INJECTIVITY/FALL-OFF TEST REPORT #1356 Copy 2 of 2

HOME PIERSON 02-09-02-29W1
SPEARFISH (1024 - 1028.5 mKB)
TEST DATE: DECEMBER 11 - 30, 1999

Prepared for:
ANDERSON EXPLORATION LTD.

Prepared by:
PETRO MANAGEMENT GROUP LTD.

JANUARY 2000

#401, 100 - 4th Avenue S.W.
Calgary, Alberta, Canada T2P 3N2
Email: pmg@petromgt.com
Bus: (403) 216-5100
Fax: (403) 216-5109
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Petro Management Group Ltd.

January 17, 2000

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

Attn.: Mr. Larry Sopko

HOME PIERSON 02-09-02-29W1
SPEARFISH (1024 - 1028.5 mKB)
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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, if available. 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. IBRAHIM

Saad Ibrahim, P. Eng.
Principal Engineer

Summary of Test Data and Results

Case Name : Finite Conductivity Fracture #1

Home Pierson 02-09-02-29W1	Fall-off Test
Spearfish (1024 - 1028.5 mKB)	Test Date: Dec. 11 - 30, 1999

Model Parameters

Water Permeability (k_w)	0.075 mD	Fracture Half Length (x_f)	42.77 m
Total Mobility $(k/\mu)_t$	0.12 mD/mPa.s	Fracture Flow Capacity ($k_f w$)	30851.816 mD.m
Total Transmissivity $(kh/\mu)_t$	0.36 mDm/mPa.s	Fracture Face Skin (sf)	0.194
Wellbore Storage Constant Dim. (C_D)	1295.48	Skin Equivalent to Xf	-5.455
		Exterior Radius (r_e)	450.00 m

Formation Parameters

Net Pay (h)	3.00 m
Total Porosity (ϕ_t)	16.00 %
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)	5.802e-7 kPa^{-1}
Total Compressibility (c_t)	4.557e-6 kPa^{-1}

Fluid Properties

Water Compressibility (c_w)	4.28544e-7 kPa^{-1}
Oil Compressibility (c_o)	1.22548e-5 kPa^{-1}
Gas Compressibility (c_g)	5.94377e-5 kPa^{-1}
Water Formation Volume Factor (B_w)	1.000
Water Viscosity (μ_w)	0.628 mPa.s
Gas Viscosity (μ_g)	18.056 μPa.s
Solution Gas Ratio (R_{sw})	0 m^3/m^3
Specific Gravity (G)	1.000
PVT Reference Pressure (p_{PVT})	16556.65 kPa

Production and Pressure

$Q_t B_t$	-1.400 m^3/d
Final Water Rate	-1.400 m^3/d
Final Gas Rate	0.000 $10^3 m^3/d$
Final Flowing Pressure (p_{wfo})	16556.65 kPa
Final Measured Pressure	10792.30 kPa
Initial Pressure (p_i)	16556.65 kPa

Synthesis Results

Average Error	-0.06 %
Synthetic Initial Pressure (p_i)	3323.50 kPa
Extrapolated Pressure at Specified Time	5415.75 kPa
Pressure Drop Due To Skin (Δp_s)	1939.49 kPa
Flow Efficiency (FE)	0.826
Damage Ratio (DR)	1.211

Forecasts

Specified Flowing Pressure (p_{wfs})	16556.65 kPa
3 - Month Constant Rate	-1.602 m^3/d
6 - Month Constant Rate	-1.337 m^3/d
Specified Forecast Time	12.00 month
Forecast Constant Rate @ Current Skin	-1.133 m^3/d
PI / II (Actual)	1.21e-4 $m^3/d/kPa$
Forecast Constant Rate @ Skin=0	-1.338 m^3/d
PI / II (Ideal)	1.49e-4 $m^3/d/kPa$

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SUMMARY OF RESULTS

SUMMARY OF RESULTS

1. The average reservoir pressure (P_R) is 5 416 kPa.

2. The effective permeability to water of the Spearfish formation is 0.08 mD.

3. The apparent wellbore skin factor of -5.5 and the fracture half length of 42.8 m confirm that the well was stimulated. The fracture face skin (S_f) of 0.2 indicates that the effectiveness of the fracture has been reduced possibly due to fine plugging from the injected water.

4. The stabilized water injection rate is 1.3 m^3/d

5. The injectivity index (I.I.) is 1.21E-4 $m^3/d/kPa$.

TEST ANALYSIS

DISCUSSION

1. Test Overview:

The Home Pierson 02-09-02-29W1 is completed in the Spearfish formation at 1024 - 1028.5 mKB and is equipped with a 60.3 mm tubing (landed at 1015.31 mKB). The well was fractured during the initial completion to improve productivity.

During the test, water was injected at 1.4 m^3/d for 3 hours at a wellhead injection pressure 3 540 kPa. Subsequently, the well was shutin for a 451 hour fall-off period.

2. Data Validation:

During the injection/fall-off test, tandem electronic pressure recorders were set at 1010.6 mCF & 1011.6 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. There is an abrupt deflection in the pressure data at a BHP of 11 000 kPa, during the fall-off period. This phenomenal has been observed in two other tests. The formation fracture pressure is calculated also at 11 000 kPa. There is a very unusual similarity between the observed pressure anomaly and the estimated formation fracture pressure. This similarity confirms that water has been injected over the formation fracture pressure. As the BHP declines close the fracture pressure of 11 000 kPa, the fracture closes (heals) causing the pressure anomaly. The three wells that exhibited this phenomena are 04-17, 02-09 and 02-17.

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.

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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 1.4 m^3/d at a sandface flowing pressure of 16 557 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". As discussed in the data validation section most of the buildup data was distorted due to the fracture closure (healing), at a BHP of approximately 11 000 kPa.

