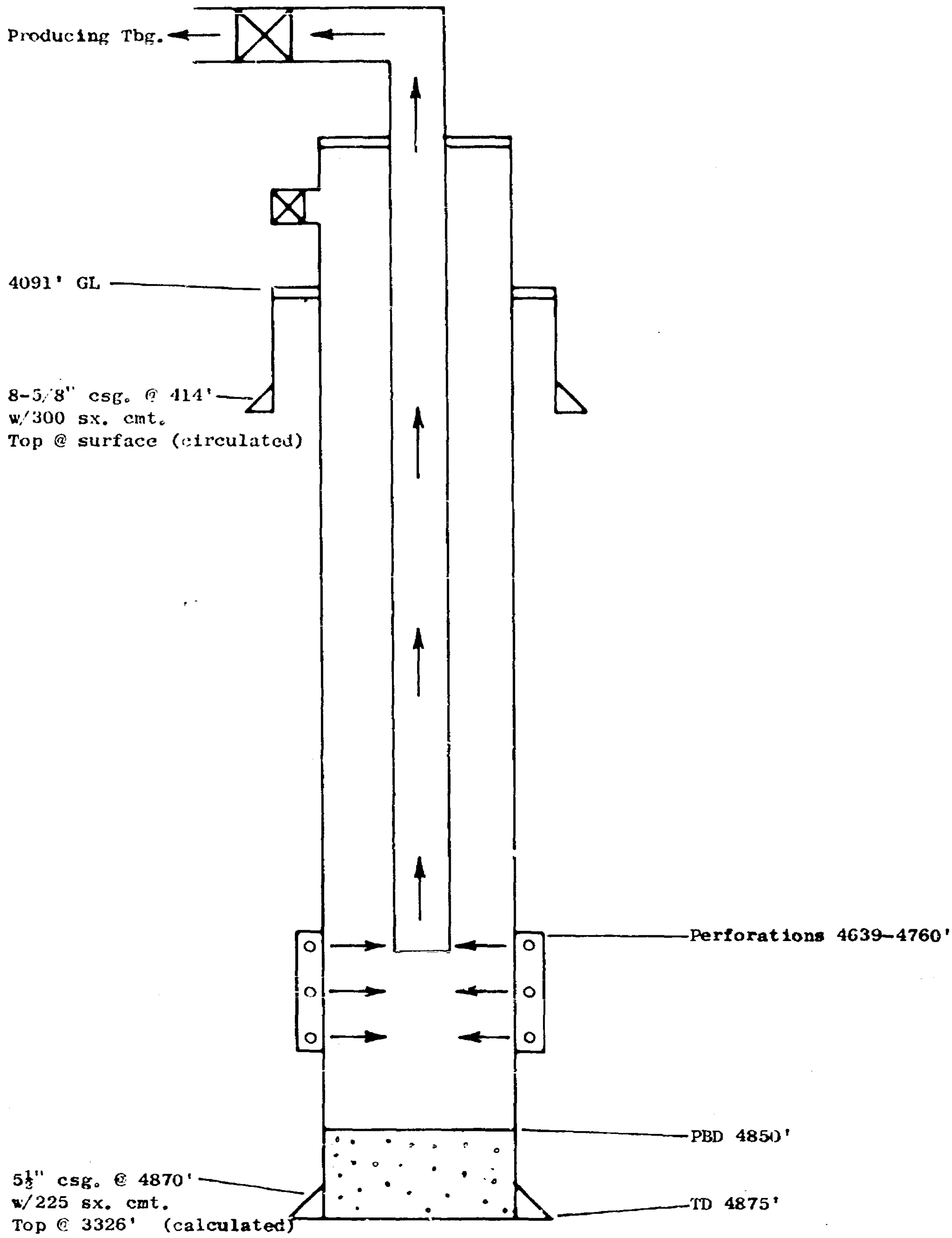


EXHIBIT NO. 50

SOHIO - PHILLIPS LEA NO. 8
Unit N 990' FSL & 1650' FWL
Section 31, T-17S, R-34E
Lea County, New Mexico

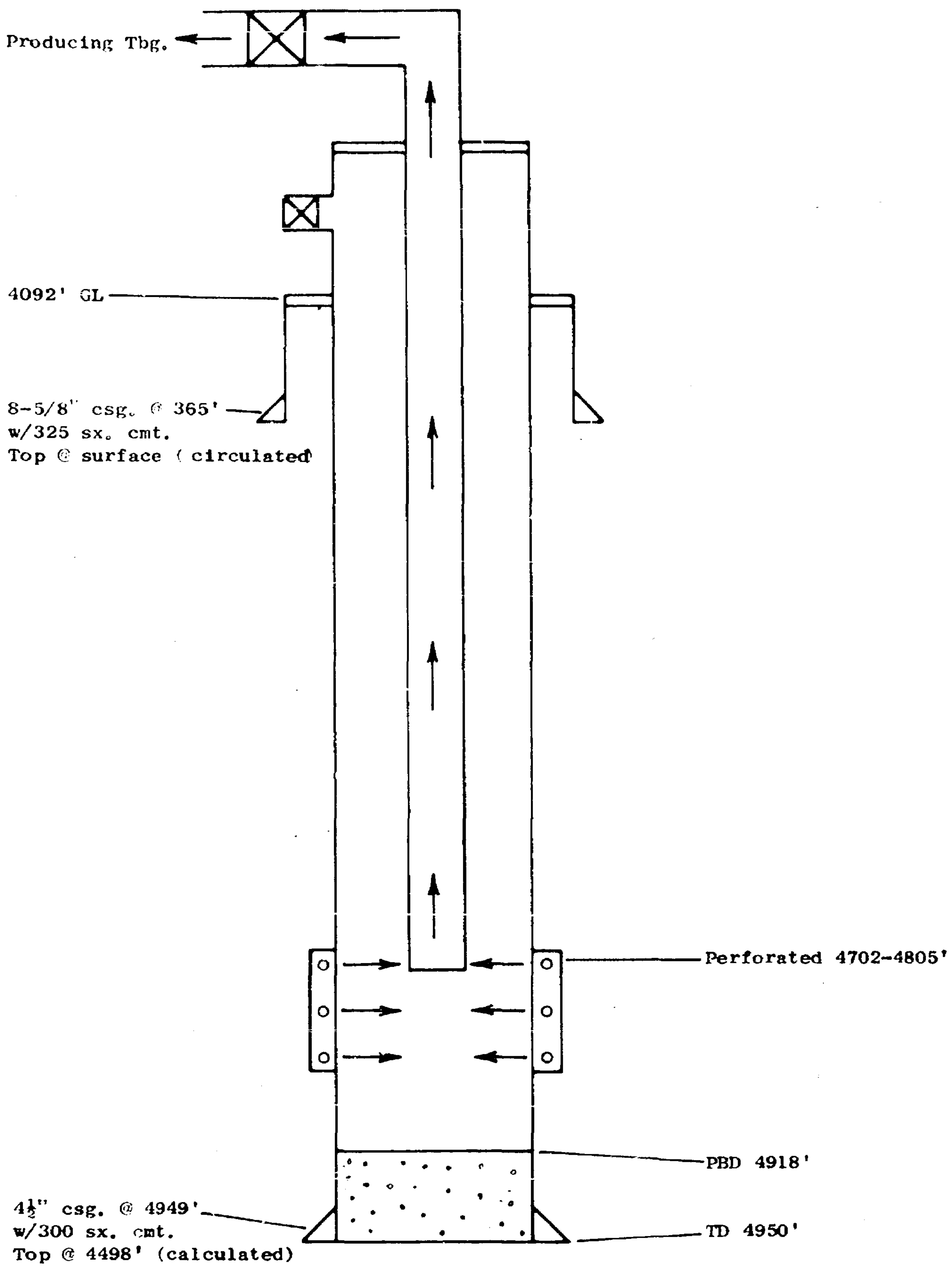


EXHIBIT NO. 51

TEXACO - NEW MEXICO "D" STATE NCT-2 NO. 2
660' FN & EL
Section 32, T-17S, R-34E
Lea County, New Mexico

P & A 2/22/48

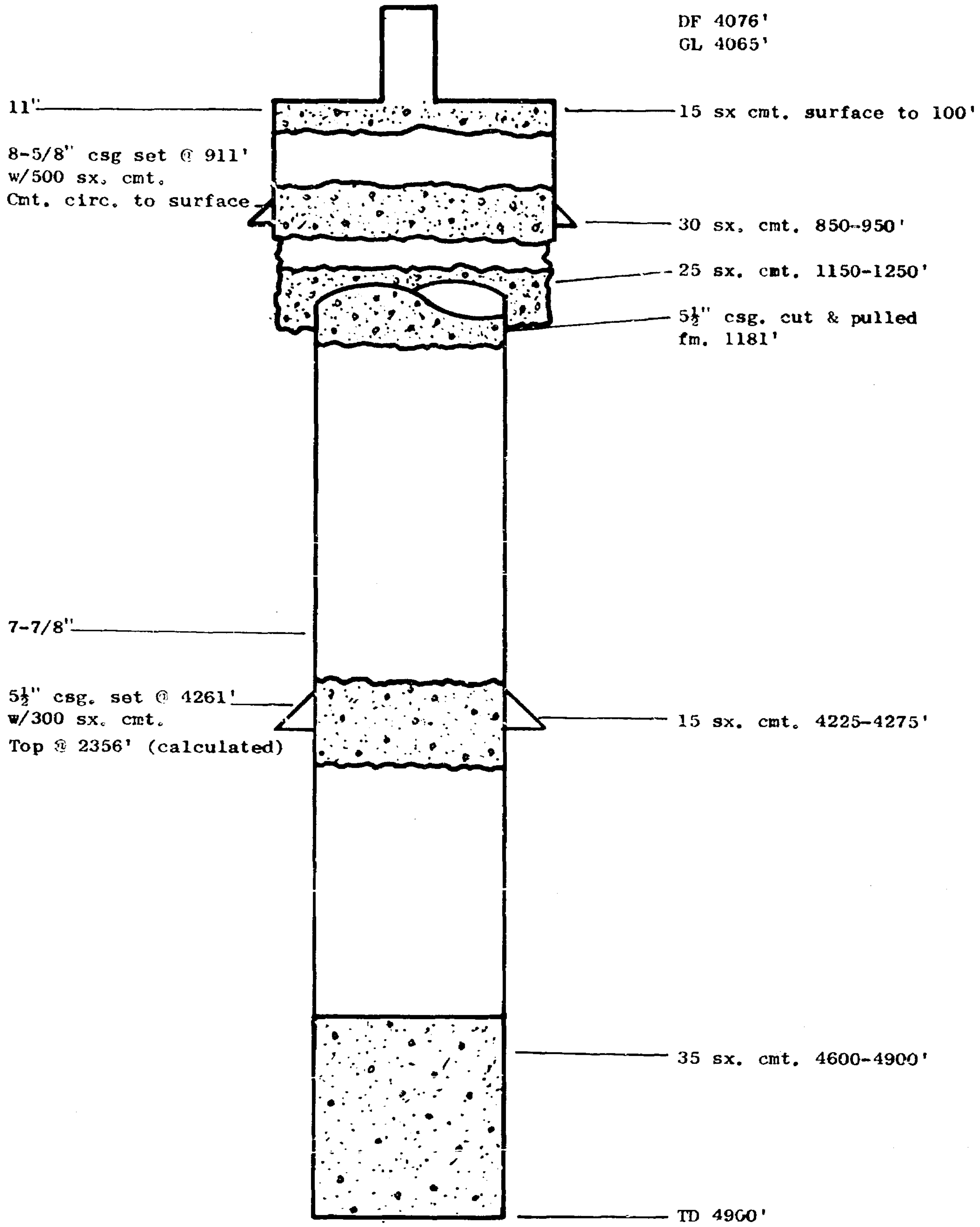


EXHIBIT NO. 52

WEST VACUUM UNIT NO. 7
(Ohio Oil Co. - State B-7998 #2)
Unit C 990' FNL & 2310' FWL
Section 33, T-17S, R-34E
Lea County, New Mexico

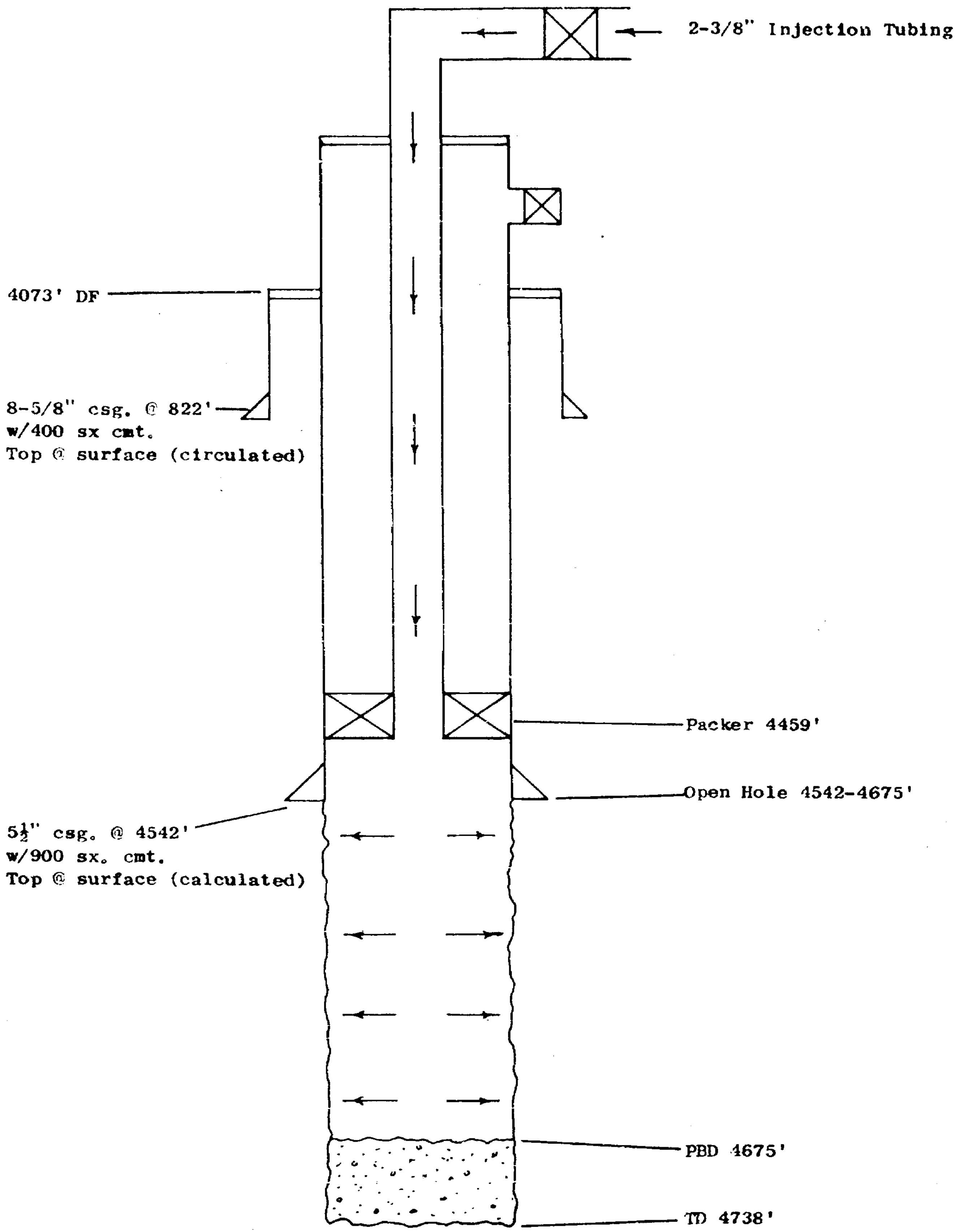


EXHIBIT NO. 53

TEXACO - WEST VACUUM UNIT NO. 14
(Ohio Oil Company - State B-8097 #1)
Unit E 1980' FNL & 660' FWL
Section 33, T-17S, R-34E
Lea County, New Mexico

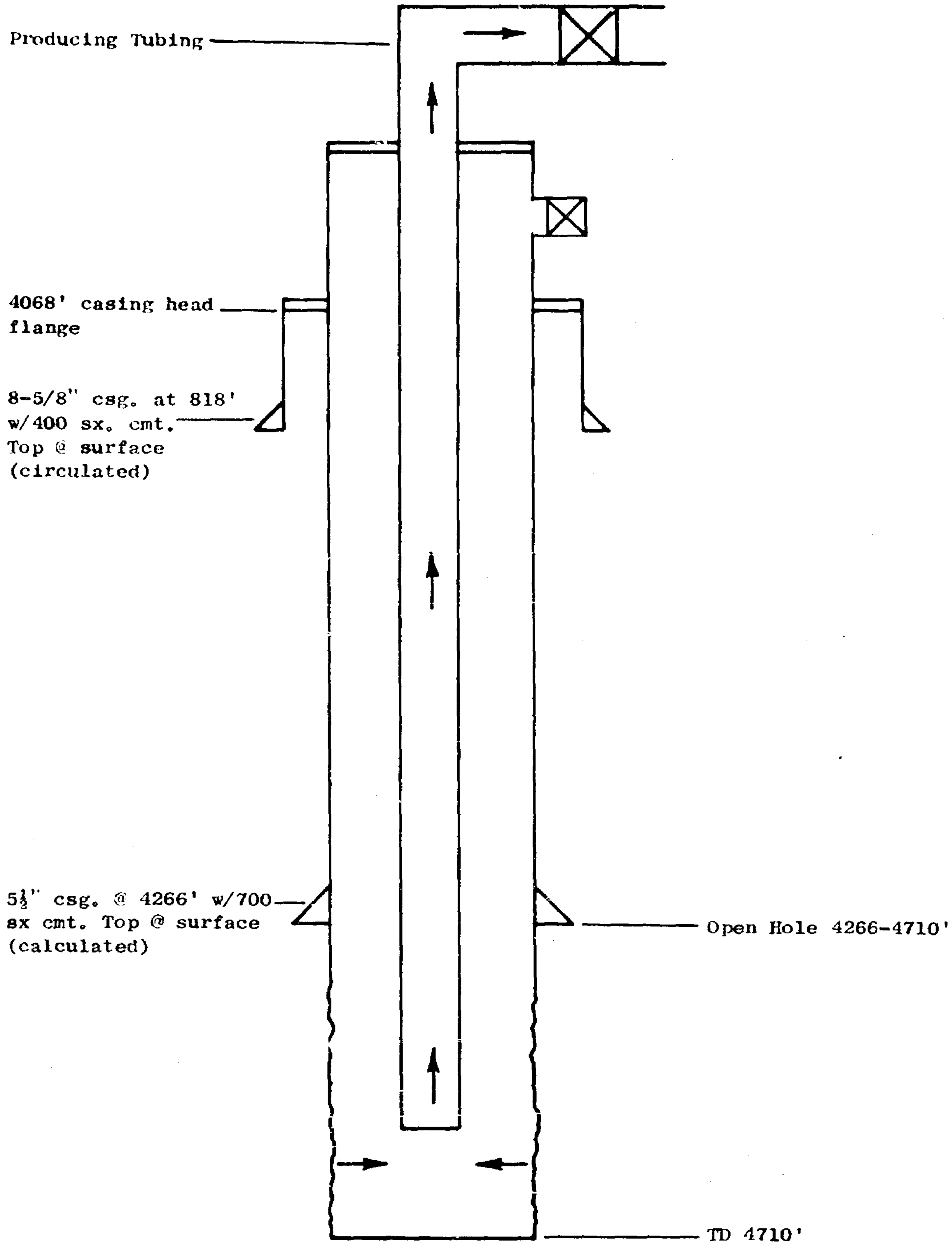


EXHIBIT NO. 54

TEXACO - WEST VACUUM UNIT NO. 15
(Ohio Oil Company - State B-7998 #1)
Unit F 1980' FN & WL
Section 33, T-17S, R-34E
Lea County, New Mexico

