RESERVOIR DATA ANALYSIS AT THE WELLSITE

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Abstract

Current drill-stem test pressure-recording techniques rely on a pressure sensor, a chart recorder and a clock. Analysis and interpretation of this recorder data can only be done after the tool string is retrieved from the well.

The subject of this paper is a computer-based system that monitors, records, analyzes and displays at the wellsite, supplying the reservoir data necessary for the well operator to make a production decision about the well.

This system uses the capabilities of full-opening testing strings to provide instantaneous display of pressure and temperature information at the time intervals selected by the operator. Because the system provides a continuous stream of data (at selected intervals) the printer-plotter can display results of computer calculations and make graphs necessary for evaluation of the reservoir. The well operator can judge by the data received when the test can be terminated, and so could shorten significantly the rig time used for the test.

A conventional 'pressure vs. time plot' is made throughout the test, and Horner, Log-Log and 'pressure vs. square root of time plots' are available on operator demand. The well operator can also obtain calculations of the well's theoretical potential at the conclusion of the test or during any flow period after closed-in pressure data accumulate.

Introduction

Recent increases in drilling and completion costs and advances in computer technology have led to improvement in reservoir evaluation techniques. One area of improvement is drill-stem testing, one of the most important reservoir evaluation methods available to the oil and gas industry.

Present techniques of recording pressure and temperature data during a drill-stem test, well known to reservoir engineers and geologists, employ mechanical recording devices located in the testing assembly to provide a permanent record of well characteristics. Interpretation of the data cannot be accomplished until these recording devices are withdrawn from the well (with the testing assembly). Over the years, these techniques have yielded valuable and accurate pressure and temperature information about reservoirs; however, a means to obtain more accurate real-time information has been demanded by the industry in order to help reduce costs and to provide sufficient data for adequate evaluation of the reservoir by the well operator.

A computer-bases data acquisition and retrieval system to monitor, record and analyze formation pressures and fluid temperatures at the wellsite has been developed to help satisfy these requirements. Subsurface data is transmitted over a single conductor wireline to a computer at the wellsite. Specialized surface BOP equipment, designed to improve the safety of the testing operation with the wireline in the testing string, can also be used for these tests.

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Elements of the System

A conventional full-opening, annulus-pressure-responsive testing tool modified to receive a measurement probe is normally used to receive data acquisition systems in cased wells (Fig. 1). Pressure-responsive tools require no pipe manipulation. In situations where the annulus-pressure-responsive tools are not desired, a full-opening testing tool requiring vertical manipulation of the drillpipe to open or close the tester valve can be used.

Computer equipment designed to receive and process the subsurface pressure and temperature measurements is suitably housed for the environment of the location. This equipment (Fig. 2) consists of signal processors, a mini-computer, two printer-plotters for recording data and plotting appropriate results, and a suitable power supply to operate the downhole probe. A tape punch is included with the equipment to enable the data to be transmitted via telex to a central location where it can be further analyzed. The computer equipment is powered by a power supply which normally provides continuous operation even if the primary source of power fails. The subsurface probe includes a quartz pressure gauge capable of measuring pressures in 11,000 psi with an accuracy of plus or minus 0.5 psi and a sensitivity of 0.01 psi, when properly corrected for temperature variation. The downhole probe includes a collar locator for establishing the position of the tool prior to its landing in the testing assembly. An electrically powered latching sub in the upper portion of the probe engages and holds the probe in the testing assembly.

Specialized lubricators are available for use on floating rigs or where manipulation of the testing string may be necessary. This wireline lubricator equipment allows latching of the elevators to the lubricator during testing operations and is capable of supporting tensile loads to 600,000 lb and pressures to 10,000 psi.

A conventional wireline logging unit is used to lower the probe into position on a 7/32" single conductor armoured cable, to set the proper tension on the cable prior to testing, and to retrieve the probe at the end of the testing operation.

Operation

Even though the unit is not limited to offshore testing, its primary use to date has been offshore. In a typical offshore testing operation where real-time pressure and temperature information is to be gathered, a conventional annulus-pressure-responsive testing assembly will be run into the cased well (Fig. 3). The conventional testing assembly is modified by placing a section above the tester valve, which is ported (Fig. 4) to allow the application of formation pressure to a sliding valve. Upon reaching the proper depth, above the perforations, the testing packer is set and the subsea test tree is landed in the BOP stack. After connection of the testing manifold, the wireline BOP and lubricator equipment are installed. The probe can then be lowered to the proper depth for landing in the surface-readout valve assembly (Fig. 5). Operation of the actuator sube allows two dogs to engage a grooved section of the surface-readout valve assembly, and further operation of the actuator sub forces the probe into the surface-readout valve and moves the valve to the open position (Fig. 6). At the time the surface-readout valve ports are aligned with the mating ports, formation pressure will be displayed on the surface computer equipment. After the latching operation, tension is placed on the wireline and a remotely operated clamp atop the wireline lubricator equipment is energized to maintain this tension.