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 7 461 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 7 792 kPa. The results of the Horner plot are summarized below:

	Horner
Effective Permeability, mD	0.24
Ave. Reservoir Pressure, kPa	7 792
Apparent Skin Factor	-3.3

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 (Figure 7), in the section "Pressure History Match". The parameters used to achieve the history match are as follows:

	History Match	
Reservoir Pressure, P_r	5 416	kPa
Effective Permeability, k	0.08	mD
Fracture conductivity, $K_f.w$	30852	mD.m
Fracture Half Length, X_f	42.8	m
Six-Month Stabilized Rate, q_s	1.3	$10^3m^3/d$

3. Well Injectivity:

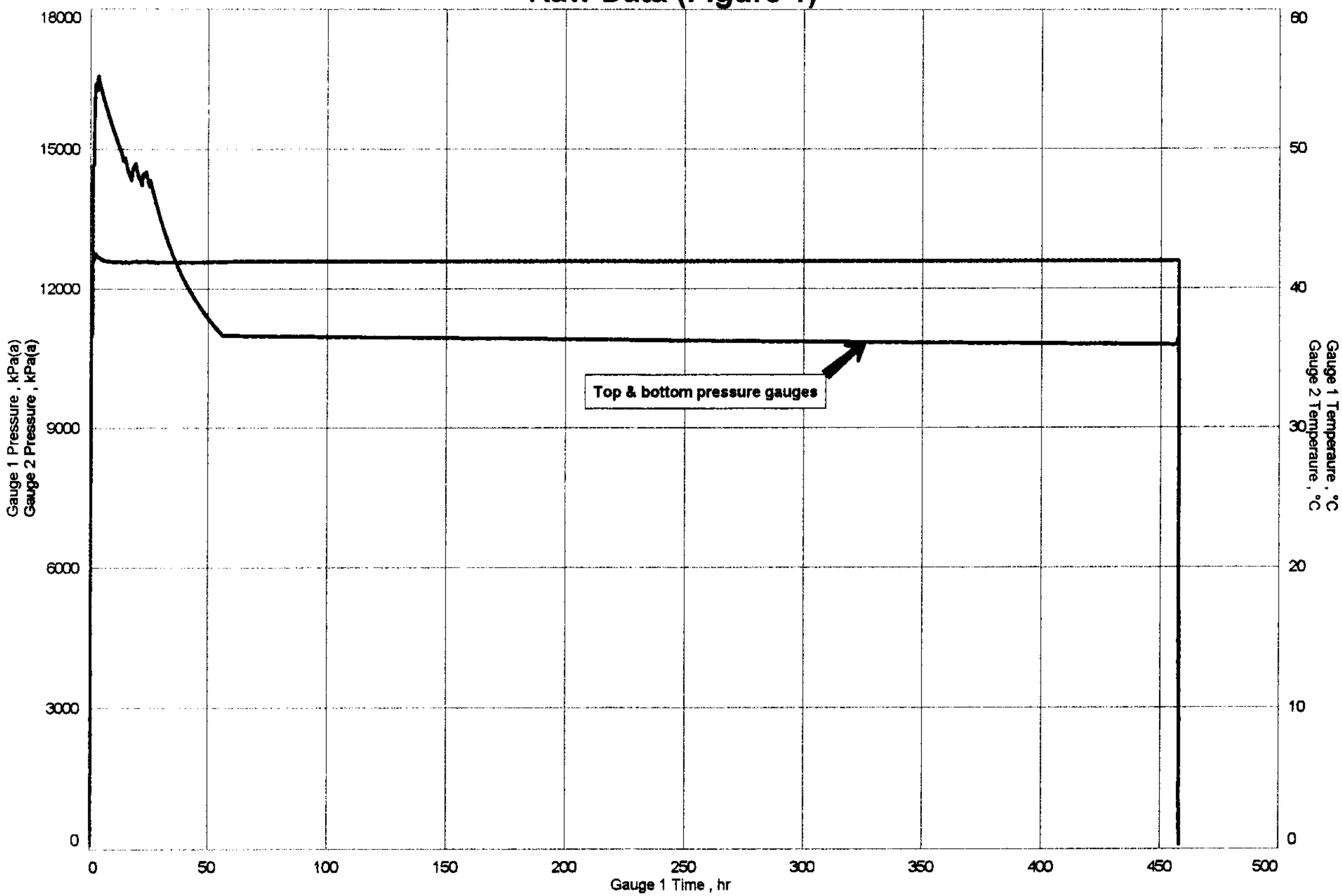
The well stabilized injection rate of 1.3 m3/d and the injectivity index (I.I.) is 1.21E-4 $m^3/d/kPa$ were obtained from the test history match at the current wellbore skin of -5.5.

TEST DATA
QUALITY

100/02-09-002-29W1/0

Home Pierson
Formation: Spearfish

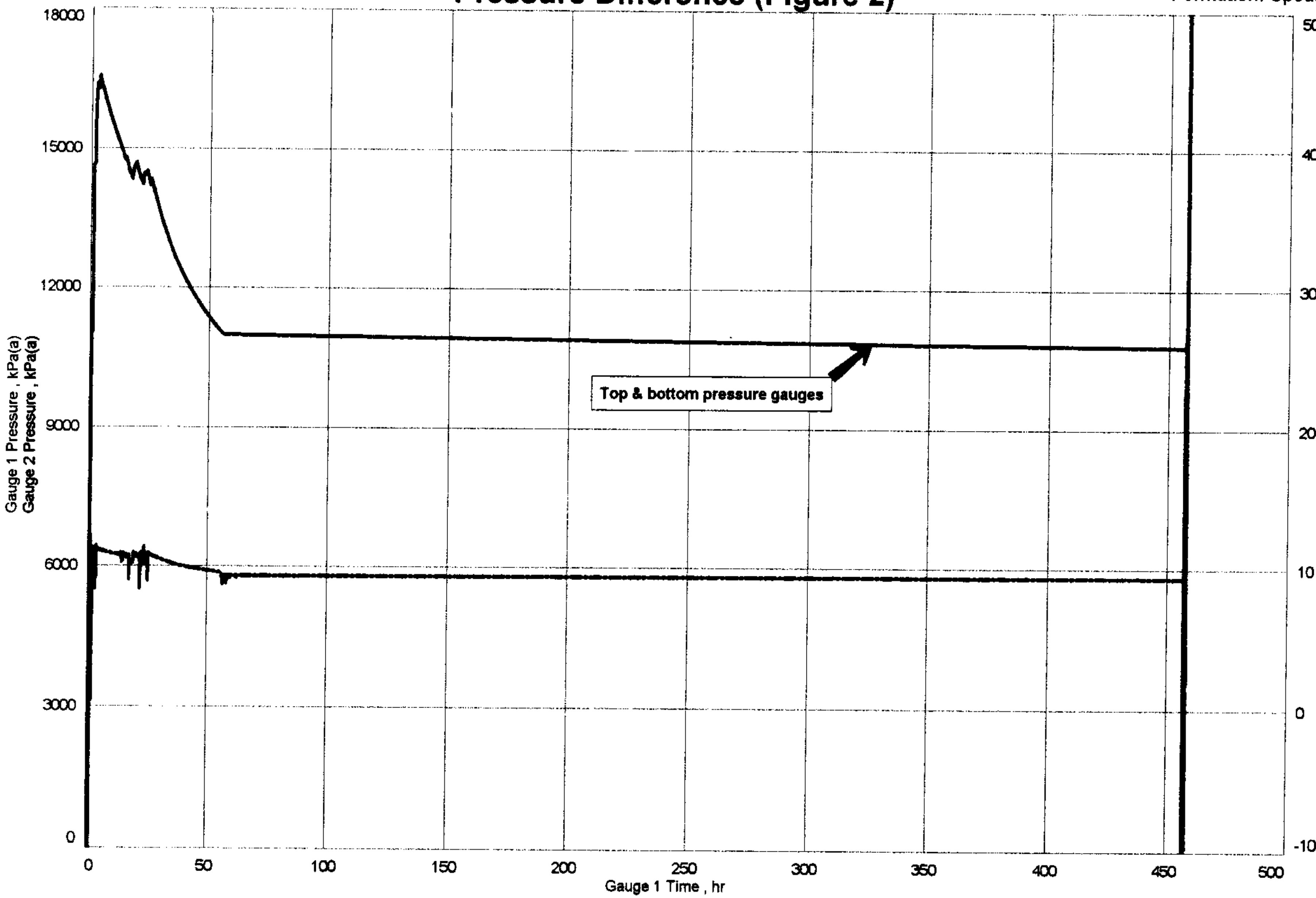
Raw Data (Figure 1)



