INJECTIVITY/FALL-OFF TEST REPORT

#16635
Copy 2 of 2

HOME PIERSON 16-05-02-29W1
SPEARFISH (1023.5 - 1028.5, 1029 - 1034 mKB)
TEST DATE: DECEMBER 10 - 29, 1999

Prepared for:

ANDERSON EXPLORATION LTD.

Prepared by:

PETRO MANAGEMENT GROUP LTD.

JANUARY 2000

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January 17, 2000

ANDERSON EXPLORATION LTD.
1600, 324 - 8th Ave. S.W.
Calgary, Alta., T2P 2Z5

Attn.: Mr. Larry Sopko

HOME PIERSON 16-05-02-29W1
SPEARFISH (1023.5 - 1028.5, 1029 - 1034 mKB)
INJECTIVITY/FALL-OFF TEST
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As requested, an injectivity/fall-off test analysis was performed on the subject well. A summary of the test data and the analysis results is attached. The report marked ORIGINAL contains the test data on a diskette. Three copies of the report are attached.

Should you have any questions, please feel free to contact me at (403) 216-5101.

Yours truly,
Petro Management Group Ltd.

COPY (Original Signed) S. IB

Saad Ibrahim, P. Eng.
Principal Engineer

Summary of test data & results

Case Name : Finite Conductivity Fracture #1

Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)

Fall-off Test
Dec. 10 - 29,1999

Model Parameters

Water Permeability (k_w)	0.791 mD	Fracture Half Length (x_f)	50.40 m
Total Mobility ($(k/\mu)_t$)	1.26 mD/mPa.s	Fracture Flow Capacity (k_{fw})	101.298 mD.m
Total Transmissivity ($(kh/\mu)_t$)	4.91 mDm/mPa.s	Fracture Face Skin (sf)	0.015
Wellbore Storage Constant Dim. (C_D)	29.05	Skin Equivalent to Xf	-5.159
		Exterior Radius (r_e)	600.00 m

Formation Parameters

Net Pay (h)	3.90 m
Total Porosity (ϕ_t)	17.00 %
Water Saturation (S_w)	70.00 %
Oil Saturation (S_o)	30.00 %
Gas Saturation (S_g)	0.00 %
Wellbore Radius (r_w)	0.091 m
Formation Temperature (T)	42.0 °C
Formation Compressibility (c_f)	5.658e-7 kPa^{-1}
Total Compressibility (c_t)	4.716e-6 kPa^{-1}

Fluid Properties

Water Compressibility (c_w)	4.29322e-7 kPa^{-1}
Oil Compressibility (c_o)	1.28311e-5 kPa^{-1}
Gas Compressibility (c_g)	6.16351e-5 kPa^{-1}
Water Formation Volume Factor (B_w)	1.000
Water Viscosity (μ_w)	0.628 mPa.s
Gas Viscosity (μ_g)	17.800 µPa.s
Solution Gas Ratio (R_{sw})	0 m^3/m^3
Specific Gravity (G)	1.000
PVT Reference Pressure (p_{PVT})	16158.87 kPa

Production and Pressure

Q_tB_t	-6.901 m^3/d
Final Water Rate	-6.900 m^3/d
Final Gas Rate	0.000 $10^3m^3/d$
Final Flowing Pressure (p_{wfo})	15628.62 kPa
Final Measured Pressure	11372.90 kPa
Initial Pressure (p_i)	16158.87 kPa

Synthesis Results

Average Error	-0.03 %
Synthetic Initial Pressure (p_i)	7790.06 kPa
Extrapolated Pressure at Specified Time	8678.69 kPa
Pressure Drop Due To Skin (Δp_s)	60.78 kPa
Flow Efficiency (FE)	0.991
Damage Ratio (DR)	1.009

Forecasts

Specified Flowing Pressure (p_{wfs})	15628.62 kPa
3 - Month Constant Rate	-7.724 m^3/d
6 - Month Constant Rate	-6.779 m^3/d
Specified Forecast Time	12.00 month
Forecast Constant Rate @ Current Skin	-6.031 m^3/d
PI / II (Actual)	9.86e-4 $m^3/d/kPa$
Forecast Constant Rate @ Skin=0	-6.077 m^3/d
PI / II (Ideal)	9.95e-4 $m^3/d/kPa$

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SUMMARY OF RESULTS

SUMMARY OF RESULTS

1. The average reservoir pressure (P_R) is 8 679 kPa.

2. The effective permeability to water of the Spearfish formation is 0.79 mD.

3. The apparent wellbore skin factor of -5.2 and the fracture half length of 50.4 m confirm that the well was stimulated. The fracture face skin (S_f) of 0.015 indicates that the effectiveness of the fracture has been slightly reduced possibly due to fine plugging from the injected water.

4. The stabilized water injection rate is 6.8 m^3/d

5. The injectivity index (I.I.) is 9.86E-4 $m^3/d/kPa$.

6. Radius of investigation is approximately 109.2 m.

TEST ANALYSIS

DISCUSSION

1. Test Overview:

The Home Pierson 16-05-02-29W1 is completed in the Spearfish formation at 1023.5 - 1028.5, 1029 - 1034 mKB and is equipped with a 60.3 mm tubing (landed at 1020.24 mKB). The well was fractured during the initial completion to improve productivity.

During the test, water was injected at 6.9 m^3/d for 24 hours at a wellhead injection pressure 4 956 kPa. Subsequently, the well was shutin for a 449 hour fall-off period.

2. Data Validation:

During the injection/fall-off test, tandem electronic pressure recorders were set at 1015.8 mCF & 1016.8 mCF. The pressure and temperature profiles of the two recorders tracked closely through out the test, as shown on the Raw Data plot (Figure 1), in the Section "Test Data Quality". The difference in pressures, measured by the two recorders, was fairly constant during the buildup period (Figure 2), indicating good quality of the pressure data.

The primary pressure derivative (PPD) plot was constructed for the bottom pressure recorder (Figure 3). The PPD showed no pressure anomalies. The PPD plot should be monotonically decreasing with time for valid buildup data. The bottom recorder was used in the test analysis.

The pressure data was reported in absolute. Depth correction was made to adjust the recorded pressures from the recorder run depth to the MPP, using a water gradient of 10.0 kPa/m.

TEST INTERPRETATION

1. Pressure Fall-off Analysis:

Pressure fall-off analysis was performed on the shut-in period. The reservoir parameters were provided by Anderson Exploration Ltd., as shown in the attached form "Summary of Test Data and Results". The final water injection rate prior to shutting in the well was 6.9 m^3/d at a sandface flowing pressure of 15 629 kPa, as shown in the Strip Chart (Figure 4) in the section "Pressure Transient Analysis".

Both the Horner Plot and the pressure derivative analysis were used in the analysis, as discussed below, and results were later fine tuned using the pressure history match techniques of the test pressure data.

Wellbore storage regime was identified by the unit slope straight of the pressure derivative as shown in the Diagnostic Derivative Analysis plot (Figure 5) in the section "Pressure Transient Analysis". Linear flow regime, which is used to evaluate the effectiveness of fracture treatment, was identified by the 1/2 slope straight line of the pressure derivative. The flattening of the pressure derivative plot, after 283 hours of shutin, confirms that radial flow was reached.

Radial flow analysis was performed to determine the reservoir parameters using the semi-log straight line drawn through the late time pressure data, as shown in the Horner plot (Figure 6). The extrapolation of the last data points yielded a P^* of 8 303 kPa. The (P^*) was corrected for the shape, areal extent of the reservoir and the location of the well to determine the average reservoir pressure of 9 378 kPa. The results of the Horner plot and the pressure derivative are summarized below:

	Horner	Derivative
Effective Permeability, mD	0.98	0.97
Ave. Reservoir Pressure, kPa	9 378	n/a
Apparent Skin Factor	-4.8	-4.8

Linear flow analysis, using the Tandem Root plot, was performed to evaluate the effectiveness of the hydraulic fracture treatment (Figure 6a). The straight line drawn through the pressure data during linear flow regime, concluded a fracture half length (X_f) of 45.6 m.

2. Pressure History Match:

The preliminary results from the Horner analysis were used as starting parameters for pressure history matching of the test data. The best match of the test data was obtained, using the Finite Conductivity Fracture Model. The overlay of simulated analysis results on the real test data is presented in the cartesian, semi-log and log-log plots (Figures 7,8 and 9), in the section "Pressure History Match". The parameters used to achieve the history match are as follows:

	History Match	
Reservoir Pressure, P_r	8 679	kPa
Effective Permeability, k	0.79	mD
Fracture conductivity, K_f.w	101.3	mD.m
Fracture Half Length, X_f	50.4	m
Six-Month Stabilized Rate, q_s	6.8	$10^3m^3/d$