Flowing of the well is begun by applying annulus pressure, which opens the ball valve within the annulus-pressure-responsive testing tool (Fig. 7). Corrected pressure, time and temperature are displayed on the surface computer equipment (Fig. 8), at 10-second intervals during the flow period. A graph of 'pressure vs. time' is generated on a printer-plotter as the test progresses (Fig. 9). A listing of pressure, time and temperature is also made on the second printer-plotter at intervals selected by the operator (Fig. 10). At the end of a flow period, the tester valve is closed by releasing the annular pressure.

During the closed-in period of the test, the pressure vs. time plot is continued. The tabular listing made by the second printer-plotter then includes not only pressure, time and temperature, but also the calculations of differential pressure and differential time. After a suitable time has elapsed and meaningful values have been established, the computer calculates and prints the static pressures derived from an extrapolated Horner plot, the pressure after one logarithmic cycle of a Horner plot and a value termed the correlation coefficient. As the correlation coefficient approaches 1.0, the well operator can evaluate the linearity of the Horner plot and ascertain whether or not sufficient data has been taken. If the operator desires, at any time during the closed-in period (Horner, 1951; Fig. 11), a Log-Log (Wattenbarger and Ramey, 1970; Fig. 12), or a pressure vs. square root of time plot (Fig. 13) can be made. Any one of these plots requires approximately 20 seconds, provides information on the progress of the tests and may indicate the additional test time required to collect adequate data.

Generally, drill-stem tests require more than one flow, with subsequent closed-in periods, to provide enough information for correlation of reservoir data analysis. At the conclusion of the test, during or after any closed-in period, the operator can request and obtain calculations of the well's theoretical potential. An example of these calculations is shown in Figure 14.

Depending on data analyzed, results can be obtained for liquid or gas production. The equations used for these calculations are shown in Appendix A. Communication between the operator and the computer system is maintained by a prompting routine which displays a request for variables required to make the calculations.

The data gathered throughout the complete testing period is recorded on magnetic tape cassettes. If desired, this data can also be transferred to a punched tape. This tape can be encoded for European or US telex transmission and provides an archival record of the data collected. The punched data can then be transmitted over telex to a central office for further analysis. Upon command, the computer will generate a report which includes a drawing of the testing assembly used with appropriate labels, ODs, IDs, lengths and depths; a pressure vs. time plot of the complete test; and a printed description of events that occurred during the test. Horner plots for each closed-in period are also included in this report, as well as Log-Log and pressure vs. square root of time plots, and calculations for liquid or gas production.

When the last closed-in period is finished, the probe is withdrawn from the surface-readout valve, closing the valve and disengaging the tool from its seated position. At this point, the probe is withdrawn from the well.

Field Use

Systems like those described have been used on floating vessels in the Adriatic Sea and the North Sea, and on land in the United Kingdom and in Europe, and have been introduced to the Asian and South American areas of operation. Drill-stem tests in many of these situations have been of many hours duration, to gain the maximum possible information on the reservoir being tested. The data provided by these tests have in many cases allowed the well operator, to plan further remedial work on the well prior to removing the testing string. Due to the full-opening characteristics of the test tools used, perforating, acidizing or fracturing can be accomplished without removing the testing string from the well, as may evaluation of fracturing and acidizing treatments.

Significant rig-time has often been saved by the system's ability to collect real-time data and analyze it with minimum delay. In many cases, where only subsurface recording gauges are used, inadequate data are obtained because of early termination of the drill-stem test. In these cases, real-time data acquisition would have enabled the well operator to continue the test until sufficient data for reservoir analysis was obtained.

The full-opening testing valve used in this system allows for adequate flows on high-potential wells, in addition to allowing for a downhole shut-in to enhance the evaluation of the reservoir. This full-opening capability also allows perforating of additional zones for tests or remedial treatment of a previously tested zone without withdrawing the testing string from the well.