100/02-09-002-29W1/0

Home Pierson
Formation: Spearfish

Pressure Difference (Figure 2)



Home Pierson 02-09-02-29W1
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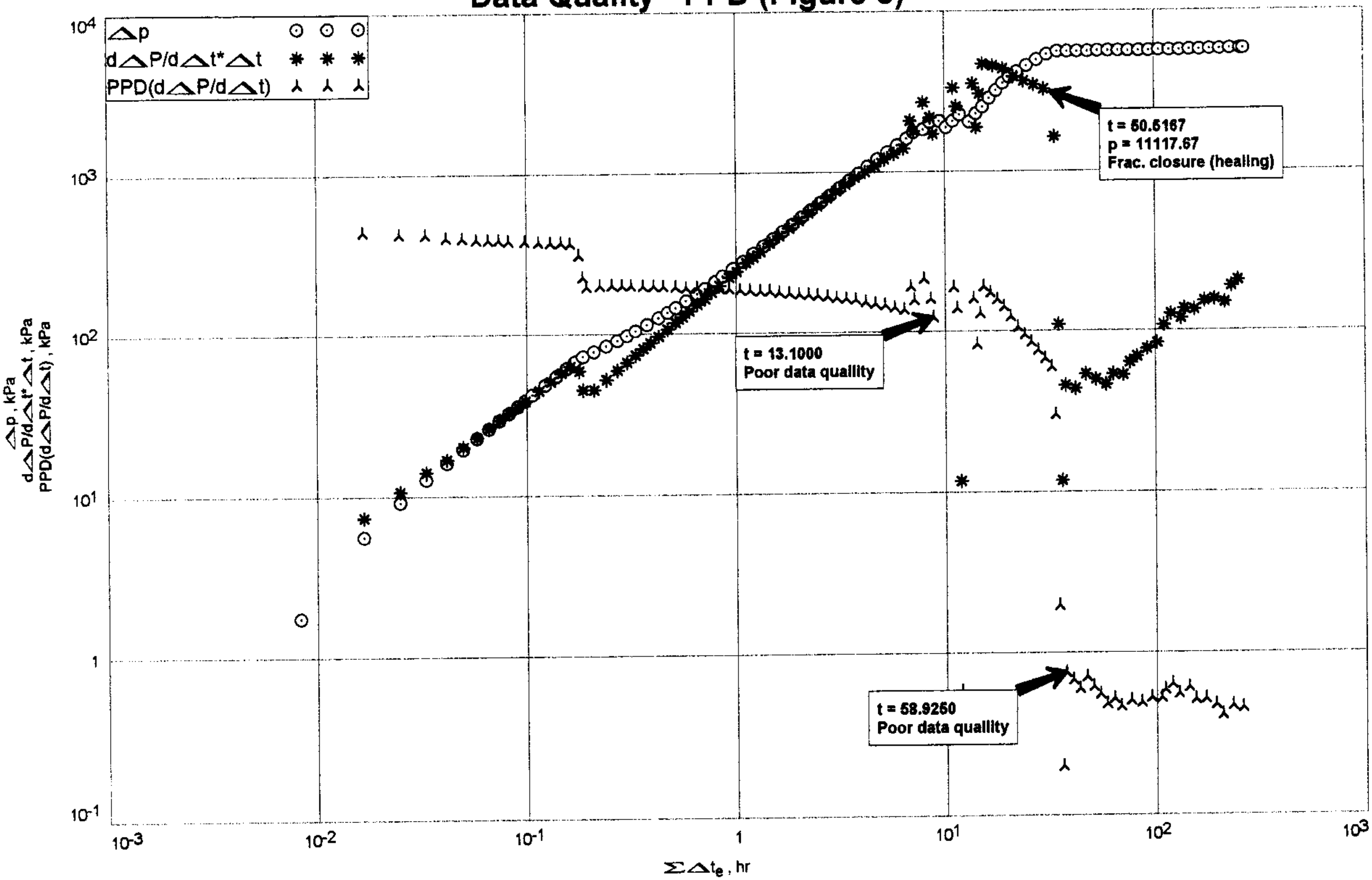
Data Quality - PPD (Figure 3)



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**PRESSURE
TRANSIENT
ANALYSIS**