3. Well Injectivity:

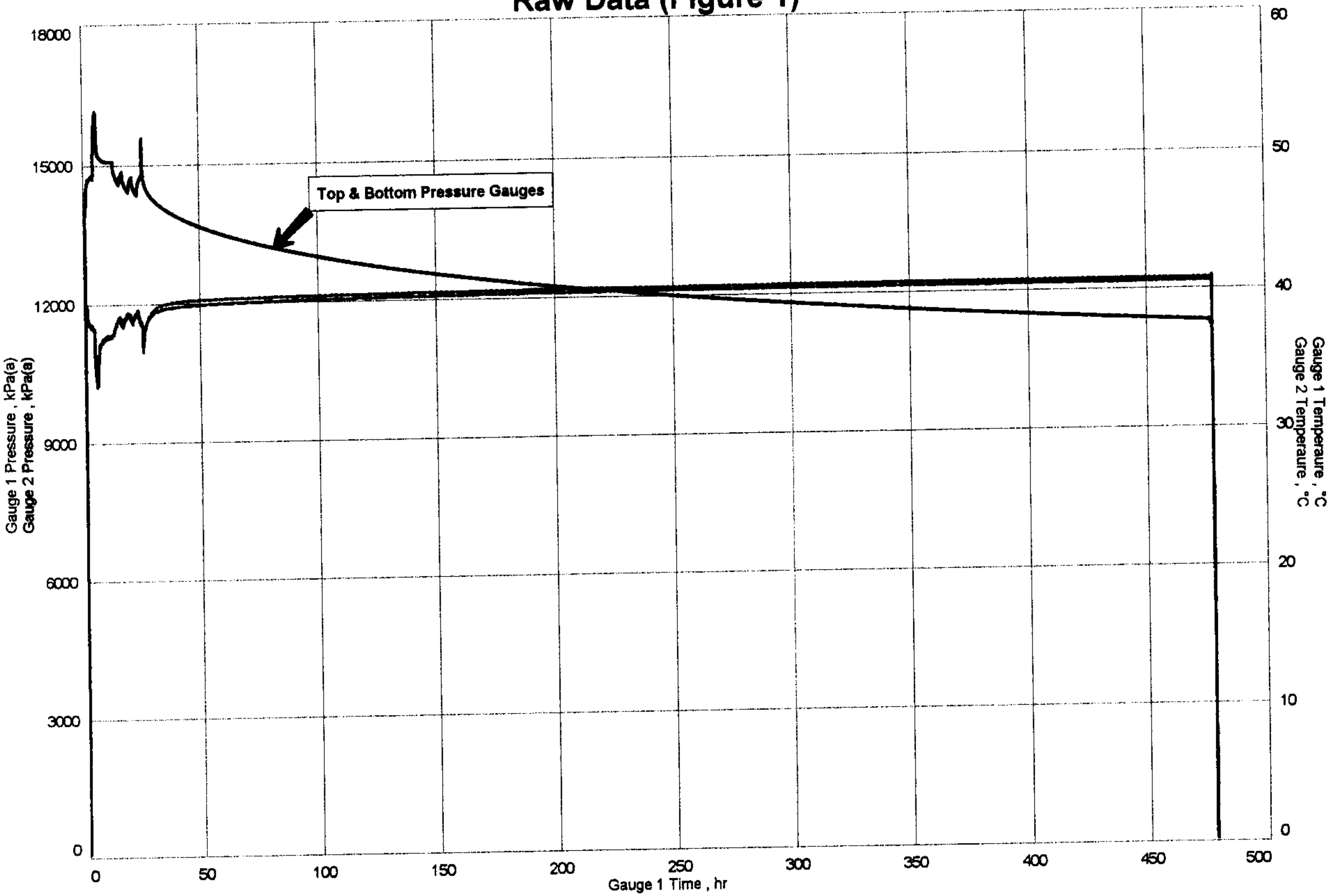
The well stabilized injection rate of 6.8 m3/d and the injectivity index (I.I.) is 9.86E-4 m^3/d/kPa were obtained from the test history match at the current wellbore skin of -5.2.

TEST DATA
QUALITY

100/16-05-002-29W1/0

Home Pierson
Formation: Spearfish

Raw Data (Figure 1)



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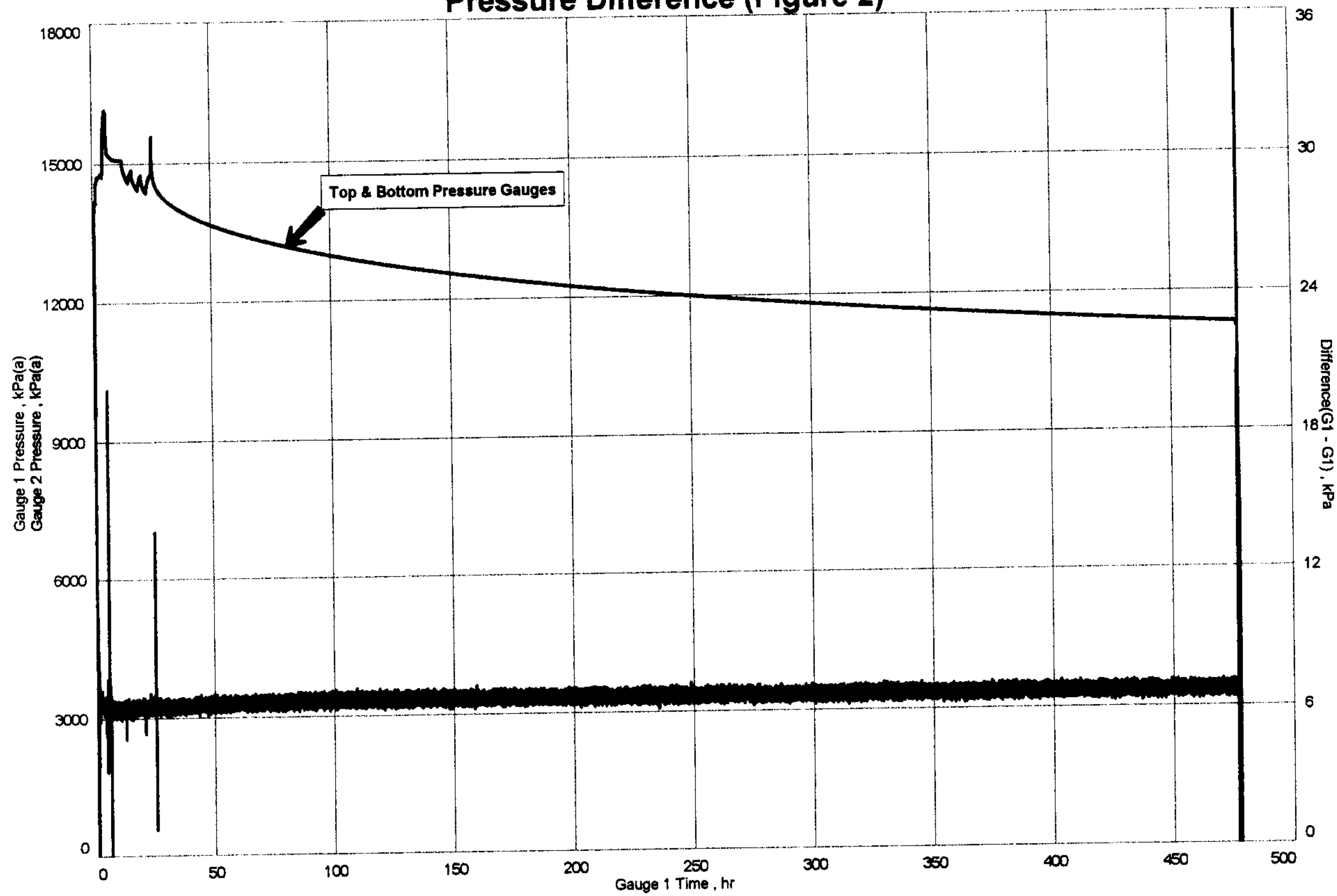
100/16-05-002-29W1/0

Home Pierson
Formation: Spearfish

Pressure Difference (Figure 2)



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Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
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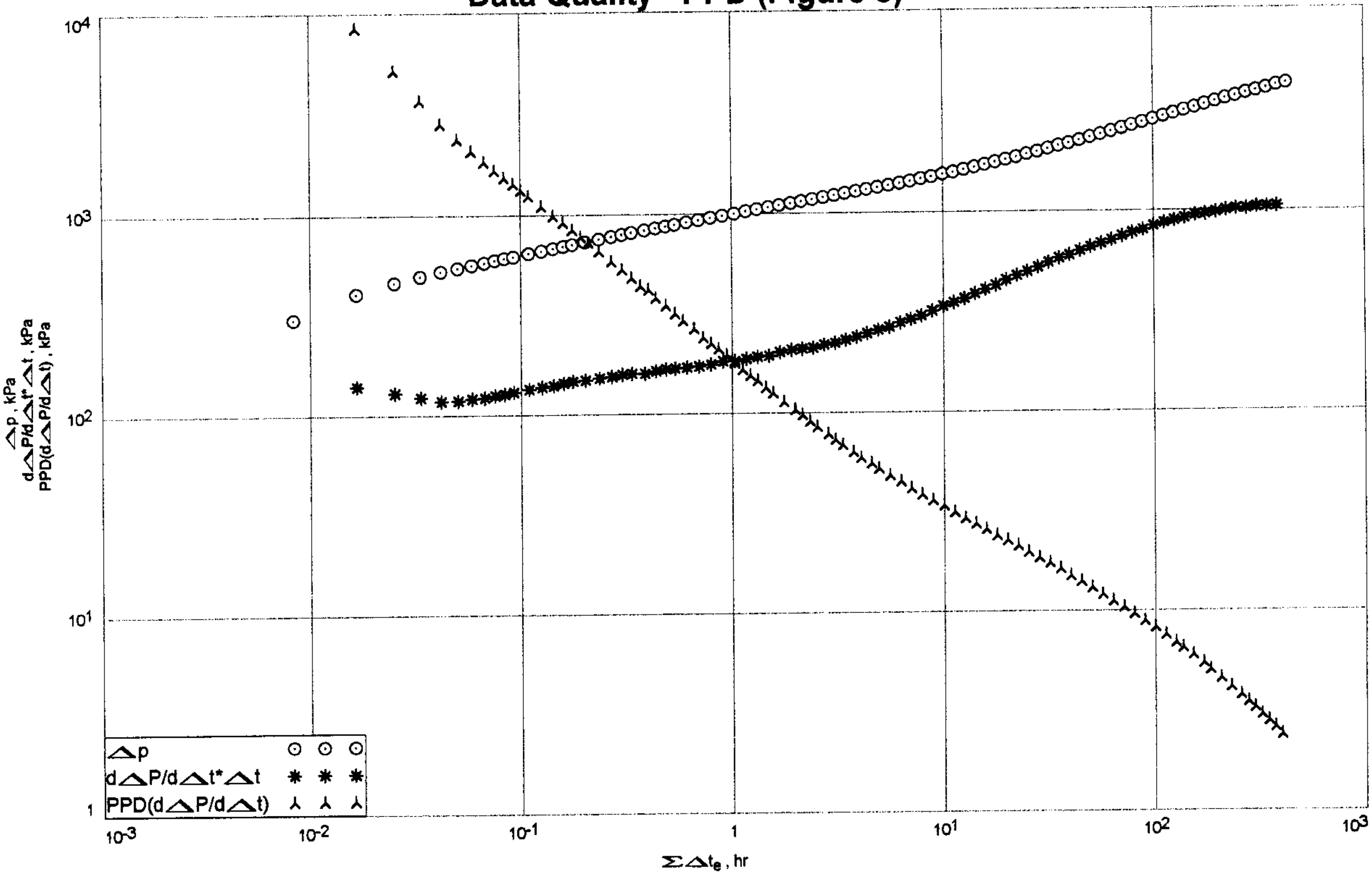
Data Quality - PPD (Figure 3)



