APPLICATION OF THE PRESSURE DERIVATIVE WITH ACOUSTIC DATA

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INTRODUCTION

A pressure buildup on a pumping well may be conducted by either of two methods. Direct measurement, of course, involves placing a gauge downhole. This presents special problems, however, for a pumping well. Since this procedure involves pulling the rods and pump in order to get the gauge downhole, it is usually economically infeasible. In addition, this "pulling" process introduces a new transient into the formation which adversely affects the analysis unless the well is restabilized once the gauge is downhole.

The second method involves acoustically determining the depth to the gas-liquid interface, measuring the casing pressure, and calculating the downhole pressure from these two measurements. With this method, an appropriate correlation must be selected in order to correct the liquid gradient for the gas in the column.

The pressure derivative is an analysis tool which has received considerable attention lately.[1-6] The two primary applications of the derivative are (1) identifying the different flow regimes and (2) obtaining a unique type curve match. Since the derivative involves a point-wise pressure difference rather than the pressure rise since the start of the test, it tends to amplify even small changes. For this reason, most examples have used data that was obtained from electronic pressure gauges.

The purpose of this paper is to show that the pressure derivative may be applied to acoustic data. Two examples will be presented showing (1) a well with wellbore storage and skin and (2) a fractured well.

ANALYSIS TECHNIQUES

Analyzing well test data involves a number of steps. The first of these is determining the system by identifying the various flow regimes. The traditional method of doing this has been to make a log-log plot of Δp versus t where $\Delta p = p_{ws} - p_{wf}$. Wellbore storage is indicated on this plot by a line of unit slope. Linear flow (representing a high conductivity vertical fracture) is indicated by a slope of one-half. Finally, radial flow is shown as the curve begins to flatten.

In order to analyze the data, a number of plots are used. Whenever the log-log plot exhibits a half-slope indicating linear flow, a plot of Δp versus the square root of time will show a straight line during that same time period. The slope of this line may then be used to calculate fracture length and permeability.

Radial flow is seen on a semilog plot (either Horner[7] or MDH[8]) when a straight line develops during the same time as radial flow on the log-log plot. From the slope of this line, permeability, skin, and average reservoir pressure may be determined.

A type curve analysis may also be performed using the appropriate type curve for the system under consideration. However, since the various curves are so similar, it can be difficult to get a unique match.

The derivative shows how quickly the rate of pressure change is slowing down. Since it tends to magnify small changes, the curve may show more "scatter" than the other plots. However, the curve has more definition and the shape is not as general as the log Δp versus log t plot. The characteristics of the derivative on a log-log plot for the various flow regimes are specific. A unit slope indicates wellbore storage. The transition period from the end of storage until the beginning of radial flow is seen as a hump with the derivative curve flattening as radial flow is reached.

The derivative for a hydraulically fractured well shows a half-slope during linear flow. The curve then flattens as pseudoradial flow is reached. Therefore, a flattening of the derivative curve indicates the beginning of the semilog straight line.

Since the derivative has more shape definition, it can be used in conjunction with the log-log plot to obtain a unique type curve match.

DIFFERENTIATION TECHNIQUES

The derivative is taken with respect to the natural logarithm of time (Horner time for a build-up). However, a number of methods are possible for the actual differentiation process. These range from a simple forward or backward difference involving two points to schemes which use a number of points on each side of the point of interest.

The initial method used on the following sets of data involved five points.[9] The character of the derivative curve was defined with this method, but the curve did contain some scatter.

The method used and presented on the graphs is the one discussed in reference 4. This method uses three points equally spaced logarithmically. The derivatives are calculated between successive points and the weighted average is then placed at the middle point. This method also retains the character of the derivative curves and produces a much smoother curve.

EXAMPLES

In the following examples, we will see acoustically obtained data giving bottomhole pressures that can be differentiated and utilized for analysis.

Example No. 1

Production information for this well is given in Table 1. The curves for the liquid level and surface pressure building up are presented in Figures 1 and 2 respectively. Together, these two curves yield the bottomhole pressure curve (Figure 3).