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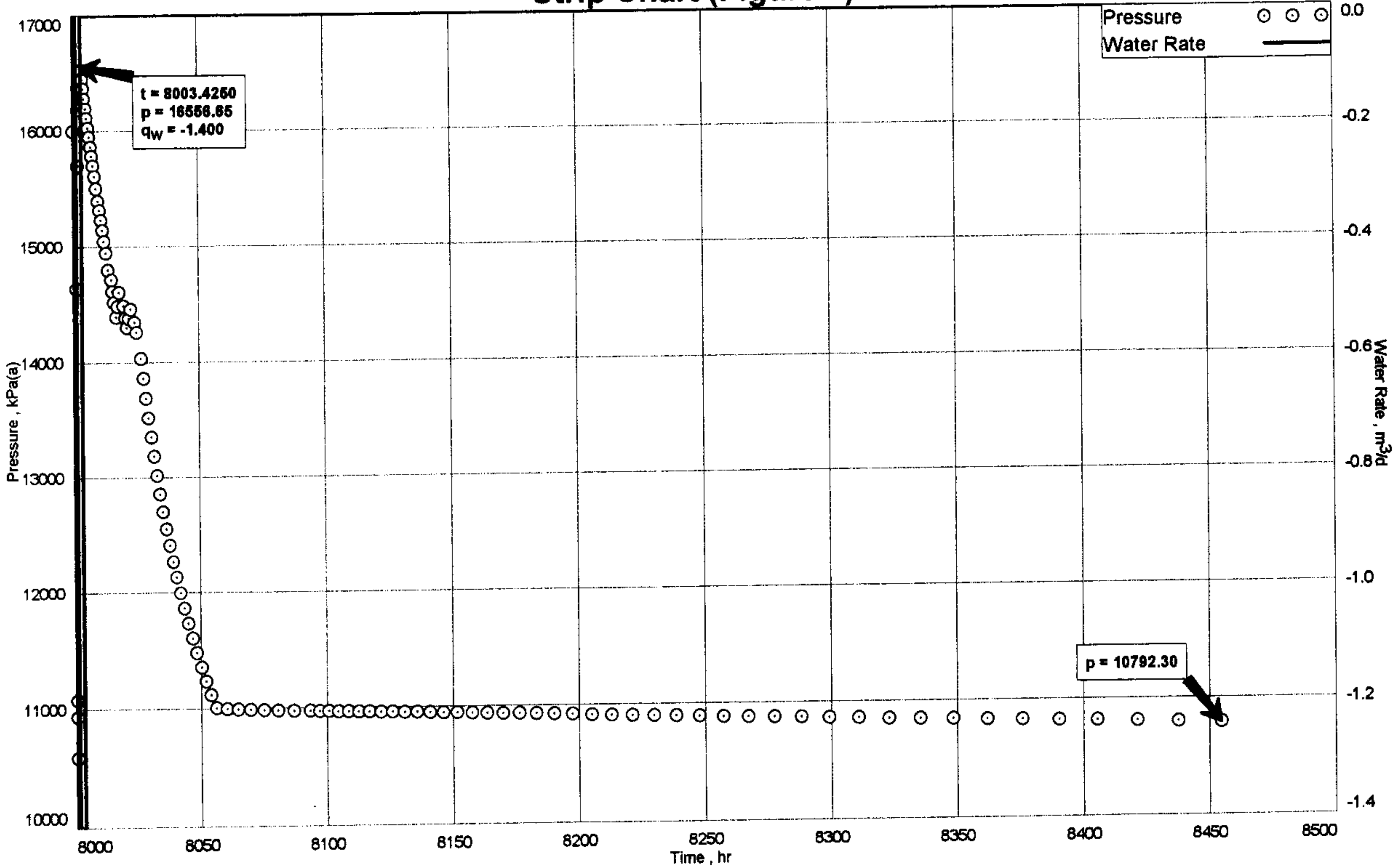
Strip Chart (Figure 4)



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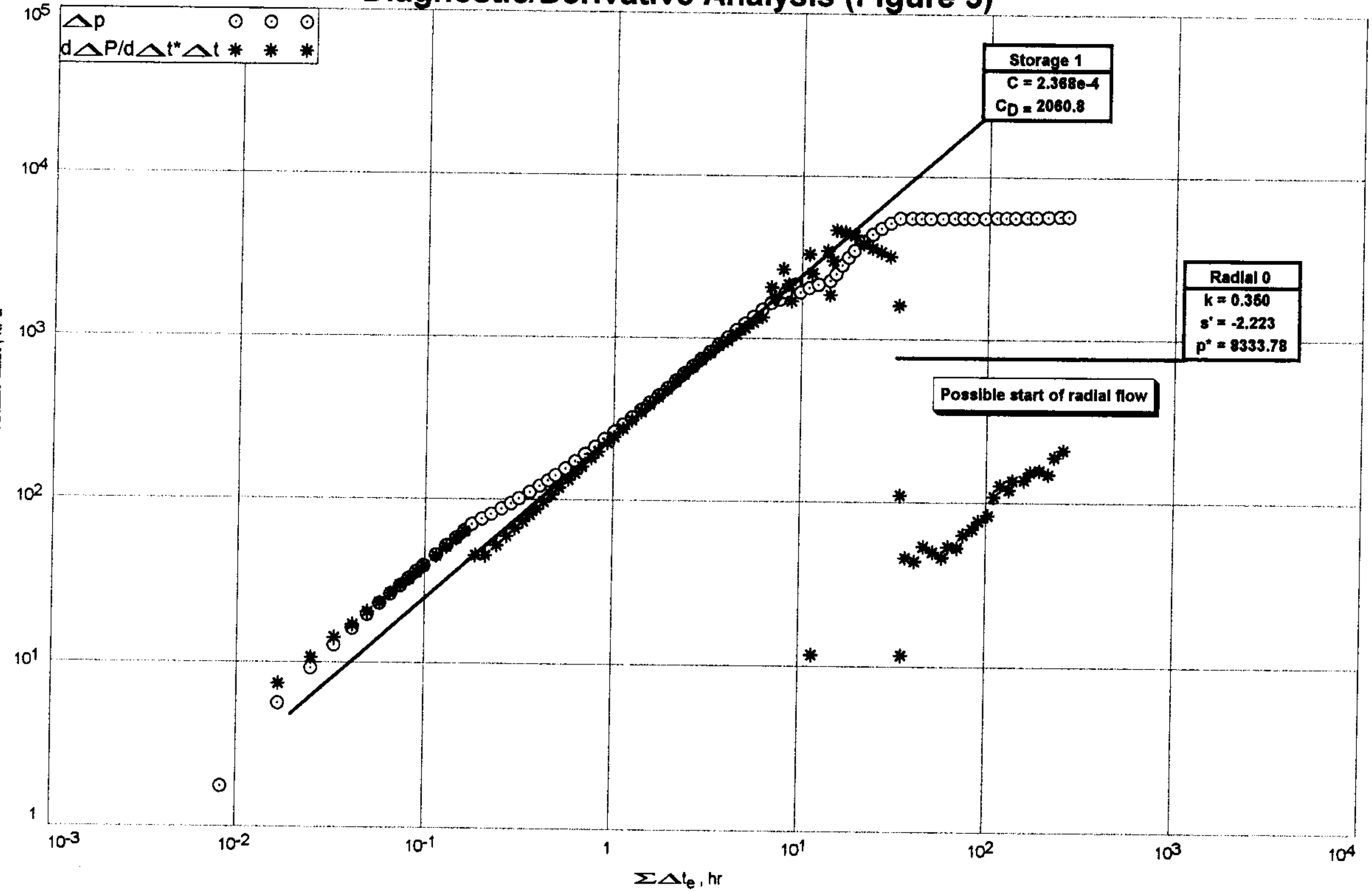
Diagnostic/Derivative Analysis (Figure 5)