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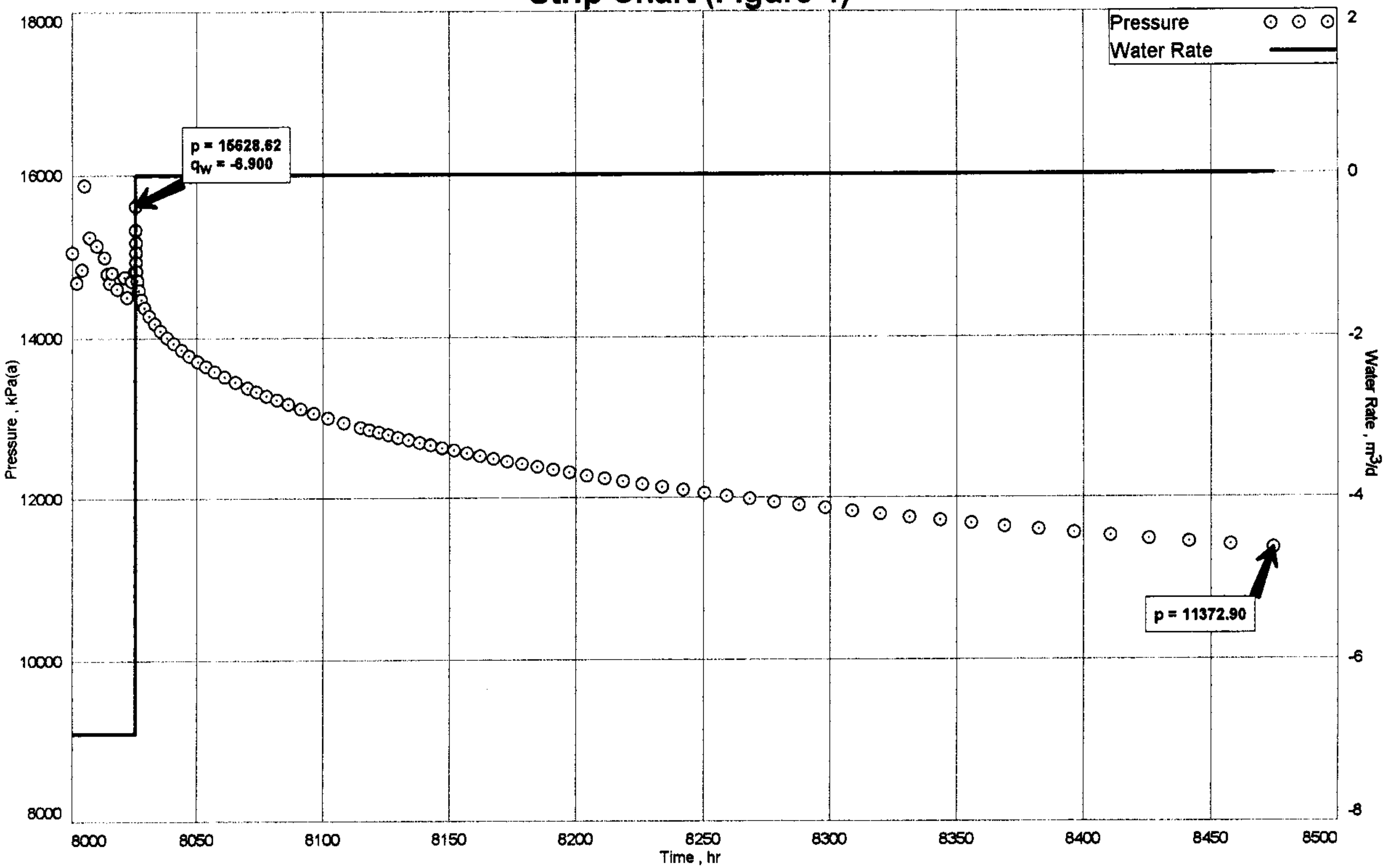
PRESSURE TRANSIENT ANALYSIS

Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

Strip Chart (Figure 4)



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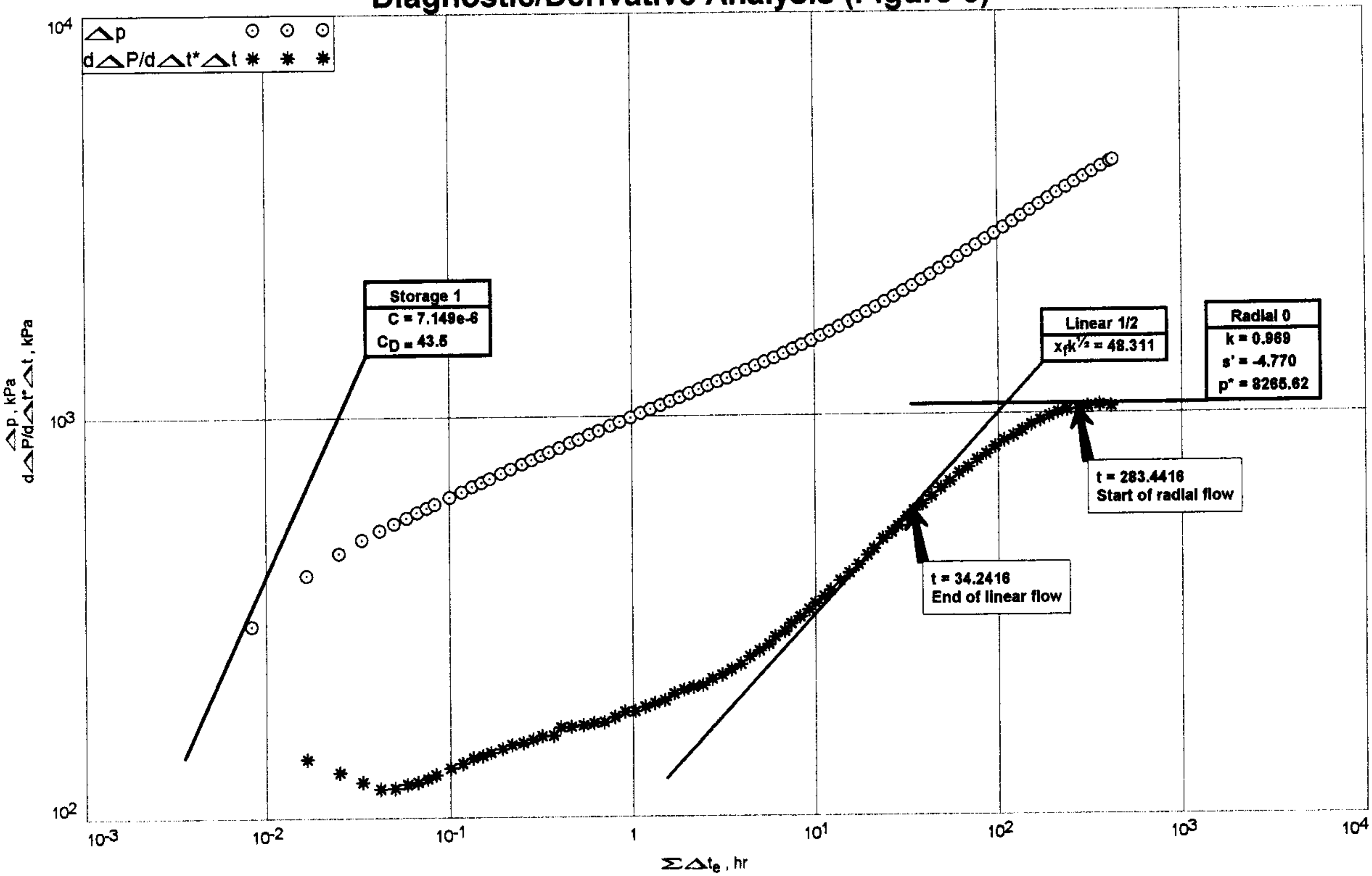
Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

Diagnostic/Derivative Analysis (Figure 5)