Now consider the analysis of the data. The regular Δp and the derivative curves are shown together on Figure 4. Both curves show a unit slope until two hours, indicating wellbore storage during that time. Going into the transition period, the derivative increases until it reaches a maximum at 20 hours. It then decreases and flattens at 85 hours. Thus, we know to look for a semilog straight line starting at this time.

Placing this plot on the type curve of Bourdet, et al. a unique match is found on the curves for $C_De^{2s} = 10^2$. Actually, the regular Δp data could match on other curves. However, the derivative will not and this determines the uniqueness of this match. Therefore, performing a type curve analysis based on this match, we obtain a total mobility of 1.7 md/cp and a skin of -1.2.

Performing a conventional Horner analysis from the slope of the straight line section of Figure 5, we obtain a total mobility of 1.3 md/cp and a skin of -1.8.

Table 2 presents the results of both the Horner analysis and the type curve analysis using both the Δp and derivative plots together.

Thus, we see that the derivative curve was well defined, determined the start of the semilog straight line, and allowed us to make a type curve analysis which compared closely with the Horner analysis.

Example No. 2

This is an example of a fractured well with storage. Production data is listed in Table 3, and the liquid level and surface pressure curves are shown in Figures 6 and 7 respectively. Figure 8 shows the bottomhole pressures determined from the liquid levels and surface pressures.

As we did in the previous example, we make a log-log plot of both the pressure difference and the pressure derivative versus time (Figure 9). Note that the shape of the derivative curve is distinctly unlike that of the previous example.

The pressure difference curve shows a half-slope until 3.5 hours, indicating linear flow during that time. Going to the square root of time plot (Figure 10), we find a straight line section ending at 2.94 hours with a slope of 110.0 psi/$\sqrt{hr}$. Using the techniques discussed in reference 10, we calculate a total mobility of 2.7 md/cp and a fracture length of 23 feet.

Using the type curve of Alagoa, et al. we are able to get a unique match and perform an analysis. The results are total mobility, $(k/u)_t$, of 3.0 md/cp, fracture length of 17 feet and a skin of -3.3.

In addition, the log-log plot helps identify the correct semi-log straight line. The derivative flattens at 32 hours, which is approximately ten times the end of linear flow so we expect to see the semilog line starting then. Checking the double Δp rule,[11] the pressure drop at 32 hours is 441 psi and the pressure drop at the end of linear flow is 214 psi. Thus, the double Δp rule is satisfied. The Horner analysis (from Figure 11) shows $(k/u)_t$ = 2.7 md/cp and s = -3.3. Since the fracture length is short, the ratio of the fracture length to the external boundary is less than 0.10. Therefore, the Raghavan and Hadinoto[12] slope and fracture length correction factor is 1, leaving the numbers unchanged. Notice how closely all methods correlate as shown in Table 4.

CONCLUSION

In this paper, examples have been presented using acoustically obtained data. These examples have shown that this data is differentiable with the derivative curve showing the very distinctive shapes, and therefore flow regimes, for both wellbore storage/skin and fracture cases.

REFERENCES

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Table 1

Production Rates:		
q_o	402	STB/day
q_w	17	STB/day
q_g	14	MCF/day
Cumulative Oil	38,523	STB
Net Pay Thickness	118	ft
Viscosities:		
u_o	145.88	cp
u_w	0.52	cp
u_g	0.03	cp
Formation Volume Factors:		
B_o	1.06	RB/STB
B_w	1.02	RB/STB
B_g	1.10	RB/MCF
Dissolved Gas, Rs	34.84	SCF/STB
Reservoir Compressibility	7.4E-5	psi^{-1}
Wellbore Radius	0.48	ft
Porosity	25.40	%

Table 2

	$(k/u)_t$	s
Horner	1.3	-1.8
Type Curve	1.7	-1.2

Table 3

Production Rates:		
q_o	5	STB/day
q_w	399	STB/day
q_g	4	MCF/day
Cumulative Oil	9123	STB
Net Pay Thickness	82	ft
Viscosities:		
u_o	2.96	cp
u_w	1.12	cp
u_g	0.01	cp
Formation Volume Factors:		
B_o	1.10	RB/STB
B_w	1.00	RB/STB
B_g	3.24	RB/MCF
Dissolved Gas, Rs	193.17	SCF/STB
Reservoir Compressibility	1.4E-4	psi^{-1}
Wellbore Radius	0.31	ft
Porosity	16.80	%
Radius of Drainage	372.00	ft