Home Pierson 02-09-02-29W1
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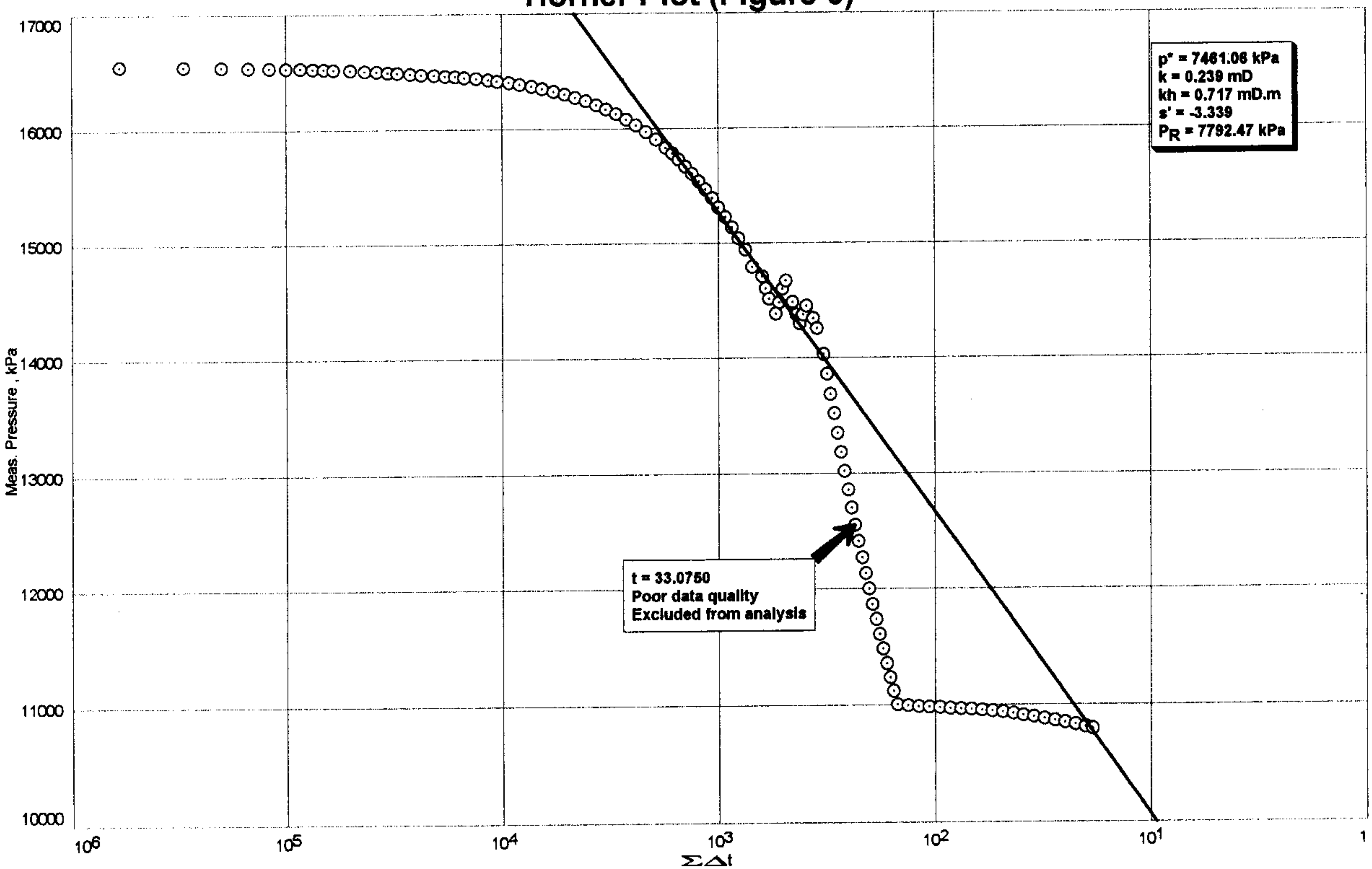
Horner Plot (Figure 6)



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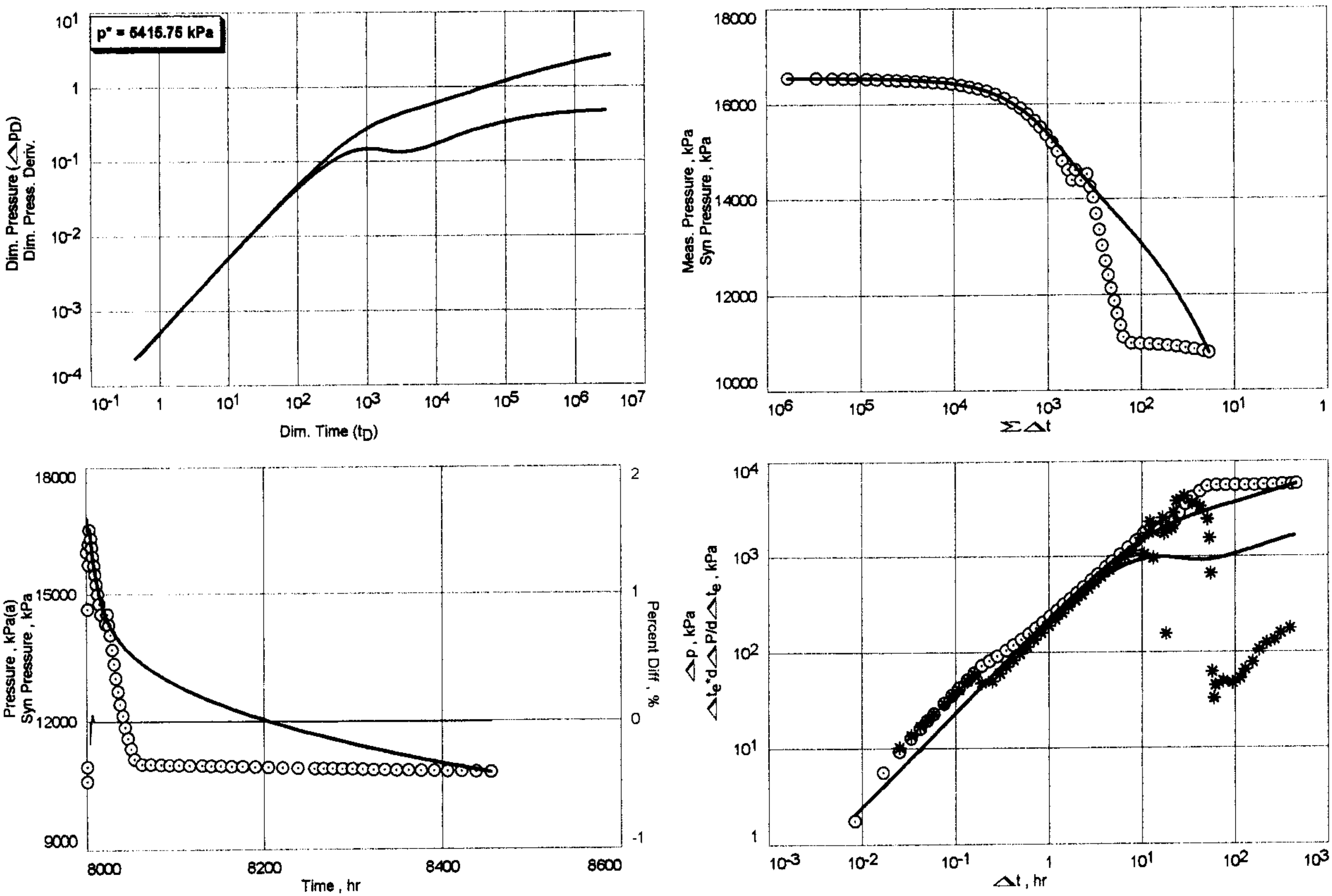
PRESSURE
HISTORY
MATCHING