Additional planning is required to help provide a safe testing situation, due to the fact that a wireline is in the well during the drill-stem test. It is common practice, where possible, to use a gel spacer above the tester valve to catch debris that might build-up in a critical section of the testing string and prevent the entry of the probe with the surface-readout valve. Use of the specialized wellhead equipment on floating rigs and proper planning in both land and offshore testing have greatly reduced the possibility of malfunction.

Conclusions

1. Collection and analysis of drill-stem testing data on a real-time basis allows for a more complete test to be conducted.
2. Significant cost advantages are possible through the use of a real-time data acquisition and analysis system.
3. Utilization of full-opening testing tools with the real-time data analysis system allows an efficient treatment or evaluation of other zones.

Acknowledgement

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WATTENBARGER, R. A., & RAMEY, H. J. Jr., 1970 — An investigation of wellbore storage and skin effect in unsteady liquid flow, Part II: finite difference treatment. Transactions of the Society of Petroleum Engineers of AIME, 249-291.

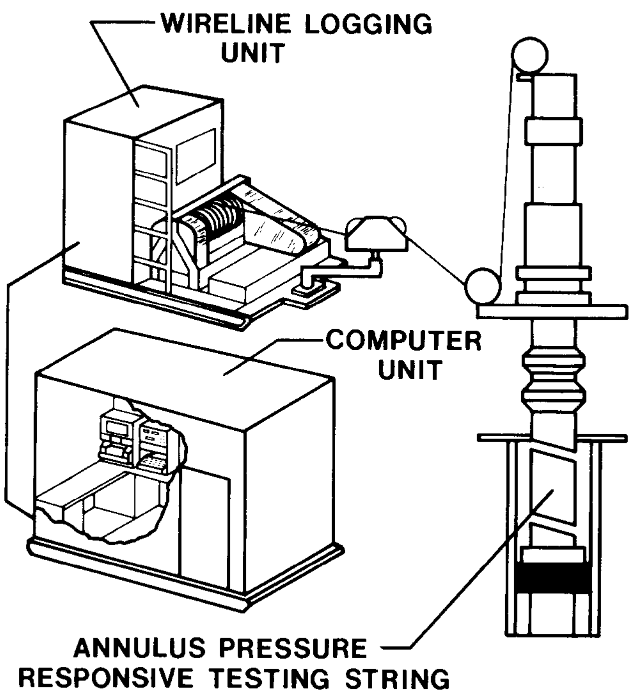

FIGURE 1 — SRO SYSTEM ELEMENTS

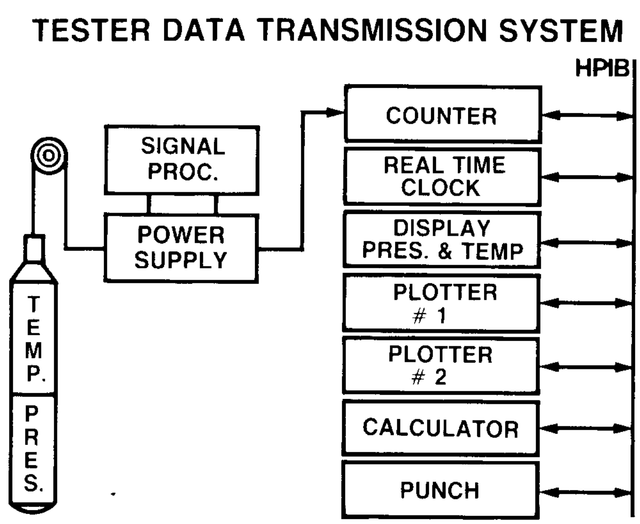

FIGURE 2 — TEST DATA TRANSMISSION SYSTEM

	O.D.	I.D.	LNGTH.	DEPTH
DRILL PIPE	4.500	3.826	200.0	
SUB-SEA TEST TREE	0.000	0.000	0.000	
DRILL PIPE	4.500	3.826	6809.0	
SLIP JOINT	5.000	2.250	13.0	
SLIP JOINT	5.000	2.250	13.0	
SLIP JOINT	5.000	2.250	13.0	
DRILL COLLARS	6.250	2.250	210.0	
APR-TYPE A-CIRC. VALVE	5.000	2.250	3.0	7071.5
DRILL COLLARS	6.250	2.250	60.0	
APR-M2 SAFETY CIRC. VLV.	5.000	2.250	7.5	7139.0
SURFACE READOUT VALVE	5.000	1.875	17.0	7156.0
APR-N TESTER	5.000	2.250	13.0	7169.0
FUL-FLO HYD. BYPASS	4.625	2.250	7.0	7176.0
JAR	4.625	2.375	5.0	
CIRC. VALVE-RTTS	4.870	2.440	3.0	7184.0
RTTS SAFETY JOINT	4.870	2.440	3.5	
PACKER-RETRIEVABLE	7.800	3.000	5.3	7192.0
BUNDLE CARRIER	5.375	2.175	8.0	7200.8

FIGURE 3 — TYPICAL OFFSHORE TESTING STRING.