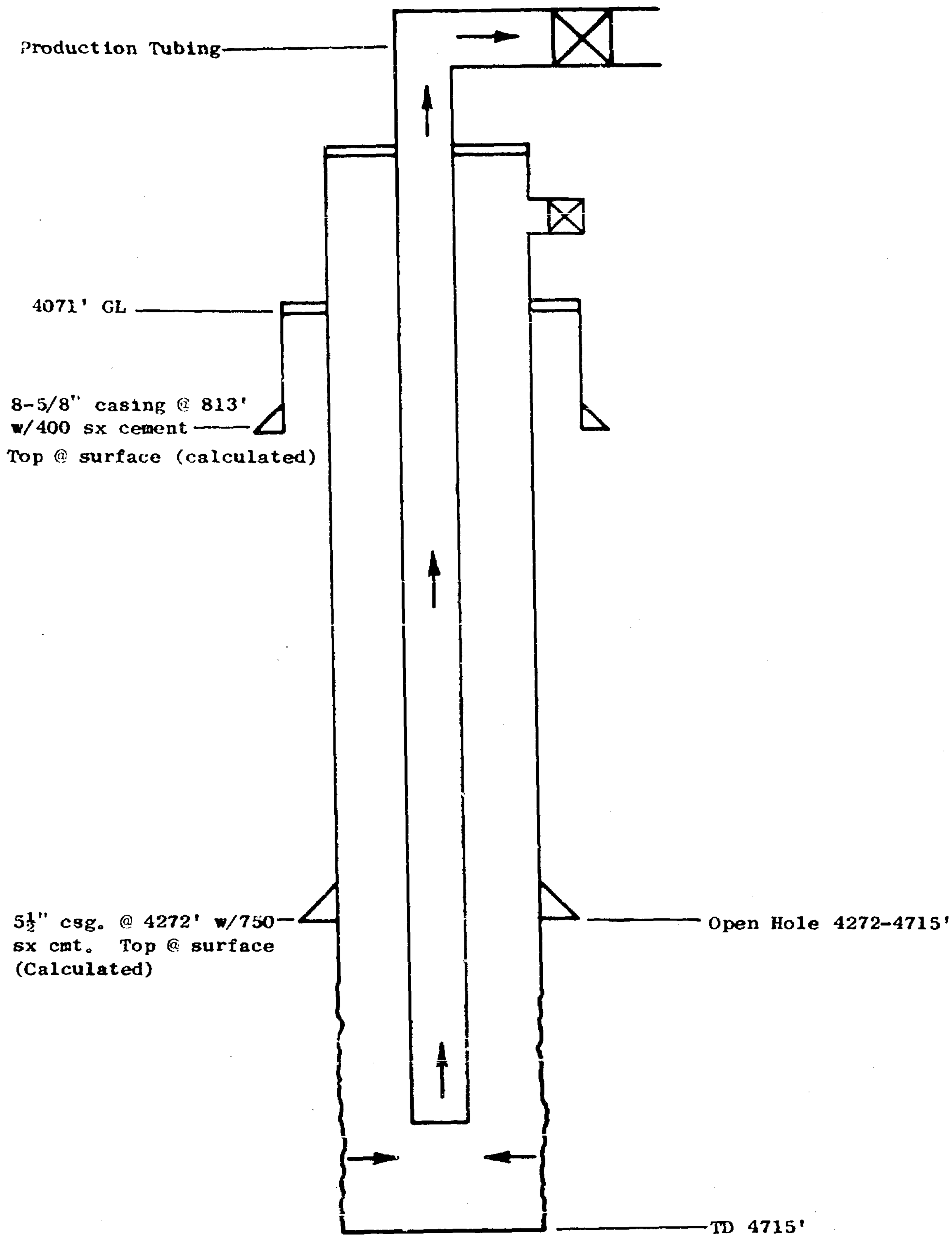


EXHIBIT NO. 55

WEST VACUUM UNIT NO. 23
(Texas Company - State of New Mexico "D" #15)
Unit K 1980' FS & WL
Section 33, T-17S, R-34E
Lea County, New Mexico

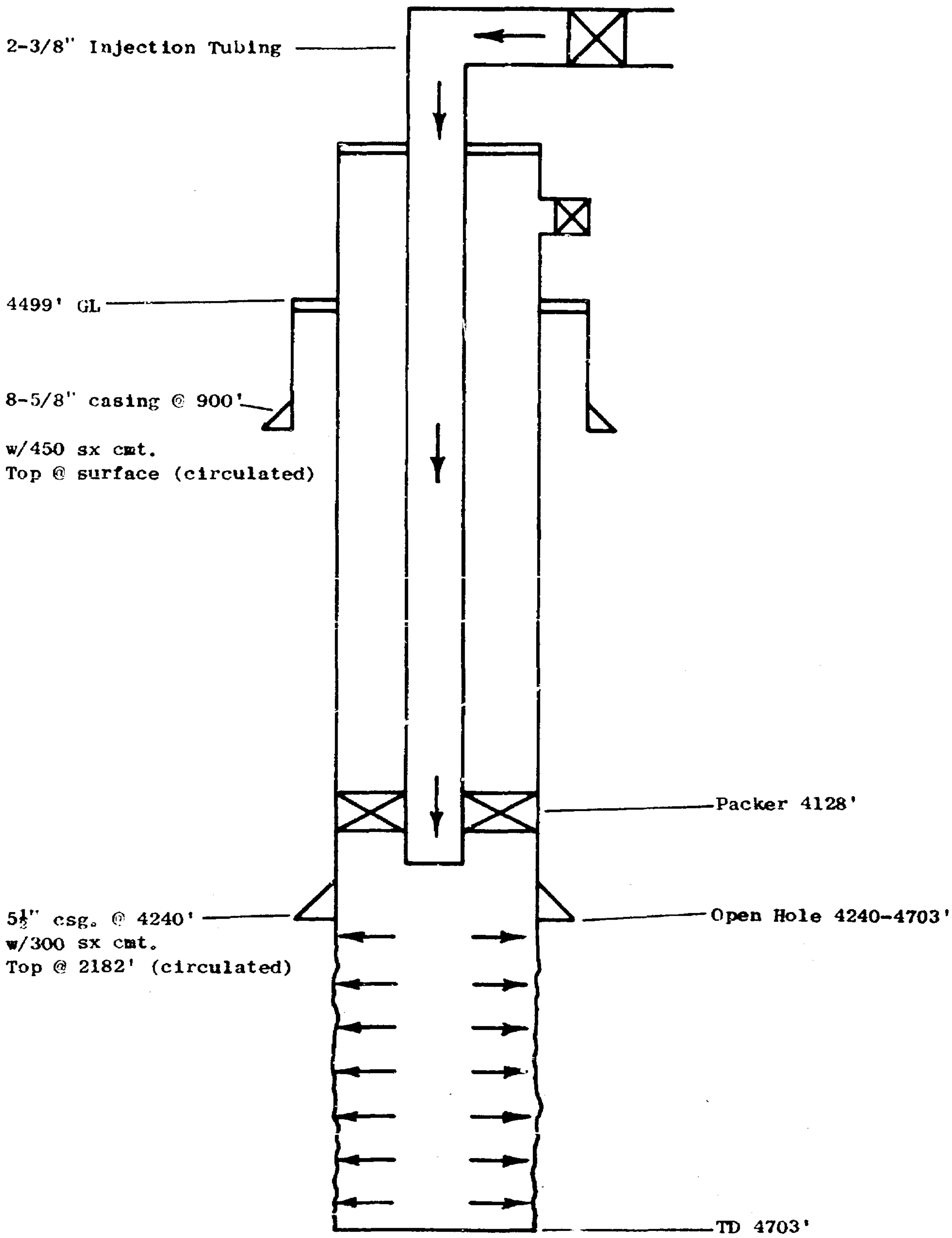


EXHIBIT NO. 56

TEXACO - WEST VACUUM UNIT No. 22
(Texaco - State of New Mexico "O" NCT-2 #16)
Unit L 1980' FSL & 660' FWL
Section 33, T-17S, R-34E
Lea County, New Mexico

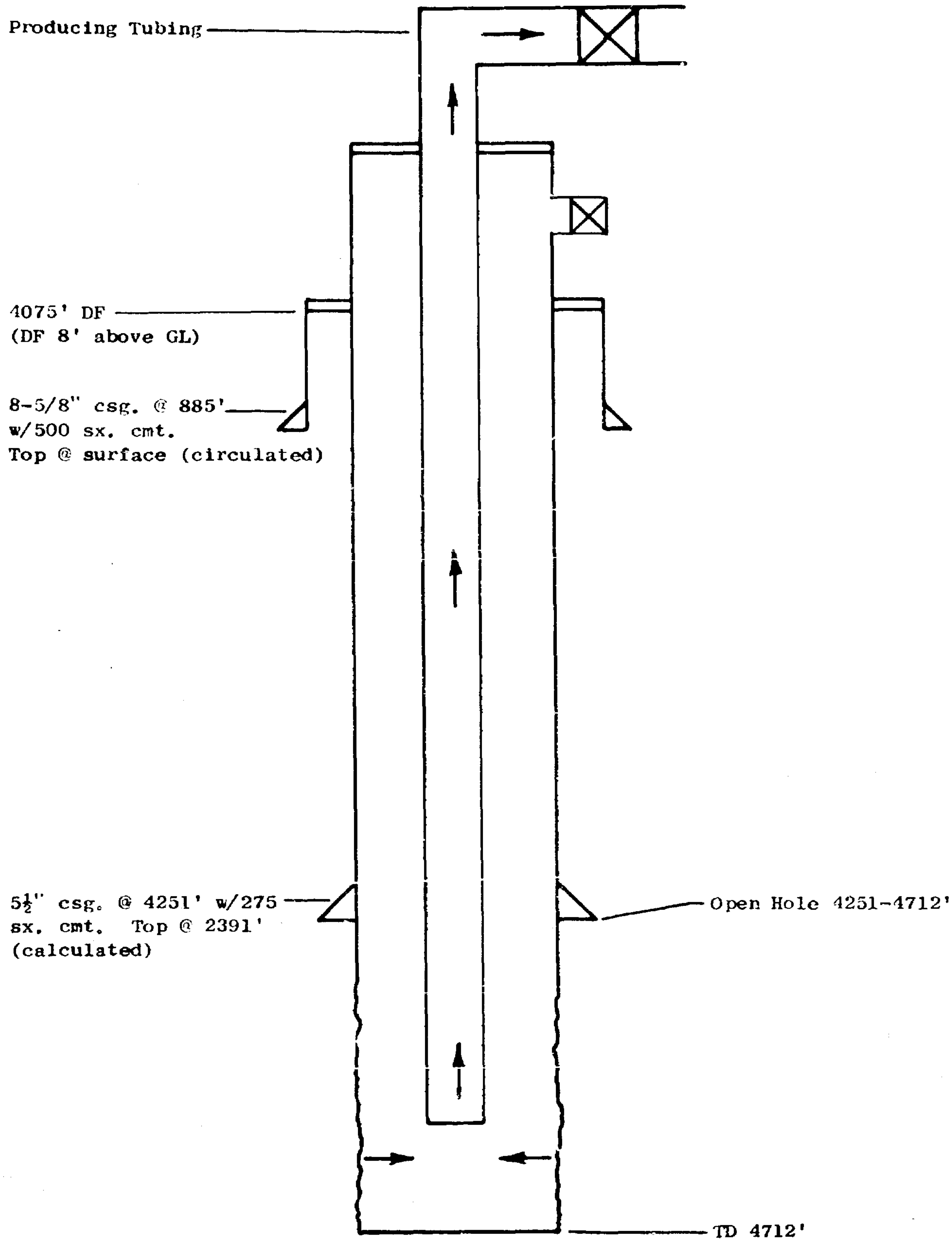


EXHIBIT NO. 57

TEXACO - NEW MEXICO "O" STATE NCT-2 NO. 21

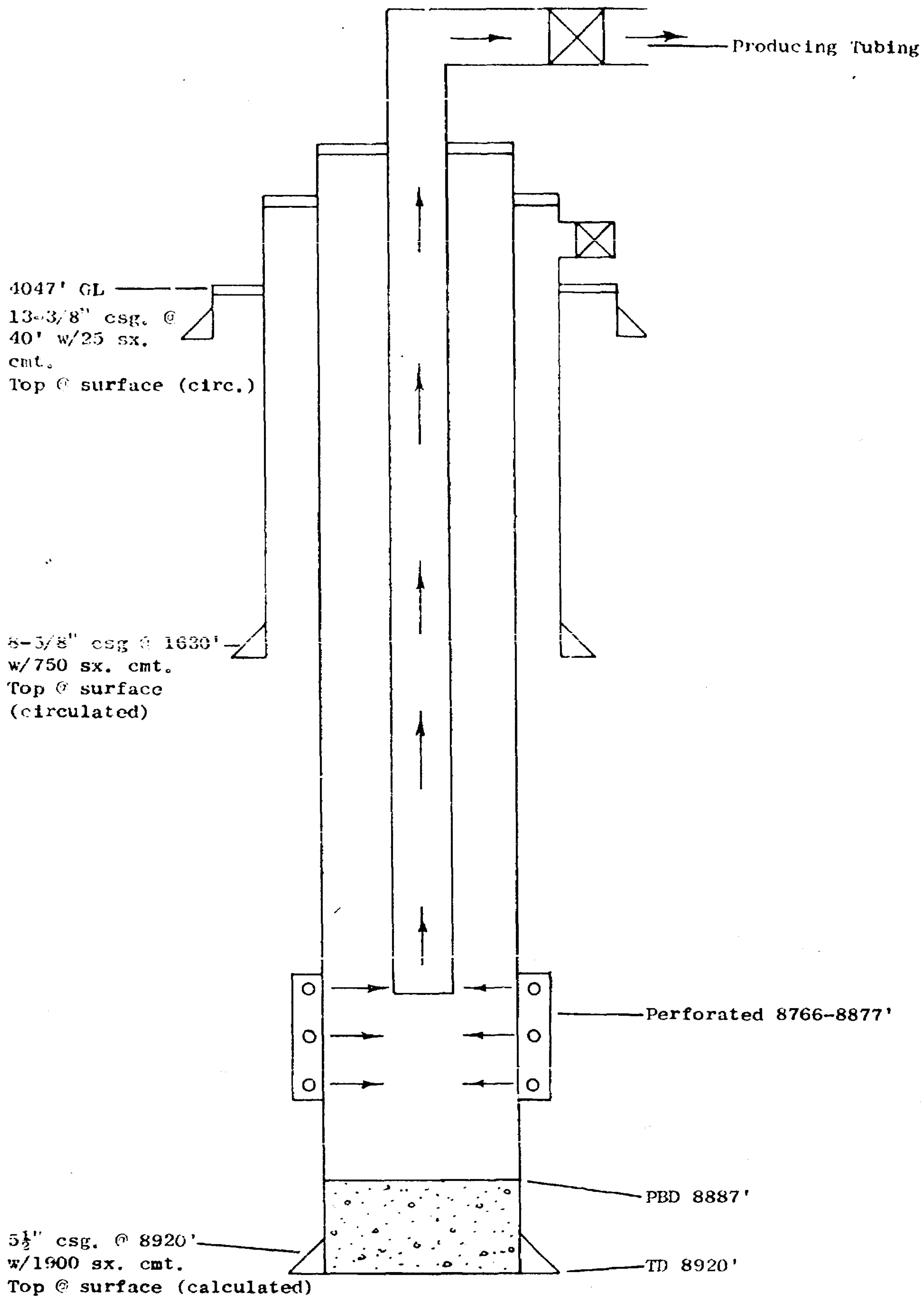


EXHIBIT NO. 58

TEXACO - WEST VACUUM UNIT NO. 30
(Texaco - State of New Mexico "O" NCT-2 #18)
Unit M 660' FS & WL
Section 33, T-17S, R-34E
Lea County, New Mexico

