RESERVOIR ENGINEERING FOR GEOLOGISTS
Part 7 – Rate Transient Analysis

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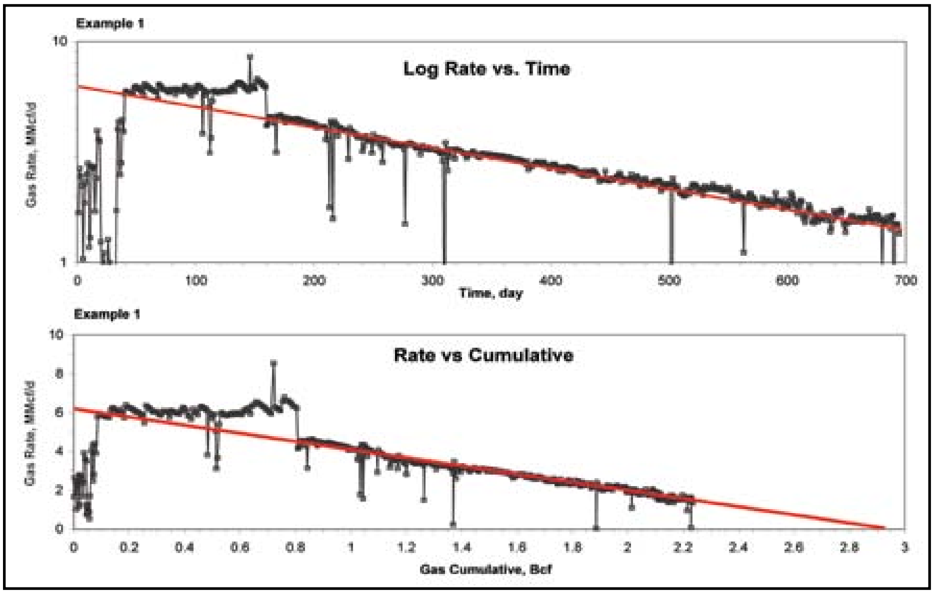

Figure 1. Traditional Decline – Example 1.

While a well is producing, a lot of information can be deduced about the well or the reservoir without having to shut it in for a well test. Analysis of production data can give us significant information in several areas:

1. **Reserves** – This is an estimate of the recoverable hydrocarbons, and is usually determined by traditional production decline analysis methods, as described in Article #4 in this series (Dean, L. and Mireault, R., 2008).

2. **ReservoirCharacteristics** – Permeability, well completion efficiency (skin), and some reservoir characteristics can be obtained from production data by methods of analysis that are extensions of well testing (Mattar, L. and Dean, L., 2008)

3. **Oil- or Gas-In-Place** – The modern methods of production data analysis (Rate Transient Analysis) can give the Original-Oil-In-Place (OOIP) or Original-Gas-In-Place (OGIP), if the flowing pressure is known in addition to the flow rate.

The principles and methods discussed in this article are equally applicable to oil and gas reservoirs, but – for brevity – will only be presented in terms of gas.

1. TRADITIONAL METHODS: RESERVES

From an economic perspective, it is not what is in the reservoir that is important, but rather what is recoverable. The industry term for this recoverable gas is “Reserves.” There are several ways of predicting reserves. One of these methods, traditional decline analysis (exponential, hyperbolic, harmonic) has already been discussed in Article #4. The method is used daily for forecasting production and for economic evaluations. Generally, the results are meaningful, but they can sometimes be unrealistic (optimistic or pessimistic), as will be illustrated by the following examples.

