726631 Results of Feasibility Study of Surface-to-Borehole Time-Domain CSEM for Water-Oil Fluid Substitution in Ghawar Field, Saudi Arabia

Colombo, Daniele [1]; Dasgupta, Shiv [1]; Strack, Kurt M.[2]; Yu, Gang [2] (1) Advanced Research Center - Geophysical Technology, Saudi Aramco, Dhahran, Saudi Arabia. (2) KMS Technologies-KJT Enterprises Inc., Houston, TX.

Monitoring the advancement of flood from water injection in carbonate reservoirs is a major challenge for geophysical methods. 4D seismic has limited applicability to Middle East reservoirs with low gas-oil-ratio in carbonate rocks. On the other hand, electromagnetic (EM) methods hold the largest potential in such reservoirs due to the large resistivity contrast (over one order of magnitude) between oil-saturated and water-saturated reservoir rocks. Electromagnetic measurements, however, are noise sensitive thus special configurations need to be implemented to enable the detection of the extremely small variations of the electromagnetic field that are induced by oil being replaced by injection water. Controlled source EM transmitters on ground surface and borehole receivers represent the most effective layout configuration to improve the signal-to-noise ratio and to augment the aperture of investigation while addressing the signal-to-noise challenge through long recording times. Transient time-domain controlled-source EM techniques also provide broadband EM measurements and adapt to most geologic scenarios and to the conditions characterizing the Ghawar field.

An advanced 3D modeling study was carried out by considering real reservoir geometry from 3D seismic interpretation, anisotropic resistivity distribution from tri-axial resistivity logs (acquired from surface to reservoir depth in the monitoring well) and time snapshots of fluid saturations modeled in reservoir simulators. The study allows the determination of EM field sensitivity to fluid saturation changes in in-situ reservoir conditions. Results indicate the vertical component of the electric field (E_z) is the most sensitive parameter to fluid replacement for a survey layout consisting of surface galvanic transmitters radially distributed around the well and a single, multi-level, borehole receiver. Repeated EM modeling over different time snapshots evidence the possibility to effectively monitor in three dimensions the resistivity changes occurring in the reservoir as the water flood front advances. Estimates of the EM field strength allow quantitative evaluations of the noise floor required to detect the variations of the electromagnetic field. These estimates will be used in a successive phase of the study where actual noise measurements and noise cancellation techniques will be tested in the field.

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