



**SPE 124049**

## **Determination of Petrophysical Parameters and Mud Filtrate Invasion Profile Using Joint Inversion of Induction Logging and Pressure Transient Measurements**

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This paper was prepared for presentation at the 2009 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, USA, 4–7 October 2009.

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### **Abstract**

Induction logging technique is one of the important tools for determining the formation resistivity of the subsurface. The near-wellbore formation resistivity is usually affected by the invasion of water-based mud-filtrate. The flushed-zone resistivity ( $R_{xo}$ ), the undisturbed-zone resistivity ( $R_i$ ) and the diameter of invasion ( $D_i$ ) can be estimated from the interpretation of array induction logging measurements through a model-based inversion process. Conventionally, the inversion assumes a layer-cake formation with three-parameter invasion model or with a four-parameter invasion model that incorporates a ramped transition zone.

In this study, we introduce a 2.5D inversion approach for interpreting the induction logging data. The inversion is constrained by using a multiphase fluid-flow model which simulates the mud-filtrate invasion process and calculates the spatial distribution of the water saturation and salt concentration, which are in turn transformed into the formation conductivity using a resistivity-saturation formula. In this way, the inverted invasion profile is consistent with the fluid flow physics. Jointly with the pressure data, the inversion estimates a parametric one-dimensional distribution of permeability and porosity.

Previous works either assumed that the mud-cake permeability is known and used the bottom-hole pressure as a boundary condition, or alternatively used an invasion model to calculate the dynamic invasion rate as a boundary condition to the fluid-flow simulator at the wellbore sandface. The dynamic invasion process is complicated and is affected by many factors. Hence, although possible, it is difficult to calculate the invasion rate. This study shows that it is possible to directly invert the mud-filtrate invasion volume from the fluid-flow-constrained inversion of the induction logging data. Moreover, this approach is not limited by the traditional interpretation of the formation test, which is based on a single phase model without taking into account invasion. The joint inversion of the induction logging and pressure data demonstrates the ability to provide a more reliable interpretation of formation permeability. The advantage of the approach presented here, is its possible generalization to three-dimensional geometries, for example dipping beds and highly deviated wells.

### **Introduction**

Induction logging measurements are sensitive to water saturation and brine concentration in the rock pores. In an active reservoir, the formation's petrophysical parameters can have a strong imprint on the temporal and spatial distribution of water saturation and salt concentration, which in turn can be transformed into the distribution of formation conductivity using an appropriate saturation-resistivity equation. This relationship between induction measurements and the petrophysical parameters offers an opportunity to integrate electromagnetics and multiphase fluid flow to provide a robust, physically consistent interpretation for reservoir characterization.

Induction logging tools can be used to determine the formation resistivity and invasion profile via a model-based inversion approach. However, this application is constrained by some simplifying assumptions, for example, assuming a vertical well penetrating a layer-cake formation with a step-profile three-parameter ( $R_{xo}$ ,  $R_i$ ,  $D_i$ ) invasion model. The quality and accuracy of the inversion results are affected by the complexity of the reservoir configuration and the actual invasion profile. In horizontal or highly deviated wells or in anisotropic formations, invasion profiles become too complex to be described by a simple invasion model. On the other hand, the mud-filtrate invasion affects the interpretation of well testing or wireline formation test. The conventional interpretation of formation test usually employs a single-phase fluid-flow model