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Crosswell Electromagnetic Tomography: from Resistivity Mapping to Interwell Fluid Distribution

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Abstract

A crosswell electromagnetic (EM) technology trial project has been conducted in Haradh field in Saudi Arabia, located in the southern part of Ghawar field. The project objective is to map the fluid distribution and monitor the movement of injected water. Crosswell EM resistivity is one of the technologies that can be deployed for deep reservoir surveillance during hydrocarbon production. This technology can provide cross-sectional resistivity maps in the interwell space surveyed. It also has the potential to provide fluid distribution mapping at interwell scale, monitor macroscopic sweep efficiency, reduce uncertainty in the reservoir simulation, optimize the production strategies, plan infill drilling, thus improve overall recovery. This technology is most useful in time lapsed applications.

The selected test site consists of three wells in the oil-water contact zone in an Upper Jurassic carbonate reservoir at the Haradh field. The well spacing is chosen at the upper limit of the normal operating envelope allowed by this technology. Extensive pre-job forward modeling was carried out to investigate the feasibility of obtaining useful results from the measurements with such large inter-well spacing.

Significant drilling and well deepening were required prior to the deployment of tools in the three-well triangle. In fact, one new well was drilled and two other wells were deepened about 200 m under the targeted reservoir layers, so that good volumetric coverage could be obtained at the oil-water contact zone. Open-hole logs, formation tests, and cores have been acquired in the selected wells and they provide deterministic saturation profiles at the near-wellbore region. Such data are utilized as control points to resistivity and fluids distribution maps obtainable from crosswell EM at the interwell scale.

Crosswell EM surveys were acquired across the three wells [Ref.1, 2, 3] in Ghawar field in Saudi Arabia (Figure 1). In spite of the large well separations (an 850 m well spacing, the world record), the acquired EM data were of high quality, and good station repeatability was obtained. Two dimensional (2D) cross-sectional resistivity maps were derived from the processed data and they revealed resistivity anisotropy in the interwell space. Consequently efforts are under way for converting resistivity to fluid distribution: formation evaluation and special core analyses are being conducted, and water resistivity maps of the interwell flooded area are being built. Assisted by geological and petrophysical information, the cross-sectional resistivity maps constitute the basis for obtaining a 3D volume of fluid distribution in the interwell area.

Introduction

Monitoring reservoir performance in a large scale has been a keen interest for Saudi Aramco. A single well permanent electrode resistivity array downhole fluid movement monitoring experiment was conducted a few years ago with the objectives of determining reservoir petrophysical properties downhole [Ref.4] and characterizing large scale reservoir heterogeneities [Ref.5]. In 2005, Saudi Aramco advanced from the single well experiment to interwell reservoir monitoring experiment using the crosswell EM technology to map the oil and water filled zones at Ghawar. This interwell reservoir monitoring project consists of three parts: in the feasibility phase, background information and a numerical simulation package were used to select candidate sites within the field to apply the technology [Ref.1]; in phase 2 the crosswell EM surveys were deployed in the field for data collection and imaging, obtaining cross-sectional resistivity maps [Ref.2]; phase 3 is focusing on petrophysical calculations to estimate the interwell fluid distribution.