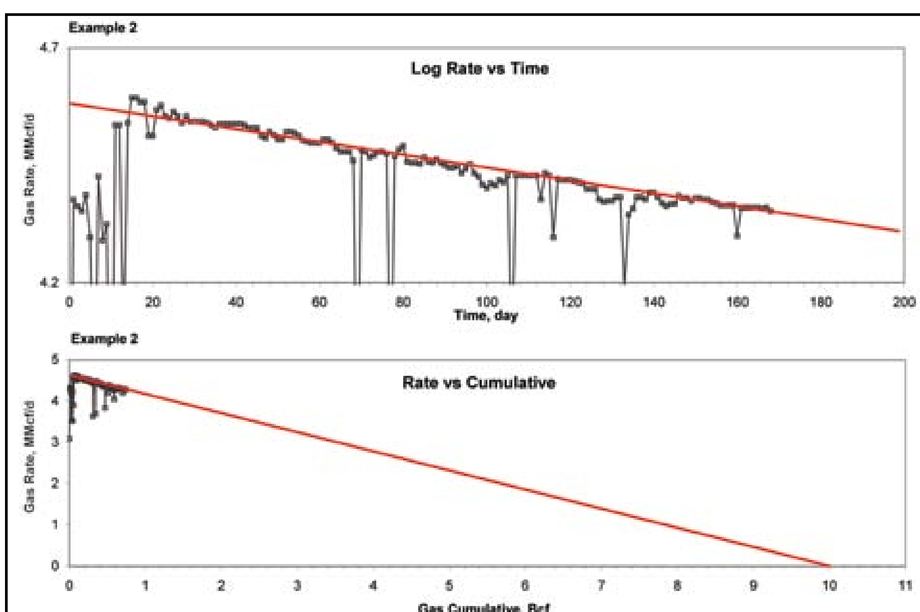

Figure 2. Traditional Decline – Example 2.

Example 1, shown in Figure 1, clearly exhibits an exponential decline. It is obvious from this Figure that the recoverable reserves are 2.9 Bcf. Typically this type of gas well has a recovery factor of 80% (0.8), and one can thereby conclude that the original-gas-in-place (OGIP) = 2.9/0.8 = 3.6 Bcf. By using the modern rate transient analysis described later in this article, it will be shown that this value of OGIP is **grossly pessimistic**.

Example 2, shown in Figure 2, also exhibits an exponential decline. It can be seen from this Figure that the recoverable reserves are 10 Bcf. Assuming a recovery factor of 80% (0.8), the OGIP = 10/0.8 = 12.5 Bcf. By using the modern rate transient analysis described later in this article, it will be shown that this value of OGIP is **optimistic**.

Example 3, shown in Figure 3 is a tight gas well and has been analyzed using hyperbolic decline. The reserves are 5.0 Bcf which (using a recovery factor of 50% for tight gas) translates to an OGIP equal to 10 Bcf. By using the modern rate transient analysis described later in this article, it will be shown that this value of OGIP is overly **optimistic**.

Typically, the traditional methods of determining reserves do not work well when the operating conditions are variable, or in the case of tight gas. The above three

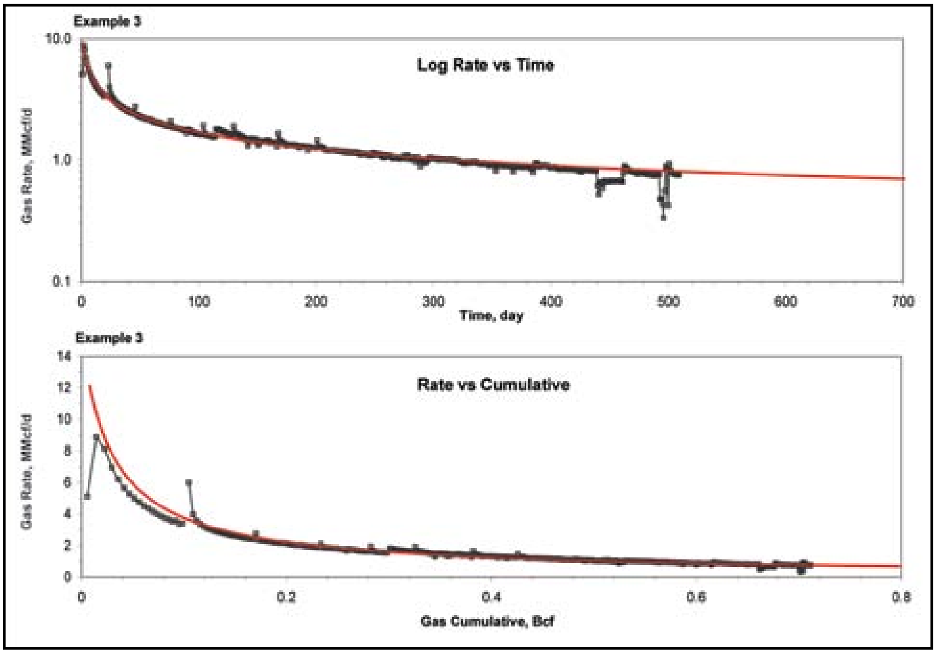

Figure 3. Traditional Decline – Example 3.

