Use of the Pressure Derivative for Diagnosing Pressure-Transient Behavior

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Summary. The combined plot of log pressure change and log derivative of pressure change with respect to superposition time as a function of log elapsed time was first introduced by Bourdet et al. as an aid to type-curve matching. Features that are hardly visible on the Horner plot or are hard to distinguish because of similarities between one reservoir system and another are easier to recognize on the pressure-derivative plot. Once the patterns have been diagnosed on the log-log plot, specialized plots can be used to compute reservoir parameters or the data can be matched to a type curve.

The Horner plot has been the most widely accepted means for analyzing pressure-buildup data since its introduction in 1951. The slope of the line obtained by plotting pressure vs. log Horner time is used to compute the reservoir permeability. (Horner time is the log of production time plus shut-in time divided by shut-in time.) The extension of this line to the time 1 hour after the start of the buildup provides a means for calculating the skin factor. The extension of this line to when the Horner time equals 1 is the extrapolated pressure used to determine the average reservoir pressure.

Another widely used aid to pressure-transient analysis is the plot of log pressure change vs. log elapsed (shut-in) time. This plot serves two purposes. First, the data can be matched to type curves, which are plots of analytically generated reservoir response patterns for specified reservoir models. Second, the type curves can illustrate the expected trends in pressure-transient data for a large variety of well and reservoir systems.

The visual impression afforded by the log-log presentation has been greatly enhanced by the introduction of the pressure derivative. In practice, the derivative of the pressure change is taken with respect to the superposition time function, which corrects for variations in the surface flow rate that occurred before the flow period being analyzed. As such, it represents the slope of the generalized Horner plot for buildup data. When the data produce a straight line on a semilog plot, the pressure derivative will, therefore, be constant. That is, the log-log pressure-derivative plot will be flat for that portion of the data that can be correctly analyzed as a straight line on the Horner plot.

Many analysts rely on the plot of log-log pressure vs. pressure derivative to diagnose which reservoir model can represent a given pressure-transient data set. Patterns visible in the log-log diagnostic and Horner plots for five frequently encountered reservoir systems are shown in Fig. 1. The simulated curves in Fig. 1 were generated from analytical models. For each case, the log-log plot illustrates the features typically seen in real data. The curves on the left represent buildup responses; the derivatives were computed with respect to the Horner time function. The curves on the right show what the same examples look like on a plot of pressure vs. log Horner time.

For each log-log plot, the upper curve is the pressure change, Δp, vs. the shut-in time, Δt, and the lower curve is the pressure change derivative, (Δp)/Δt. Patterns in the pressure derivative that are characteristic of a particular reservoir model are shown in a different type of line that is reproduced on the Horner plot. The portions of the derivative curves that appear flat determined where to draw the lines on the Horner plots, which were determined from a least-squares fit using the points between the arrows on the plot. When the Horner plot line has been diagnosed from the derivative response, the values computed for permeability, skin, and extrapolated pressure will be based on the radial flow response required for the Horner analysis.

The Horner plots were drawn with Horner time increasing on the horizontal plot axis. This means that the earliest data points appear to the right of the plot and the last data point appears farthest to the left. For this reason, the flow regimes represented by different line types appear in reverse order on the Horner plots.

Using common response patterns like those shown in Fig. 1 as a reference, even the novice can begin to spot trends in actual data that characterize certain well/reservoir systems. Once the system has been diagnosed, various portions of the data can be replotted in specialized plots that produce a line for points within a specific range of values identified on the log-log pressure/pressure-derivative diagnostic plot.

The following examples should help the reader to discern what to look for in the log-log diagnostic plots shown in Fig. 1.

Example A illustrates the most common response—that of a homogeneous reservoir with wellbore storage and skin. Wellbore-storage derivative transients are recognized as a "hump" in early time. The flat derivative portion in late time is easily analyzed as the Horner semilog straight line.

Example B shows behavior of an infinite conductivity, which is characteristic of a well that penetrates a natural fracture. The half slopes in both the pressure change and its derivative result in two parallel lines during the flow regime, representing linear flow to the fracture.

Example C shows the homogeneous reservoir with a single vertical planar barrier to flow or a fault. The level of the second-derivative plateau is twice the value of the level of the first-derivative plateau, and the Horner plot shows the familiar slope-doubling effect.

Example D illustrates the effect of a closed drainage volume. Unlike the drawdown pressure transient, which has a unit-slope line in late time that is indicative of pseudosteady-state flow, the buildup pressure derivative drops to zero. The permeability and skin cannot be determined from the Horner plot because no portion of the data exhibits a flat derivative for this example. When transient data resemble Example D, the only way to determine the reservoir parameters is with a type-curve match.

Example E exhibits a valley in the pressure derivative that is indicative of reservoir heterogeneity. In this case, the feature...
Fig. 1—Examples A through E, adapted from Ref. 12.

Well with Wellbore Storage and Skin in a Homogeneous Reservoir

Well with Infinite Conductivity Vertical Fracture in a Homogeneous Reservoir

Well with Wellbore Storage and Skin in a Homogeneous Reservoir with One Sealing Fault

Well with Wellbore Storage and Skin in a Homogeneous Reservoir with Closed Outer Boundary

Well with Wellbore Storage and Skin in a Dual Porosity System with Pseudo-Steady State Flow from Matrix to Fractures
results from dual-porosity behavior, for the case of pseudosteady flow from matrix to fractures. Fig. 1 clearly shows the value of the pressure/pressure-derivative presentation. An important advantage of the log-log presentation is that the transient patterns have a standard appearance as long as the data are plotted with square log cycles. The visual patterns in semilog plots are amplified by adjusting the range of the vertical axis. Without adjustment, many or all of the data may appear to lie on one line and subtle changes can be overlooked.

Some of the pressure-derivative patterns shown are similar to those characteristic of other models. For example, the pressure-derivative doubling associated with a fault (Example C) can also indicate transient interporosity flow in a dual-porosity system. The sudden drop in the pressure derivative in buildup data can indicate either a closed outer boundary or a constant-pressure outer boundary resulting from a gas cap, an aquifer, or pattern-injection wells. The valley in the pressure derivative (Example E) could indicate a layered system instead of dual porosity. For these cases and others, the analyst should consult geological, seismic, or core-analysis data to decide which model to use in an interpretation. With additional data, a more conclusive interpretation for a given transient data set may be found.

An important place to use the pressure/pressure-derivative diagnosis is on the wellsite. If the objective of the test is to determine permeability and skin, the test can be terminated once the derivative plateau is identified. If heterogeneities or boundary effects are detected in the transient, the test can be run longer to record the entire pressure/pressure-derivative response pattern needed for the analysis. Ref. 6 provides a method for computing the pressure derivative. Modern electronic gauges typically produce data that are readily differentiable and, often, data from a mechanical gauge produce an adequate derivative presentation. Hence, to avoid errors caused by analyzing the “wrong” straight line on a Horner plot, a look at the log-log plot of pressure and its derivative is always recommended. With some experience, the analyst can readily recognize the most common transient-behavior patterns on this plot and can learn much more from each data set.

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References