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Determining Multilayer Formation Properties from Transient Temperature and Pressure Measurements

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Abstract

Multilayer transient testing commonly relies on a series of step rate changes in surface flow rate with acquisition of stabilized rate profiles before each rate change and stationary downhole transient rate and pressure measurements after each rate change. The procedure requires one rate change for each layer to be characterized, and overall test duration can be quite long depending on the number of layers to be characterized. This study introduces an entirely new testing approach that uses transient temperature data at multiple locations together with a single-point transient pressure measurement. Because the temperature sensors acquire multipoint temperature simultaneously, this technique requires only one surface flow rate changes, thereby reducing the test duration significantly.

A coupled wellbore/reservoir thermal model developed in a previous study showed that the combination of transient temperature and pressure is sufficiently sensitive to individual layer properties to determine layer permeability and skin values in multilayered systems. In this work, the inverse problem is solved using the Levenberg-Marquardt regression algorithm.

In this new testing method, temperature data from only n+1 locations are required to determine layer permeability and skin values in an n-layer reservoir, and strategic sampling over time accelerates the regression convergence. The inversion has been tested on many synthetic cases with wide variations in layer permeability and skin values and has proven to be both accurate and robust. In addition, temperature resolution and data signal to noise impacts have been studied along with a data filtering approach that enable selection of suitable pressure and temperature sensor technologies for applying the new testing method. With the interpreted permeability and skin values, well productivity can then be enhanced by hydraulically fracturing in low permeability layers and/or by applying matrix stimulation in layers with high skin.

Introduction

Most oil and gas reservoirs are stratified with different layer properties as a result of sedimentary deposition processes. Since layer properties are critical information for multilayer reservoir development, many testing and analysis approaches have been presented to understand the behavior of multilayered reservoir and to quantify formation properties.

Lefkovits (1961) first studied the behavior of the two-layer commingled reservoir system and presented a detailed mathematical derivation. In his work, the average formation properties can be determined using buildup curves. Following Lefkovits' work, many authors improved his mathematical model. Ehlig-Economides et al. (1987a) extended the model to an arbitrary number of layers and included interlayer crossflow and the effects of wellbore storage. A more general analytic solution for multilayer testing in commingled reservoirs was presented by Kuchuk et al. in 1991. Their solutions are applicable to a variety of commingled reservoir systems in which individual layer may have different initial and outer-boundary conditions. Their study extended the application of multilayer testing in practice.

Quantitative interpretation techniques were first introduced in the 1980s. Kuchuk et al. (1986) presented a new data acquisition and analysis technique called a "multilayer test", which made it possible to uniquely determine individual-layer permeabilities and skin factors for reservoirs with commingled layers. Their multilayer testing technique starts with the well flowing at a constant production or injection rate. A production log (PL) flow rate survey is acquired during stabilized flow. Then the flow meter is stationed above one of the layers to be characterized, and a step change in surface rate is made while the PL string is kept in a stationary position. After some time, usually several hours, another flow rate survey is acquired, the PL string is stationed above another of the layers, and the surface flow rate is changed again. The test continues repeating these same steps until transient measurements of pressure and flow rate have been made above each of the layers to be characterized.

In the multilayer transient test analysis (Ehlig-Economides, 1987b), stabilized profile data are used to determine individual layer pressures, and transient pressure and flow rate data are used to estimate individual layer properties using nonlinear least-squares regression.

In recent years, the multilayer testing technique has been gradually improved by Spath (1994), Larsen (1999), and Prats (1999), and has been applied for more complex reservoir and wellbore conditions. However, the fundamental principles are still the same, and thus the inherent drawbacks in the testing technique have not been eliminated. In particular, the long