Table 4

	$(k/u)_t$	s	x_f
Horner	2.7	-3.3	---
$\sqrt{\text{Time}}$	2.7	----	23
Type Curve	3.0	-3.3	17

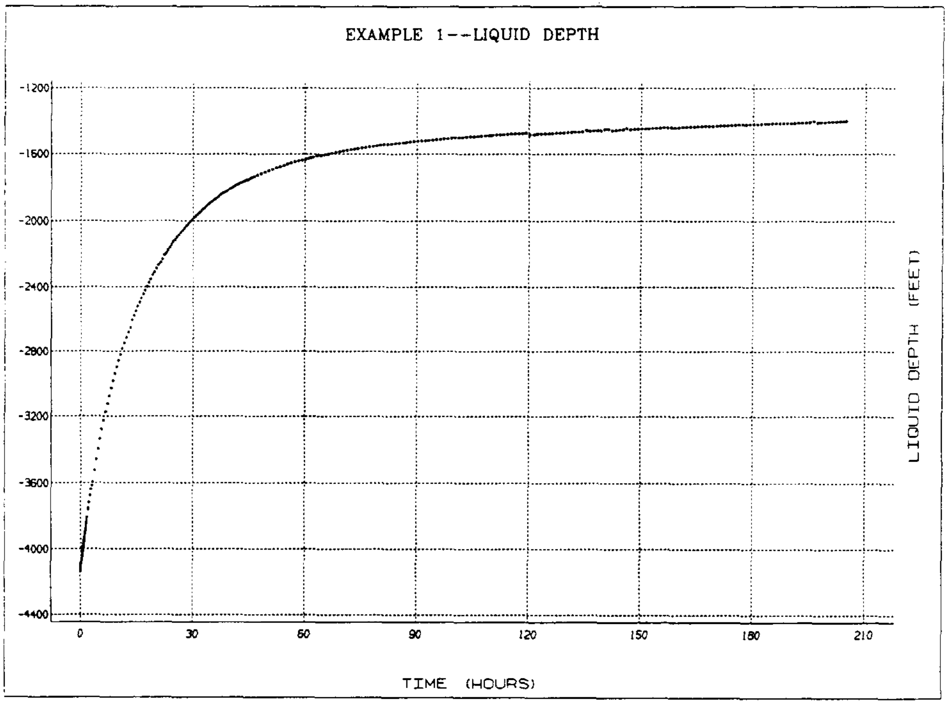

Figure 1 - Example 1 - Liquid depth