Finite Conductivity Fracture #1



SUBSURFACE
PRESSURES

Home Pierson 02-09-02-29W1
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	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	16000.00	0.000	0.000	-1.400
2	-0.1000	8000.1000	16000.00			
3	0.5083	8000.5083	10589.11	0.000	0.000	0.000
4	0.5417	8000.5417	10939.15			
5	0.5750	8000.5750	11079.37			
6	0.6167	8000.6167	11102.37			
7	0.6583	8000.6583	11035.54			
8	0.7000	8000.7000	11035.13			
9	0.7417	8000.7417	11036.96			
10	0.7917	8000.7917	11024.77			
11	0.8417	8000.8417	11082.32			
12	0.8917	8000.8917	11077.47			
13	0.9500	8000.9500	11074.66			
14	- 1.0083	8001.0083	11072.07			
15	1.0750	8001.0750	11069.16			
16	1.1417	8001.1417	14637.05			
17	1.2167	8001.2167	14646.71			
18	1.2917	8001.2917	14654.03			
19	1.3583	8001.3583	14660.09			
20	1.3667	8001.3667	14660.89			
21	1.6167	8001.6167	14680.66			-1.400
22	1.8667	8001.8667	15700.30			
23	2.1250	8002.1250	16186.80			
24	2.3750	8002.3750	16375.02			
25	2.6250	8002.6250	16351.40			
26	2.8750	8002.8750	16319.57			
27	3.1250	8003.1250	16336.10			
28	3.3750	8003.3750	16531.48			-1.400
29	3.4167	8003.4167	16553.59			
30	3.4250	8003.4250	16556.65	0.000		-1.400
31	3.4333	8003.4333	16554.90			0.000
32	3.4417	8003.4417	16551.07			
33	3.4500	8003.4500	16547.44			
34	3.4583	8003.4583	16543.94			
35	3.4667	8003.4667	16540.53			
36	3.4750	8003.4750	16537.16			
37	3.4833	8003.4833	16533.83			
38	3.4917	8003.4917	16530.57			
39	3.5000	8003.5000	16527.28			
40	3.5083	8003.5083	16524.07			
41	3.5167	8003.5167	16520.83			
42	3.5250	8003.5250	16517.66			

Print Filter Used: Nth Line = 1.000

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	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	3.5333	8003.5333	16514.48			
44	3.5417	8003.5417	16511.33			
45	3.5500	8003.5500	16508.15			
46	3.5583	8003.5583	16505.02			
47	3.5667	8003.5667	16501.88			
48	3.5750	8003.5750	16498.77			
49	3.5833	8003.5833	16495.66			
50	3.5917	8003.5917	16492.56			
51	3.6000	8003.6000	16489.47			
52	3.6083	8003.6083	16486.39			
53	3.6167	8003.6167	16484.21			
54	3.6250	8003.6250	16482.56			
55	3.6333	8003.6333	16480.90			
56	3.6417	8003.6417	16479.23			
57	3.6583	8003.6583	16475.87			
58	3.6750	8003.6750	16472.51			
59	3.6917	8003.6917	16469.12			
60	3.7083	8003.7083	16465.77			
61	3.7250	8003.7250	16462.40			
62	3.7417	8003.7417	16459.05			
63	3.7583	8003.7583	16455.70			
64	3.7750	8003.7750	16452.35			
65	3.7917	8003.7917	16448.99			
66	3.8083	8003.8083	16445.66			
67	3.8250	8003.8250	16442.34			
68	3.8417	8003.8417	16439.05			
69	3.8583	8003.8583	16435.72			
70	3.8833	8003.8833	16430.75			
71	3.9083	8003.9083	16425.78			
72	3.9333	8003.9333	16420.82			
73	3.9583	8003.9583	16415.90			
74	3.9833	8003.9833	16411.00			
75	4.0083	8004.0083	16406.05			
76	4.0333	8004.0333	16401.17			
77	4.0583	8004.0583	16396.29			
78	4.0833	8004.0833	16391.41			
79	4.1167	8004.1167	16384.96			
80	4.1500	8004.1500	16378.50			
81	4.1833	8004.1833	16372.03			
82	4.2167	8004.2167	16365.59			
83	4.2500	8004.2500	16359.20			
84	4.2833	8004.2833	16352.79			

Print Filter Used: Nth Line = 1.000

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	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	4.3250	8004.3250	16344.76			
86	4.3667	8004.3667	16336.75			
87	4.4083	8004.4083	16328.75			
88	4.4500	8004.4500	16320.79			
89	4.4917	8004.4917	16312.83			
90	4.5417	8004.5417	16303.39			
91	4.5917	8004.5917	16293.97			
92	4.6417	8004.6417	16284.54			
93	4.6917	8004.6917	16275.19			
94	4.7417	8004.7417	16265.84			
95	4.8000	8004.8000	16254.94			
96	4.8583	8004.8583	16244.09			
97	4.9167	8004.9167	16233.23			
98	4.9833	8004.9833	16220.90			
99	5.0500	8005.0500	16208.60			
100	5.1167	8005.1167	16196.34			
101	5.1833	8005.1833	16184.07			
102	5.2583	8005.2583	16170.37			
103	5.3333	8005.3333	16156.69			
104	5.4083	8005.4083	16143.09			
105	5.4917	8005.4917	16128.18			
106	5.5750	8005.5750	16113.30			
107	5.6667	8005.6667	16097.01			
108	5.7583	8005.7583	16080.77			
109	5.8500	8005.8500	16064.60			
110	5.9500	8005.9500	16046.99			
111	6.0500	8006.0500	16029.45			
112	6.1583	8006.1583	16010.50			
113	6.2667	8006.2667	15991.62			
114	6.3833	8006.3833	15971.34			
115	6.5000	8006.5000	15951.14			
116	6.6250	8006.6250	15929.67			
117	6.7583	8006.7583	15906.83			
118	6.8917	8006.8917	15884.13			
119	7.0333	8007.0333	15860.08			
120	7.1750	8007.1750	15836.07			
121	7.3250	8007.3250	15810.81			
122	7.4833	8007.4833	15784.33			
123	7.6500	8007.6500	15756.75			
124	7.8167	8007.8167	15729.28			
125	7.9917	8007.9917	15700.58			
126	8.1750	8008.1750	15670.73			