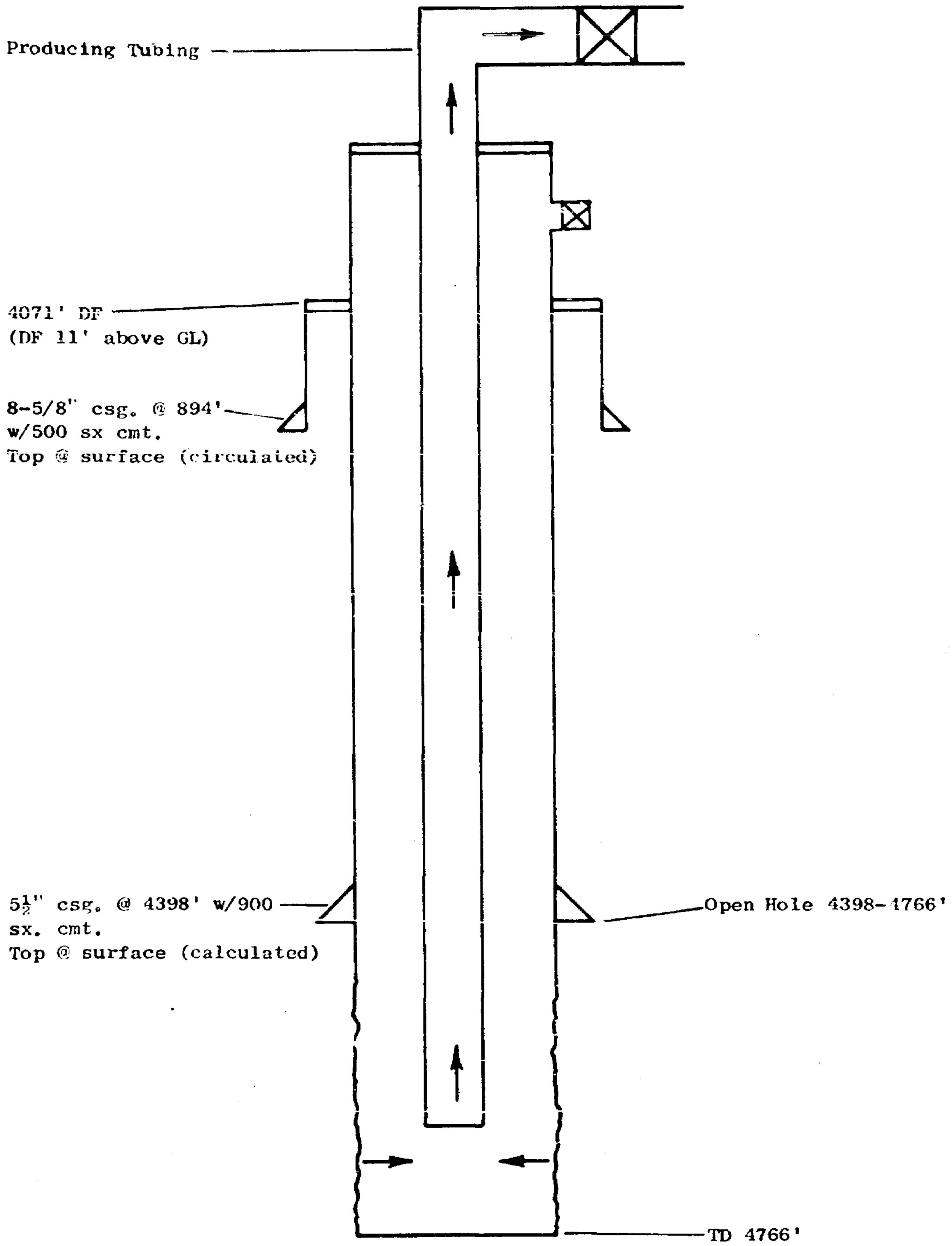


EXHIBIT NO. 59

TEXACO -- WEST VACUUM UNIT NO. 31)
(Texaco - State of New Mexico "O" NCT-2 #17)
Unit N 660' FSL & 1980' FWL
Section 33, T-17S, R-34E
Lea County, New Mexico

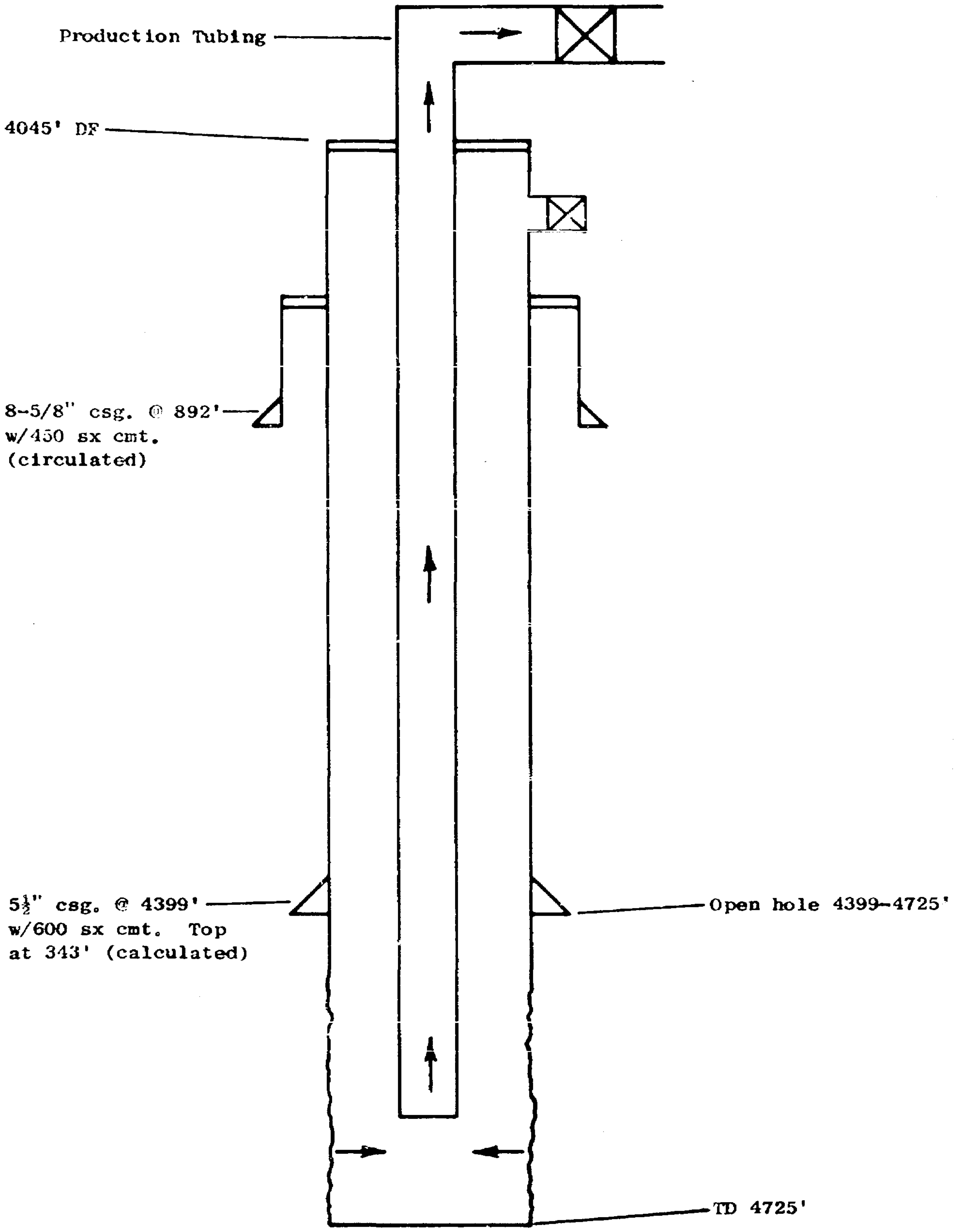


EXHIBIT NO. 60

TEXACO - WEST VACUUM UNIT NO. 40
(Texaco - State of New Mexico 'AA' NCT-2 No. 1)
Unit C 660' FNL & 1980' FWL
Section 4, T-18S, R-34E
Lea County, New Mexico

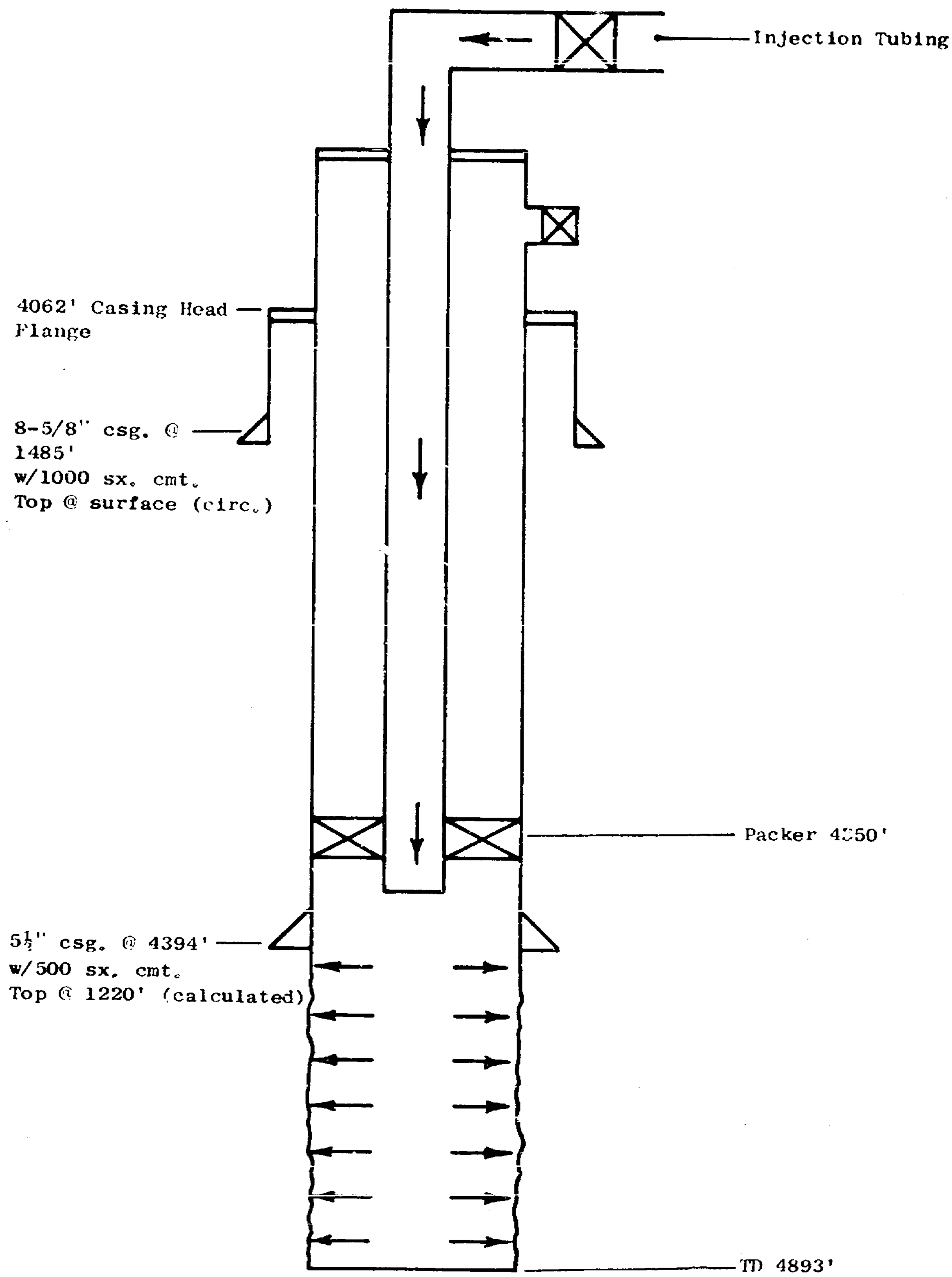


EXHIBIT NO. 61

TEXACO - WEST VACUUM UNIT NO. 39
(Mesa Retailers, Inc. - State #1)
Unit D 330' FN & WL
Section 4, T-18S, R-34E
Lea County, New Mexico

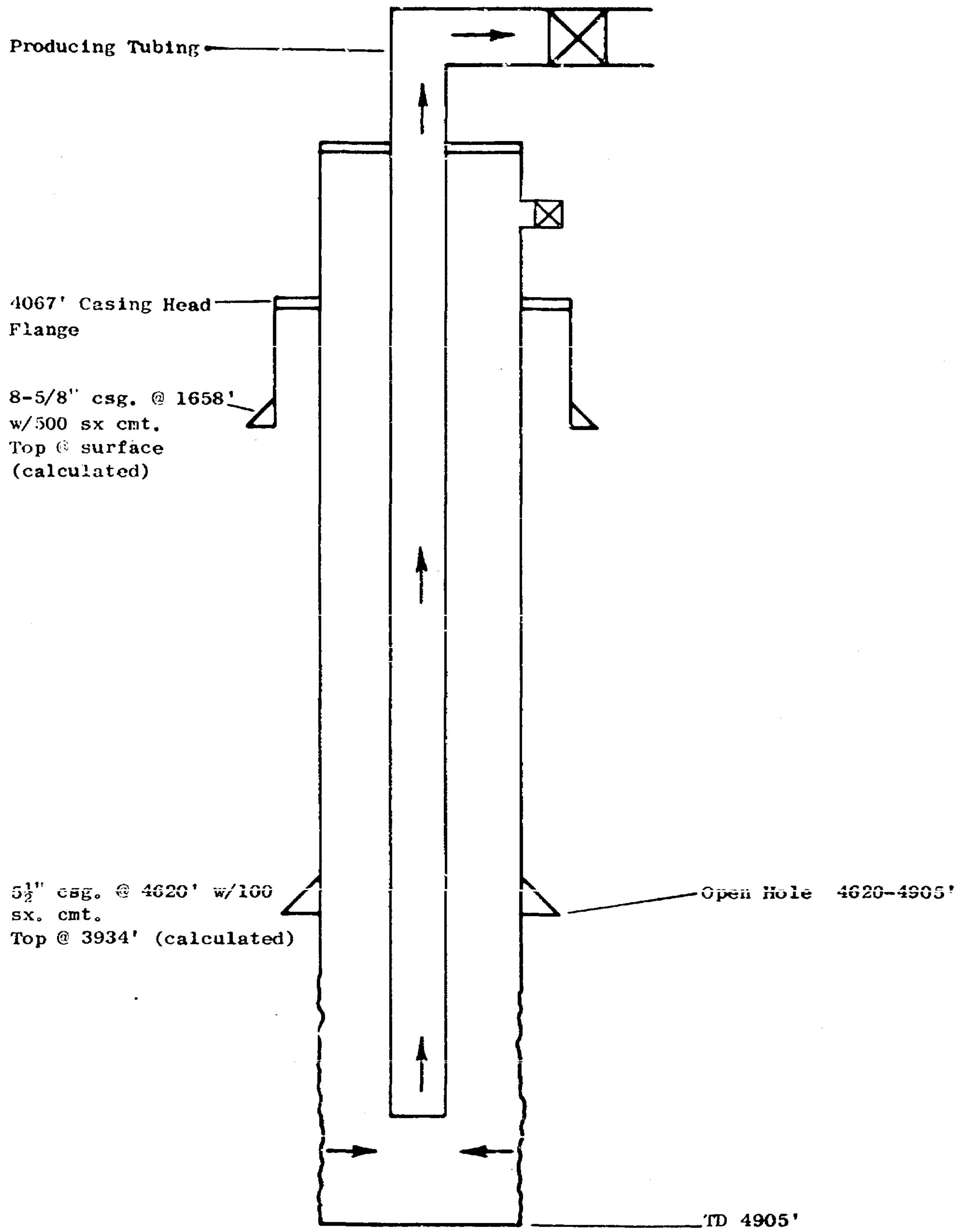


EXHIBIT NO. 62

Dalport Oil Corporation - Stanolind-State "A" #3
Unit F 1650' FNL & 2310' FWL
Section 4, T-18S, R-34E
Lea County, New Mexico

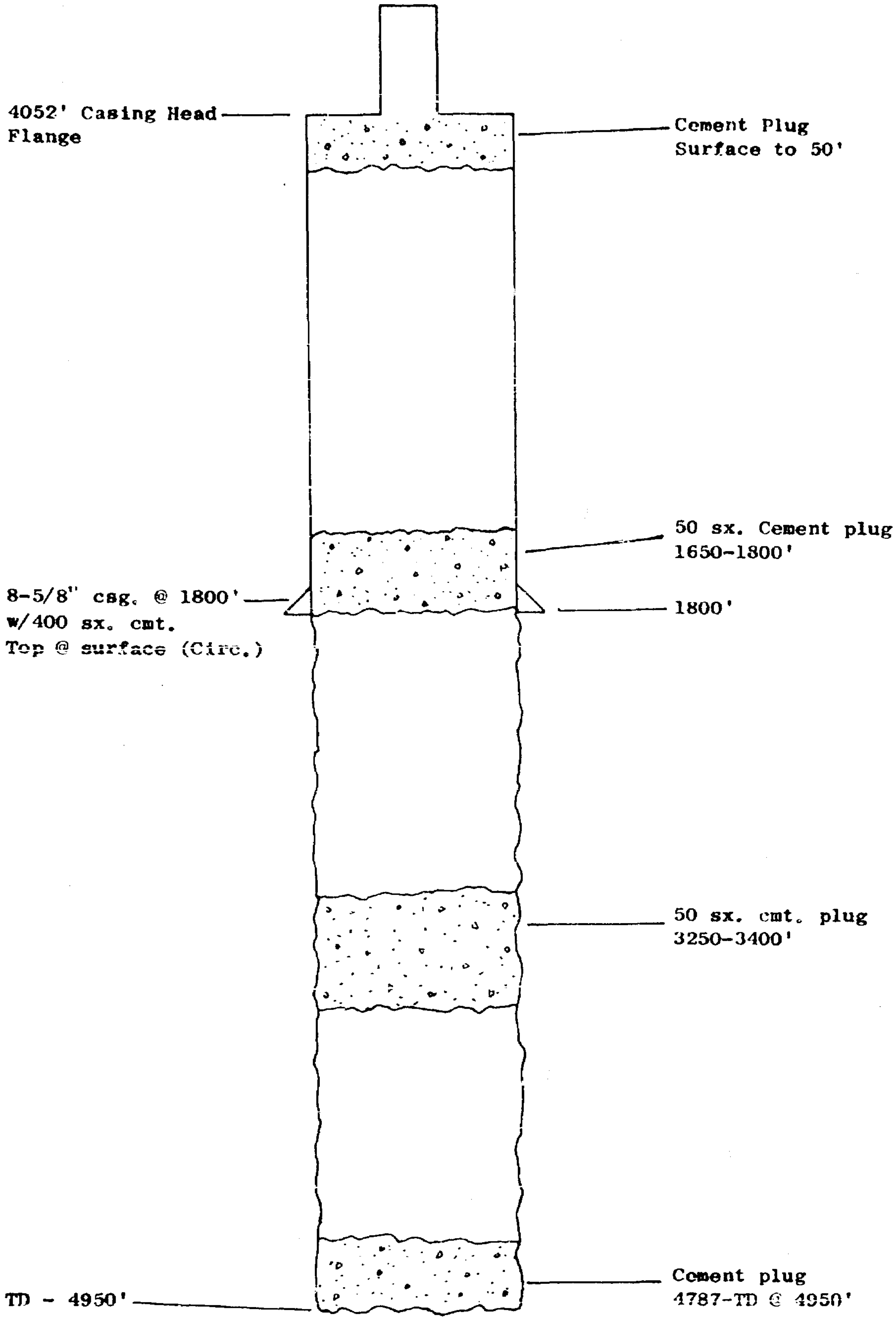
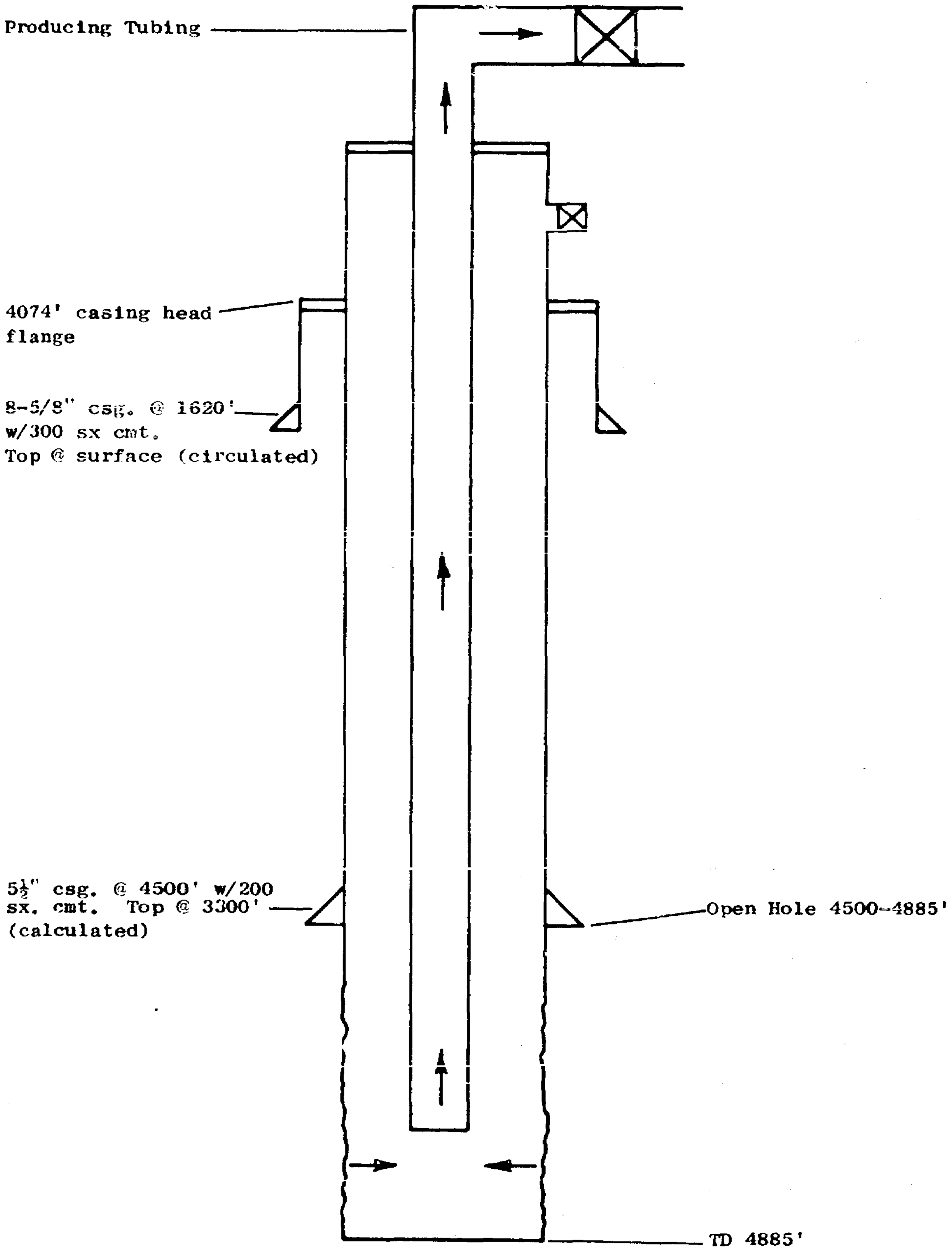