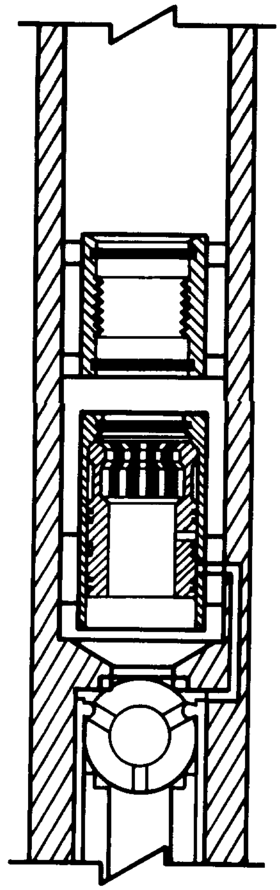

FIGURE 4 — SRO TESTER SUB.

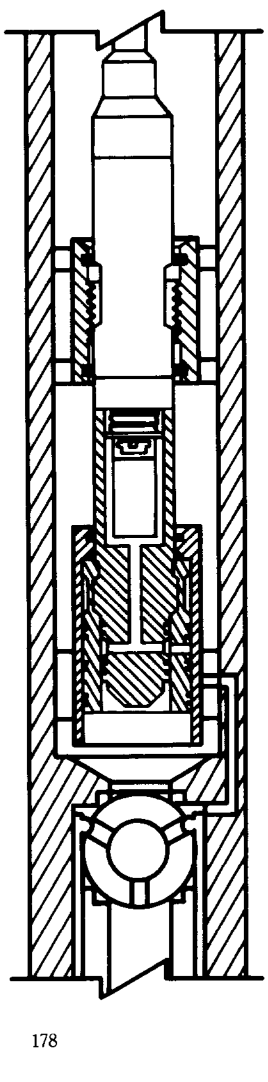

FIGURE 5 — PROBE LANDING.

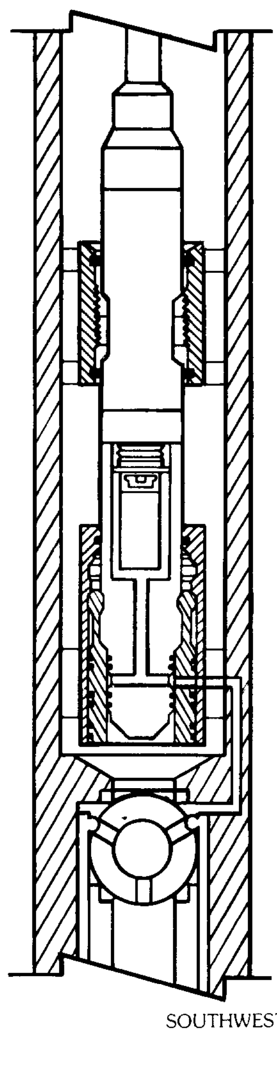

FIGURE 6 — PROBE ACTUATOR OPENS SRO VALVE.

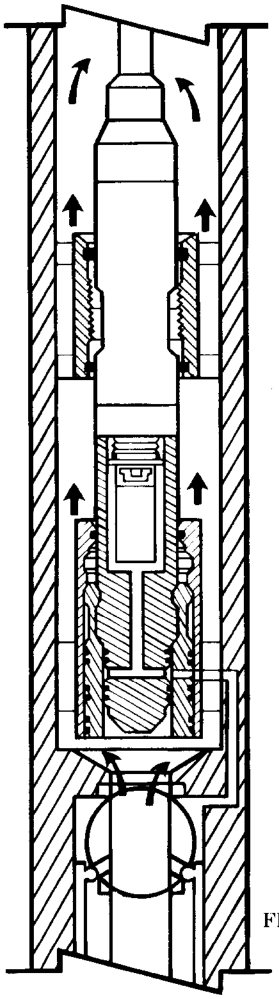

FIGURE 7 — SRO—DST TEST FLOW BEGINS.