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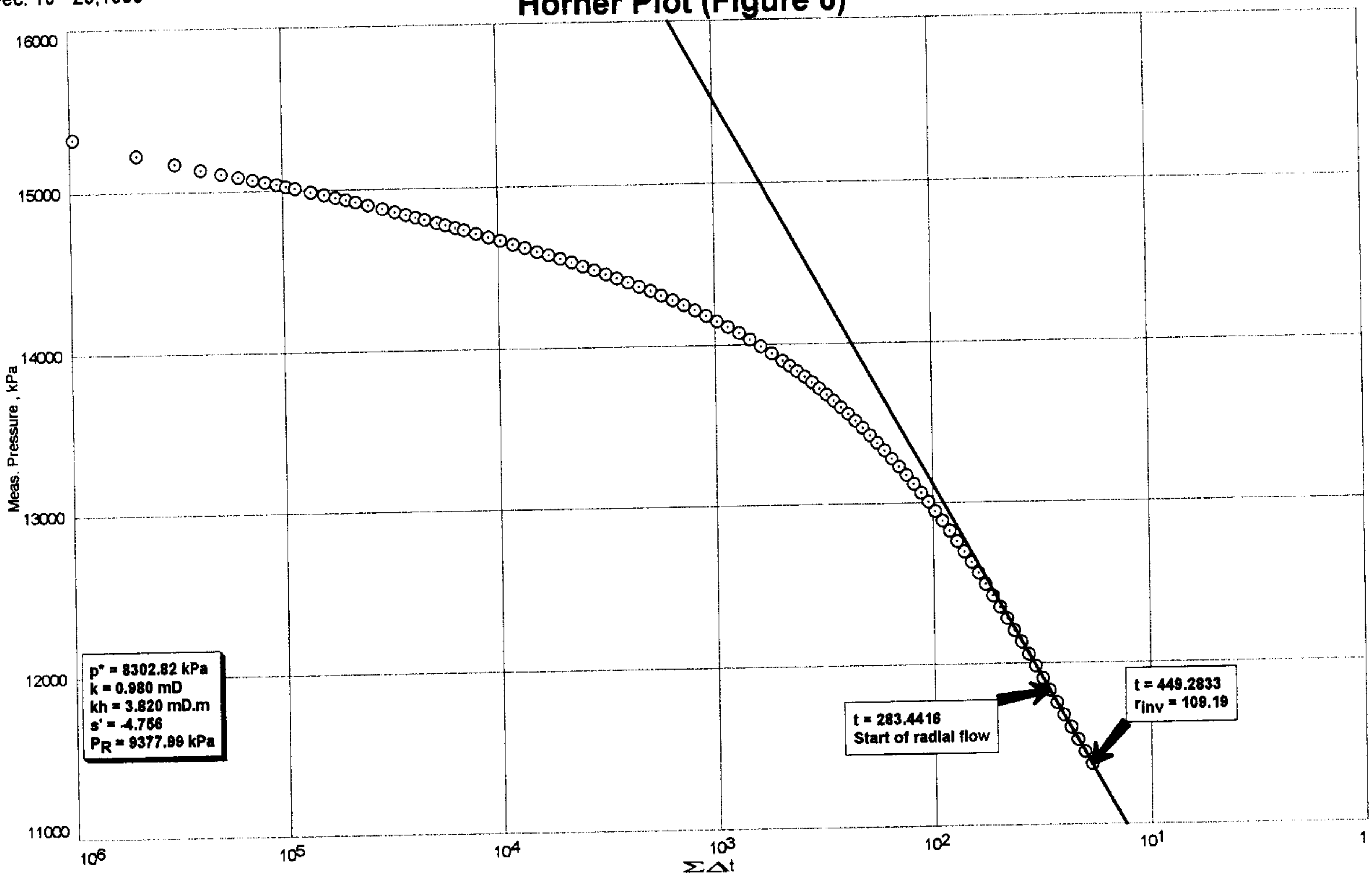
Horner Plot (Figure 6)



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Spearfish (1023.5-28.5, 1029-34)
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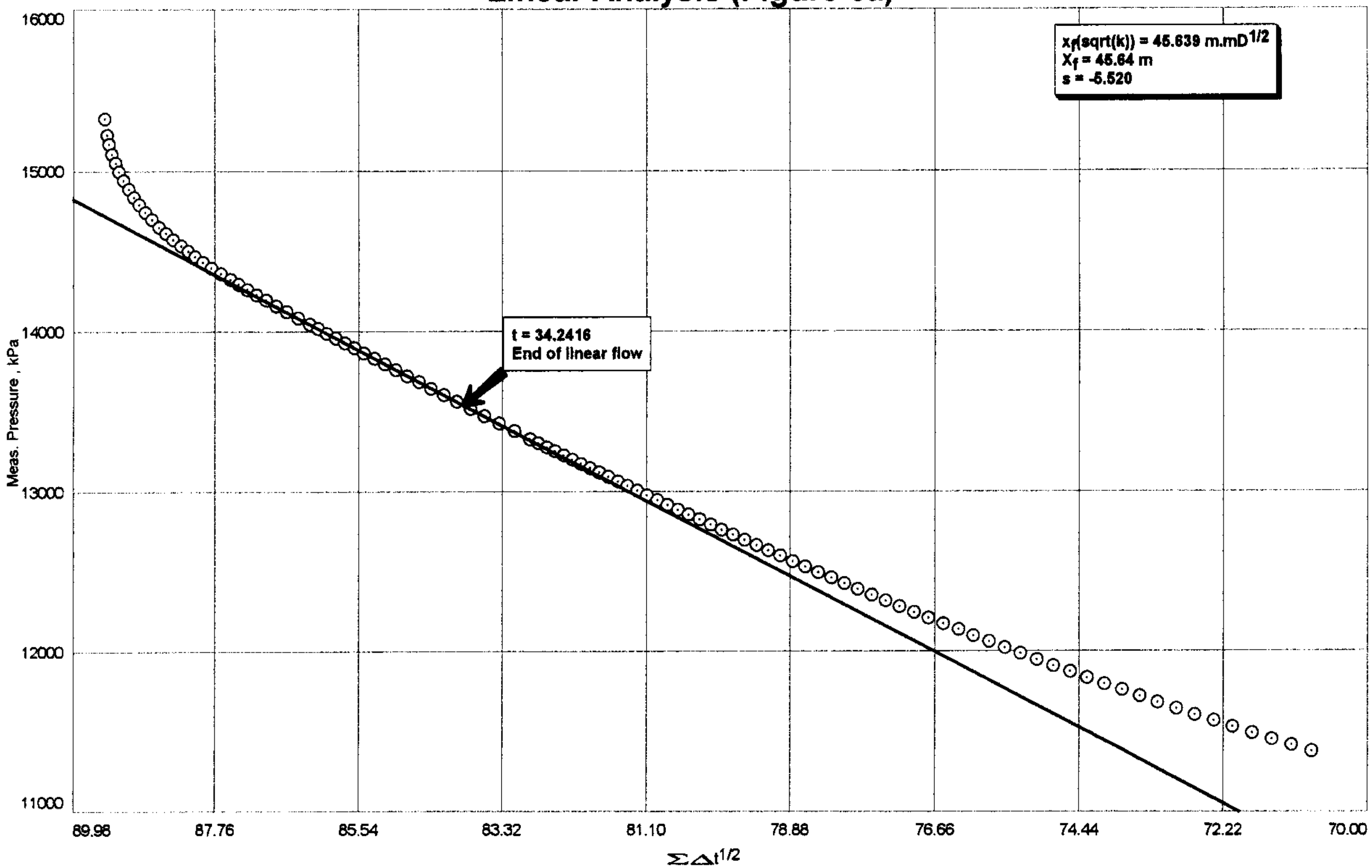
Linear Analysis (Figure 6a)



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PRESSURE
HISTORY
MATCHING

Finite Conductivity Fracture Water Well Model

Case Name : Finite Conductivity Fracture #1

Home Pierson 16-05-02-29W1

Spearfish (1023.5-28.5, 1029-34)

Fall-off Test

Dec. 10 - 29,1999

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Total Compressibility (c_t)	4.716e-6 kPa^{-1}

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Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
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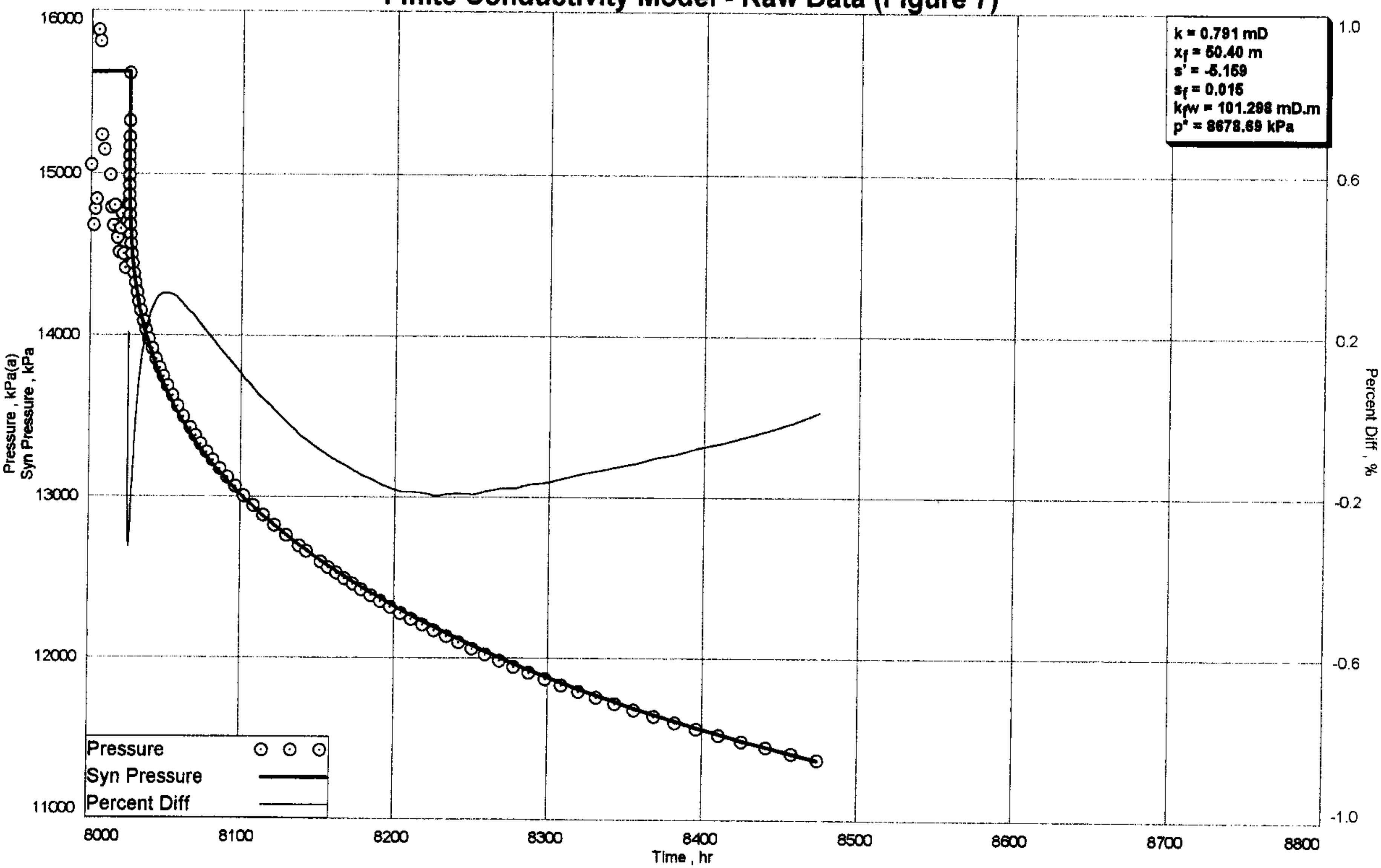
Finite Conductivity Model - Raw Data (Figure 7)