EXHIBIT NO. 63

TEXACO - WEST VACUUM UNIT NO. 38
(Dalport Oil Co. - Phillips State "B" #1)
Unit A 330' FNL & 660' FEL
Section 5, T-18S, R-34E
Lea County, New Mexico



MALCO PHILLIPS - STATE NO. 1
Unit B 330' FNL & 1980' FEL
Section 6, T-18S, R-34E
Lea County, New Mexico

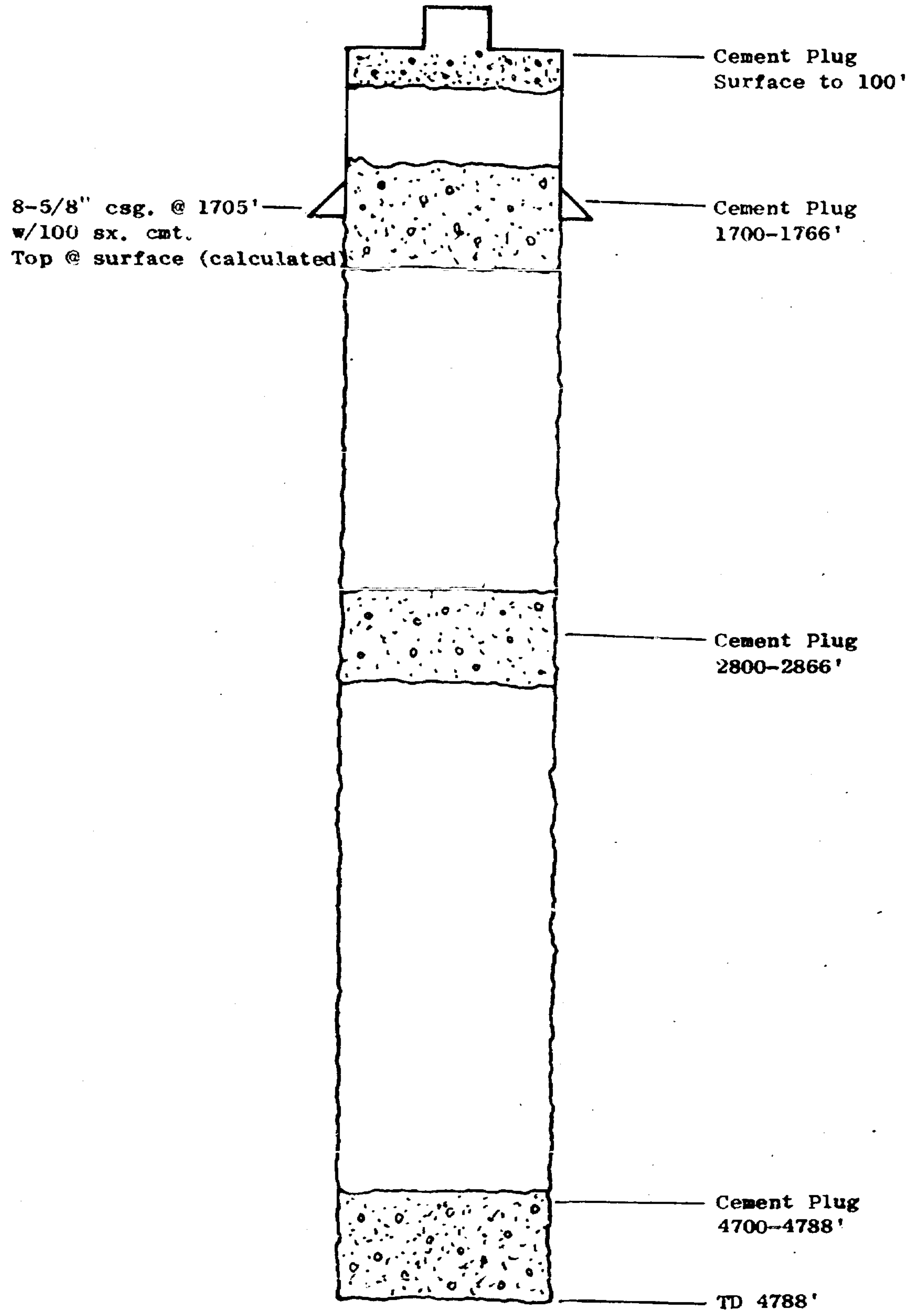


EXHIBIT NO. 65

MURPHY BAXTER - NORTH E-K QUEEN UNIT TRACT 3 NO. 3
(Phillips - Lea #15)
Unit F 2310' FNL & 1650' FWL
Section 6, T-18S, R-34E
Lea County, New Mexico

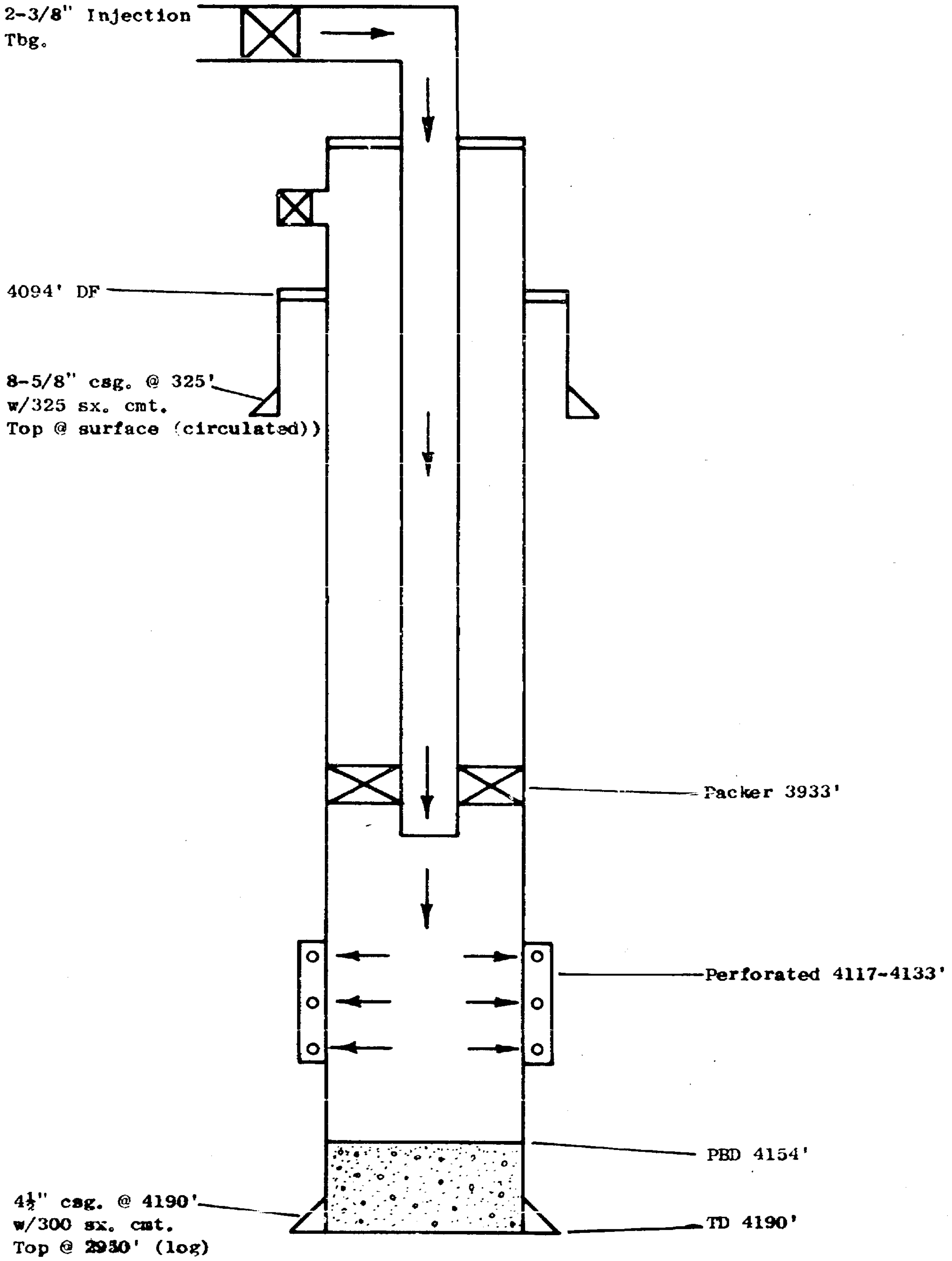
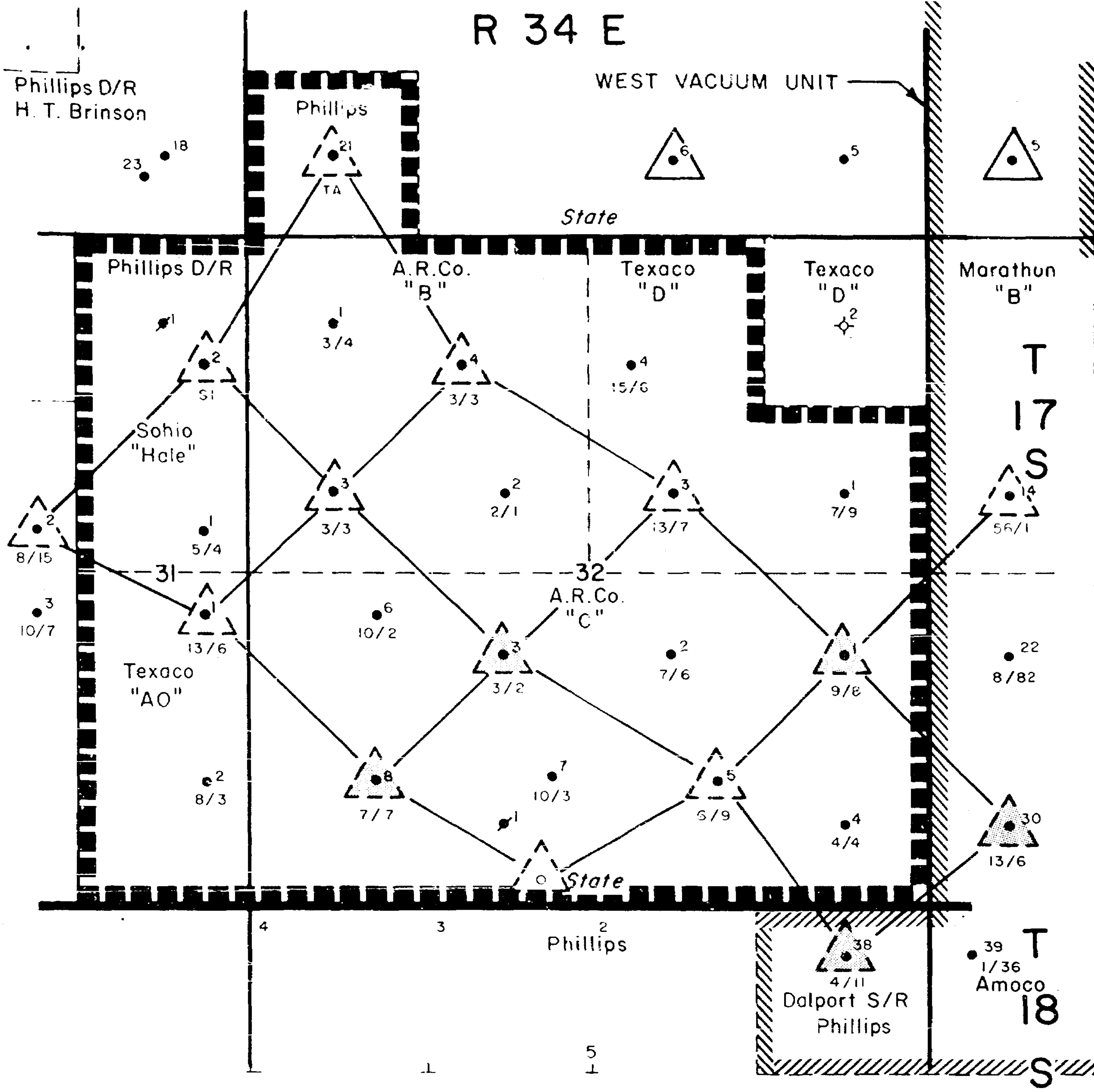


EXHIBIT NO. 66



LEGEND

4/4	BOPD / BWPD — MAY PRODUCTION
(triangle with dot)	PROPOSED INJECTION WELL
(triangle with circle)	PROPOSED INJECTION WELL TO BE DRILLED
■■■	PROPOSED WATERFLOOD BOUNDARY

EXHIBIT NO 67

Atlantic Richfield Company

VACUUM FIELD
Lea County, New Mexico

STATE VACUUM UNIT
PROPOSED
INJECTION PATTERN

R. M. MALAISE
WEST AREA ENGR.

OIL CONSE COMMISSION
P. (.088
SANTA FE, NE IEXICO 87501

Case File 5762
Order R-5295

May 23, 1978

Mr. J. L. Tweed
Atlantic Richfield Company
Box 1610
Midland, Texas 79701

Dear Mr. Tweed:

As requested in your letter of May 19, 1978, and as provided in Order No. R-5295, the injection pressure in your State Vacuum unit can be increased to 1130 pounds per square inch. The tests attached to the above mentioned letter, indicate the formation parting pressure in this area to be above the authorized pressure increase.