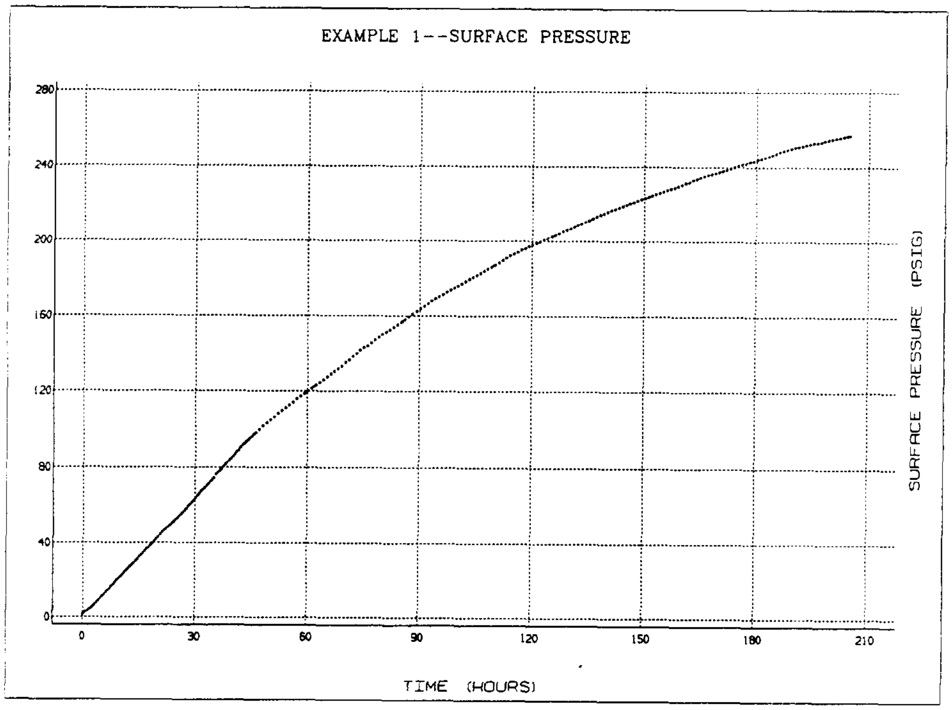

Figure 2 - Example 1 - Surface pressure

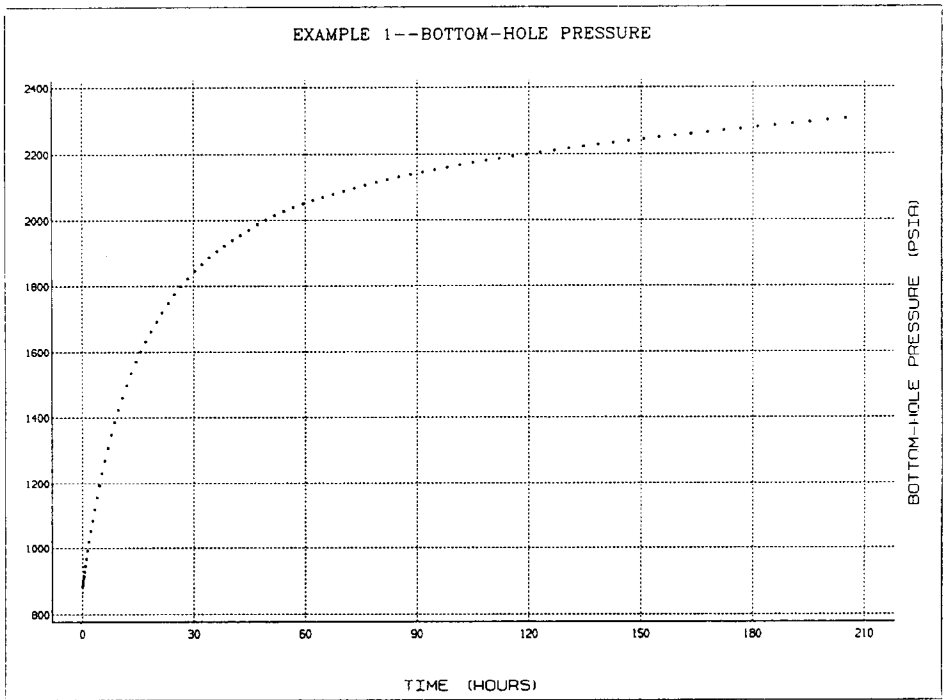

Figure 3 - Example 1 - Bottom-hole pressure