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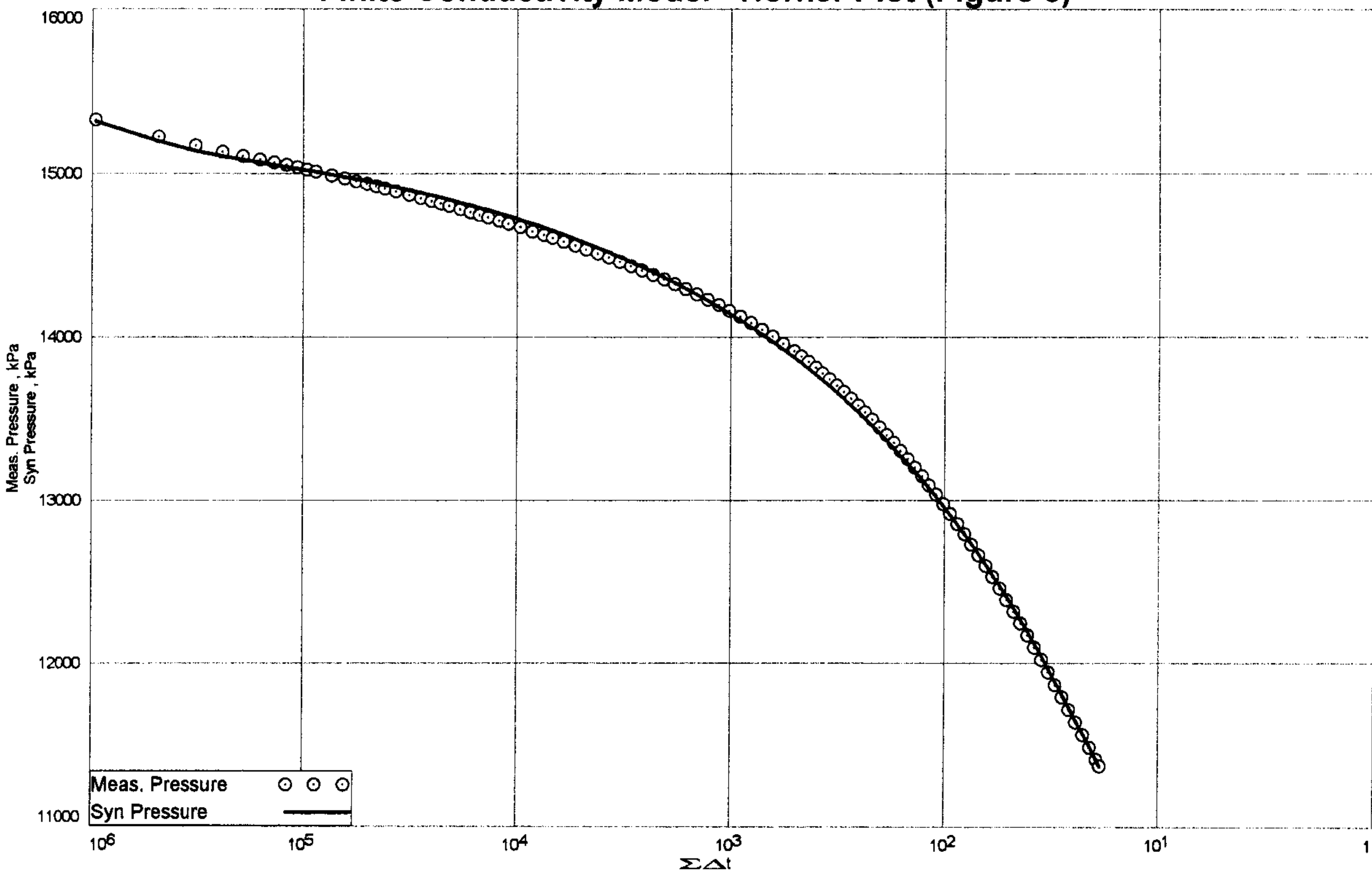
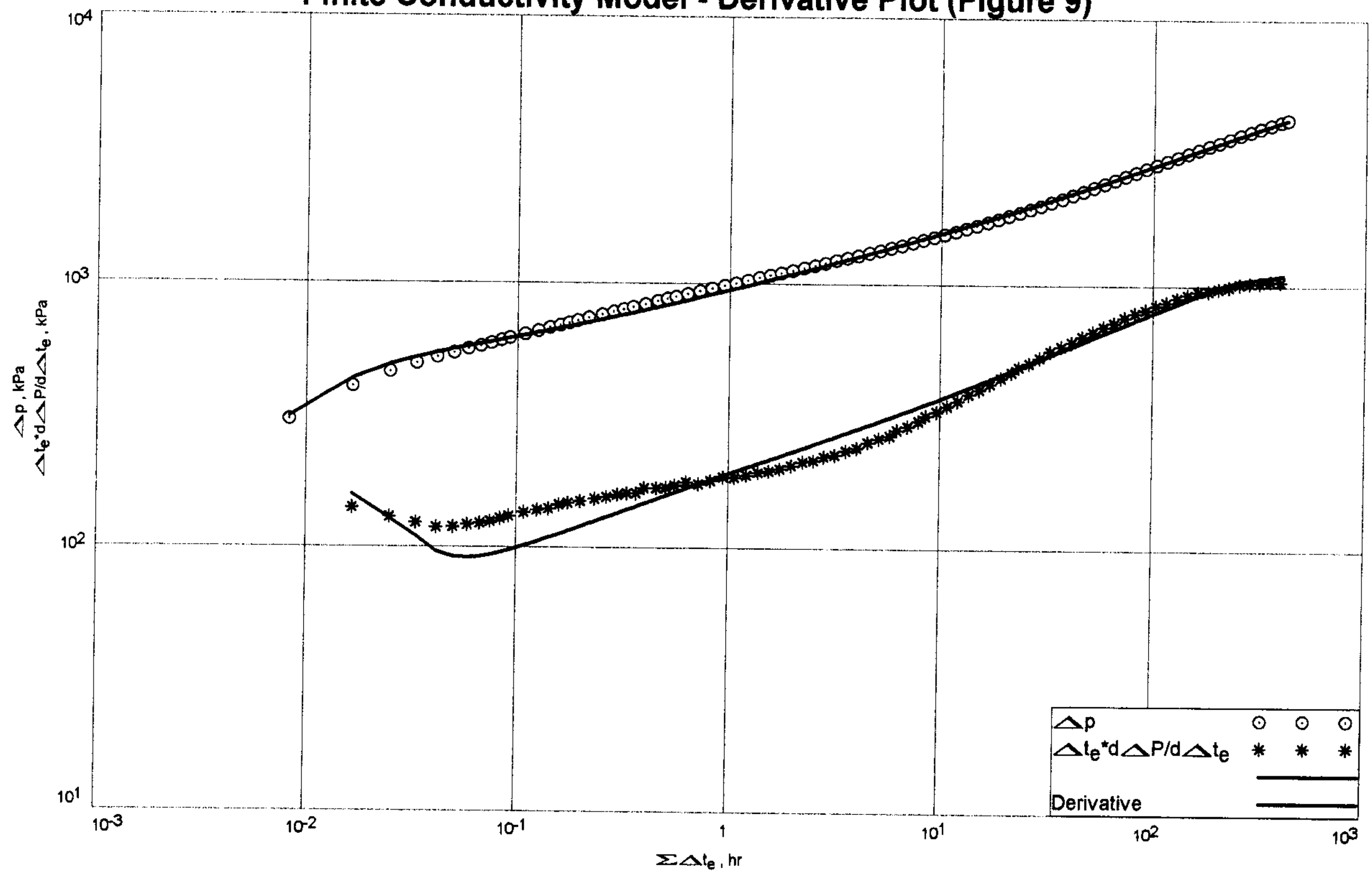
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

Finite Conductivity Model - Horner Plot (Figure 8)



Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

Finite Conductivity Model - Derivative Plot (Figure 9)