Very truly yours,

Joe D. Ramey
Division Director

JDR/og

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 1 (Phillips Lea No. 21)
660' FSL & 680' FWL Section 29, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

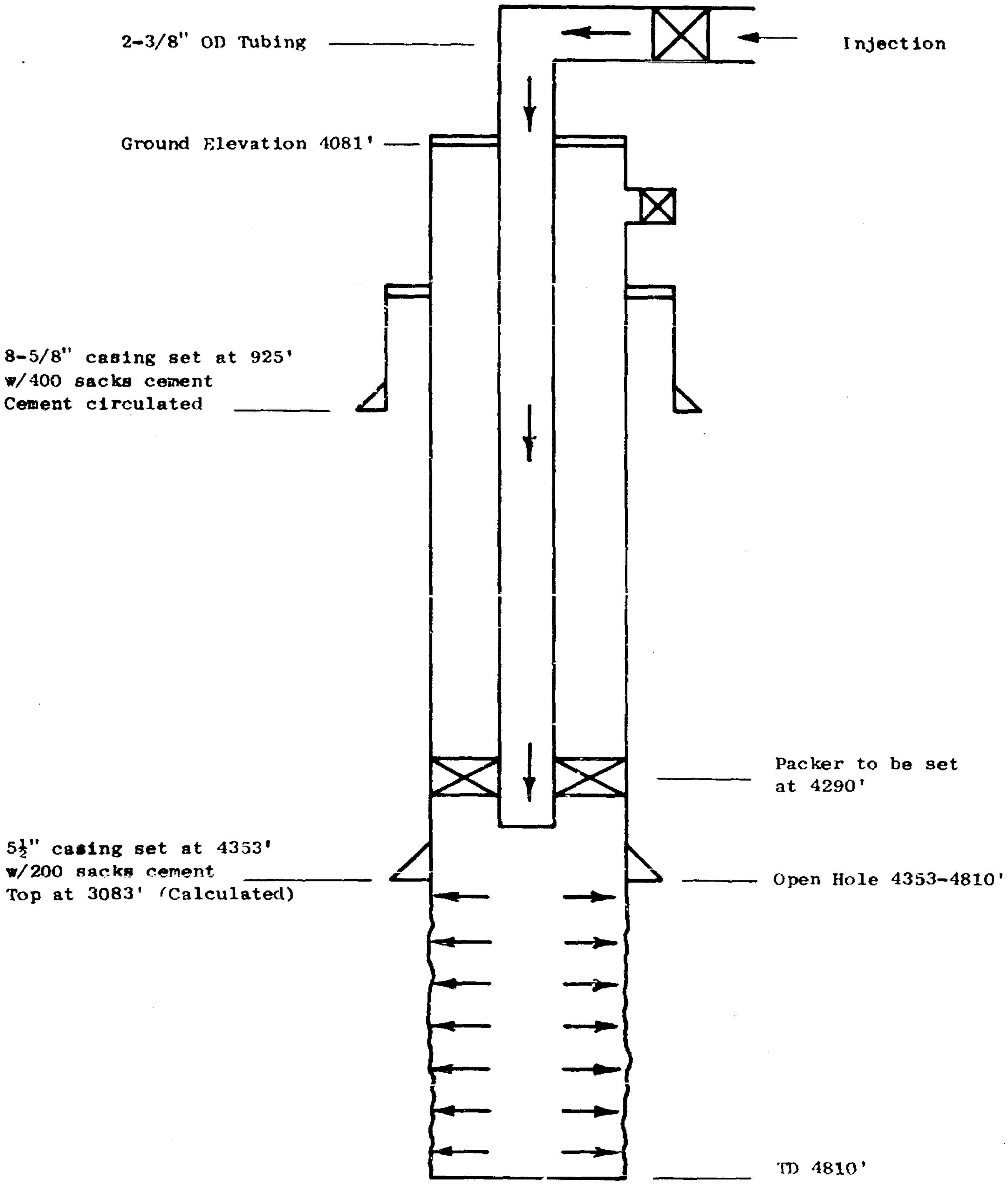


EXHIBIT NO. 3

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 2 (Sohio Hale-State No. 2)
990' FNL & 330' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All Measurements are from KB 2.5' above GL

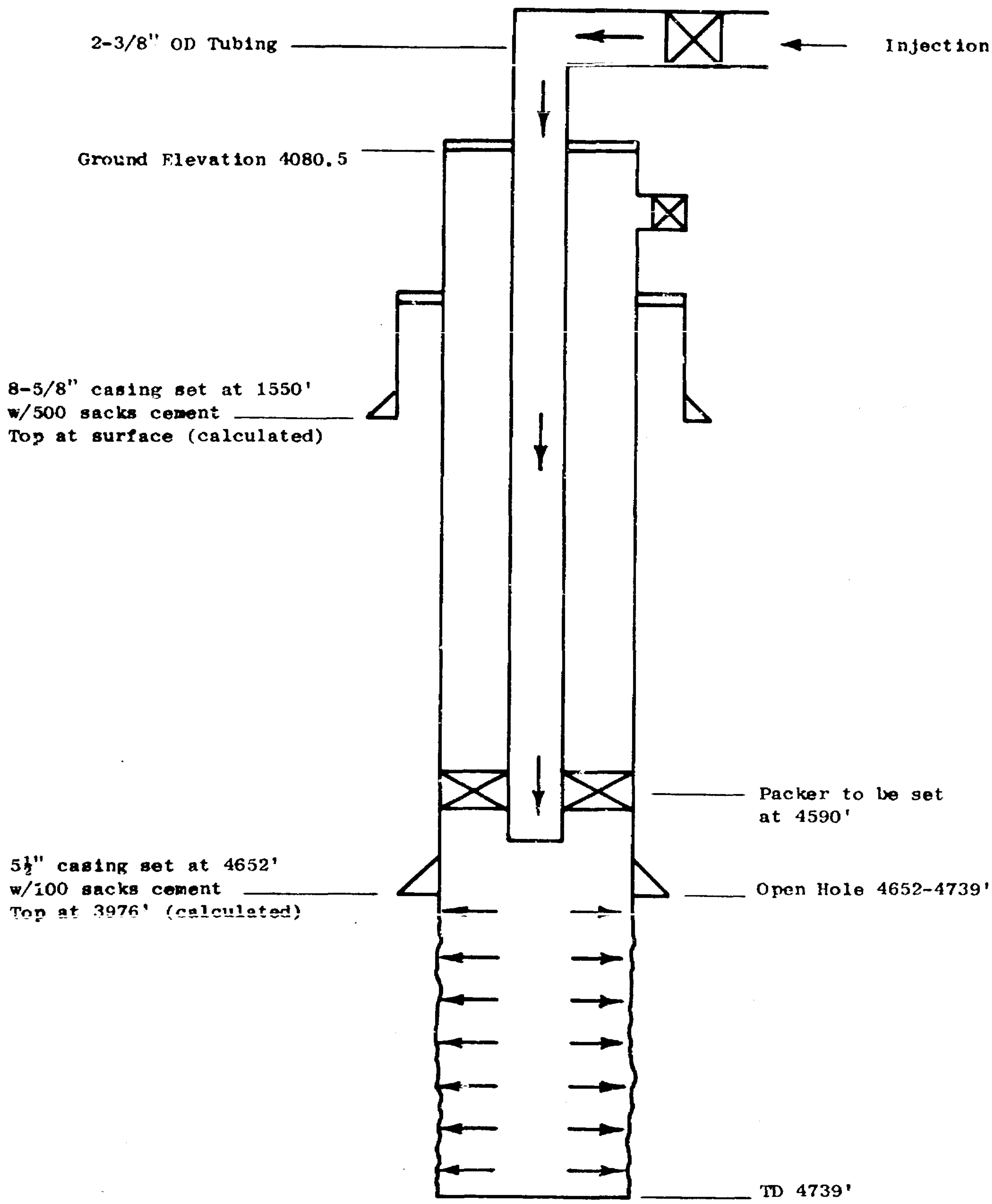


EXHIBIT NO. 5

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 4 (A.R.Co. State "B" TG No. 4)
990' FNL & 1650' FWL Section 32, T-17S R-34E
Lea County, New Mexico

All Measurements are from KB 2' above GL

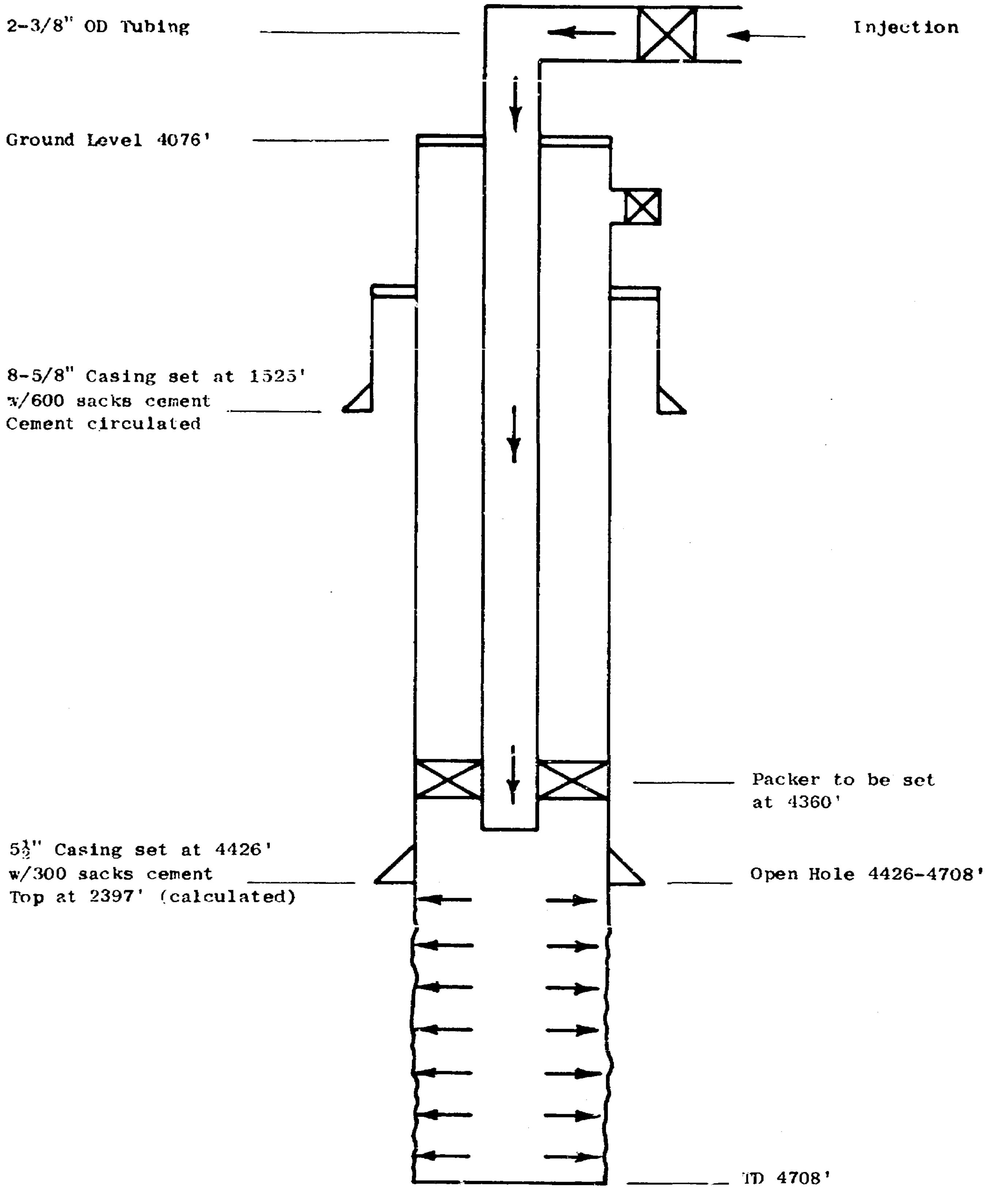


EXHIBIT NO. 7

REFERENCE No. A 400-A

LANE WELLS COMPANY — RADIOACTIVITY LOG

Location of Well

COMPANY: TEXAS-GULF PROD. CO.
WELL: STATE B NO. 3 [illegible]
FIELD: WEST VACUUM
COUNTY: LEA STATE: N.M.
LOCATION: [illegible] FSL [illegible] FWL
SEC [illegible]

[illegible]' DF

LOG MEASURED FROM ROTARY TABLE ELEVATION [illegible]
DRILLING MEASURED FROM ROTARY T. ELEVATION [illegible]
PERMANENT DATUM [illegible] ELEVATION [illegible]

COMPANY: TEXAS-GULF PROD. CO.
WELL: STATE B NO. 3 [illegible]
FIELD: WEST VACUUM
COUNTY: LEA STATE: N.M.
LOCATION

RUN NUMBER	1	1		
TYPE OF LOG	GAMMA RAY	NEUTRON		
DATE	[illegible]	APR. [illegible]		
COMPANY DEPTH [illegible]	[illegible]	4740'		
MAXIMUM DEPTH REACHED	[illegible]	[illegible]		
WELL FLUID	OIL	OIL		
FLUID LEVEL	FULL	FULL		
MAXIMUM TEMPERATURE				
O.D. OF INSTRUMENT—INCHES	[illegible]	[illegible]		
SENSITIVITY REFERENCE	[illegible]	[illegible]		
RECORDED BY	KELLY	KELLY		
WITNESSED BY	[illegible]	[illegible]		

CASING RECORD

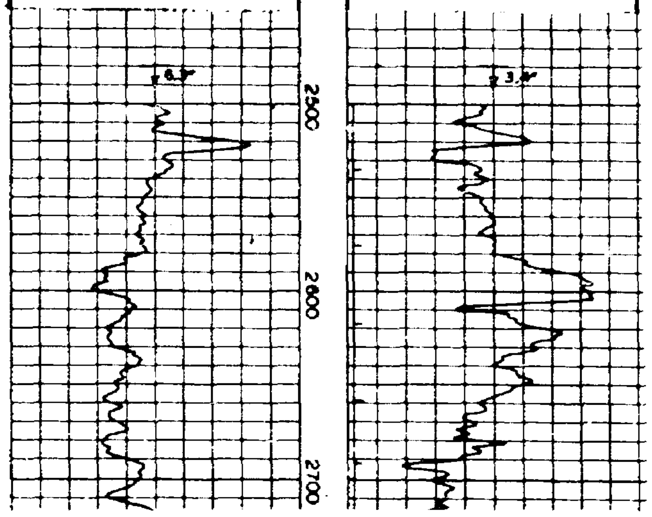
RUN NO.	SIZE—IN.	WT.—LB.	INTERVAL	
1	[illegible]	LINER	[illegible]	TO [illegible]
				TO
				TO
				TO
				TO

OPEN HOLE RECORD

BIT SIZE—IN.	INTERVAL	
[illegible]	[illegible]	TO T.D.
		TO
		TO
		TO
		TO

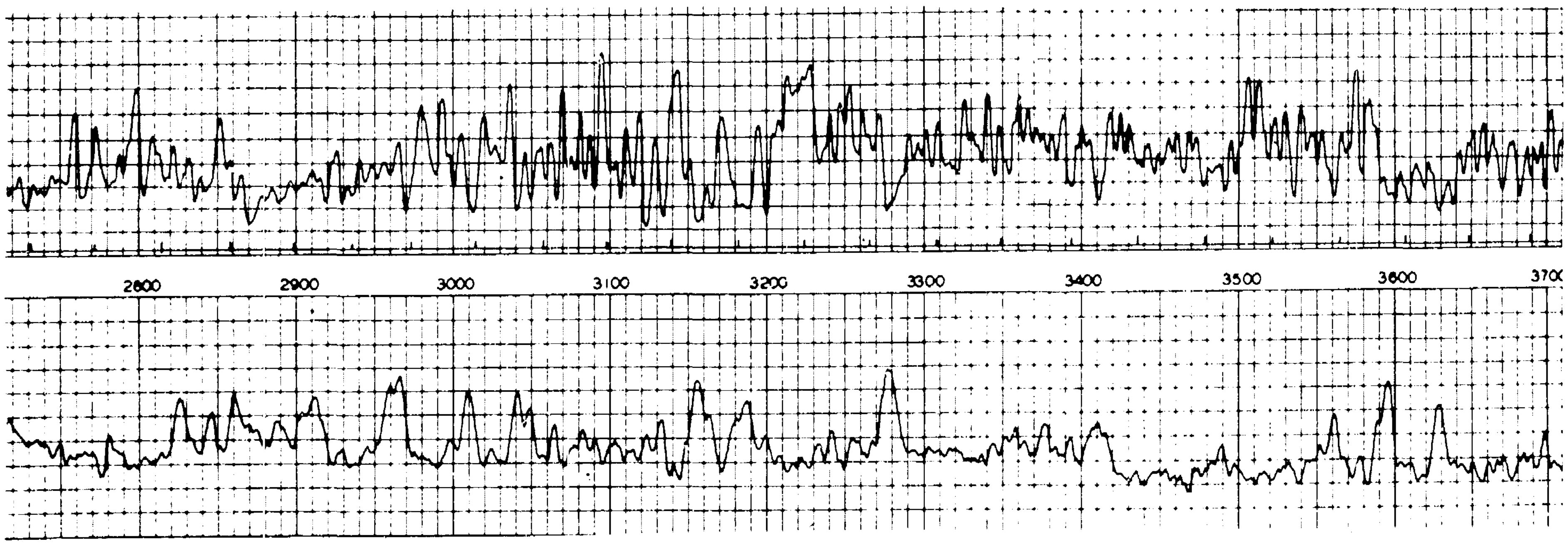
REMARKS OR OTHER DATA

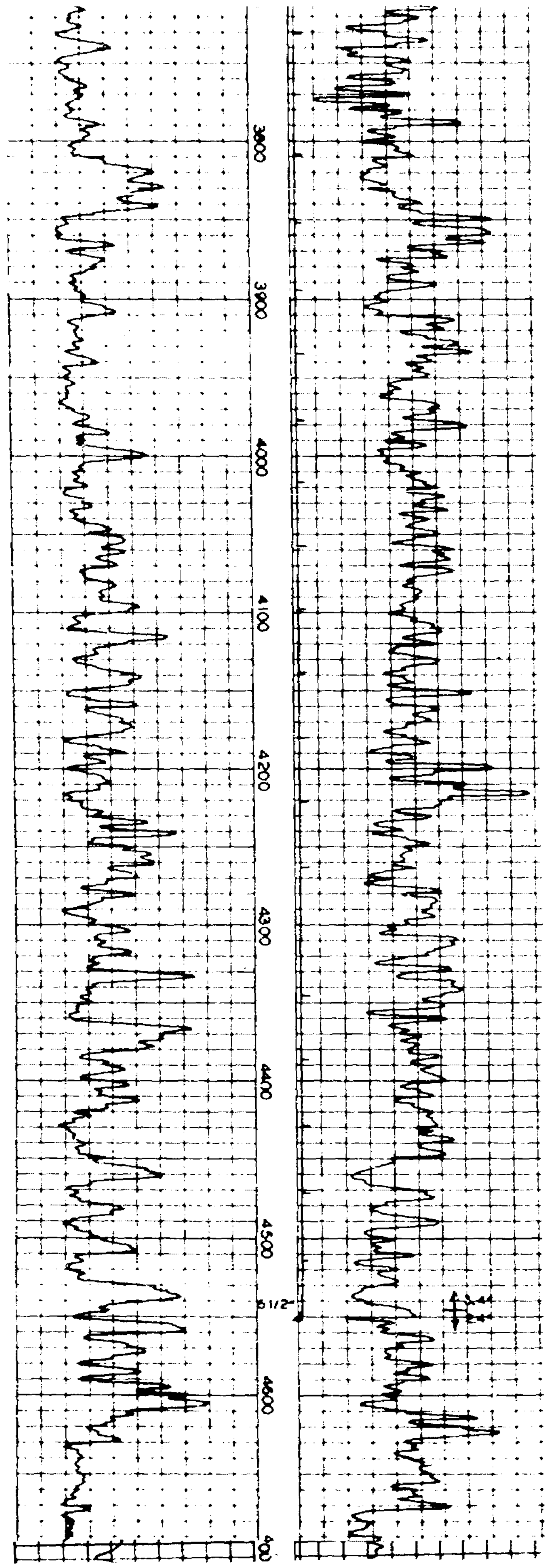
GAMMA RAY	CASING & COLLAR LOG DEPTH	NEUTRON
RADIATION INTENSITY INCREASES →		RADIATION INTENSITY INCREASES →