Print Filter Used: Nth Line = 1.000

	Time	Cum Time	Pressure	Gas Rate	Oil Rate	Water Rate
	hr	hr	kPa(a)	$10^3m^3/d$	m^3/d	m^3/d
127	8.3667	8008.3667	15639.74			
128	8.5667	8008.5667	15607.04			
129	8.7750	8008.7750	15573.94			
130	8.9917	8008.9917	15539.78			
131	9.2167	8009.2167	15504.76			
132	9.4500	8009.4500	15468.42			
133	9.6917	8009.6917	15431.24			
134	9.9417	8009.9417	15393.11			
135	10.2000	8010.2000	15354.00			
136	10.4667	8010.4667	15313.98			
137	10.7500	8010.7500	15271.79			
138	11.0417	8011.0417	15228.33			
139	11.3417	8011.3417	15184.32			
140	11.6583	8011.6583	15138.59			
141	11.9833	8011.9833	15092.04			
142	12.3250	8012.3250	15043.78			
143	12.6750	8012.6750	14994.80			
144	13.0417	8013.0417	14944.18			
145	13.4250	8013.4250	14887.84			
146	13.8167	8013.8167	14794.96			
147	14.2250	8014.2250	14760.24			
148	14.6500	8014.6500	14803.41			
149	15.0917	8015.0917	14712.37			
150	15.5500	8015.5500	14609.06			
151	16.0250	8016.0250	14514.35			
152	16.5250	8016.5250	14452.14			
153	17.0417	8017.0417	14389.00			
154	17.5750	8017.5750	14483.14			
155	18.1333	8018.1333	14604.82			
156	18.7167	8018.7167	14671.51			
157	19.3167	8019.3167	14623.27			
158	19.9417	8019.9417	14485.42			
159	20.5917	8020.5917	14379.96			
160	21.2667	8021.2667	14298.56			
161	21.9667	8021.9667	14379.08			
162	22.7000	8022.7000	14455.75			
163	23.4583	8023.4583	14517.42			
164	24.2500	8024.2500	14345.32			
165	25.0667	8025.0667	14258.26			
166	25.9167	8025.9167	14206.75			
167	26.8000	8026.8000	14032.54			
168	27.7167	8027.7167	13860.35			

Print Filter Used: Nth Line = 1.000

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Fall-off Test
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	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	28.6750	8028.6750	13688.43			
170	29.6667	8029.6667	13519.19			
171	30.7000	8030.7000	13350.57			
172	31.7750	8031.7750	13183.75			
173	32.8917	8032.8917	13019.17			
174	34.0500	8034.0500	12857.33			
175	35.2500	8035.2500	12700.27			
176	36.5000	8036.5000	12552.11			
177	37.8000	8037.8000	12409.33			
178	39.1500	8039.1500	12269.88			
179	40.5500	8040.5500	12132.60			
180	42.0083	8042.0083	11997.01			
181	43.5250	8043.5250	11863.92			
182	45.1000	8045.1000	11733.06			
183	46.7333	8046.7333	11605.02			
184	48.4333	8048.4333	11479.28			
185	50.2000	8050.2000	11355.93			
186	52.0333	8052.0333	11235.37			
187	53.9417	8053.9417	11117.67			
188	55.9250	8055.9250	11003.49			
189	57.9833	8057.9833	10994.85			
190	60.1250	8060.1250	10995.30			
191	62.3500	8062.3500	10993.97			
192	64.6583	8064.6583	10991.87			
193	67.0583	8067.0583	10990.19			
194	69.5500	8069.5500	10988.53			
195	72.1417	8072.1417	10986.91			
196	74.8333	8074.8333	10985.35			
197	77.6333	8077.6333	10983.43			
198	80.5417	8080.5417	10981.30			
199	83.5667	8083.5667	10979.43			
200	86.7083	8086.7083	10977.47			
201	89.9667	8089.9667	10975.68			
202	93.3583	8093.3583	10973.77			
203	96.8833	8096.8833	10972.00			
204	100.5417	8100.5417	10970.30			
205	104.3417	8104.3417	10968.32			
206	108.2917	8108.2917	10966.26			
207	112.4000	8112.4000	10964.16			
208	116.6667	8116.6667	10962.34			
209	121.1000	8121.1000	10960.19			
210	125.7083	8125.7083	10958.05			

Print Filter Used: Nth Line = 1.000

Home Pierson 02-09-02-29W1
Spearfish (1024 - 1028.5 mKB)
Fall-off Test
Test Date: Dec. 11 - 30, 1999

	Time hr	Cum Time hr	Pressure kPa(a)	Gas Rate $10^3 m^3/d$	Oil Rate m^3/d	Water Rate m^3/d
211	130.5000	8130.5000	10955.43			
212	135.4750	8135.4750	10952.87			
213	140.6417	8140.6417	10950.25			
214	146.0167	8146.0167	10947.68			
215	151.6000	8151.6000	10945.01			
216	157.4000	8157.4000	10941.91			
217	163.4250	8163.4250	10938.78			
218	169.6917	8169.6917	10935.74			
219	176.2000	8176.2000	10932.52			
220	182.9667	8182.9667	10928.77			
221	189.9917	8189.9917	10924.40			
222	197.2917	8197.2917	10919.68			
223	204.8833	8204.8833	10914.87			
224	212.7667	8212.7667	10910.10			
225	220.9583	8220.9583	10905.88			
226	229.4750	8229.4750	10901.15			
227	238.3250	8238.3250	10895.67			
228	247.5167	8247.5167	10890.16			
229	257.0667	8257.0667	10885.08			
230	266.9917	8266.9917	10880.12			
231	277.3083	8277.3083	10874.86			
232	288.0250	8288.0250	10869.66			
233	299.1667	8299.1667	10863.51			
234	310.7417	8310.7417	10857.36			
235	322.7667	8322.7667	10851.54			
236	335.2667	8335.2667	10845.69			
237	348.2500	8348.2500	10840.26			
238	361.7417	8361.7417	10834.78			
239	375.7667	8375.7667	10829.26			
240	390.3417	8390.3417	10822.82			
241	405.4833	8405.4833	10815.32			
242	421.2167	8421.2167	10807.89			
243	437.5667	8437.5667	10800.24			
244	454.5583	8454.5583	10792.30			

Print Filter Used: Nth Line = 1.000

EQUATIONS

and

NOMENCLATURE

(METRIC UNITS)

