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Development and Baseline Comparison of a New Pulsed-Neutron Spectroscopy Tool for Carbon- Oxygen Analysis and Three-Phase Saturation Monitoring

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Abstract:

A new multidetector pulsed-neutron logging tool is introduced. Pulsed-neutron capture (PNC) and carbon/oxygen (C/O) measurements from pulsed-neutron logging tools are used as part of a fundamental assessment for multiphase fluid saturation quantification, formation evaluation, and reservoir monitoring. The C/O ratio is traditionally acquired from integrating gamma ray inelastic count rates from two discrete energy windows as a proxy for C and O, requiring baseline normalization for interpretations. Taking advantage of the new tool's enhanced spectroscopy characteristics, a spectral deconvolution method based on carbon and oxygen elemental yields for determining hydrocarbon saturation insensitive to water salinity is presented.

An advanced slim tool has been developed to acquire an optimized combination of PNC sigma, C/O, and gas saturation measurements in a single pass to provide multiphase fluid saturation analysis behind casing or in openhole environments. The design combines a high-output neutron source, a fully digital pulse processing and data acquisition system, and three high-resolution shielded LaBr3 gamma ray detectors. The new design allows the reduction of logging time by as much as three times without loss of precision.

Tool development was performed at an instrument characterization facility for a series of controlled conditions, including lithology, porosity, formation fluids, borehole sizes, borehole fluids, casing, and cement thickness. Extensive Monte Carlo N-Particle (MCNP) modeling results were matched with lab measurements and provided additional simulated response conditions beyond the practical limits of physical testing. New elemental standards were developed for a spectral deconvolution method using a weighted non-negative least-squares (WNNLS) algorithm to determine C and O yields in addition to other elemental components.

Hydrocarbon saturation is determined from C/O measurements using a custom MCNP simulation process as a reference to predict tool response in well-logging environments. Measured C/O values are then compared to the predicted C/O references for water and hydrocarbons at specific conditions.

Validation and verification of the new pulsed-neutron tool and spectral C/O analysis were initially performed for two-phase saturation evaluation baseline comparison at thoroughly studied and characterized test wells. Multiple passes of C/O, PNC, and optimized simultaneous C/O and PNC acquisition modes were logged. Each measurement was compared to previously acquired reference data. A statistical assessment was performed to compare and evaluate acquisition modes, logging speeds, and the number of logging passes.

A sensitivity test of spectral C/O measurements compared to windows C/O methods was performed in a high-temperature casedhole heavy oil sandstone well. As a continuation of a long-term observation study, this well provided a unique opportunity to compare against several years of monitoring. Three-phase saturation evaluation (heavy oil, water, steam) was then performed using an advanced analysis workflow. The workflow uses a patented triangulation technique combining spectral C/O values that are proportional to hydrocarbon saturation with inelastic ratio-based gas saturation measurements. Spectral C/O measurements were found to be comparable to windows C/O measurements and with increased accuracy. Especially valuable is the opportunity to reduce multiple logging passes and the inherent uncertainty associated with depth matching and integrating multiple acquisitions. With the available combination of sigma, spectral C/O, gas saturation ratios, and porosity, a triangulation of multiphase saturation assessment is feasible in any reservoir conditions (salinity and oil density independent methods). Simultaneous oxygen activation measurements allow detection and velocity determination of shielded water flow, which can provide insight into channeling, leaks, and other well integrity problems that can affect reservoir performance.

Bio:

Ian McGlynn is a Global Advisor for mineralogy and petrophysics at Baker Hughes. He serves as Global SME for mineralogy and geochemistry, with research interests in chemical weathering and petrogenesis of siliciclastic sediments and reservoir quality. He is involved with research and development of pulsed-neutron induced gamma-ray spectroscopy applications, conducts chemostratigraphic studies, and provides laboratory core analysis including mineralogy, petrography, inorganic geochemistry, and organic geochemistry. He received a MS in environmental science from the University of Virginia and PhD in geology from the University of Tennessee.