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Significant Improvement in the Accuracy of Pressure Transient Analysis Using Total Least Squares

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Abstract

In this study we show significant improvements over conventional pressure transient analysis based on nonlinear regression, by using total least squares (TLS). The TLS algorithm we have developed estimates reservoir parameters by minimizing errors in both pressure and time simultaneously. Our technique is in contrast to other approaches that also have been named TLS but which considered errors in flow rates and pressures simultaneously, rather than errors in time.

TLS regression, which is based on minimization of orthogonal distances of measured data points to the fitted curve, is not an easy problem to solve mathematically, especially for nonlinear pressure transient model functions. To our knowledge, TLS has not been applied to pressure transient analysis before in this sense. In our work, we formulated a robust approximation of the TLS solution, which can handle a variety of tests and reservoir models yet does not compromise the performance of the analysis. We used our TLS algorithm on various different reservoirs and transient tests successfully, including dual-porosity and fractured reservoirs, reservoirs with rectangular boundaries, cyclic buildup-drawdown tests, and general multirate data. We show that our technique reduces ambiguity in the estimation of parameters to a large extent, especially in the presence of noise. Using our TLS algorithm we obtained much narrower confidence intervals on the parameter estimates compared to the regular least squares approach used conventionally today.

In this paper we compare four different versions of total least squares: (1) errors in time and pressure (horizontal error and vertical error) summed in the same objective function; (2) orthogonal distance regression in linear p vs. linear t , (3) orthogonal distance regression in linear p vs. $\log t$, (4) orthogonal distance regression in $\log p$ vs. $\log t$. We have observed much greater robustness against noise in the estimation of reservoir parameters. In the presence of errors in pressure only, the confidence intervals were at least as good as regular least squares. However, in the presence of errors in time in addition to pressure, the performance of TLS algorithms was substantially better. On a variety of both real and synthetic data sets, we have observed much narrower confidence intervals on the estimated parameters, even for large noise. For synthetic data sets, we observed that the reservoir parameter estimates from TLS are often closer to the true values than estimates made with conventional least squares, especially for poorly determined problems. We therefore expect that our technique will provide more accurate estimation of reservoir parameters, allowing for better forecasting of reservoir performance.

Introduction

The problem of reservoir parameter estimation based on well test data has been studied extensively. With the advance of computers to solve nonlinear regression problems efficiently, computer-aided well test analysis has provided a capability that allows solving complicated problems. Nowadays, almost all techniques in computer-based well testing rely on least-squares based nonlinear regression. In pressure transient analysis, this corresponds to minimizing errors in pressure: the objective is to reduce the difference between calculated pressure values and pressure values in the measured data. Many algorithmic improvements, such as using the derivative curve, wavelet transform, least absolute value analysis, etc., can all be categorized in the same process that only errors in pressure are taken into account. These approaches inherently assume all the errors are in pressure and try to minimize these errors. Yet, measurement errors in time are not uncommon and may play an important role. For example Horne (*Horne, 1994*) discussed the significance of a constant shift in time. This can result in substantial difference in the estimated values of the parameters.

Total least squares (TLS) approaches account for errors in the time domain as well as the pressure domain. We have to point out an important distinction between the TLS approaches we will be discussing in this paper and other fundamentally different approaches in the literature that have also been called Total Least Squares. In those approaches, the term “total least