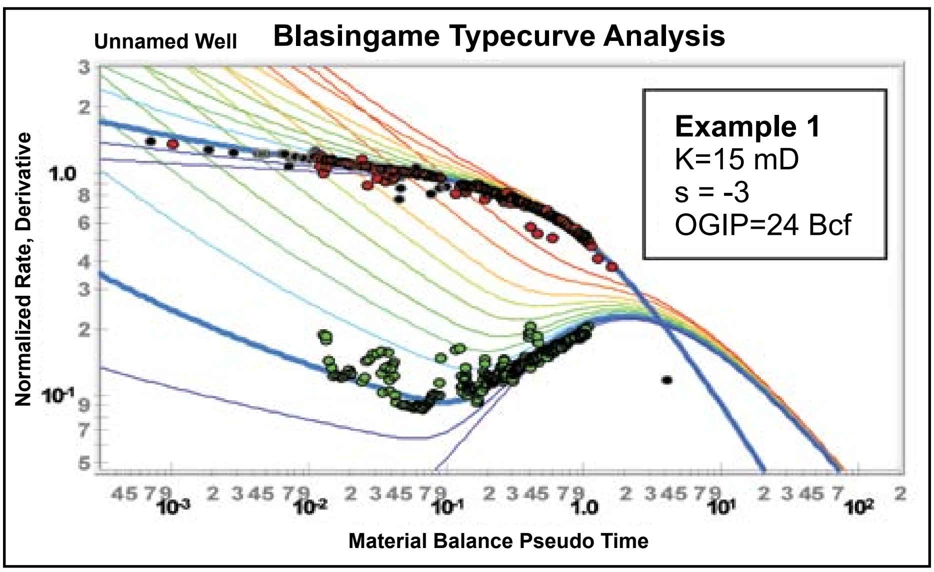

Figure 4. Rate Transient Analysis – Type Curve Match - Example 1.

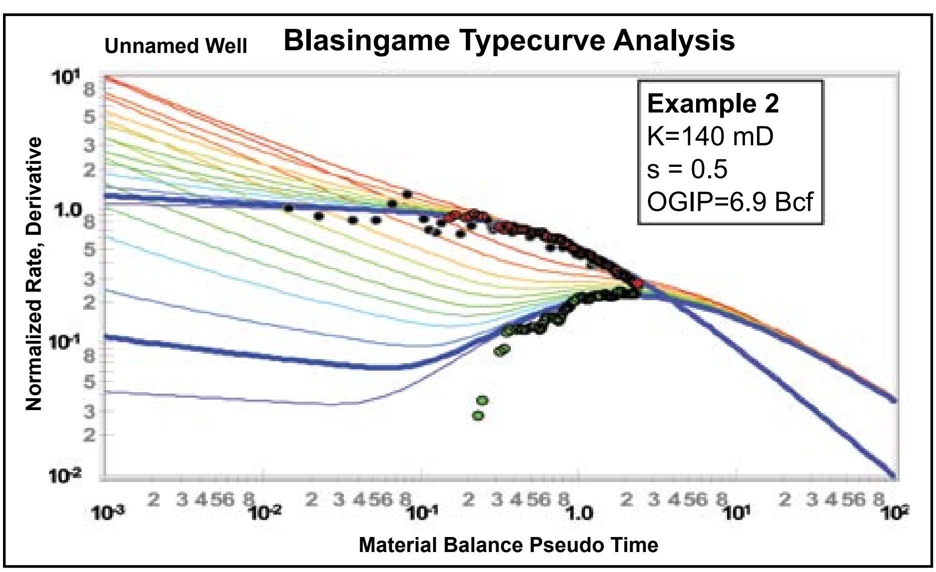

Figure 5. Rate Transient Analysis – Type Curve Match - Example 2.

examples fall into these categories, and while the results appear to be reasonable, it will be shown using the modern methods described below, that they are in error; sometimes by a significant amount.