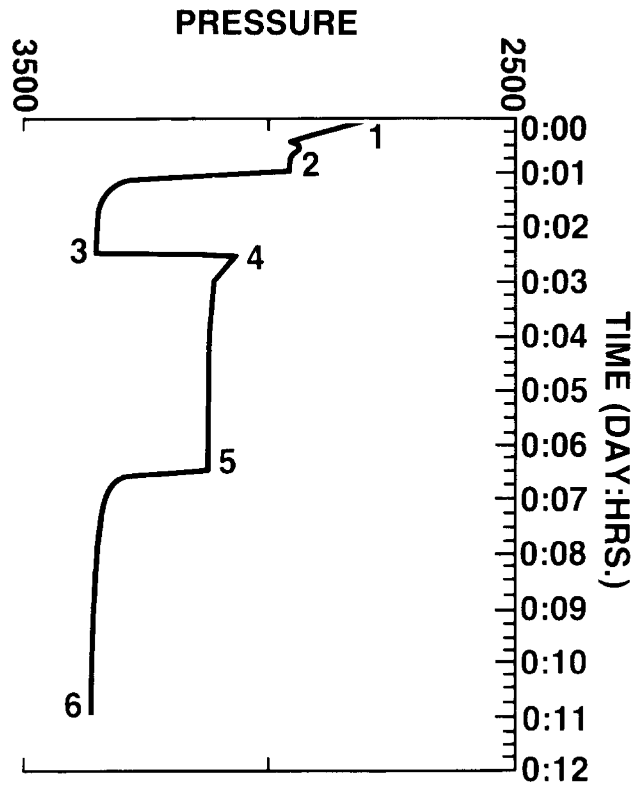

FIGURE 9 — PRESSURE BUILD-UP CURVES.