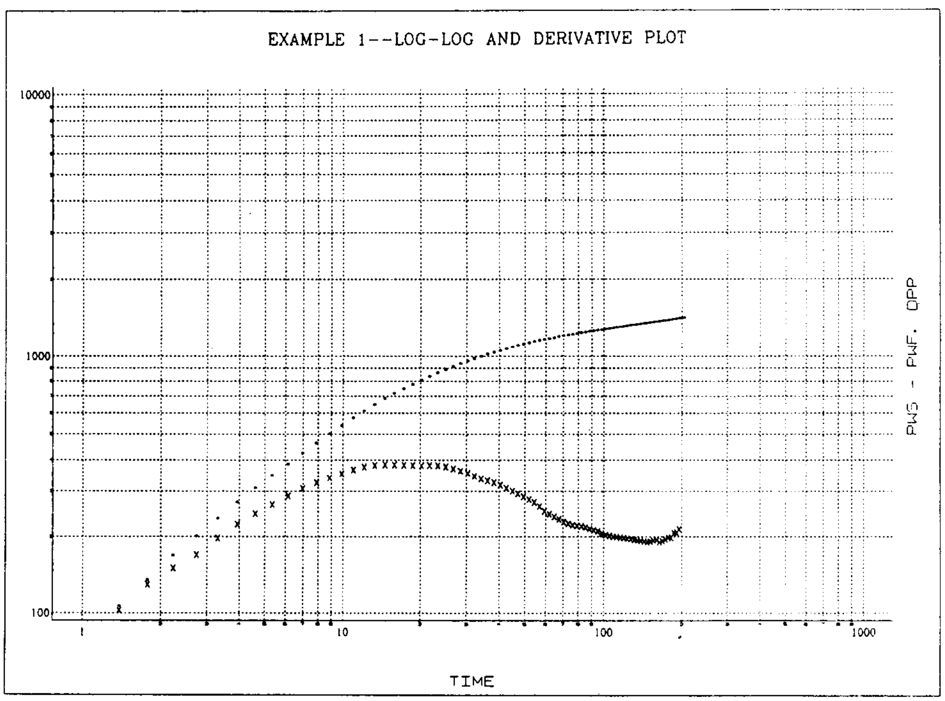

Figure 4 - Example 1 - Log-log and derivative plot

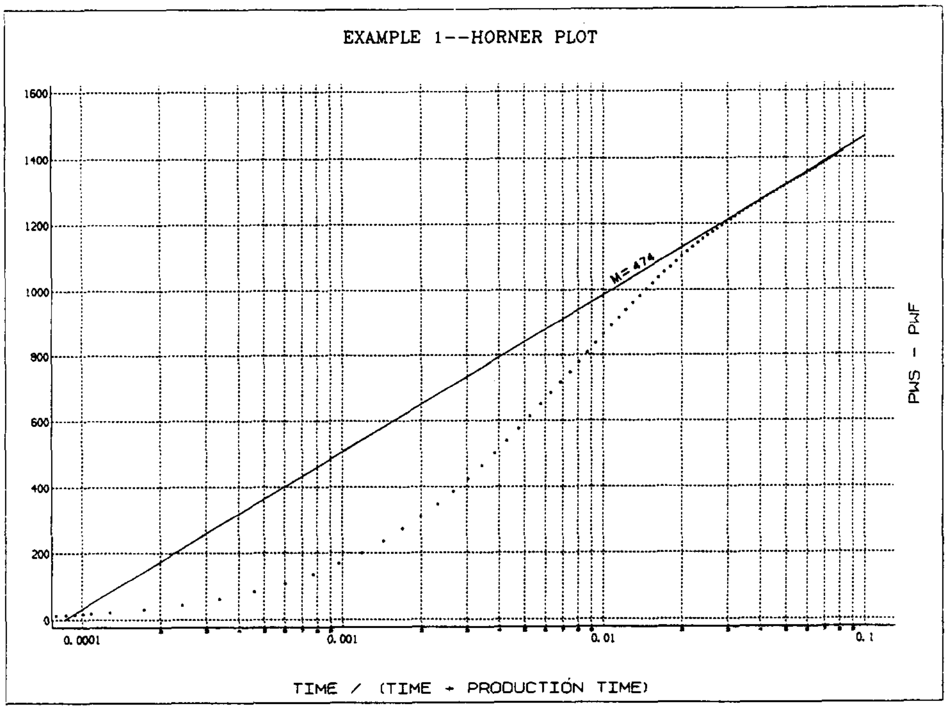

Figure 5 - Example 1 - Horner plot