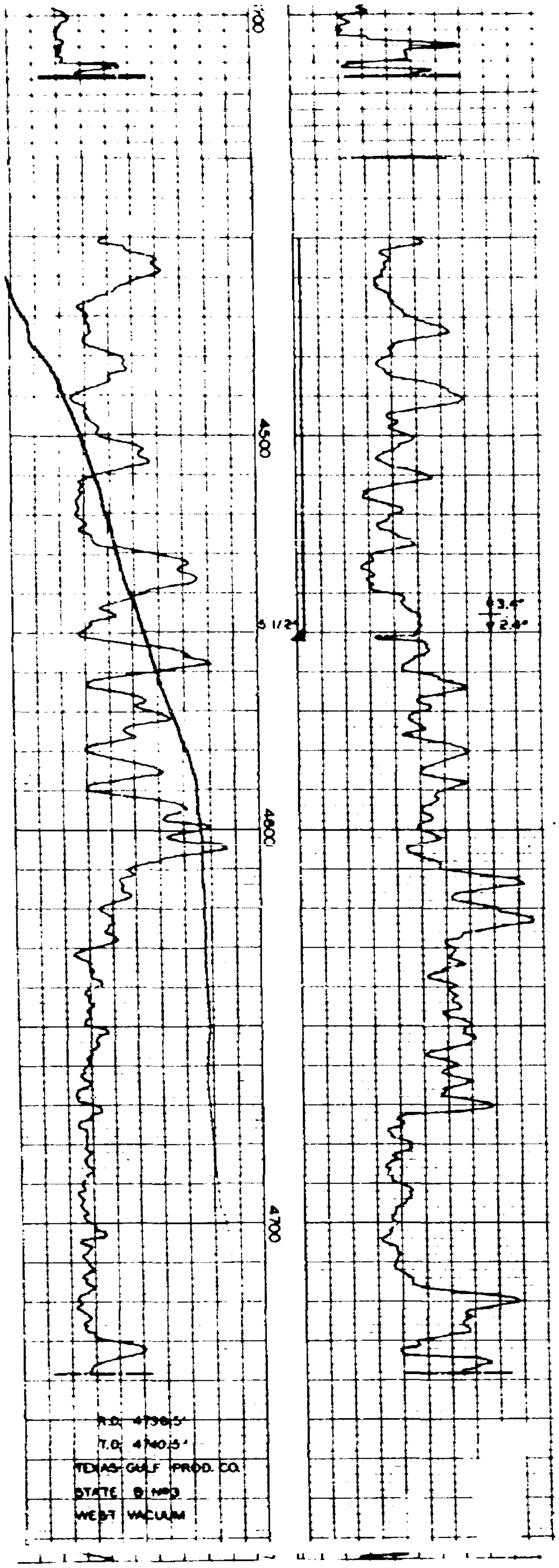
ATLANTIC RICHFIELD COMPANY
Unit Well No. 7 (A.R.Co. State "B" TG No. 3)
STATE VACUUM UNIT
Lea County, New Mexico

EXHIBIT NO. 8


2800
2900
3000
3100
3200
3300
3400
3500
3600
370



3800
3900
4000
4100
4200
4300
4400
4500
8 1/2
4600


4500
5 1/2"
3.4"
2.8"
4600
4700
T.D. 4740.5'
TEXAS GULF PROD. CO.
STATE
WEST VACUUM

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 7 (A.R.Co. State "B" TG No. 3)
1980' FNL & 660' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

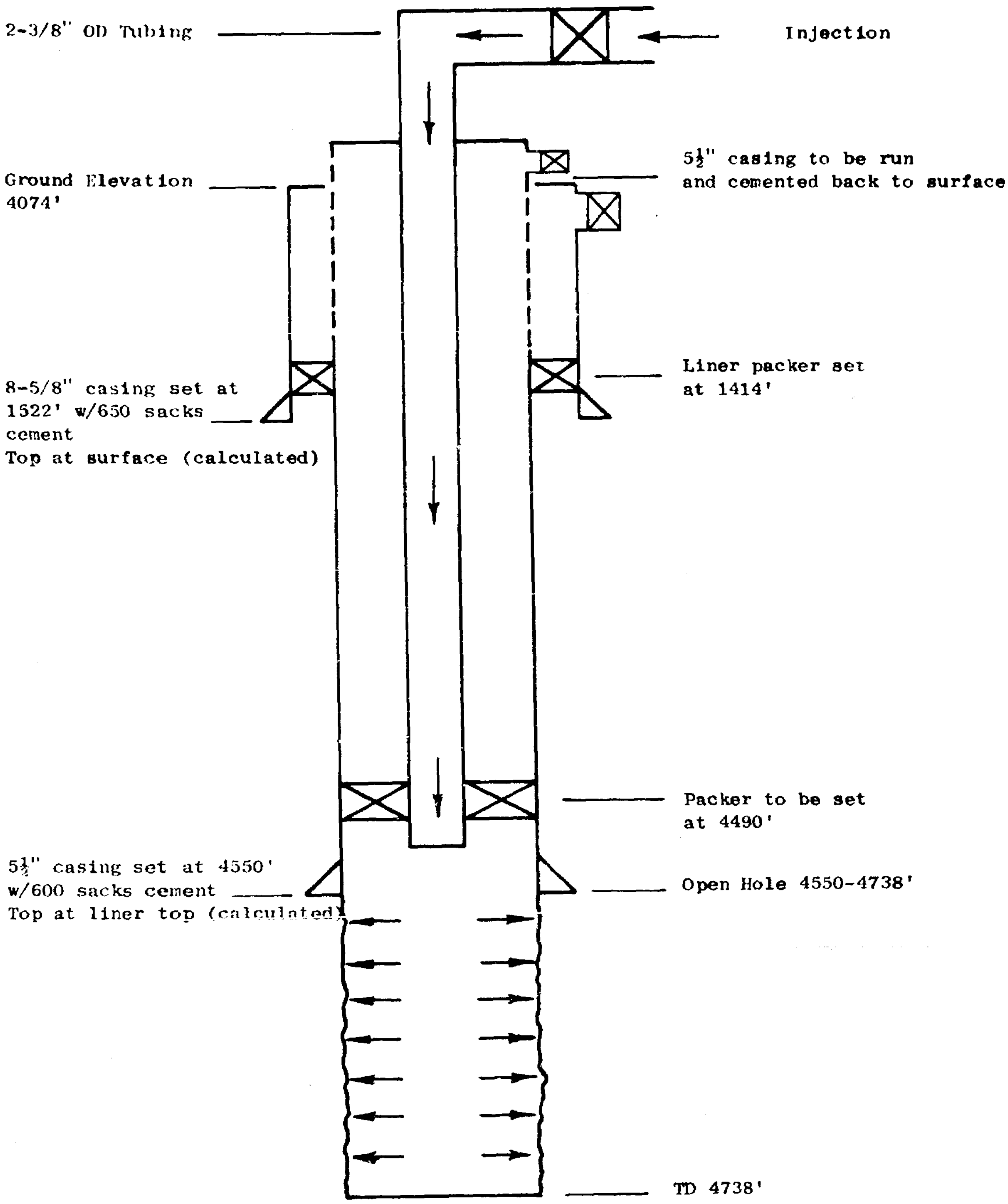


EXHIBIT NO. 9

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 9 (Texaco New Mexico "D" State NCT-2 No. 3)
1980' FNL & 1980' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 9' above GL

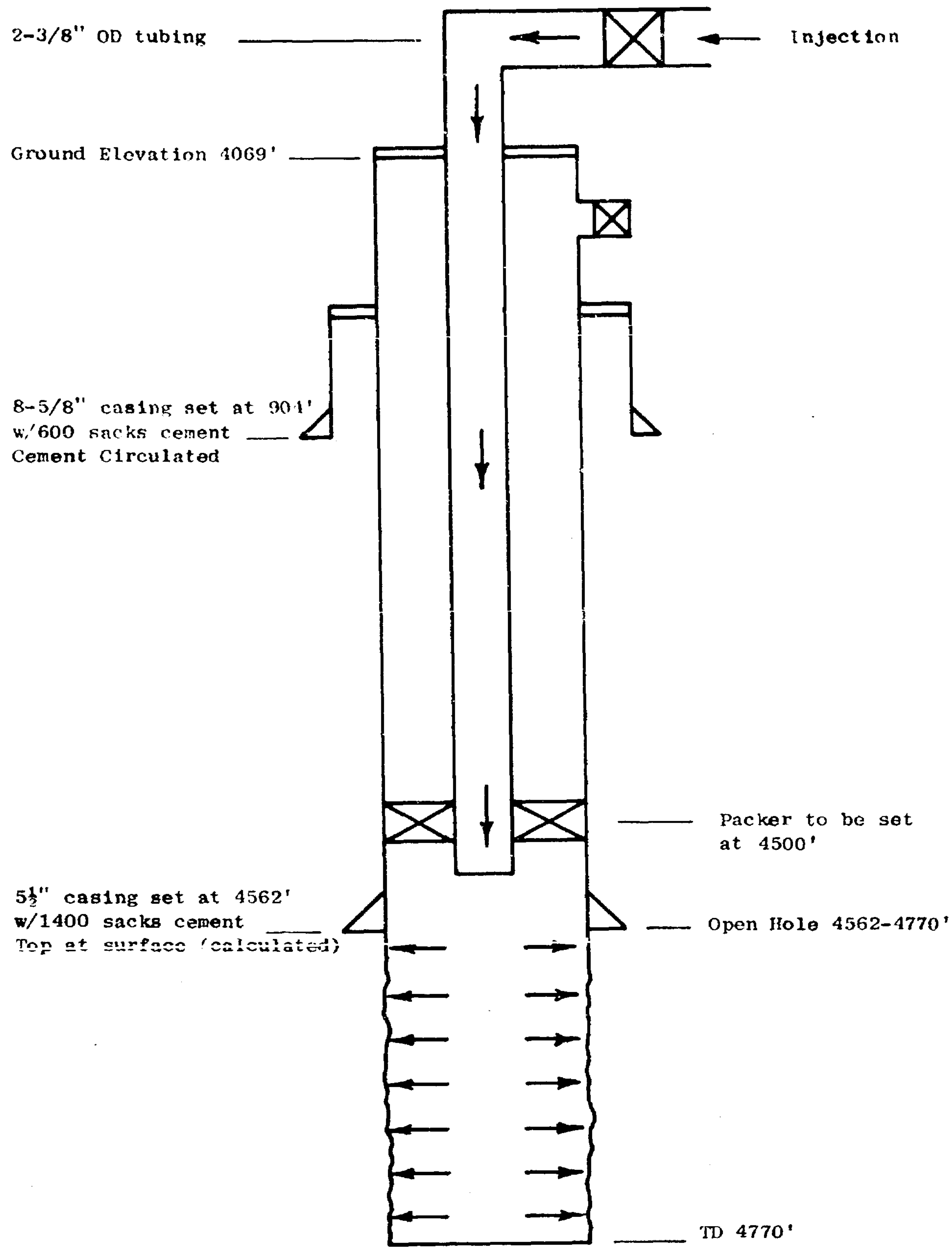


EXHIBIT NO. 11

Case 5262

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 11 (Texaco New Mexico "AO" State No. 1)
2310' FSL & 330' FEL Section 31, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

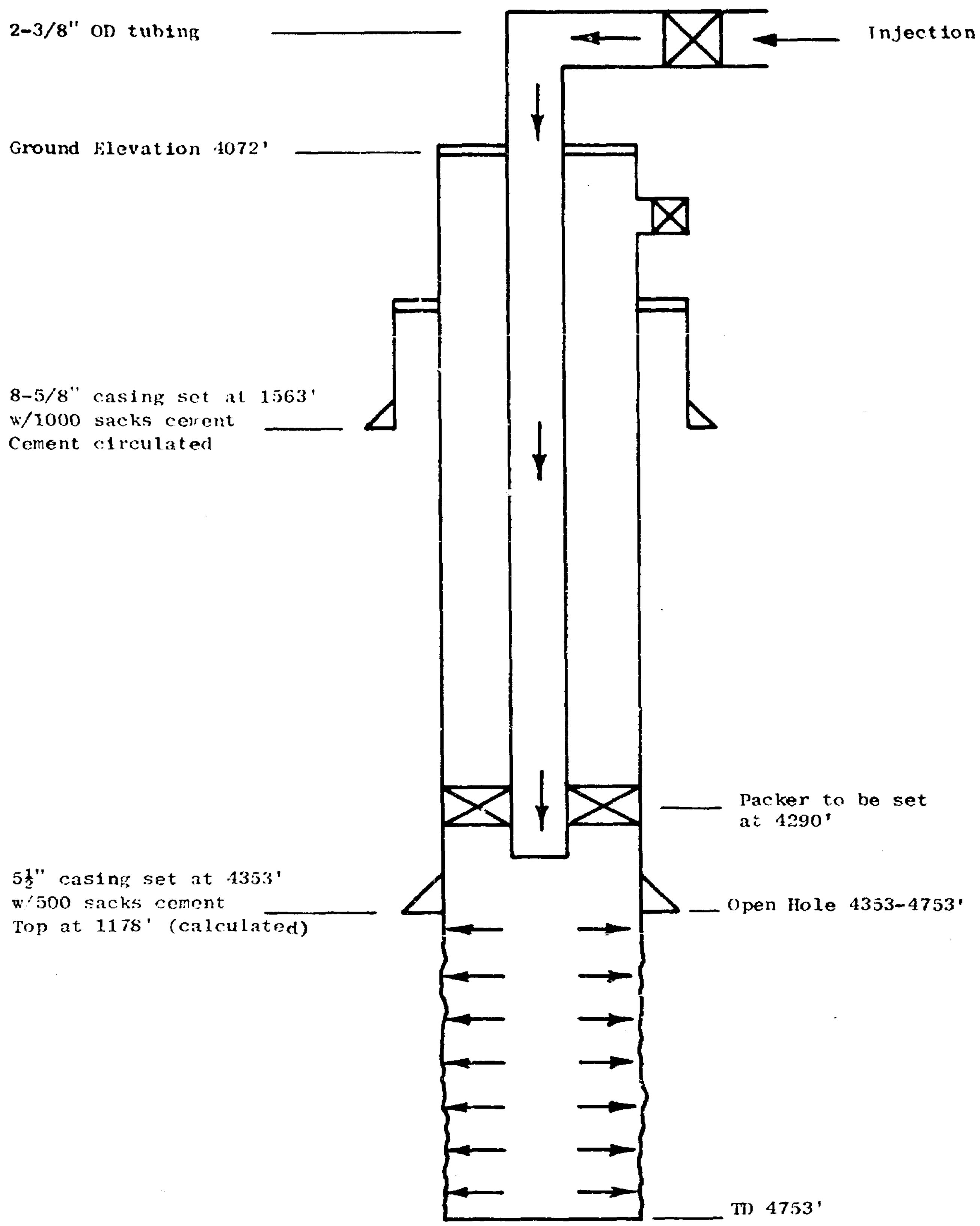


EXHIBIT NO. 13

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 13 (A.R.Co. State "C" TG No. 3)
1980' FSL & 1980' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10.5' above GL

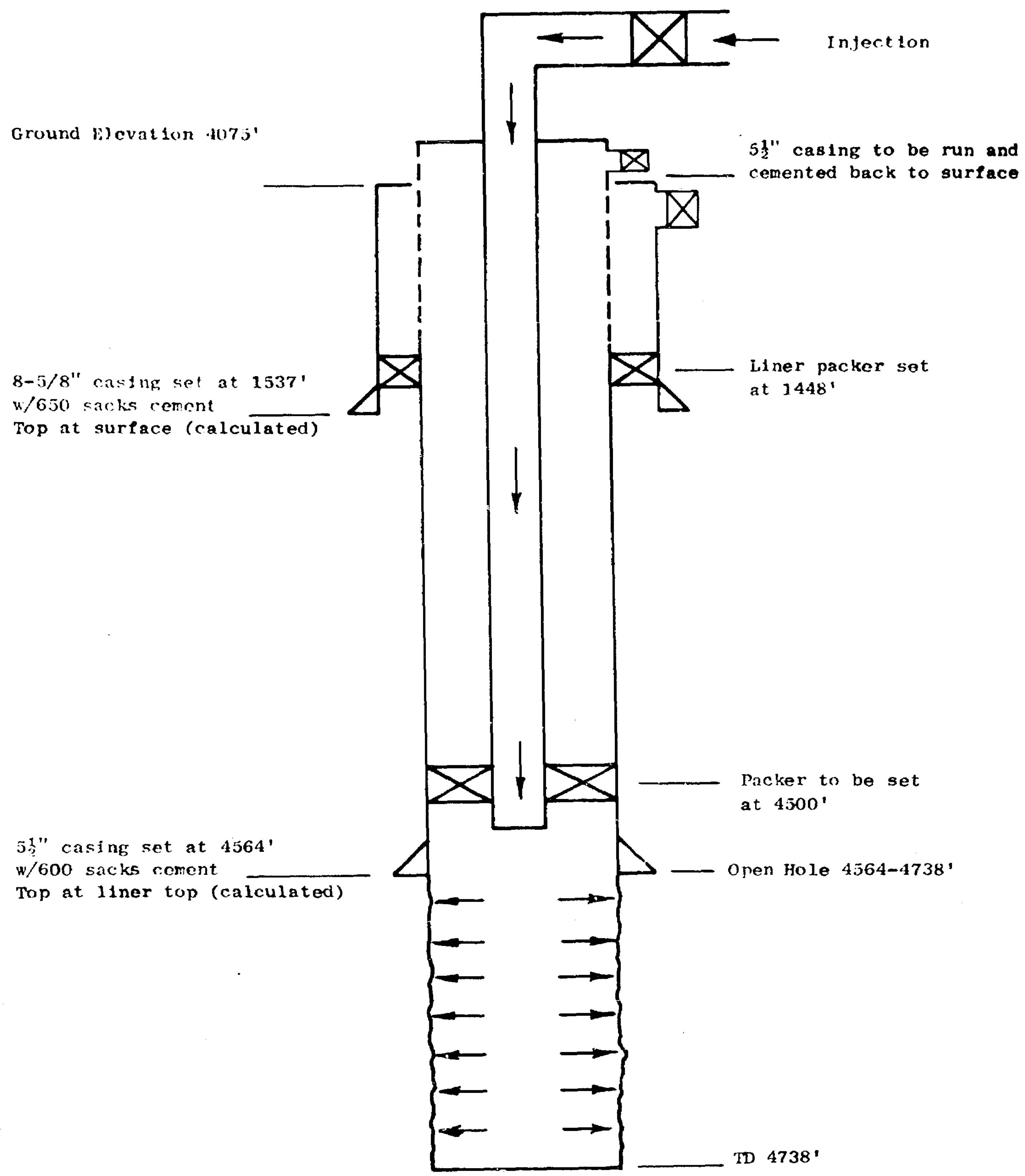


EXHIBIT NO. 15

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 15 (A.R.Co. State "C" TG No. 1)
1980' FSL & 660' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 10' above GL