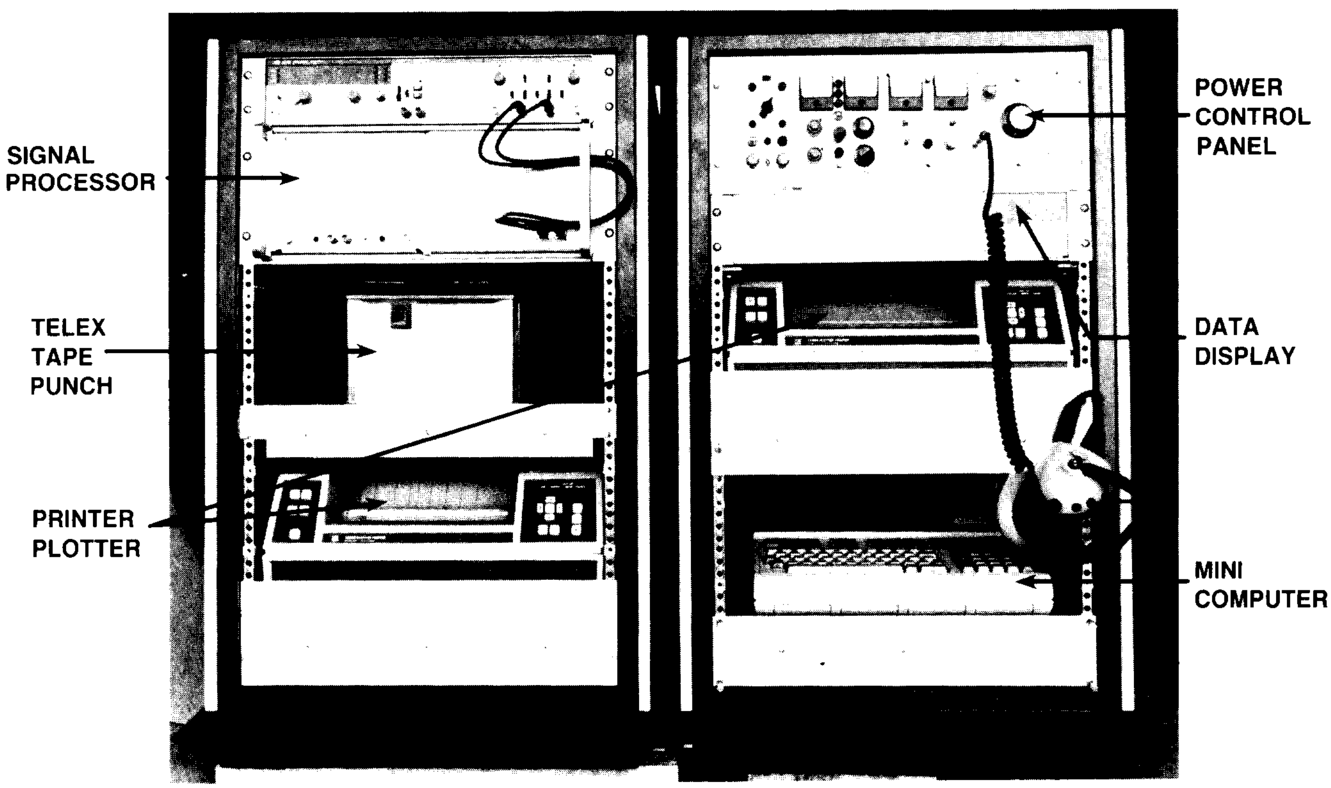

FIGURE 8 — DATA ANALYSIS SYSTEM.

Lease Name EXAMPLE Date TODAY Ticket No ###### Period # 1

Time	Press.	Temp	Delta t	P5	P10	CCc	
0:02:30:10	3050.00	123					initial flow # 2
0:03:00:00	3100 10	123	29.8				
0:03 30:00	3107.20	123	59.8				
0:04 00:00	3109.40	123	89.8				
0:04:30:00	3112.60	123	119.8				
0:05:00:00	3110.70	123	149.8				
0:05:30:00	3110.10	123	179 8				
0:06:00:00	3111 30	123	209.8				
0:06:30:00	3110.80	123	239.8				final flow # 2
0:06:31:60	3170 10	123	2 0				
0:06:34:00	3231 66	123	4.0				
0:06:36:00	3261 67	123	6.0				
0:06:37:00	3275.00	123	7.0				
0:06:40:00	3292.33	123	10.0				
0:06 42:00	3300.16	123	12 0	3549 36	3377.50	0 992439	
0:06:43:00	3304.67	123	13.0	3478 53	3352.39	0.994303	
0:06:46:00	3311.66	123	16.0	3451 19	3343 79	0 997962	
0:06 48:00	3315.00	123	18.0	3443 77	3341 29	0.996093	
0:06:49:06	3318.33	123	19.1	3442 21	3340 78	0.996764	
0:07 00:00	3328.30	123	30.0	3400 60	3331 52	0 992357	
0:07 10:00	3332.90	123	40.0	3387 03	3329 33	0 992108	
0:07 30:00	3338.00	123	60 0	3376 72	3328 30	0.988762	
0:07 49:60	3341.40	123	80.0	3370 25	3328.58	0 992358	
0:08:10:00	3343.80	123	100 0	3364 91	3329.84	0.999073	
0:08 30:00	3345.80	123	120 0	3363 84	3330.33	0.999974	
0:08 49:60	3347.30	123	140 0	3363 79	3330.34	0.999977	
0:09 10:00	3348.60	123	160 0	3363.78	3330.35	0.999961	
0:09:30:00	3349.70	123	180 0	3363 78	3330.35	0 999985	
0:09 49:60	3350.70	123	200 0	3363.82	3330.33	0 999981	
0:10:10.00	3351.50	123	220 0	3364.16	3329 88	0.999944	
0:10:30:00	3352.20	123	240.0	3364 10	3329 96	0.999946	
0:10:49:60	3352.90	123	260.0	3364.16	3329.89	0 999940	
0:11:10:00	3353.50	123	280.0	3364.22	3329.81	0 999933	
0:11:30:00	3354.00	123	300.0	3364.23	3329.79	0 999947	closed in # 2

FIGURE 10 — EXAMPLE OF TABULAR PRINT-OUT.

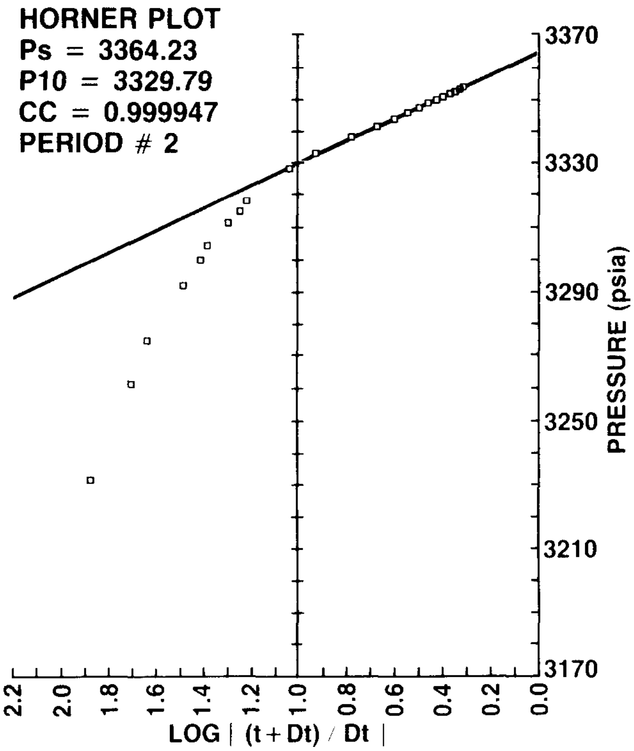

FIGURE 11 — HORNER PLOT.