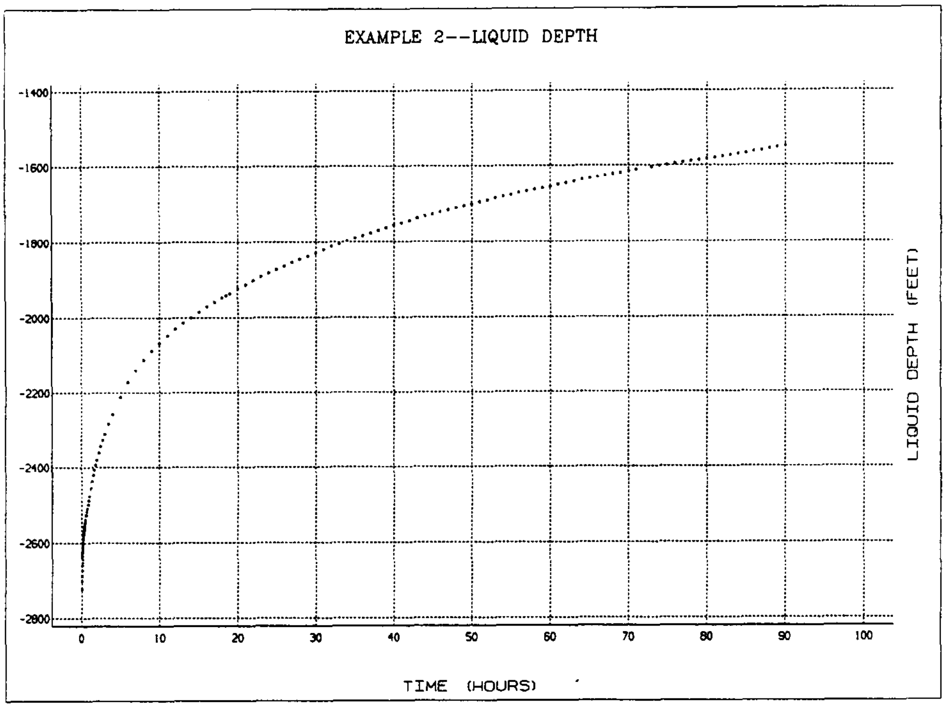

Figure 6 - Example 2 - Liquid depth

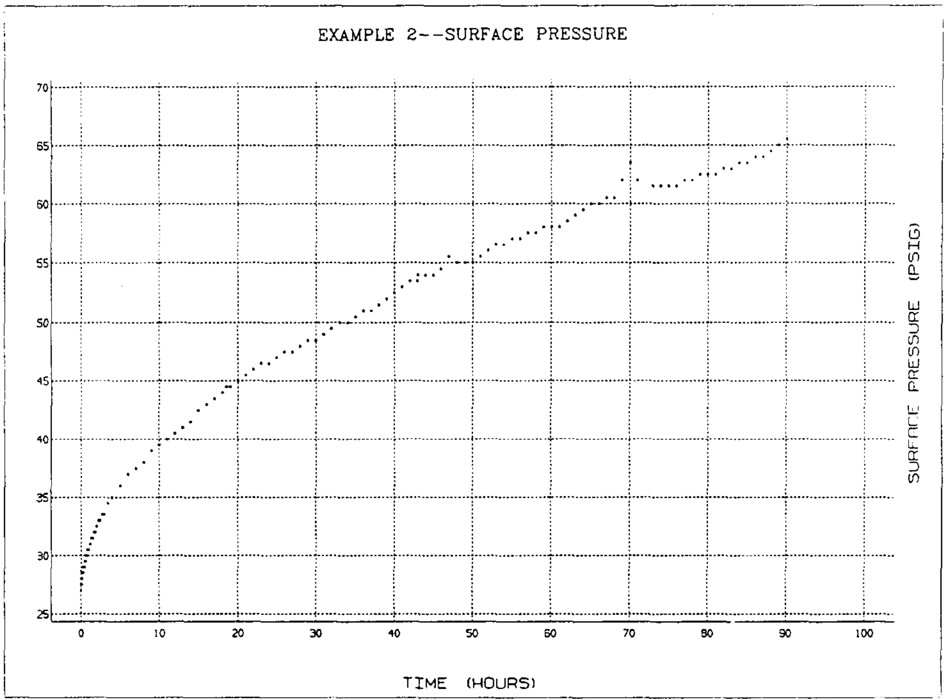

Figure 7 - Example 2 - Surface pressure

