Explicit Deconvolution of Wellbore-Storage-Distorted Well-Test Data

The analysis and interpretation of wellbore-storage-distorted pressure-transient-test data remain significant challenges. Deconvolution (i.e., conversion of a variable-rate-distorted pressure profile into the pressure profile for an equivalent constant-rate-production sequence) has been in limited use as a conversion mechanism for the last 25 years. Unfortunately, standard deconvolution techniques require accurate measurements of flow rate and pressure at downhole (or sandface) conditions. While accurate pressure measurements are commonplace, the measurement of sandface flow rates is rare, essentially nonexistent in practice. An explicit (direct) deconvolution of wellbore-storage-distorted pressure-test data that uses only those pressure data was developed.

Introduction

To eliminate wellbore-storage effects in pressure-transient-test data, several methods have been proposed. An approximate direct method corrects the pressure-transient data distorted by wellbore storage into the equivalent-pressure function for the constant-rate case. Despite its simplicity, it has several shortcomings such as limited accuracy and erroneous skin-factor estimation.

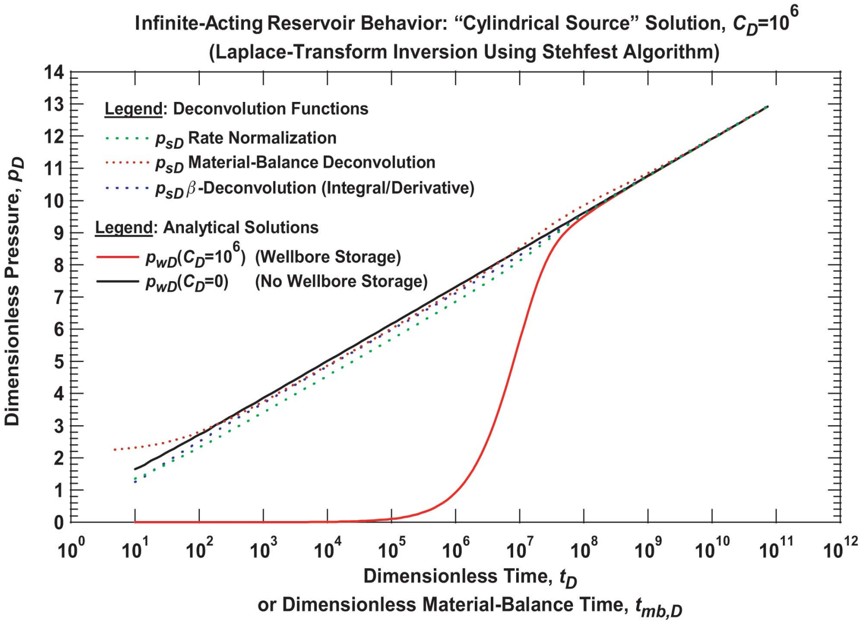

Fig. 1—Synthetic example using various deconvolution techniques (infinite-acting-reservoir case with wellbore-storage effects).

Rate-normalization techniques have been used to correct for wellbore-storage effects, and these methods were successful in some cases. The most appropriate application of rate normalization is its use for pressure-transient data influenced by continuously varying flow rates. Application of rate normalization requires sandface-flow-rate measurements and generally yields a shifted result trend that has the correct slope but incorrect intercept on a semilog graph (i.e., incorrect skin factor).

Material-balance deconvolution has been shown to be a practical approach for the analysis of pressure-transient data distorted by wellbore-storage effects. In particular, this approach remedies the issue of a poor skin-factor estimate that typically is obtained with rate normalization. Material-balance deconvolution also is thought to require continuously varying sandface-flow-rate measurements. It is shown that sandface flow rates can be approximated from the observed pressure data.

Methodology

This work was put forth as an attempt to provide a set of simple, explicit deconvolution formulas that could be used on wellbore-storage-distorted pressure-transient-test data. The material-balance deconvolution was successful and should be considered sufficiently accurate for use as a practical tool for field applications. The other major method considered was the direct β-deconvolution algorithm modified to estimate the β-parameter from pressure rather than flow-rate data as originally proposed. The mod-

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This article, written by Technology Editor Dennis Denney, contains highlights of paper SPE 103216, "Explicit Deconvolution of Wellbore-Storage-Distorted Well-Test Data," by ***O. Bahabanian,*** *SPE,* ***D. Ilk,*** *SPE,* ***N. Hosseinpour-Zonoozi,*** *SPE, and* ***T.A. Blasingame,*** *SPE, Texas A&M U., prepared for the 2006 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 24–27 September.*

ification of the β-deconvolution algorithm, given only in terms of pressure variables, also was successful.