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SUBSURFACE
PRESSURES

Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
1	-8000.0000	8000.0000	15052.00	0.000	0.000	-6.900
2	-0.0100	8000.0100	15052.00	0.000	0.000	
3	1.7250	8001.7250	14681.95			
4	2.7250	8002.7250	14780.61	0.000	0.000	-6.900
5	3.7250	8003.7250	14842.02			
6	4.7333	8004.7333	15876.46			
7	5.7333	8005.7333	15809.20			
8	6.7333	8006.7333	15237.78			
9	7.7333	8007.7333	15187.17			
10	8.7333	8008.7333	15149.71			
11	9.7333	8009.7333	15133.59			
12	10.7333	8010.7333	15129.03			
13	11.7333	8011.7333	15129.97			
14	12.7333	8012.7333	14989.80			
15	13.7333	8013.7333	14791.91			
16	14.7333	8014.7333	14677.25			
17	15.7333	8015.7333	14803.04			
18	16.7333	8016.7333	14781.87			
19	17.7333	8017.7333	14602.15			
20	18.7333	8018.7333	14513.60			
21	19.7333	8019.7333	14660.50			
22	20.7333	8020.7333	14749.93			
23	21.7333	8021.7333	14501.68			
24	22.7333	8022.7333	14416.41			
25	23.7333	8023.7333	14703.25			
26	24.7333	8024.7333	14815.92			
27	25.2333	8025.2333	15617.10			
28	25.2417	8025.2417	15628.62	0.000		
29	25.2500	8025.2500	15326.28	0.000		0.000
30	25.2583	8025.2583	15224.49			
31	25.2667	8025.2667	15169.40			
32	25.2750	8025.2750	15133.56			
33	25.2833	8025.2833	15106.92			
34	25.2917	8025.2917	15085.53			
35	25.3000	8025.3000	15066.93			
36	25.3083	8025.3083	15050.71			
37	25.3167	8025.3167	15036.01			
38	25.3250	8025.3250	15022.73			
39	25.3333	8025.3333	15010.46			
40	25.3417	8025.3417	14998.87			
41	25.3500	8025.3500	14988.22			
42	25.3583	8025.3583	14978.13			

Print Filter Used: Nth Line = 1.000

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Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
43	25.3667	8025.3667	14968.88			
44	25.3750	8025.3750	14959.69			
45	25.3833	8025.3833	14951.13			
46	25.3917	8025.3917	14943.19			
47	25.4000	8025.4000	14935.27			
48	25.4083	8025.4083	14928.06			
49	25.4167	8025.4167	14920.69			
50	25.4250	8025.4250	14914.03			
51	25.4333	8025.4333	14907.47			
52	25.4417	8025.4417	14901.09			
53	25.4500	8025.4500	14895.01			
54	25.4583	8025.4583	14889.07			
55	25.4750	8025.4750	14877.76			
56	25.4917	8025.4917	14867.19			
57	25.5083	8025.5083	14857.31			
58	25.5250	8025.5250	14847.83			
59	25.5417	8025.5417	14838.82			
60	25.5583	8025.5583	14830.25			
61	25.5750	8025.5750	14822.01			
62	25.5917	8025.5917	14814.19			
63	25.6083	8025.6083	14806.76			
64	25.6250	8025.6250	14799.65			
65	25.6417	8025.6417	14792.81			
66	25.6583	8025.6583	14785.69			
67	25.6750	8025.6750	14779.40			
68	25.7000	8025.7000	14770.04			
69	25.7250	8025.7250	14761.06			
70	25.7500	8025.7500	14752.63			
71	25.7750	8025.7750	14744.51			
72	25.8000	8025.8000	14736.73			
73	25.8250	8025.8250	14729.08			
74	25.8500	8025.8500	14722.08			
75	25.8750	8025.8750	14714.98			
76	25.9000	8025.9000	14708.09			
77	25.9333	8025.9333	14699.55			
78	25.9667	8025.9667	14691.44			
79	26.0000	8026.0000	14683.54			
80	26.0333	8026.0333	14675.98			
81	26.0667	8026.0667	14668.61			
82	26.1000	8026.1000	14661.48			
83	26.1417	8026.1417	14652.88			
84	26.1833	8026.1833	14644.58			

Print Filter Used: Nth Line = 1.000

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Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
85	26.2250	8026.2250	14636.51			
86	26.2667	8026.2667	14629.00			
87	26.3083	8026.3083	14621.60			
88	26.3583	8026.3583	14613.18			
89	26.4083	8026.4083	14605.09			
90	26.4583	8026.4583	14597.06			
91	26.5083	8026.5083	14589.63			
92	26.5583	8026.5583	14582.14			
93	26.6167	8026.6167	14573.88			
94	26.6750	8026.6750	14565.77			
95	26.7333	8026.7333	14558.20			
96	26.7917	8026.7917	14550.54			
97	26.8583	8026.8583	14542.47			
98	26.9250	8026.9250	14534.25			
99	26.9917	8026.9917	14526.45			
100	27.0667	8027.0667	14518.15			
101	27.1417	8027.1417	14509.97			
102	27.2167	8027.2167	14501.80			
103	27.3000	8027.3000	14493.53			
104	27.3833	8027.3833	14485.31			
105	27.4750	8027.4750	14476.42			
106	27.5667	8027.5667	14467.89			
107	27.6583	8027.6583	14459.73			
108	27.7583	8027.7583	14451.11			
109	27.8583	8027.8583	14442.65			
110	27.9667	8027.9667	14433.78			
111	28.0750	8028.0750	14425.17			
112	28.1917	8028.1917	14416.15			
113	28.3083	8028.3083	14407.45			
114	28.4333	8028.4333	14398.47			
115	28.5583	8028.5583	14389.73			
116	28.6917	8028.6917	14380.60			
117	28.8333	8028.8333	14371.29			
118	28.9750	8028.9750	14362.07			
119	29.1250	8029.1250	14352.77			
120	29.2833	8029.2833	14343.11			
121	29.4417	8029.4417	14333.89			
122	29.6083	8029.6083	14324.28			
123	29.7833	8029.7833	14314.38			
124	29.9667	8029.9667	14304.36			
125	30.1583	8030.1583	14294.41			
126	30.3583	8030.3583	14283.82			

Print Filter Used: Nth Line = 1.000

PMG

Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
127	30.5667	8030.5667	14273.53			
128	30.7833	8030.7833	14262.59			
129	31.0083	8031.0083	14252.24			
130	31.2417	8031.2417	14241.30			
131	31.4833	8031.4833	14230.12			
132	31.7333	8031.7333	14219.12			
133	31.9917	8031.9917	14207.63			
134	32.2583	8032.2583	14196.73			
135	32.5333	8032.5333	14185.14			
136	32.8250	8032.8250	14173.35			
137	33.1250	8033.1250	14161.56			
138	33.4417	8033.4417	14149.59			
139	33.7667	8033.7667	14137.09			
140	34.1083	8034.1083	14124.69			
141	34.4583	8034.4583	14112.12			
142	34.8250	8034.8250	14099.32			
143	35.2000	8035.2000	14086.50			
144	35.5917	8035.5917	14073.28			
145	36.0000	8036.0000	14059.82			
146	36.4250	8036.4250	14046.36			
147	36.8667	8036.8667	14032.57			
148	37.3250	8037.3250	14018.57			
149	37.8000	8037.8000	14004.49			
150	38.2917	8038.2917	13990.21			
151	38.8083	8038.8083	13975.41			
152	39.3417	8039.3417	13960.45			
153	39.9000	8039.9000	13945.37			
154	40.4750	8040.4750	13930.05			
155	41.0750	8041.0750	13914.39			
156	41.7000	8041.7000	13898.40			
157	42.3500	8042.3500	13882.22			
158	43.0250	8043.0250	13865.75			
159	43.7250	8043.7250	13849.15			
160	44.4500	8044.4500	13832.27			
161	45.2083	8045.2083	13814.84			
162	45.9917	8045.9917	13797.32			
163	46.8083	8046.8083	13779.27			
164	47.6583	8047.6583	13761.17			
165	48.5417	8048.5417	13742.48			
166	49.4583	8049.4583	13723.45			
167	50.4083	8050.4083	13704.42			
168	51.4000	8051.4000	13685.05			

Print Filter Used: Nth Line = 1.000

PMG

Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
169	52.4250	8052.4250	13665.42			
170	53.4917	8053.4917	13645.43			
171	54.6000	8054.6000	13625.08			
172	55.7500	8055.7500	13604.56			
173	56.9500	8056.9500	13583.58			
174	58.1917	8058.1917	13562.03			
175	59.4833	8059.4833	13540.24			
176	60.8250	8060.8250	13518.00			
177	62.2250	8062.2250	13495.57			
178	63.6750	8063.6750	13472.87			
179	65.1833	8065.1833	13449.84			
180	66.7500	8066.7500	13426.74			
181	68.3750	8068.3750	13403.16			
182	70.0667	8070.0667	13379.02			
183	71.8250	8071.8250	13354.62			
184	73.6500	8073.6500	13329.94			
185	75.5500	8075.5500	13304.71			
186	77.5250	8077.5250	13279.27			
187	79.5750	8079.5750	13253.48			
188	81.7083	8081.7083	13227.36			
189	83.9250	8083.9250	13200.76			
190	86.2250	8086.2250	13173.70			
191	88.6167	8088.6167	13146.50			
192	91.1000	8091.1000	13118.97			
193	93.6833	8093.6833	13091.24			
194	96.3667	8096.3667	13062.79			
195	99.1500	8099.1500	13034.29			
196	102.0417	8102.0417	13004.93			
197	105.0500	8105.0500	12975.77			
198	108.1750	8108.1750	12945.87			
199	111.4250	8111.4250	12915.71			
200	114.8000	8114.8000	12885.38			
201	118.3083	8118.3083	12854.72			
202	121.9500	8121.9500	12823.54			
203	125.7417	8125.7417	12791.76			
204	129.6750	8129.6750	12759.78			
205	133.7667	8133.7667	12727.81			
206	138.0167	8138.0167	12694.69			
207	142.4333	8142.4333	12661.94			
208	147.0250	8147.0250	12628.72			
209	151.7917	8151.7917	12595.25			
210	156.7500	8156.7500	12561.33			