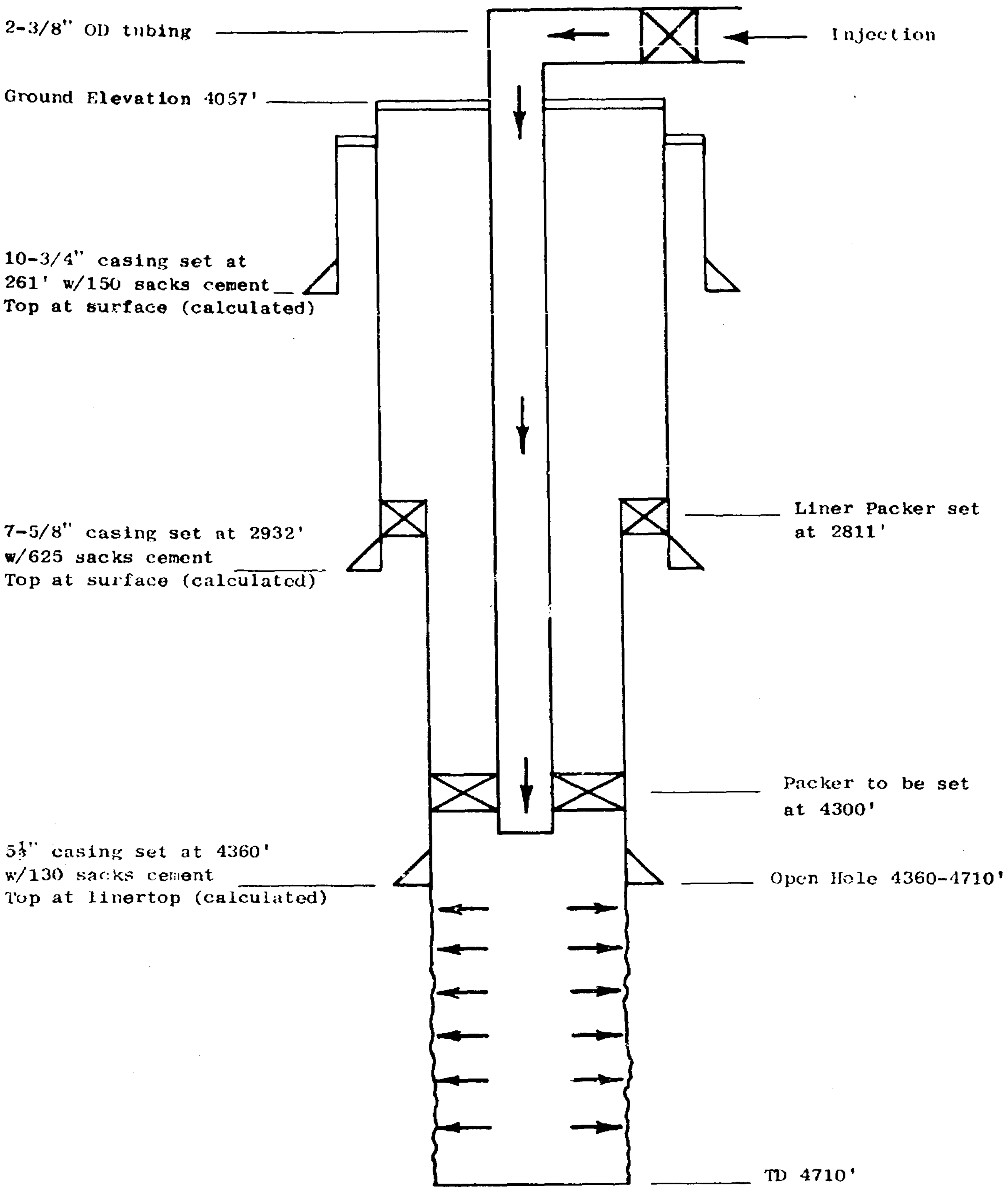


EXHIBIT NO. 17

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 17 (A.R.Co. State "C" TG No. 8)
990' FSL & 990' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 4' above GL

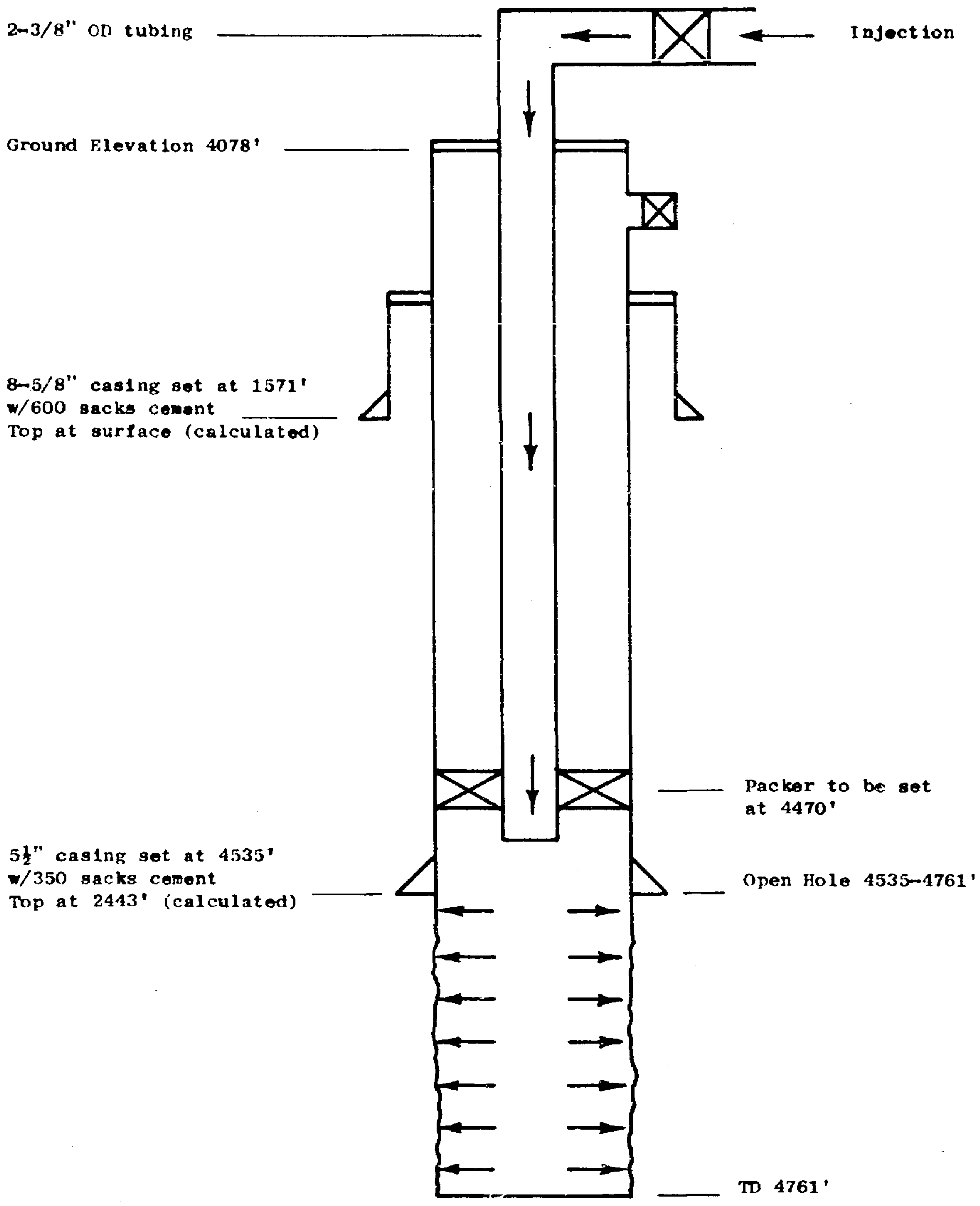


EXHIBIT NO. 19

Case 5762

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT
Schematic Drawing of Injection Well
Unit Well No. 19 (A.R.Co. State "C" TG No. 5)
990' FSL & 1650' FEL Section 32, T-17S, R-34E
Lea County, New Mexico

All measurements are from KB 2' above GL

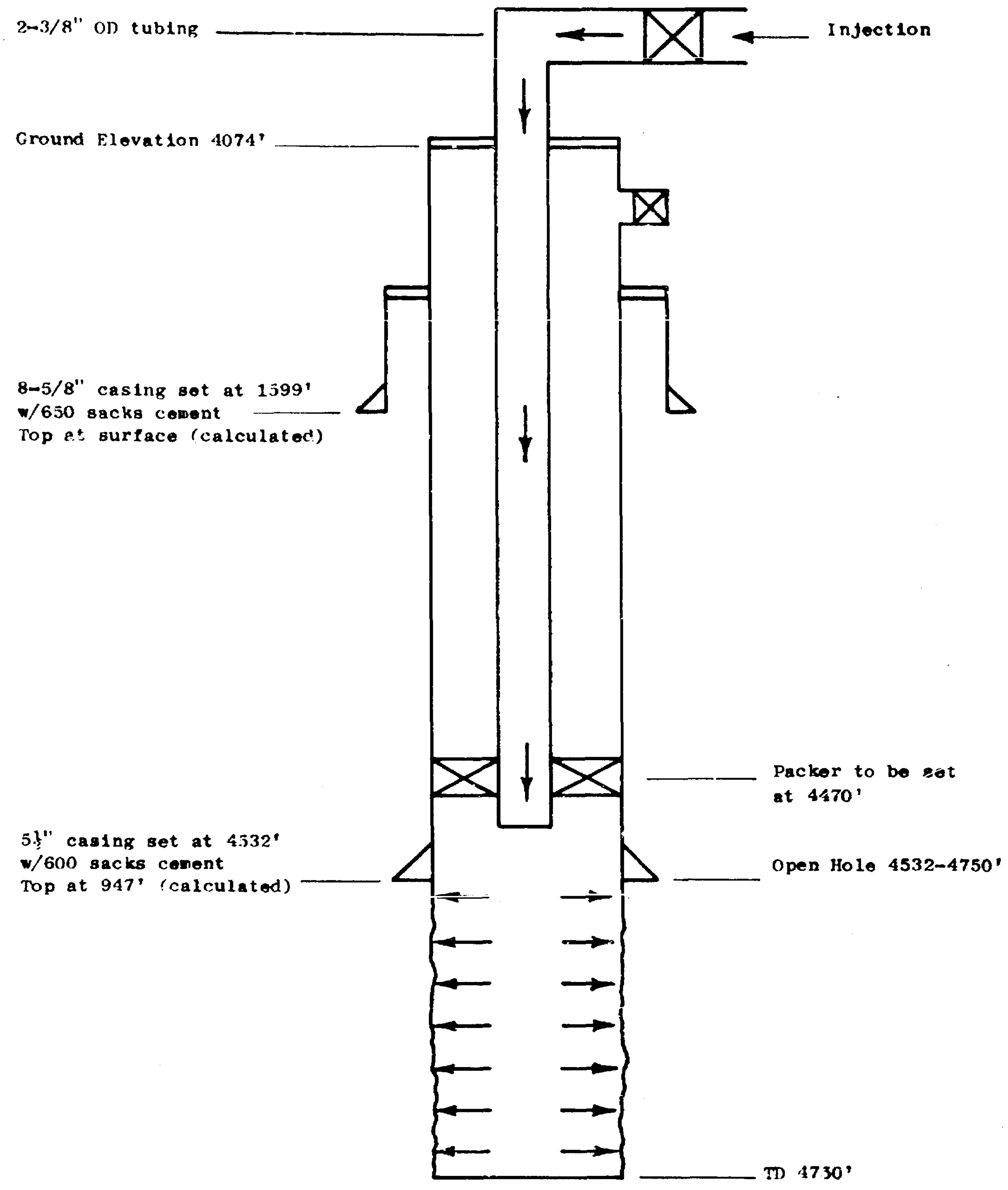


EXHIBIT NO. 21

Case 5762

ATLANTIC RICHFIELD COMPANY
STATE VACUUM UNIT NO. 21
Schematic Drawing of Injection Well
To be drilled approximately 330' FSL & 2310' FWL Section 32, T-17S, R-34E
Lea County, New Mexico

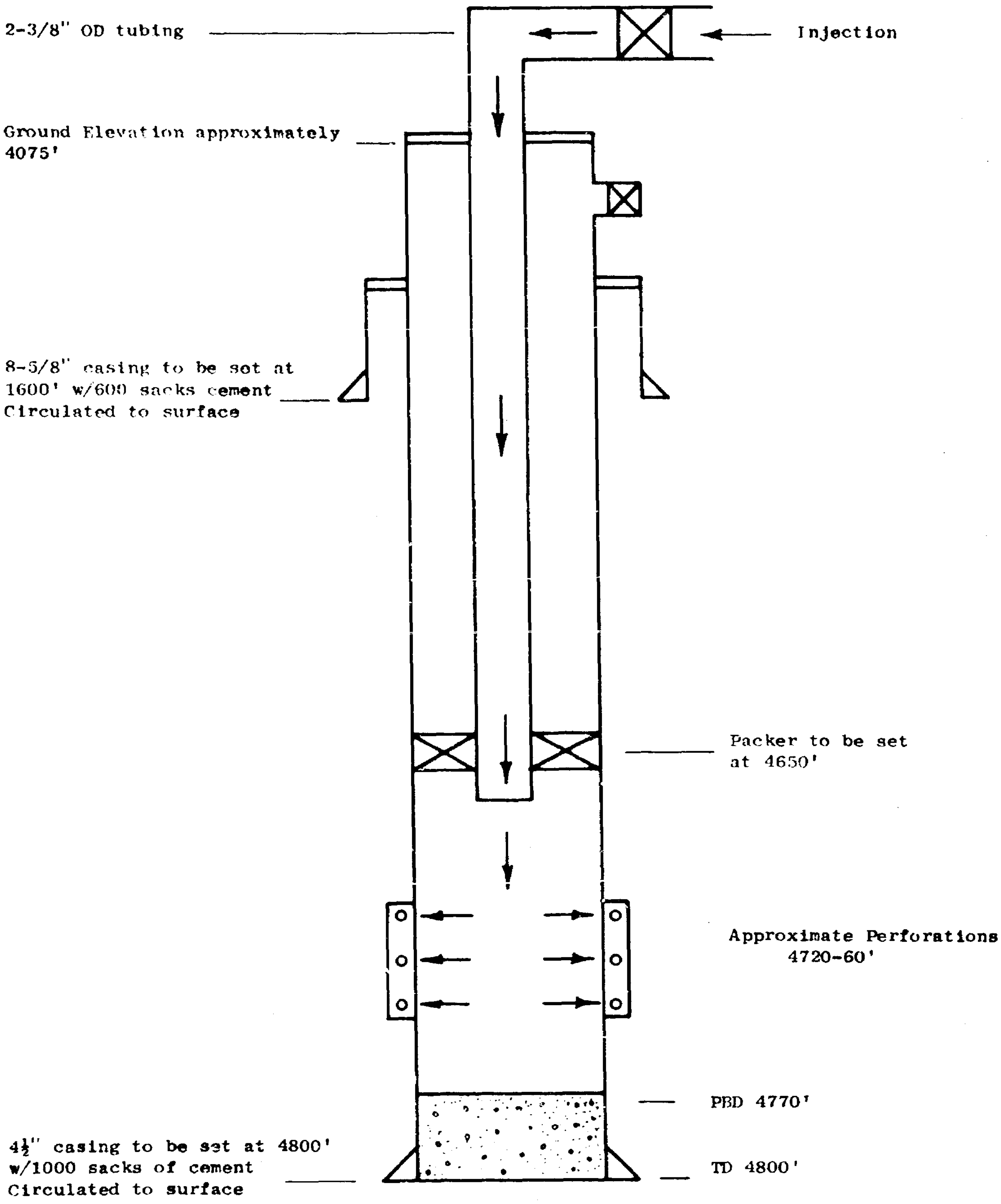


EXHIBIT NO. 22

Case 5762

LAW OFFICES
HINKLE, BONDURANT, COX & EATON
600 HINKLE BUILDING
POST OFFICE BOX 10
ROSWELL, NEW MEXICO 88201

CLARENCE E. HINKLE
W. E. BONDURANT, JR. (1914-1973)
LEWIS C. COX, JR.
PAUL W. EATON, JR.
CONRAD E. COFFIELD
HAROLD L. HENSLEY, JR.
STUART D. SHANOR
C. D. MARTIN
PAUL J. KELLY, JR.
JAMES H. BOZARTH
RONALD G. HARRIS
JAMES H. ISBELL
DOUGLAS L. LUNSFORD
PAUL M. BOHANNON

TELEPHONE (505) 622-6510

MR. ISBELL LICENSED IN TEXAS ONLY

MIDLAND, TEXAS OFFICE
521 MIDLAND TOWER
(915) 683-4691

August 12, 1976

Oil Conservation Commission
P.O. Box 2088
Santa Fe, New Mexico 87501

Gentlemen:

We enclose herewith in triplicate two applications by Atlantic Richfield, one for approval of the State Vacuum Unit Agreement embracing 800 acres of land of the State of New Mexico in Township 17 South, Range 34 East, Lea County, and the other for a waterflood project in connection with said unit.

We would like to have these applications set for hearing on the examiner's docket for September 15.

Yours very truly,

HINKLE, BONDURANT, COX & EATON

CDH:cs
Enc.
cc: Phillips Petroleum Company
cc: Texaco Inc.
cc: Sohio Petroleum Company

Case 5762

BEFORE THE OIL CONSERVATION COMMISSION

STATE OF NEW MEXICO

APPLICATION OF ATLANTIC RICHFIELD COMPANY FOR APPROVAL OF A WATERFLOOD PROJECT IN CONNECTION WITH THE PROPOSED UNIT AGREEMENT FOR THE OPERATION AND DEVELOPMENT OF THE STATE VACUUM UNIT AREA EMBRACING 800 ACRES OF LANDS OF THE STATE OF NEW MEXICO IN TOWNSHIP 17 SOUTH, RANGE 34 EAST, LEA COUNTY. APPLICANT PROPOSES TO INJECT WATER INTO THE GRAYBURG-SAN ANDRES FORMATION THROUGH 11 INJECTION WELLS. APPLICANT ALSO SEEKS ESTABLISHMENT OF A PROJECT ALLOWABLE AND AN ADMINISTRATIVE PROCEDURE WHEREBY THE LOCATION OF THE INJECTION WELLS MAY BE CHANGED.