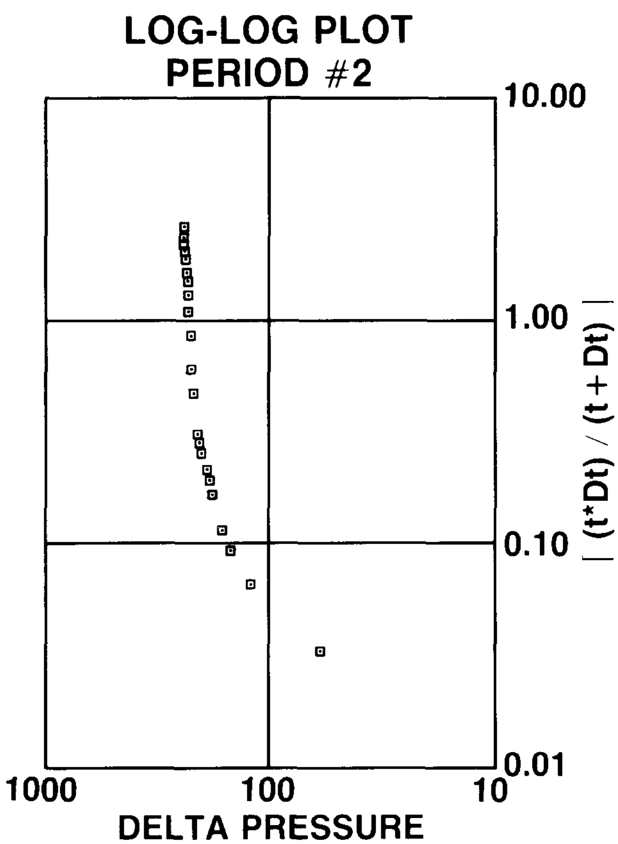

FIGURE 12 — LOG-LOG PLOT.

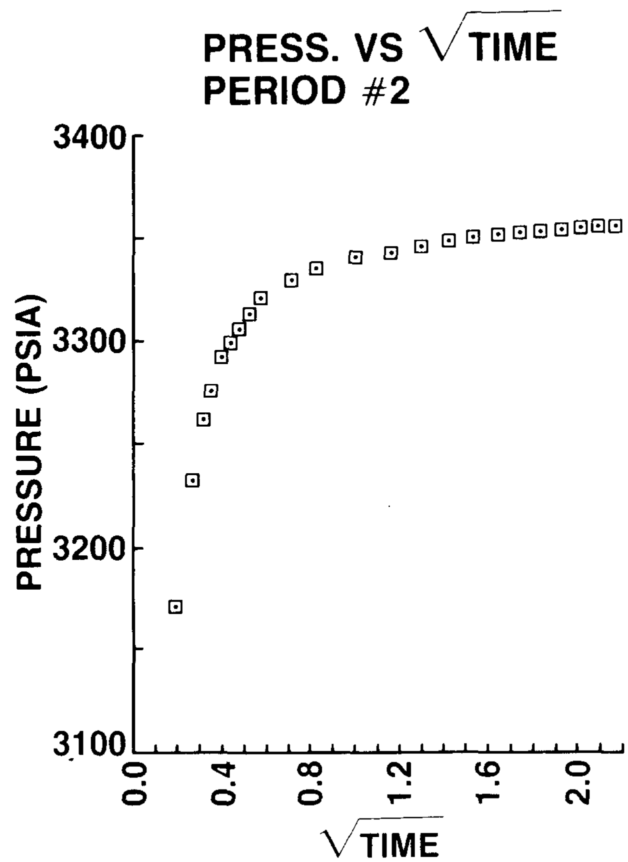

FIGURE 13 — PRESSURE VS. SQUARE ROOT OF TIME PLOT.

