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Reservoir Characterization for Energy Security

Insights into the As-Received Electrical Responses in Unconventional Reservoirs

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ABSTRACT

Unconventional reservoirs are characterized by matrix permeabilities typically spanning the nanodarcy to microdarcy range. This ultra-low permeability severely restricts fluid mobility, rendering conventional core-based methods for deriving Archie's parameters highly challenging and often impractical. Formation-water resistivity (R_w) serves as an essential input parameter for Archie's equation. Classical methods to determine R_w include: (1) calculation using resistivity and porosity logs, (2) direct analysis of produced water, (3) displacement testing of fresh-state core plugs, and (4) reconstruction via crush-and-leach techniques on preserved samples. However, these conventional methods for determining formation-water resistivity (R_w) are ill-suited for unconventional reservoirs and frequently yield inaccurate results.

A patented method utilizing resistivity dispersion to measure formation water resistivity (R_w) on "as-received" (AR) core samples has been applied to develop a new core analysis workflow for determining Resistivity Index (RI), Formation Factor (FF), and other petrophysical parameters directly from AR core samples. The workflow begins with AR cores in the laboratory. Initial porosity and water saturation (S_w) are measured via nuclear magnetic resonance (NMR). Formation water resistivity (R_w) is measured using a patented resistivity-dispersion technique. Bulk resistivity (R_t) is acquired with a two-electrode system. Controlled de-saturation is performed by centrifuge at two drainage pressures, with S_w and R_t measured at each state. A regression of the R_t-S_w series yields R_0 (resistivity at 100% water saturation), FF, RI, and Archie cementation (m) and saturation (n) exponents. With the implementation of this new workflow, traditional steps such as cleaning, drying, and re-saturating the core samples are no longer required, thereby minimizing the risk of altering their native wetting state. This streamlined approach significantly reduces laboratory analysis time, from several months to just a few weeks, while maintaining data integrity.

The capability to obtain reliable Formation Factor (FF) and Resistivity Index (RI) measurements directly from (AR) samples is particularly valuable, as these parameters are critical for estimating hydrocarbons in place using Archie's equation and for evaluating partial oil-wet conditions. This approach is equally applicable to permeable, conventional reservoir rocks, thereby extending the utility of this core analysis method beyond unconventional systems. The most reliable estimation of R_o is obtained from paired S_w and R_t measurements collected both at the (AR) state and following the initial de-saturation step. Similar to traditional electrical property measurements, a series of diagnostic cross-plots are employed to derive the key petrophysical exponents 'm' and 'n.' Specifically, a cross-plot of Formation Factor (FF) versus porosity provides a graphical determination of the porosity exponent (m), while a cross-plot of water saturation (S_w) versus Resistivity Index (RI) yields the saturation exponent (n). These relationships, when combined, enable accurate characterization of electrical behavior in unconventional formations under native-state conditions.

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