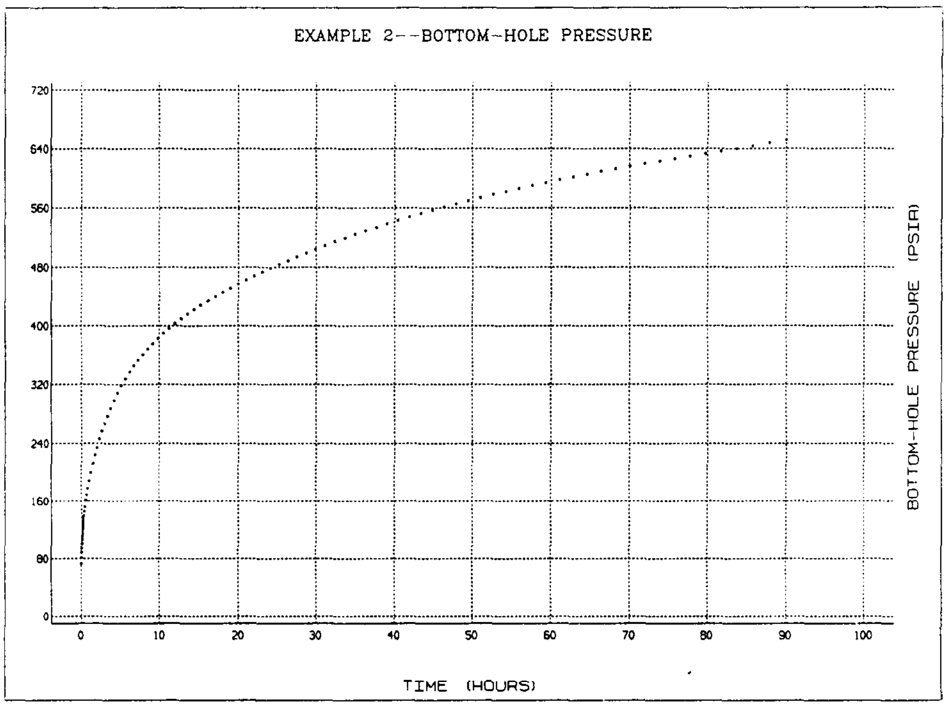

Figure 8 - Example 2 - Bottom-hole pressure

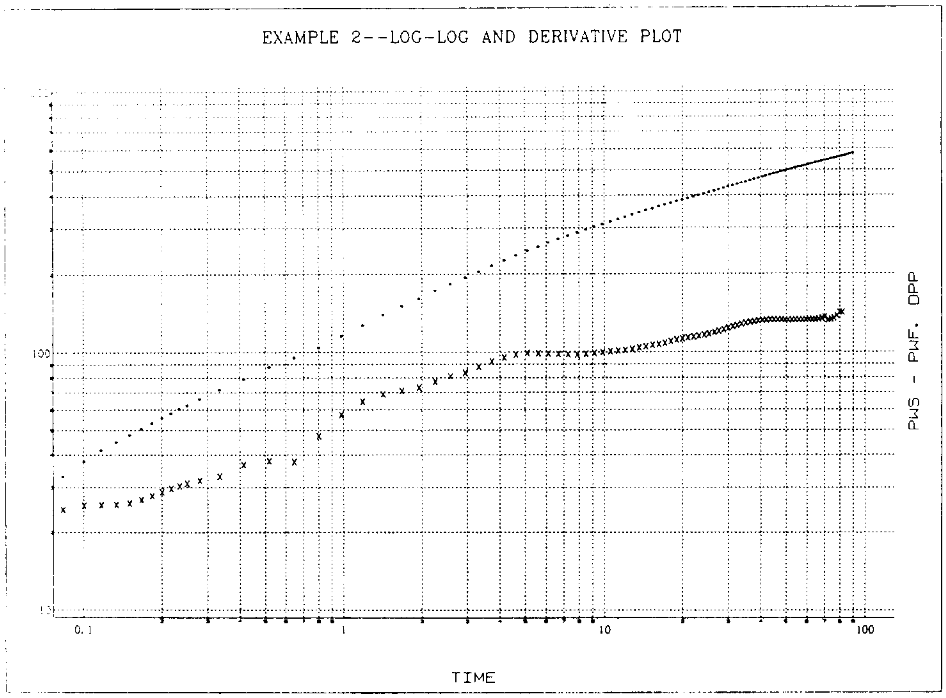

Figure 9 - Example 2 - Log-log and derivative plot

