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3D Geophysical reservoir monitoring using borehole electric field measurements

Gary W. McNeice[1], Daniele Columbo[1]

[1]ExpecARC, Saudi Aramco, Dhahran, SAUDI ARABIA

ABSTRACT

Geophysical monitoring of enhanced oil recovery (EOR) is an area of active investigation with a range of proposed solutions involving seismic, gravity and electromagnetic applications. Electromagnetic techniques are promising because of the large dependence of electrical resistivity on changes of oil-gas-water saturations. In typical Saudi Arabian reservoir formations, electrical resistivity can change by greater than 90% over the development of an oil field due to peripheral water injection techniques used for oil production. In contrast, density and seismic velocity typically change by less than 3%. 2D borehole to borehole (Cross-well) electromagnetic methods are commercially available while 3D Surface-to-Borehole EM (SBEM) techniques are widely used in mining exploration but have never been applied for monitoring oil reservoirs. Cross-well techniques have shown some effectiveness for monitoring waterflood operations in oil reservoirs even if limited to the 2D geometry of the method. Both techniques employ magnetic sources and magnetic borehole receivers exploiting the electromagnetic induction principle and, as a consequence, are biased toward the mapping of conductors (e.g. water rather than oil). Here we present a new approach targeting the measurement of electric field variations in the borehole to enhance sensitivity to reservoir fluids. This can be achieved in the simplest scheme by a wireline tool with metal plates clamped to the borehole walls (uncased) to generate a galvanic contact. Enhancements in the acquisition technology can be achieved by the use of capacitive electrodes completely detached from the borehole walls and sensitive to the capacitance variations generated by the electric field. We use three-dimensional finite difference simulation to investigate the use of borehole electric field data in typical Saudi Arabian reservoir conditions. Surface-borehole and cross-well EM responses are simulated from both one-time and time-lapse surveys. Sensitivity analysis shows that electric field data have enhanced sensitivity over magnetic field data necessary for monitoring waterflood and CO_2 injection operations. 3D inversion results confirm that the inversion of electric field data provide sharper images of reservoir properties, relative to what can be achieved by the commercially available magnetic field-based methods.