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A New Pressure/Rate Deconvolution Algorithm to Analyze Wireline Formation Tester and Well-Test Data

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Abstract

The deconvolved pressure change and its natural-logarithmic time (or Bourdet) derivative are very important for wellbore/reservoir system identification in pressure transient interpretation because they represent the constant-rate drawdown response of the system. In recent years, the use of pressure/rate deconvolution has increased considerably due to significant improvement of the mathematical algorithms. In this paper, we present a robust deconvolution algorithm based on a weighted Euclidean norm in the Tikhonov regularized objective function so that one can assign weights to individual pressure and rate measurement points, and thus define different error estimates for different sections of the data. Incorporating such features into the deconvolution algorithm is very useful to mitigate the effects of unreliable pressure and rate measurements and the sections of the data not obviously consistent with the wellbore/reservoir model. In the deconvolution algorithm, the Levenberg-Marquardt method with a restricted step procedure is used for the minimization of the objective function.

We present several applications of the new algorithm using real field pressure/rate transient data sets. In addition to well test data, we apply the algorithm to wireline formation-tester pressure transients which are usually also referred to as Interval Pressure Transient Tests (IPTT). The examples include data with cleanup effects as well as an IPTT test, followed by a conventional Drill Stem Test (DST). To the best of our knowledge, applications of deconvolution to wireline formation-tester pressure transients have been limited to a single publication before. Hence, the deconvolution algorithm and the results in this paper will be useful in designing and interpreting wireline formation tester pressure transients in addition to pressure transient well tests.

Introduction

Each wellbore/reservoir system has a characteristic impulse function $g(t)$ which is a time derivative of constant-unit-rate drawdown pressure response $p_u(t)$, i.e. $g(t) = dp_u(t)/dt$. The function $g(t)$ is also called as the impulse response or the influence function. The wellbore/reservoir system could be considered as linear, if this system is governed by the pressure diffusion equation with linear time-dependent inner boundary condition. This is a common assumption for well testing. In this case, superposition principle holds and the relationship between the measured flow rate $q(t)$ and the measured pressure drop $\Delta p = p_0 - p(t)$ is given by Duhamel's convolution integral (van Everdingen and Hurst 1949):

$$\Delta p(t) = \int_0^t q(t-t')\,g(t')\,dt' \,, \qquad (1)$$

where $p(t)$ is the measured pressures (the solution of the time-dependent boundary value problem), p_0 is the initial reservoir pressure. Both $p(t)$ and $q(t)$ are measured in the wellbore and may contain some noise (measurement errors). The magnitude of noise could vary significantly depending on measurement technology, wellbore environment and fluid: 0.01 to 5% for pressures and 1 to 15% for flow rates.

Mathematically, the pressure/rate deconvolution problem is the estimation of unknown wellbore/reservoir impulse response, $g(t)$ and the constant-unit-rate drawdown pressure drop, $p_u(t)$ from Eq. 1 using measured pressures $p(t)$ and flow rates $q(t)$ with a known initial reservoir pressure p_0. Duhamel's convolution integral given by Eq. 1 is widely known as Volterra equation of the first-kind in mathematics literature. Solving this equation is known to be an ill-posed inverse problem, mainly due to the violation of a solution stability condition, thus small errors in $p(t)$ and flow rates $q(t)$ results large oscillations in the solution. As stated above, noise always exists in measured $p(t)$ and $q(t)$, thus solving Eq. 1 is an ill-posed