Print Filter Used: Nth Line = 1.000

Home Pierson 16-05-02-29W1
Spearfish (1023.5-28.5, 1029-34)
Fall-off Test
Dec. 10 - 29,1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
211	161.9000	8161.9000	12527.13			
212	167.2500	8167.2500	12492.76			
213	172.8083	8172.8083	12457.88			
214	178.5833	8178.5833	12422.63			
215	184.5833	8184.5833	12387.23			
216	190.8250	8190.8250	12351.20			
217	197.3083	8197.3083	12315.09			
218	204.0417	8204.0417	12278.88			
219	211.0417	8211.0417	12243.14			
220	218.3167	8218.3167	12206.71			
221	225.8750	8225.8750	12169.46			
222	233.7250	8233.7250	12133.23			
223	241.8833	8241.8833	12096.14			
224	250.3667	8250.3667	12058.09			
225	259.1750	8259.1750	12021.18			
226	268.3333	8268.3333	11983.69			
227	277.8500	8277.8500	11945.15			
228	287.7333	8287.7333	11907.65			
229	298.0083	8298.0083	11869.11			
230	308.6833	8308.6833	11831.28			
231	319.7750	8319.7750	11793.32			
232	331.3000	8331.3000	11755.08			
233	343.2750	8343.2750	11716.75			
234	355.7250	8355.7250	11678.36			
235	368.6583	8368.6583	11640.30			
236	382.1000	8382.1000	11601.64			
237	396.0667	8396.0667	11563.49			
238	410.5750	8410.5750	11524.83			
239	425.6583	8425.6583	11486.50			
240	441.3250	8441.3250	11448.22			
241	457.6083	8457.6083	11410.36			
242	474.5250	8474.5250	11372.90			

Print Filter Used: Nth Line = 1.000

EQUATIONS

and

NOMENCLATURE

(METRIC UNITS)

BASIC TIME FUNCTIONS

Flow Time	t
Shut-In Time	Δt
Horner Time	$\frac{t + \Delta t}{\Delta t}$
Superposition Time	$t_n = \sum_{j=1}^{n} \frac{q_j - q_{j-1}}{q_n} \log(t - t_{j-1})$
	$\Delta t_n = \sum_{j=1}^{n} \frac{q_j}{q_n} \log \frac{t_n + \Delta t - t_{j-1}}{t_n + \Delta t - t_j}$
Equivalent Time	$\Delta t_e = \frac{t \cdot \Delta t}{t + \Delta t}$
Root Time	$\sqrt{t}$
	$\sqrt{\Delta t}$
Tandem Root Time	$\sqrt{t+\Delta t} - \sqrt{\Delta t}$

BASIC TIME FUNCTIONS (cont'd)

Quad Root Time $\sqrt[4]{t}$

$\sqrt[4]{\Delta t}$

Tandem Quad Root Time $\sqrt[4]{t+\Delta t} - \sqrt[4]{\Delta t}$

TYPECURVES - DIMENSIONLESS VARIABLES

$$\Delta p_D = \frac{(kh/\mu)_t \ \Delta p}{141.2 \ q_t \ B_t}$$

$$t_D = \frac{2.637E{-}4(k/\mu)_t \ t}{\phi c r_w^2}$$

$$\frac{t_D}{C_D} = 0.000295 \ (\frac{kh}{\mu})_t \frac{t}{C}$$

$$C_D e^{2s} = \frac{0.8936 \ C \ e^{2s}}{\phi c h r_w^2}$$

$$t_{DA} = \frac{2.637E{-}4 \ (k/\mu)_t \ t}{\phi c A}$$

$$t_{Dxf} = \frac{2.637E{-}4 \ (k/\mu)_t \ t}{\phi c x_f^2}$$

$$(k_f w)_D = \frac{k_f w}{k x_f}$$

PMG

McKINLEY ANALYSIS

Wellbore Capacity

$$F = \left(\frac{\Delta p \ F}{qB}\right)\left(\frac{qB}{\Delta p}\right)$$

Alpha

$$\alpha = \frac{F}{5.615}$$

Note: Alpha is the same as C

Wellbore Storage Constant
Compressible Fluid

$$C = c_{ws} V_{ws}$$

Wellbore Storage Constant
Changing Liquid Level

$$C = \frac{cross-sectional\ area}{5.615\ liquid\ gradient}$$

Transmissivity

$$\frac{kh}{\mu} = \left(\frac{T}{F}\right) F$$

Pressure Drop Skin

$$\Delta p_s = \left[1 - \frac{kh_{(wellbore)}}{kh_{(formation)}}\right] \Delta p_{(departure)}$$

Flow Efficiency

$$FE = \frac{p^* - p_{wf} - \Delta p_s}{p^* - p_{wf}}$$

PMG

SEMILOG ANALYSIS

Transmissivity

$$\left(\frac{kh}{\mu}\right)_t = \frac{162.6\ q_t\ B_t}{m}$$

Permeability

$$k = \frac{162.6\ q_o\ B_o\ \mu_o}{mh}$$

Skin Factor

$$s' = 1.151\left[\frac{p_{ws} - p_{wfo}}{m} - \log\frac{t\Delta t}{t+\Delta t} - \log\left(\frac{(k/\mu)_t}{\phi_t c_t r_w^2}\right) + 3.23\right]$$

Pressure Drop
due to Skin

$$\Delta p_s = 0.869\ ms'$$

Flow Efficiency

$$FE = \frac{\bar{p}_R - p_{wfo} - 0.869\ ms'}{\bar{p}_R - p_{wfo}}$$

Damage Ratio

$$DR = \frac{1}{FE}$$

Radius of Investigation

$$r_{inv} = \sqrt{\frac{(k/\mu_t)\ t}{948\phi_t c_t}}$$

Time to Stabilization

$$t_s = \frac{\phi\ c\ A}{2.637E\text{-}4\ (k/\mu)_t}(t_{DA})_{pss}$$

SEMILOG ANALYSIS (cont"d)

Stabilized Rate

$$q_s = \frac{p_i - p_{wfo}}{\frac{162.6\ B_o}{(k/\mu)_o\ h}\left(\log\left(\frac{4A}{1.781\ r_w^2 C_A}\right) + \frac{4\pi (t_{DA})_{pss}}{2.303} + \frac{2s'}{2.303}\right)}$$

Productivity Index

$$P\,I = \frac{q}{\bar{p}_R - p_{wfo}}$$

MBH Average Pressure

$$\bar{p}_R = p^* - \frac{m}{2.303}\,(MBH\ function)$$

DIETZ Average Pressure

$$(\Delta t)_{\bar{p}_R} = \frac{\phi\ c_t\ A}{2.637E{-4}\ C_A (k/\mu)_t}$$

LINEAR ANALYSIS

Fracture half-length

$$x_f = \frac{4.064\ q_t\ B_t}{mh(\phi c k/\mu)_t^{1/2}}$$

Channel width

$$W = \frac{8.128\ q_t\ B_t}{mh(\phi c k/\mu)_t^{1/2}}$$

Skin Factor

$$s = \ln \frac{2\ r_w}{x_f}$$

BI-LINEAR ANALYSIS

Fracture Conductivity

$$k_f w = \left[\frac{44.1\ qB\mu}{mh(\phi \mu c k)^{1/4}}\right]^2$$

PMG

NOMENCLATURE

Symbol	Description	Metric (SI)	Field
a	LIT flow equation coefficient	-	-
A	drainage area	m^2	ft^2
AOF	absolute open flow potential (gas)	$10^3m^3/d$	MMcfd
b	LIT flow equation coefficient	-	-
B	formation volume factor	-	-
c	compressibility	kpa^{-1}	psi^{-1}
c_{ws}	compressibility of wellbore fluids	kpa^{-1}	psi^{-1}
C	wellbore storage/unloading constant	m^3/kPa	bbl/psi
C	simplified flow equation coefficient	-	-
C_A	shape factor	-	-
C_{aD}	apparent wellbore storage constant	-	-
C_D	dimensionless wellbore storage constant	-	-
C_{pD}	storage pressure parameter	-	-
DR	damage ratio	-	-
F	wellbore capacity (McKinley)	m^3/kPa	ft^3/psi
FE	flow efficiency	-	-
G	relative density (gas)	-	-
GOR	gas-oil ratio	m^3/m^3	ft^3/bbl
h	net pay	m	ft
k	permeability	mD	md
$k_{(x,y,z)}$	permeability in the x,y,z direction	mD	md
k_f	fracture permeability	mD	md
k_fw	fracture conductivity	mD.m	md.ft
kh	flow capacity	mD.m	md.ft
k/μ	mobility	-	-
kh/μ	transmissivity	-	-

PMG

Symbol	Description	Metric (SI)	Field
L	length of horizontal well	m	ft
L_e	effective length of horizontal well	m	ft
m	slope of transient plots	-	-
n	simplified flow equation coefficient	-	-
p	pressure	kPa	psia
p_{bp}	bubble point pressure	kPa	psia
p_c	gas pseudo-critical pressure	kPa	psia
p_i	initial pressure	kPa	psia
p_R	average reservoir pressure	kPa	psia
p_{tf}	flowing wellhead pressure	kPa	psia
p_{ts}	shut-in wellhead pressure	kPa	psia
p_{wf}	flowing sandface pressure	kPa	psia
P_{wfo}	final flowing pressure	kPa	psia
p_{ws}	shut-in sandface pressure	kPa	psia
p^*	extrapolated pressure	kPa	psia
Δp_D	dimensionless pressure	-	-
Δp	pressure drop	kPa	psi
PI	productivity index	m^3/d/kPa	bbl/d/psi
q	flow rate - gas - liquid	$10^3 m^3$/d m^3/d	MMcf/d bbl/d
q_j	j^{th} flow rate	m^3/d	bbl/d
q_n	n^{th} flow rate	m^3/d	bbl/d
q_s	stabilized rate - gas - liquid	$10^3 m^3$/d m^3/d	MMcf/d bbl/d
r_e	external radius	m	ft
r_{inv}	radius of investigation	m	ft
r_w	wellbore radius	m	ft
R_s	solution gas ratio	m^3/m^3	ft^3/bbl