Material-Balance Deconvolution. The relations for deconvolution of wellbore-storage-distorted well-test data by use of material-balance deconvolution are provided in Appendix D of the full-length paper.

β-Deconvolution. Also presented is the application of a β-deconvolution algorithm derived from wellbore-storage-distorted pressure functions. The final result developed for application is detailed in the full-length paper.

Of the methods reviewed and developed in this work, modifications of the material-balance-deconvolution approach and the β-deconvolution algorithm perform well in field applications. Note that both of these methods have been specifically recast for the analysis of wellbore-storage-distorted pressure-transient-test data.

Example Applications

In a synthetic case for a well in an infinite-acting reservoir, with wellbore storage effects, the dimensionless wellbore-storage coefficient is set at 1×10^6. The solid red line in **Fig. 1** shows the results of this model. The no-storage solution is shown as the solid black line in Fig. 1.

The rate-normalization process yielded excellent results. The deconvolved response lies below the no-storage response, but it was concluded that this was a very good performance for the rate-normalization method.

The material-balance-deconvolution technique performed extremely well in this case, with minor discrepancies at the beginning of the data set and at the point where the wellbore-storage and no-wellbore-storage solutions merge. This performance was very strong, suggesting that on the basis of simplicity of the material-balance-deconvolution method, it probably is the most practical approach for the analysis of pressure-transient-test data distorted by wellbore storage.

The β-deconvolution technique also was a very strong performer because of the analytical nature of the data (i.e., the dimensionless pressure and auxiliary functions). The analytical (i.e., exact) solutions in this process most likely account for the success of the β-deconvolution technique for this example.

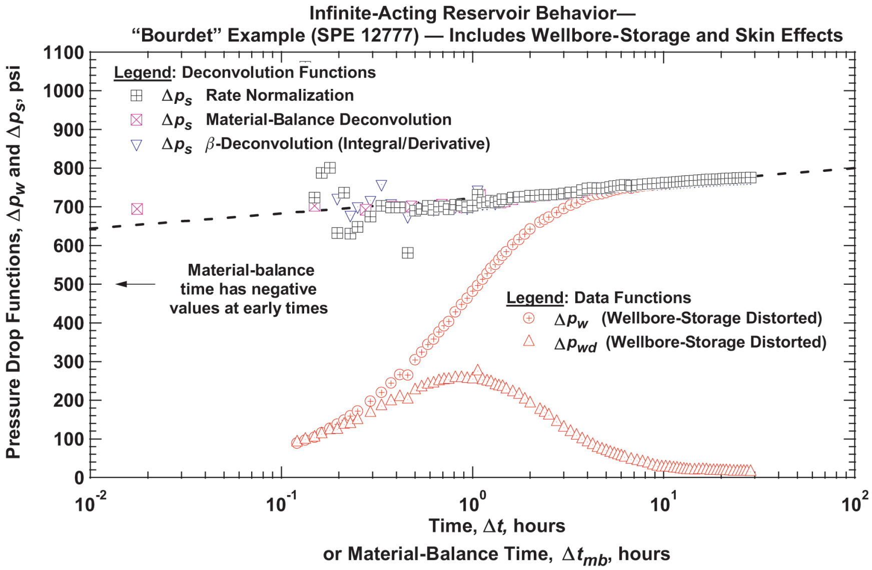

Fig. 2—Semilog graph of field example with various deconvolution techniques (infinite-acting-reservoir case with wellbore-storage effects).