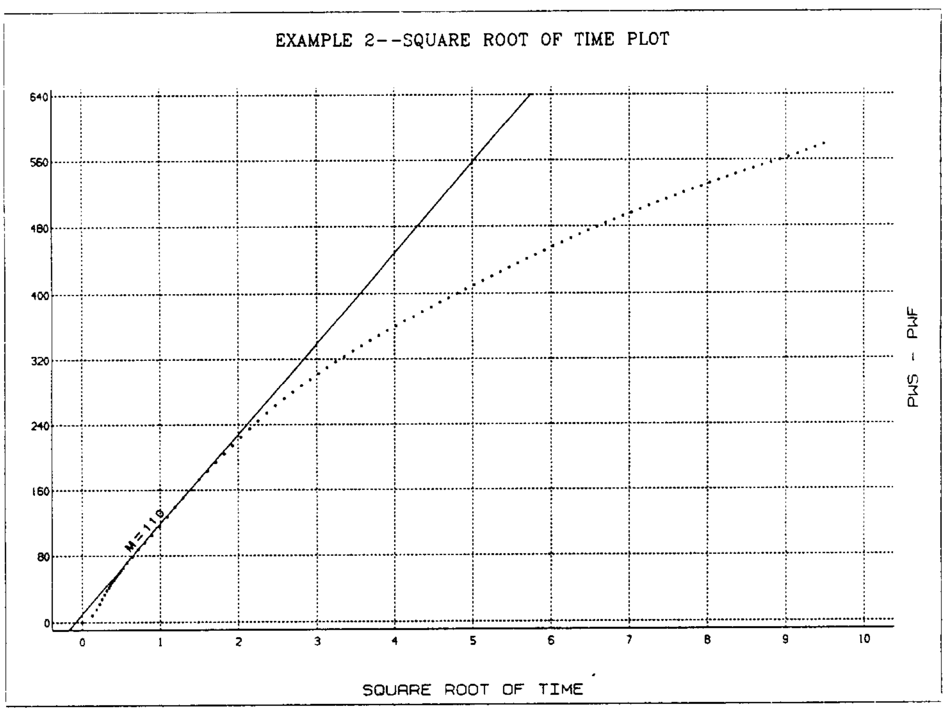

Figure 10 - Example 2 - Square root of time plot

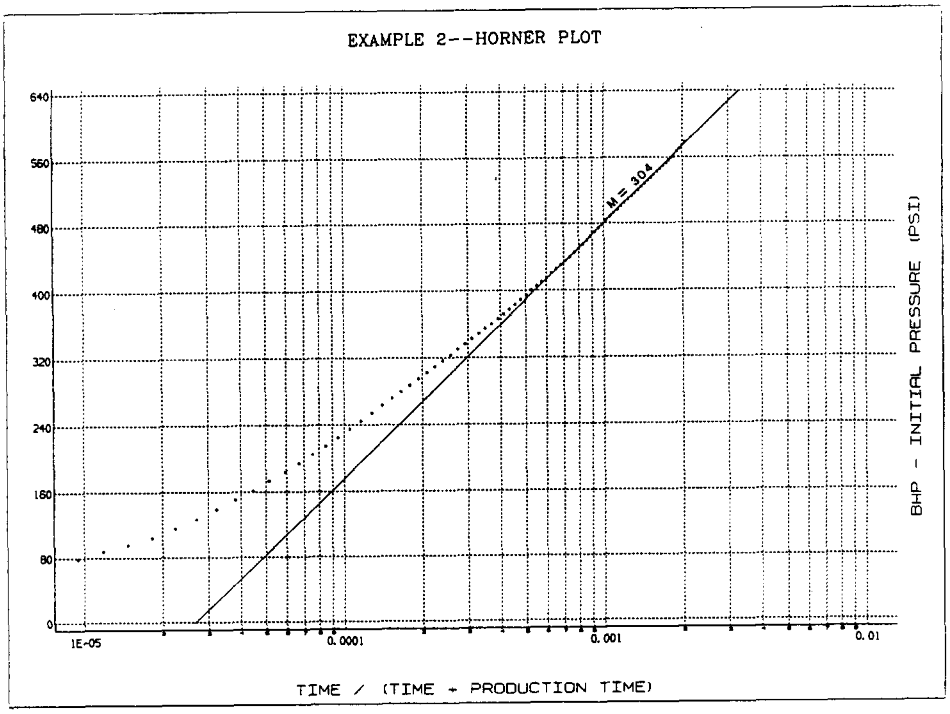

Figure 11 - Example 2 - Horner plot