PMG

Symbol	Description	Metric (SI)	Field
s	skin factor	-	-
s'	apparent skin factor	-	-
S	saturation (oil, gas, water)	-	-
t	time	hr	hr
t_D	dimensionless time	hr	hr
t_a	pseudo-time	hr	hr
t_{DA}	dimensionless time (based on drainage area)	hr	hr
t_{Dxf}	dimensionless time (based on fracture 1/2 length)	hr	hr
t_n	n^{th} flow period, or superposition time	-	-
Δt	shut-in time	hr	hr
Δt_a	shut-in pseudo-time	hr	hr
Δt_e	equivalent time	hr	hr
$(t_{DA})_{pss}$	dimensionless time at pseudo-steady state	-	-
t_s	time to stabilization	hr	hr
T	temperature	K	°R
T_c	gas pseudo-critical temperature	K	°R
V_{ws}	wellbore volume - gas	m^3	ft^3
	- liquid	m^3	bbl
W	channel width	m	ft
w	fracture width	m	ft
x_e	length of reservoir	m	ft
x_f	fracture half-length	m	ft
x_o	x -location of observation well	m	ft
x_w	x- location of centre of active well	m	ft
y_e	width of reservoir	m	ft
y_o	y- location of observation well	m	ft
y_w	y- location of centre of active well	m	ft
Z	gas compressibility factor	-	-
z_w	z-location of centre of active well	m	ft

PMG

Symbol	Description	Metric (SI)	Field
α	wellbore storage/unloading constant	m^3/kPa	bbl/psi
μ	viscosity - gas - liquid	μPa.s mPa.s	cp cp
λ	inter-porosity flow coefficient	-	-
T	transmissivity (McKinley)	mD.m/mPa.s	md.ft/cp
ϕ	porosity	-	-
Ψ	pseudo-pressure	$kPa^2/\mu Pa.s$	$psia^2$/cp
ω	storativity ratio	-	-

Subscripts

D	dimensionless
DA	dimensionless based on area
Dxf	dimensionless based on fracture half -length
f	formation or flowing
g	gas
i	initial
o	oil
R	reservoir
s	shut-in, skin, stabilized or storage
t	total, transient, or wellhead (tubing head)
w	water or wellbore (sandface)
ref	evaluated at reference pressure

Superscripts

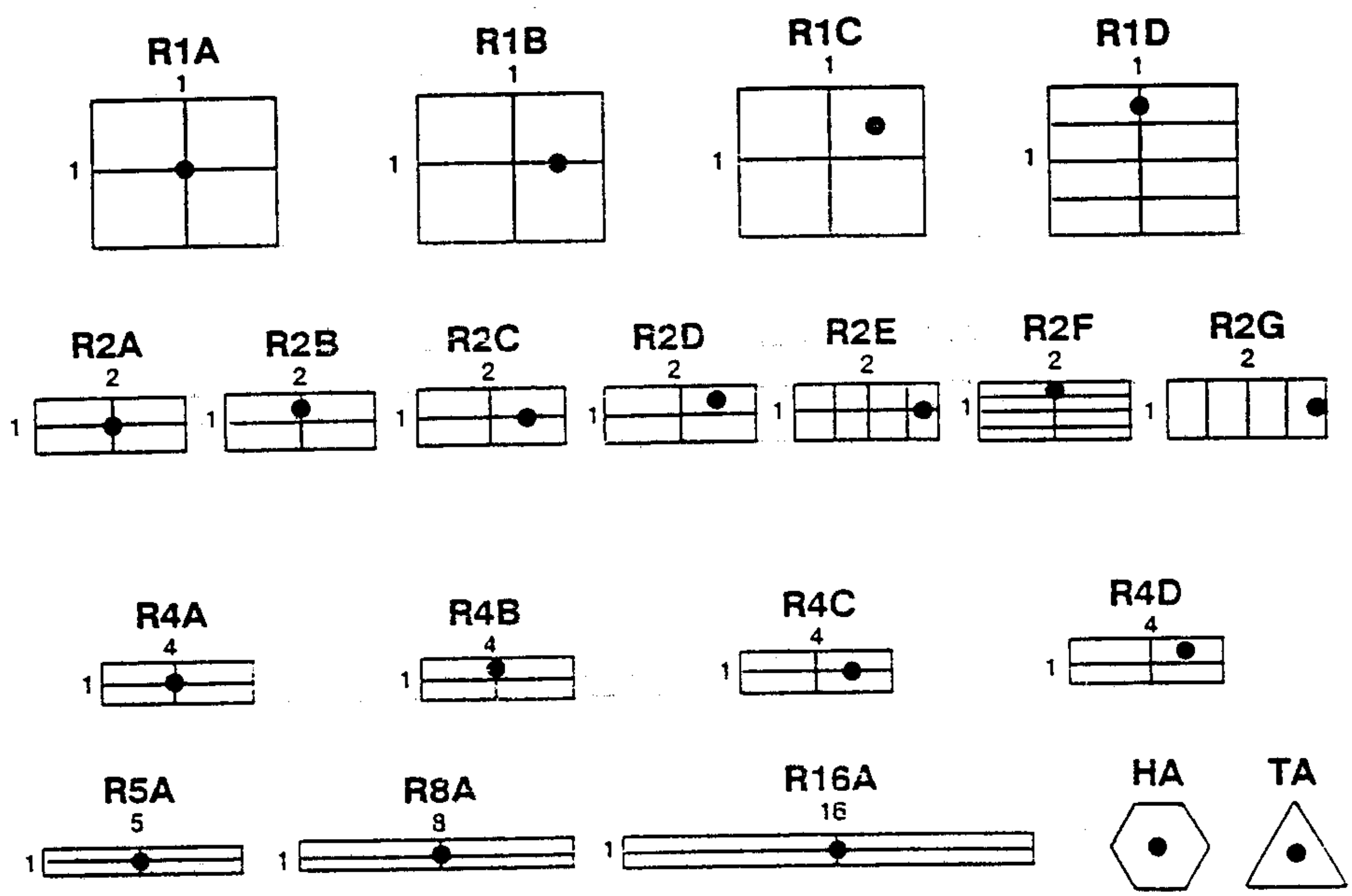
-	average

PMG

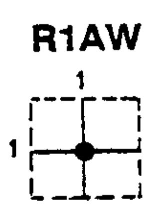
DIETZ SHAPE CODES

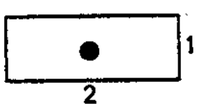
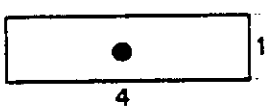
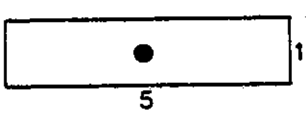
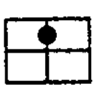
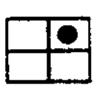
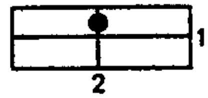
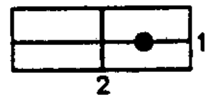
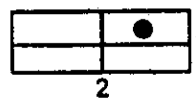
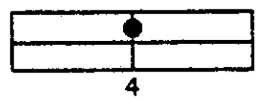
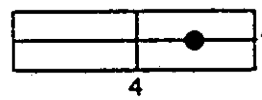
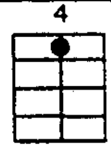
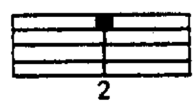
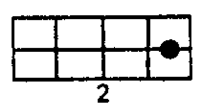
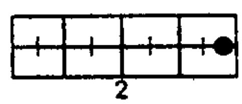
AVERAGE RESERVOIR PRESSURE - MBH CORRECTIONS

NO FLOW OUTER BOUNDARY



CONSTANT PRESSURE OUTER BOUNDARY



	$\ln C_A$	C_A	STABILIZED CONDITIONS FOR t_{DA} >
IN BOUNDED RESERVOIRS			
	3.45	31.6	0.1
	3.43	30.9	0.1
	3.45	31.6	0.1
	3.32	27.6	0.2
	3.30	27.1	0.2
	3.09	21.9	0.4
	3.12	22.6	0.2
	1.68	5.38	0.7
	0.86	2.36	0.7
	2.56	12.9	0.6
	1.52	4.57	0.5
	2.38	10.8	0.3
	1.58	4.86	1.0
	0.73	2.07	0.8
	1.00	2.72	0.8
	-1.46	0.232	2.5
	-2.16	0.115	3.0
	1.22	3.39	0.6
	1.14	3.13	0.3
	-0.50	0.607	1.0
	-2.20	0.111	1.2
	-2.32	0.098	0.9
IN WATER DRIVE RESERVOIRS			
	2.95	19.1	0.1
IN RESERVOIRS OF UNKNOWN PRODUCTION CHARACTER			
	3.22	25	0.1

PSEUDO-STEADY STATE SHAPE FACTORS FOR VARIOUS RESERVOIRS

FROM DIETZ (1965)

PMG

UNITS CONVERSION AND PREFIXES

METRIC (SI) UNIT	FIELD UNIT	DIVIDED BY	
$10^3 m^3/d$	MMcfd	2.817 399	E+01
kPa	psia	6.894 757	E+00
mD	md	9.869 233	E-01
mD.m	md.ft	3.008 142	E-01
m	ft	3.048	E-01
m^3	bbl (35 Imp gal) (42 US gal)	1.589 873	E-01
Pa.s	cp	1.0	E+03
°C	°F	(°F-32)5/9	E+00
K	°R	5/9	E+00
m^2	section (640 acres)	2.589 988	E+06
ha	section (640 acres)	2.589 988	E+02
m^3	gallon (Imp)	4.546 09	E-03
m^3	gallon (US)	3.785 412	E-03
$m^3/10^3 m^3$	bbl/MMcf	5.643 052	E-03

Standard conditions: Metric (SI) 15°C, 101.325 kPa
Field 60°F, 14.65 psia

PMG