PMG

BASIC TIME FUNCTIONS

Flow Time t

Shut-In Time Δt

Horner Time $\dfrac{t + \Delta t}{\Delta t}$

Superposition Time $t_n = \sum_{j=1}^{n} \dfrac{q_j - q_{j-1}}{q_n} \log(t - t_{j-1})$

$$\Delta t_n = \sum_{j=1}^{n} \frac{q_j}{q_n} \log \frac{t_n + \Delta t - t_{j-1}}{t_n + \Delta t - t_j}$$

Equivalent Time $\Delta t_e = \dfrac{t \cdot \Delta t}{t + \Delta t}$

Root Time $\sqrt{t}$

$$\sqrt{\Delta t}$$

Tandem Root Time $\sqrt{t + \Delta t} - \sqrt{\Delta t}$

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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

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

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

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

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

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

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

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

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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

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

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

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

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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

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

NOMENCLATURE

Symbol	Description	Metric (SI)	Field
a	LIT flow equation coefficient	-	-
A	drainage area	m^2	ft^2
AOF	absolute open flow potential (gas)	$10^3 m^3/d$	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
$k_f w$	fracture conductivity	mD.m	md.ft
kh	flow capacity	mD.m	md.ft
k/μ	mobility	-	-
kh/μ	transmissivity	-	-

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

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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 - liquid	m^3 m^3	ft^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

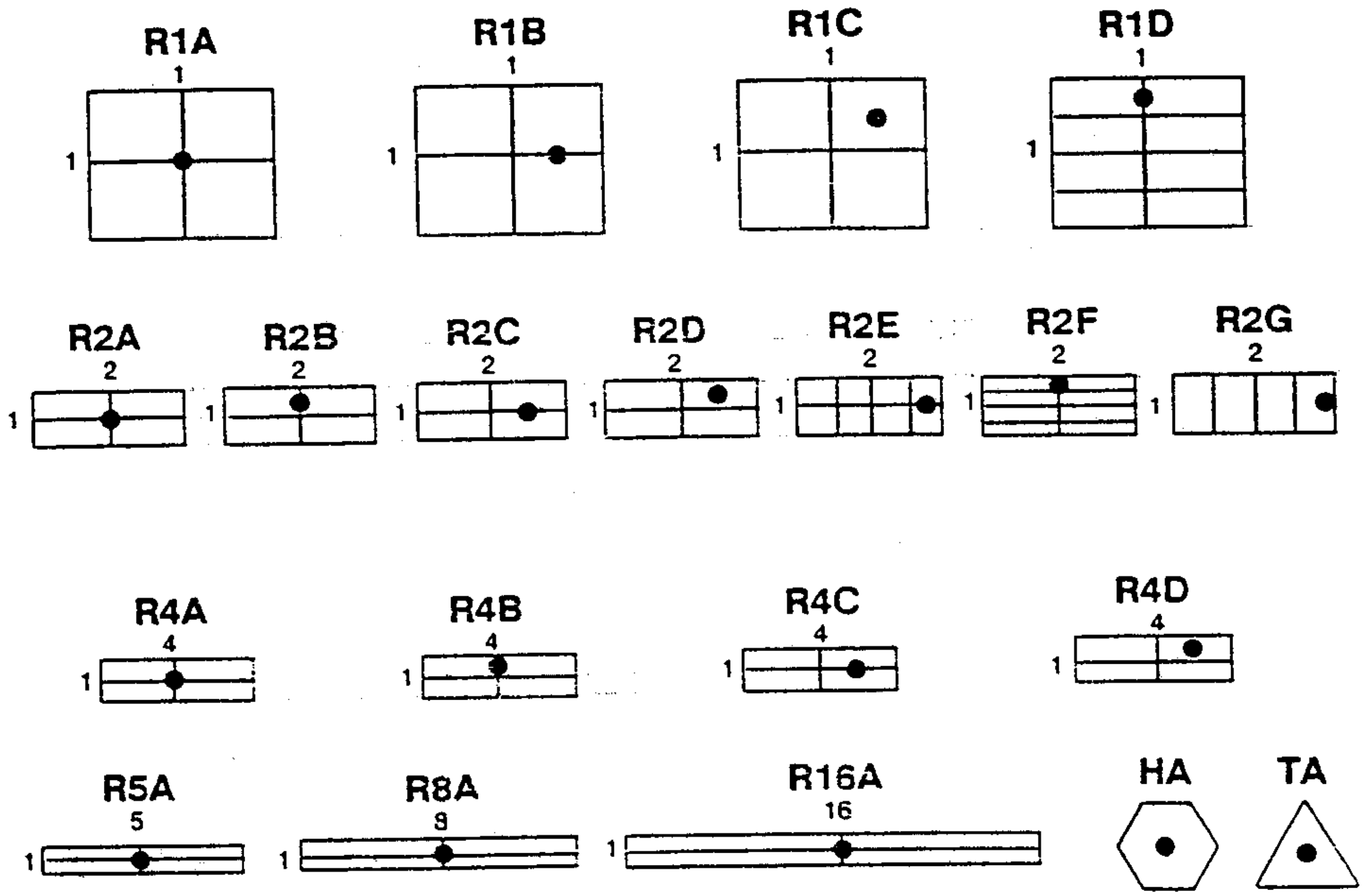
Superscripts

-	average

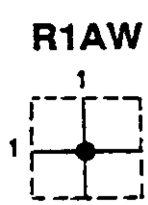
DIETZ SHAPE CODES

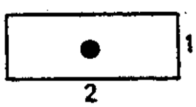
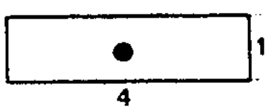
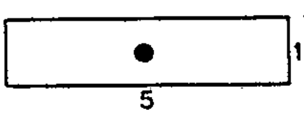
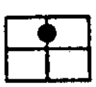
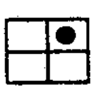
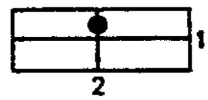
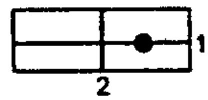
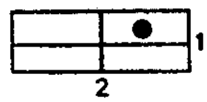
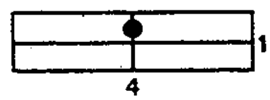
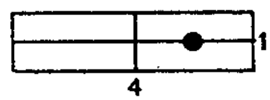
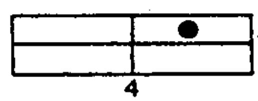
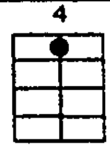
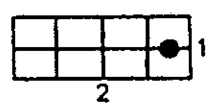
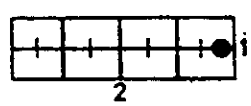
AVERAGE RESERVOIR PRESSURE - MBH CORRECTIONS

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