2. MODERN METHODS: HYDROCARBONS-IN-PLACE AND RESERVOIR CHARACTERISTICS

There are two significant differences between the traditional methods and the modern methods:

a. The traditional methods are empirical, whereas the modern methods are mechanistic, in that they are derived from reservoir engineering fundamentals.

b. The traditional methods only analyze the flow rate, whereas the modern methods utilize both the flow rates and the flowing pressures.

The modern methods are known as rate transient analysis. They are an extension of well testing (Mattar, L. and Dean, L., 2008). They combine Darcy's law with the equation of state and material balance to obtain a differential equation, which is then solved analytically (Anderson, D. 2004; Mattar, L. 2004). The solution is usually presented as a "dimensionless type curve," one curve for each of the different boundary conditions, such as: vertical well, horizontal well, hydraulically fractured well, stimulated or damaged well, bounded reservoir, etc.

To analyze production data using rate transient analysis, the instantaneous flow rate (q) and the corresponding flowing pressure (p_{wf}) are combined into a single variable called the normalized rate (= $q/(\Delta p)$) and this is graphed against a time function called material-balance time. As in well testing (Mattar, L. and Dean, L., 2008), a derivative is also calculated. The resulting data set is plotted on a log-log plot of the same scale as the type curve, and the data moved vertically and horizontally until a match is obtained with one set of curves. Figure 4 shows the type curve match for the data of Example 1. This procedure is known as type curve matching, and the match point is used to calculate reservoir characteristics such as permeability, completion (fracture) effectiveness, and original-gas-in-place.

The data sets of Examples 2 and 3 have been analyzed in the same way, and the type curve matches are shown in Figures 5 and 6. Note that the type curves for each of these examples have different shapes because they represent different

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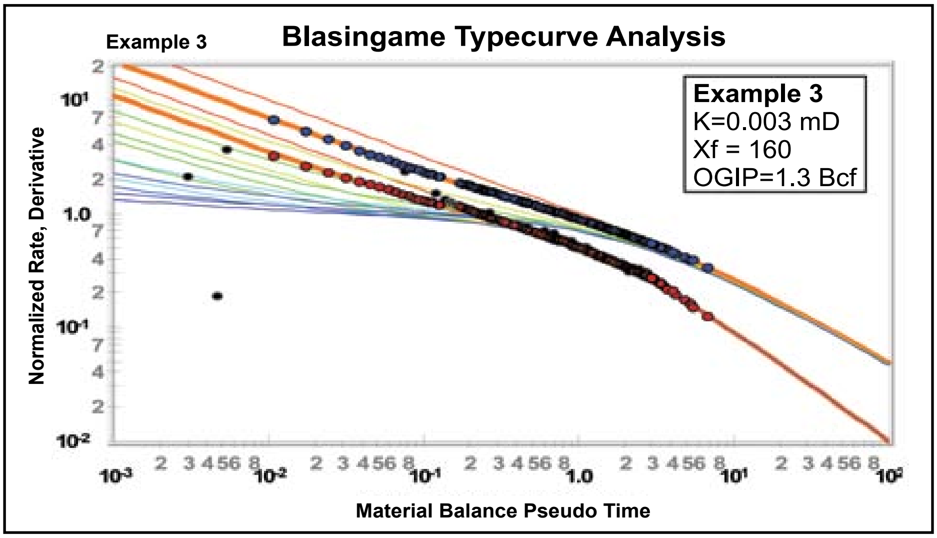

Figure 6. Rate Transient Analysis – Type Curve Match - Example 3.