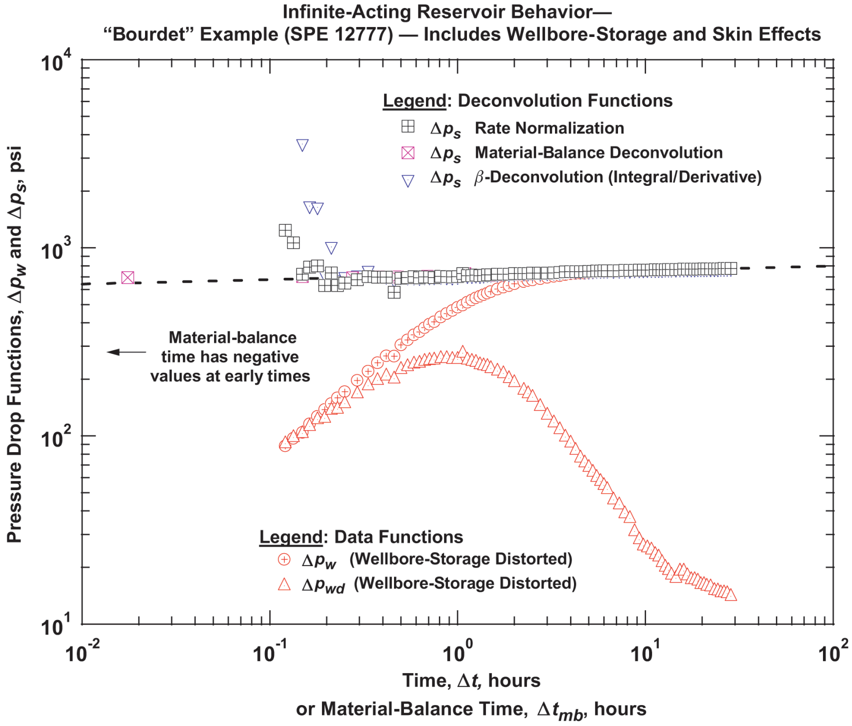

Fig. 3—Log-Log graph of field example with various deconvolution techniques (infinite-acting-reservoir case with wellbore-storage effects).

Field Example. In this case, the explicit deconvolution of field data is presented. The data are taken from a pressure-buildup test and should be considered reasonably well behaved for field data. The deconvolution-conversion results are shown in **Fig. 2** (semilog format) and **Fig. 3** (log-log format) to emphasize the character in the data.

The most positive aspect of applying the explicit-deconvolution method in this example is the gain of approximately 1.5 log cycles of results, which can be analyzed with conventional well-test-interpretation methods (i.e., data in the shut-in-time range of 0.01 to 4 hours are effectively deconvolved and can be analyzed by use of traditional semilog or log-log analysis/interpretation methods for well-test data). These data are clearly distorted (if not dominated) by wellbore-storage effects.

Rate Normalization. Note that from Figs. 2 and 3 the rate-normalization profile is more stable than the β-deconvolution profile, but it is not as accurate as the material-balance-deconvolution profile. In particular, the rate-normalization profile is slightly unstable at early times.

Material-Balance Deconvolution. The response of the material-balance-deconvolution method, shown in Figs. 2 and 3, appears to be the most accurate deconvolution. Negative values were encountered in the material-balance time function caused by the negative rates computed from the wellbore-storage-distorted data. These negative rates also affected the rate-normalization and β-deconvolution results, as indicated by the off-trend performance at early times.

β-Deconvolution. The β-deconvolution results shown in Figs. 2 and 3 are reasonably stable, and they suggest a good performance of this approach for this data set. More stability in the β-deconvolution was expected at early times, but all of the explicit-deconvolution methods were affected at early times for this case.

Summary

The expectation of success for the deconvolution of pressure-transient-test data with explicit-deconvolution techniques (rate normalization, material-balance deconvolution, and β-deconvolution) must be tempered with the knowledge that an inherent bias is created when the rate profile is not used. The rate profile is inferred from a wellbore-storage model imposed (in some manner) on the pressure data.

Having made those qualifying comments, it is recognized that the theory of each method provides some confidence that these methods should perform well in practice. The primary concern must be the quality and relevance of the pressure data.

Nomenclature

C_D = dimensionless wellbore-storage coefficient
p_D = dimensionless pressure
p_{sD} = dimensionless constant rate pressure
p_{wD} = dimensionless pressure distorted by wellbore storage
t_D = dimensionless time
$t_{mb,D}$ = dimensionless material-balance time
β = beta-deconvolution variable
Δp_s = constant-rate-pressure drop
Δp_w = wellbore-storage-distorted pressure drop
Δp_{wd} = wellbore-storage-distorted pressure-drop derivative
Δt = shut-in time
Δt_{mb} = material-balance time **JPT**