LIQUID PRODUCTION FOR OIL PERIOD # 2

GAS GRAVITY	0.600000		FLUID GRADIENT	0.368240	psi/ft
GAS/OIL RATIO	500.000000	cfpb	FORMATION VOL FACTOR	1.255827	v/v
TEMPERATURE	123.000000	F	FLUID PROPERTIES AT	3354.000000	Psig
VISCOSITY	1.462060	cp	NET PAY	11.000000	ft
API GRAVITY OF OIL	35.000000				
PIPE CAPACITY FACTORS	0.004918		0.014220 bbl/ft		

GAUGE DEPTH		7156.000000	ft
FINAL FLOW PRESSURE	Pf	3110.800000	Psig
TOTAL FLOW TIME	t	294.833333	min
EXTRAPOLATED PRESS.	Ps	3364.229115	Psig
ONE CYCLE PRESSURE		3329.792015	Psig
PRODUCTION RATE	Q	400.000000	BPD
TRANSMISSIBILITY	kh/u	2371.831913	mf/c
FLOW CAPACITY	kh	3467.760980	mdft
PERMEABILITY	k	315.250998	md
DAMAGE RATIO	DR	1.346732	
POTENTIAL RATE	Q1	538.692601	BPD

FIGURE 14 — CALCULATION OF A WELL'S THEORETICAL POTENTIAL: LIQUID PRODUCTION EXAMPLE.

APPENDIX A

NOMENCLATURE

B	= Formation Volume Factor (Res Vol Std Vol)	—
c_t	= System Total Compressibility	(Vol Vol) psi
DR	= Damage Ratio	—
h	= Estimated Net Pay Thickness	Ft
k	= Permeability	md
m	= (Liquid) Slope Extrapolated Pressure Plot	psi cycle
	(Gas) Slope Extrapolated m(P) Plot	MM psi^2 cp cycle
$m(P^*)$	= Real Gas Potential at P^*	MM psi^2 cp
$m(P_f)$	= Real Gas Potential at P_f	MM psi^2 cp
AOF_1	= Maximum Indicated Absolute Open Flow at Test Conditions	MCFD
AOF_2	= Minimum Indicated Absolute Open Flow at Test Conditions	MCFD
P^*	= Extrapolated Static Pressure	Psig
P_f	= Final Flow Pressure	Psig
Q	= Liquid Production Rate During Test	BPD
Q_1	= Theoretical Liquid Production w Damage Removed	BPD
Q_g	= Measured Gas Production Rate	MCFD
r_1	= Approximate Radius of Investigation	Ft
r_w	= Radius of Well Bore	Ft
S	= Skin Factor	
t	= Total Flow Time Previous to Closed-in	Minutes
Δt	= Closed-in Time at Data Point	Minutes
T	= Temperature Rankine	R
ϕ	= Porosity	—
μ	= Viscosity of Gas or Liquid	cp
Log	= Common Log	

EQUATIONS FOR DST LIQUID WELL ANALYSIS

Transmissibility	$\frac{kh}{\mu} = \frac{162.6\ QB}{m}$	$\frac{\text{md-ft}}{\text{cp}}$
Indicated Flow Capacity	$kh = \frac{kh}{\mu}\mu$	md-ft
Average Effective Permeability	$k = \frac{kh}{h}$	md
Damage Ratio	$DR = 183\ \frac{P^*\ P_f}{m}$	—
Theoretical Potential w Damage Removed	$Q_1 = Q\ DR$	BPD
Approx. Radius of Investigation	$r_1 = 4.63\sqrt{kt}$	ft

EQUATIONS FOR DST GAS WELL ANALYSIS

Indicated Flow Capacity	$kh = \frac{1637\ Q_g\ T}{m}$	md-ft
Average Effective Permeability	$k = \frac{kh}{h}$	md
Skin Factor	$S = 1.151\left[\frac{m(P^*) - m(P_f)}{m} - \text{LOG}\ \frac{kt}{\phi\ \mu\ c_t r_w^2} + 3.23\right]$	—
Damage Ratio	$DR = \frac{m(P^*) - m(P_f)}{m(P^*) - m(P_f) - 0.87\ mS}$	—
Indicated Flow Rate (Maximum)	$AOF_1 = \frac{Q_g\ m(P^*)}{m(P^*) - m(P_f)}$	MCFD
Indicated Flow Rate (Minimum)	$AOF_2 = Q_g\sqrt{\frac{m(P^*)}{m(P^*) - m(P_f)}}$	MCFD
Approx. Radius of Investigation	$r_1 = 0.032\sqrt{\frac{kt}{\phi\mu c_t}}$	ft