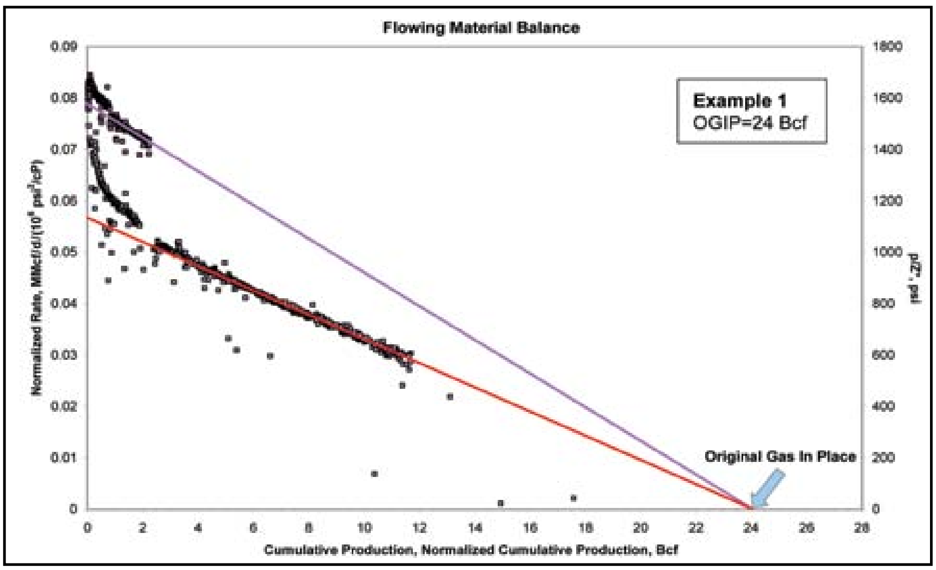

Figure 7. Flowing Material Balance - Example 1.

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well/reservoir configurations. Figures 4 and 5 represent a damaged or acidized well in radial flow, whereas Figure 6 represents a hydraulically fractured well in linear flow.

In addition to the type curve matching procedure described above, another useful method of analysis is known as the flowing material balance (Mattar, L. and Anderson, D. M., 2005). The flow rates and the flowing pressures are manipulated in such a way that the flowing pressure at any time (while the well is producing) is converted mathematically into the average reservoir pressure that exists at that time. This calculated reservoir pressure is then analyzed by material balance methods (Mireault, R. and Dean, L., 2008), and the original-gas-in-place determined. The flowing material balance plot for the data set of Example 1 is shown in Figure 6, and the results are consistent with those of the type curve matching of Figure 4.

SUMMARY OF RESULTS:

When Examples 1, 2, and 3 are analyzed using modern Rate Transient Analysis, and the results compared to those from the traditional methods, the following volumes are obtained:

Example#:	OGIP (Traditional)	OGIP (Modern)
#1	3.6 Bcf	24 Bcf
#2	12.5 Bcf	6.9 Bcf
#3	10.0 Bcf	1.3 Bcf

The reasons for the discrepancies are different in each case. In Example 1, the flowing pressure was continuously increasing due to infill wells being added into the gathering systems, which caused an excessive production rate decline. In Example 2, the flow rate and flowing pressure were declining simultaneously. The decline in flow rate would have been more severe with a constant flowing pressure. In Example 3, the permeability is so small that the data is dominated by linear flow into the fracture (traditional methods are NOT valid in this flow regime).

In rate transient analysis, once the reservoir characteristics have been determined, a reservoir model is constructed to history-match the measured data. The model is then used to forecast future production scenarios, such as different operating pressures, different completions, or well drilling density.

A word of caution is warranted. Data quality can range from good to bad. Multiphase flow, liquid loading in the wellbore, wellhead to bottomhole pressure conversions, interference from infill wells, multiwell pools, rate allocations, re-completions, and multi-layer effects can all compromise data quality and complicate the analysis. Notwithstanding these potential complications, it has been our experience that significant knowledge has been gained by analyzing production data using the modern methods of rate transient analysis.

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Look for our next article on "Monte Carlo Simulation" in the next issue of the Reservoir.

This article was contributed by Fekete Associates, Inc. For more information, contact Lisa Dean at Fekete Associates Inc.

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