Oil Conservation Commission
P.O. Box 2088
Santa Fe, New Mexico 87501

Comes now Atlantic Richfield Company, acting by and through the undersigned attorneys, and hereby makes application for approval of a water flood project in connection with the proposed Unit Agreement for the Operation and Development of the State Vacuum Unit Area embracing 800 acres of lands of the State of New Mexico in Township 17 South, Range 34 East, Lea County. Applicant proposes to inject water into the Grayburg-San Andres formation through 11 injection wells. Applicant also seeks establishment of a project allowable and an administrative procedure whereby the location of the injection wells may be changed. In support of this application, applicant respectfully shows:

1. Applicant is in the process of forming a unit agreement to be known as the State Vacuum Unit in which the Grayburg-San Andres formation will be unitized as to the following described lands in Lea County:

<u>Township 17 South, Range 34 East, N.M.P.M.</u>
Section 29 - SW¼SW¼
Section 31 - E½E½
Section 32 - W½, SE¼, NW¼NE¼, S½NE¼
containing 800 acres, more or less

Case 5762

2. It is contemplated that applicant will be the unit operator under the terms of the unit agreement and the primary objective of the unit will be to formulate and put into effect a secondary recovery project in order to effect additional recovery of unitized substances, prevent waste and conserve natural resources consistent with good engineering practices.

3. There is attached hereto as Exhibit No. 1 a plat showing the outlines of the proposed unit area, the location of all wells producing from the proposed unitized formation within the unit area and all other wells within a radius of two miles thereof and the formations from which the same are producing. This exhibit also indicates the ownership of the respective leases and the 11 proposed injection wells within the unit or project area.

4. There are filed herewith logs of the respective injection wells and also diagrammatic sketches of each injection well showing all casing strings including diameters and setting depths, quantities used and tops of cement and perforated intervals, tubing strings including diameters and setting depths, and the type and location of packers. There is attached as Exhibit "A" a list of the names and locations of the proposed injection wells. All of these wells except one are producing wells which will be converted to injection wells. It is proposed to drill one well for injection purposes, which will be located approximately 330 feet from the south line and 2,310 feet from the west line of Section 32, Township 17 South, Range 34 East. The proposed completion of this well is also shown by one of the diagrammatic sketches.

5. Applicant proposes to inject water into the unitized formation through the 11 injection wells referred to above. It is anticipated that the injection of water will be started in all the injection wells at approximately the same time and it is estimated that the initial rate of injection will be approximately 5,500 barrels per day. The water will be obtained from the City of Carlsbad water supply system which obtains water from the Ogalalla supply wells in Lea County. It is also anticipated that produced water from the project will be injected as it becomes available.

6. Applicant has made application for approval of the State Vacuum Unit Agreement above referred to.

7. Applicant also seeks the establishment of a project allowable in accordance with the provisions of Rule 701 of the Commission and also the establishment of an administrative procedure for any changes which may prove necessary in connection with the injection wells.

Case 5762

8. Applicant requests that this matter be heard before an examiner and included on the first available examiner's docket.

Respectfully submitted,

ATLANTIC RICHFIELD COMPANY

By ______________________
HINKLE, BONDURANT, COX & EATON
P.O. Box 10
Roswell, New Mexico 88201
Attorneys for Applicant

Case 5762

EXHIBIT "A"

Unit Well No. 1 (Phillips Lea No. 21) - 660' FSL and 680' FWL Section 29, T. 17 S., R. 34 E.

Unit Well No. 2 (Sohio Hale-State No. 2) - 990' FNL and 330' FEL Section 31, T. 17 S., R. 34 E.

Unit Well No. 4 (A.R.Co. State "B" TG No. 4) - 990' FNL and 1650' FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 7 (A.R.Co. State "B" TG No. 3) - 1980' FNL and 660' FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 9 (Texaco New Mexico "D" State NCT-2 No. 3)- 1980' FNL and 1980' FEL Section 32, T. 17 S., R. 34 E.

Unit Well No. 11 (Texaco New Mexico "AO" State No. 1 - 2310' FSL and 330' FEL Section 31, T. 17 S., R. 34 E.

Unit Well No. le (A.R. Co. State "C" TG No. 3) - 1980' FSL and 1980 FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 15 (A.R. Co. State "C" TG No. 1) - 1980 FSL and 660' FEL Section 32, T. 17 S., R. 34 E.

Unit Well No. 17 (A. R. Co. State "C" TG No. 8) - 990' FSL and 990' FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 19 (A.R.Co. State "C" TG No. 5)- 990' FSL and 1650' FEL Section 32, T. 17 S., R. 34 E.

dr/

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE NO. 5762

Order No. R-5295

APPLICATION OF ATLANTIC RICHFIELD COMPANY
FOR A WATERFLOOD PROJECT, LEA
COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 a.m. on September 15, 19 76, at Santa Fe, New Mexico, before Examiner Richard L. Stamets.

NOW, on this ______ day of September, 19 76, the Commission, a quorum being present, having considered the testimony, the record, and the recommendations of the Examiner, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That the applicant, Atlantic Richfield Company, seeks authority to institute a waterflood project on its State Vacuum Unit ~~Lease~~, Vacuum Pool, by the injection of water into the Grayburg-San Andres formation through 11 injection wells located in Unit M of Section 29, and Units C, E, G, I, K, M, N, and O of Section 32, all in Township 17 South, Range 34 East, NMPM, Lea County, New Mexico.

(3) That the wells in the project area are in an advanced state of depletion and should properly be classified as "stripper" wells.

(4) That the proposed waterflood project should result in the recovery of otherwise unrecoverable oil, thereby preventing waste.

(5) That the Cole Darden Oil Company Hale State Well No. 1 in Unit A, Section 31, Township 17 South, Range 34 East, NMPM, Lea County, New Mexico, was not plugged and abandoned in such a manner as to assure that water injected through said State Vacuum Unit injection wells will not migrate from Grayburg-San Andres formation to to other formations or the surface.

(6) That injection pressure around said Cole Darden Oil Company Hale State Well No. 1 should be limited to prevent such migration.

(7) That the operator should take all steps necessary to ensure that the injected water enters only the proposed injection interval and is not permitted to escape to other formations or onto the surface from injection, production, or plugged and abandoned wells.

(8) That the subject application should be approved and the project should be governed by the provisions of Rules 701, 702, and 703 of the Commission Rules and Regulations.

IT IS THEREFORE ORDERED:

(1) That the applicant, Atlantic Richfield Company, is hereby authorized to institute a waterflood project on its State Vacuum Unit, Vacuum Pool, by the injection of water into the Grayburg-San Andres formation through the following-described wells in Township 17 South, Range 34 East, NMPM, Lea County, New Mexico:

State Vacuum Unit Well No.	Unit	Section	Township	Range
1	M	29	17S	34E
2	A	31	17S	34E
4	C	32	17S	34E
7	E	32	17S	34E
9	G	32	17S	34E
11	I	31	17S	34E
13	K	32	17S	34E
15	I	32	17S	34E
17	M	32	17S	34E
19	O	32	17S	34E
21	N	32	17S	34E

(2) That injection into each of said wells should be through internally coated tubing, set in a packer which shall be located as near as practicable to the uppermost perforation, or in the case of open-hole completion, to the casing shoe; that the casing-tubing annulus of each injection well shall be tested for leaks, be loaded with an inert fluid and equipped with an approved pressure gauge or attention-attracting leak detection device and that the injection wells or system shall be equipped in such a manner as to limit wellhead pressure to no more than 860 psi.

(3) That the Secretary-Director of the Commission may administratively authorize a pressure limitation in excess of 860 psi upon a showing by the operator that such higher pressure will not result in fracturing of the confining strata.

(4) That there shall be no injection under pressure ~~through wells on any 40-acre unit with or immediately or directly off-setting~~ the Cole Darden Oil Company Hale State Well No. 1 in Unit A of Section 31, Township 17 South, Range 32 East, NMPM, Lea County, New Mexico, until said well is reentered and replugged in accordance with a new Commission approved plugging program or said well is equipped in such a manner as to monitor for leaks below the salt section.

(5) That the operator shall immediately notify the supervisor of the Commission's Hobbs district office of the failure of the tubing or packer in any of said injection wells, the leakage of water or oil from around any producing well, or the leakage of water or oil from any plugged and abandoned well within the project area and shall take such timely steps as may be necessary or required to correct such failure or leakage.

(6) That the subject waterflood project is hereby designated the ARCO State Vacuum Unit Waterflood Project and shall be governed by the provisions of Rules 701, 702, and 703 of the Commission Rules and Regulations.

(7) That monthly progress reports of the waterflood project herein authorized shall be submitted to the Commission in accordance with Rules 704 and 1120 of the Commission Rules and Regulations.

(8) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

Case 5762

BEFORE THE OIL CONSERVATION COMMISSION

STATE OF NEW MEXICO

APPLICATION OF ATLANTIC RICHFIELD COMPANY FOR APPROVAL OF A WATERFLOOD PROJECT IN CONNECTION WITH THE PROPOSED UNIT AGREEMENT FOR THE OPERATION AND DEVELOPMENT OF THE STATE VACUUM UNIT AREA EMBRACING 800 ACRES OF LANDS OF THE STATE OF NEW MEXICO IN TOWNSHIP 17 SOUTH, RANGE 34 EAST, LEA COUNTY. APPLICANT PROPOSES TO INJECT WATER INTO THE GRAYBURG-SAN ANDRES FORMATION THROUGH 11 INJECTION WELLS. APPLICANT ALSO SEEKS ESTABLISHMENT OF A PROJECT ALLOWABLE AND AN ADMINISTRATIVE PROCEDURE WHEREBY THE LOCATION OF THE INJECTION WELLS MAY BE CHANGED.

Oil Conservation Commission
P.O. Box 2088
Santa Fe, New Mexico 87501

Comes now Atlantic Richfield Company, acting by and through the undersigned attorneys, and hereby makes application for approval of a water flood project in connection with the proposed Unit Agreement for the Operation and Development of the State Vacuum Unit Area embracing 800 acres of lands of the State of New Mexico in Township 17 South, Range 34 East, Lea County. Applicant proposes to inject water into the Grayburg-San Andres formation through 11 injection wells. Applicant also seeks establishment of a project allowable and an administrative procedure whereby the location of the injection wells may be changed. In support of this application, applicant respectfully shows:

1. Applicant is in the process of forming a unit agreement to be known as the State Vacuum Unit in which the Grayburg-San Andres formation will be unitized as to the following described lands in Lea County:

<u>Township 17 South, Range 34 East, N.M.P.M.</u>
Section 29 - SW¼SW¼
Section 31 - E½E½
Section 32 - W½, SE¼, NW¼NE¼, S½NE¼
containing 800 acres, more or less

Case 5762

2. It is contemplated that applicant will be the unit operator under the terms of the unit agreement and the primary objective of the unit will be to formulate and put into effect a secondary recovery project in order to effect additional recovery of unitized substances, prevent waste and conserve natural resources consistent with good engineering practices.

3. There is attached hereto as Exhibit No. 1 a plat showing the outlines of the proposed unit area, the location of all wells producing from the proposed unitized formation within the unit area and all other wells within a radius of two miles thereof and the formations from which the same are producing. This exhibit also indicates the ownership of the respective leases and the 11 proposed injection wells within the unit or project area.

4. There are filed herewith logs of the respective injection wells and also diagrammatic sketches of each injection well showing all casing strings including diameters and setting depths, quantities used and tops of cement and perforated intervals, tubing strings including diameters and setting depths, and the type and location of packers. There is attached as Exhibit "A" a list of the names and locations of the proposed injection wells. All of these wells except one are producing wells which will be converted to injection wells. It is proposed to drill one well for injection purposes, which will be located approximately 330 feet from the south line and 2,310 feet from the west line of Section 32, Township 17 South, Range 34 East. The proposed completion of this well is also shown by one of the diagrammatic sketches.

5. Applicant proposes to inject water into the unitized formation through the 11 injection wells referred to above. It is anticipated that the injection of water will be started in all the injection wells at approximately the same time and it is estimated that the initial rate of injection will be approximately 5,500 barrels per day. The water will be obtained from the City of Carlsbad water supply system which obtains water from the Ogalalla supply wells in Lea County. It is also anticipated that produced water from the project will be injected as it becomes available.

6. Applicant has made application for approval of the State Vacuum Unit Agreement above referred to.

7. Applicant also seeks the establishment of a project allowable in accordance with the provisions of Rule 701 of the Commission and also the establishment of an administrative procedure for any changes which may prove necessary in connection with the injection wells.

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8. Applicant requests that this matter be heard before an examiner and included on the first available examiner's docket.

Respectfully submitted,

ATLANTIC RICHFIELD COMPANY

By ____________________

HINKLE, BONDURANT, COX & EATON
P.O. Box 10
Roswell, New Mexico 88201
Attorneys for Applicant

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EXHIBIT "A"

Unit Well No. 1 (Phillips Lea No. 21) - 660' FSL and 680' FWL Section 29, T. 17 S., R. 34 E.

Unit Well No. 2 (Sohio Hale-State No. 2) - 990' FNL and 330' FEL Section 31, T. 17 S., R. 34 E.

Unit Well No. 4 (A.R.Co. State "B" TG No. 4) - 990' FNL and 1650' FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 7 (A.R.Co. State "B" TG No. 3) - 1980' FNL and 660' FWL Section 32, T, 17 S., R. 34 E.

Unit Well No. 9 (Texaco New Mexico "D" State NCT-2 No. 3)- 1980' FNL and 1980' FEL Section 32, T. 17 S., R. 34 E.

Unit Well No. 11 (Texaco New Mexico "AO" State No. 1 - 2310' FSL and 330' FEL Section 31, T. 17 S., R. 34 E.

Unit Well No. 1e (A.R. Co. State "C" TG No. 3) - 1980' FSL and 1980 FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 15 (A.R. Co. State "C" TG No. 1) - 1980 FSL and 660' FEL Section 32, T. 17 S., R. 34 E.

Unit Well No. 17 (A. R. Co. State "C" TG No. 8) - 990' FSL and 990' FWL Section 32, T. 17 S., R. 34 E.

Unit Well No. 19 (A.R.Co. State "C" TG No. 5)- 990' FSL and 1650' FEL Section 32, T. 17 S., R. 34 E.

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING
CALLED BY THE OIL CONSERVATION
COMMISSION OF NEW MEXICO FOR
THE PURPOSE OF CONSIDERING:

CASE NO. 5762
Order No. R-5295

APPLICATION OF ATLANTIC RICHFIELD
COMPANY FOR A WATERFLOOD PROJECT,
LEA COUNTY, NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 a.m. on September 15, 1976, at Santa Fe, New Mexico, before Examiner Richard L. Stamets.

NOW, on this 12th day of October, 1976, the Commission, a quorum being present, having considered the testimony, the record, and the recommendations of the Examiner, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That the applicant, Atlantic Richfield Company, seeks authority to institute a waterflood project on its State Vacuum Unit, Vacuum Pool, by the injection of water into the Grayburg-San Andres formation through 11 injection wells located in Unit M of Section 29, Units A and I of Section 31 and Units C, E, G, I, K, M, N, and O of Section 32, all in Township 17 South, Range 34 East, NMPM, Lea County, New Mexico.

(3) That the wells in the project area are in an advanced state of depletion and should properly be classified as "stripper" wells.

(4) That the proposed waterflood project should result in the recovery of otherwise unrecoverable oil, thereby preventing waste.

(5) That the Cole Darden Oil Company Hale State Well No. 1 in Unit A, Section 31, Township 17 South, Range 34 East, NMPM, Lea County, New Mexico, was not plugged and abandoned in a manner such as to assure that water injected through said State Vacuum Unit injection wells will not migrate from the Grayburg-San Andres formation to other formations or the surface.

(6) That injection pressure around said Cole Darden Oil Company Hale State Well No. 1 should be limited to prevent such migration.

(7) That the operator should take all steps necessary to ensure that the injected water enters only the proposed injection interval and is not permitted to escape to other formations or onto the surface from injection, production, or plugged and abandoned wells.

(8) That the subject application should be approved and the project should be governed by the provisions of Rules 701, 702, and 703 of the Commission Rules and Regulations.

IT IS THEREFORE ORDERED:

(1) That the applicant, Atlantic Richfield Company, is hereby authorized to institute a waterflood project on its State Vacuum Unit, Vacuum Pool, by the injection of water into the Grayburg-San Andres formation through the following-described wells in Township 17 South, Range 34 East, NMPM, Lea County, New Mexico:

State Vacuum Unit Well No.	Unit	Section	Township	Range
1	M	29	17S	34E
2	A	31	17S	34E
4	C	32	17S	34E
7	E	32	17S	34E
9	G	32	17S	34E
11	I	31	17S	34E
13	K	32	17S	34E
15	I	32	17S	34E
17	M	32	17S	34E
19	O	32	17S	34E
21	N	32	17S	34E

(2) That injection into each of said wells should be through internally coated tubing, set in a packer which shall be located as near as practicable to the uppermost perforation, or in the case of an open-hole completion, to the casing shoe; that the casing-tubing annulus of each injection well shall be tested for leaks, be loaded with an inert fluid and equipped with an approved pressure gauge or attention-attracting leak detection device, and that the injection wells or system shall be equipped in such a manner as to limit wellhead pressure to no more than 860 psi.

(3) That the Secretary-Director of the Commission may administratively authorize a pressure limitation in excess of 860 psi upon a showing by the operator that such higher pressure will not result in fracturing of the confining strata.

(4) That there shall be no injection under pressure into the Cole Darden Oil Company Hale State Well No. 1 in Unit A of Section 31, Township 17 South, Range 32 East, NMPM, Lea County, New Mexico, or into any well on said 40-acre tract or any 40-acre tract directly or diagonally offsetting said well, until said well has been reentered and replugged in accordance with a Commission approved plugging program or said well has been equipped in such a manner as to monitor for leaks below the salt section.

(5) That the operator shall immediately notify the supervisor of the Commission's Hobbs district office of the failure of the tubing or packer in any of said injection wells, the leakage of water or oil from around any producing well, or the leakage of water or oil from any plugged and abandoned well within the project area and shall take such timely steps as may be necessary or required to correct such failure or leakage.

(6) That the subject waterflood project is hereby designated the ARCO State Vacuum Unit Waterflood Project and shall be governed by the provisions of Rules 701, 702, and 703 of the Commission Rules and Regulations.

(7) That monthly progress reports of the waterflood project herein authorized shall be submitted to the Commission in accordance with Rules 704 and 1120 of the Commission Rules and Regulations.

(8) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

PHIL R. LUCERO, Chairman

EMERY C. ARNOLD, Member

JOE D. RAMEY, Member & Secretary

S E A L

jr/