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Vertical Sweep Evaluation in the Lost Hills Diatomite Waterflood Using Carbon/Oxygen Logs

A. Badruzzaman, SPE, Chevron Energy Technology Company; T. Badruzzaman, Pacific Consultants & Engineers; and M.F. Morea and D.J. Julander, Chevron North America E&P Company

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Abstract

We discuss our experience to date with the Carbon/Oxygen logging technique to determine vertical sweep in Belridge Diatomite in the Lost Hills Field. We describe early interpretation challenges with overly optimistic saturation estimation. This required in-house Monte Carlo modeling to understand the tool response in very high porosity reservoirs. A newer vendor algorithm, however, underestimated the oil saturation. In-house test algorithms were then developed with significantly more accurate estimation of the oil saturation from a centralized-detector C/O tool in water-filled boreholes; results reported here are primarily for this tool. The C/O technique is also being tested in producers using the corresponding focused tool; we include an example of a successful test of the tool in an upper perforated well. The paper identifies further development needed to use C/O techniques, especially the focused tool, optimally in either monitor or producer wells in diatomite.

Introduction

The Belridge Diatomite in the Lost Hills Field in San Joaquin Valley, California, contains over 2 billion barrels of original oil in place (Wilt and Morea, 2004). This represents one of the largest components of the State's oil reserves estimated at over 24 billion barrels (Bopp, 2006). Figure 1 displays the location of oil fields in San Joaquin Valley with Lost Hills highlighted. The Belridge diatomite formation at Lost Hills is thick (~800 ft average), highly porous (~50% average porosity), has

low permeability (~1 md average), and has average oil saturation of ~45%. The majority of production from the formation is from central Lost Hills, where recovery is obtained from a waterflood started 15 years ago. Determining aerial and vertical sweep in the diatomite water flood is of interest. Based on our success in Kern River (Badruzzaman et al., 1998; Harness et al., 1998), we have been evaluating the Carbon/Oxygen (C/O) technique which appears most promising due to its salinity independence and field-wide applicability.

The earliest tests of the C/O technique in Lost Hills date back to the early 1990s's, when water flooding the diatomite was first initiated. However, C/O technology has been slow to mature in the field due to erroneous oil saturation predictions when compared to core or open-hole log saturations. Ostermeier (1993) conducted tests with an older C/O tool (Hertzog and Plasek, 1979; Roscoe and Grau, 1988) in diatomite in the nearby South Belridge Field. Here, he showed that log-derived C/O ratios had a similar shape to core-derived C/O ratios but that there was an inexplicable offset, with log C/O ratio reading significantly higher. In the mid 1990's, a modern dual-detector C/O tool (Roscoe et al., 1991) produced oil saturation estimates that were often too high. Our in-house Monte Carlo modeling studies to understand this established that this was most likely due to poorly understood tool response in high-porosity diatomite. The vendor subsequently developed a high-porosity correction. However, Badruzzaman et al., (2002) found that the oil saturation from the new algorithm of this tool appeared too pessimistic as did another vendor's dual-detector C/O tool (Jacobson et al., 1998) of the same vintage.

One possible cause of these effects is inadequate representation of the physics of the problem in vendor algorithms. Extensive core analysis revealed that the compositional properties driving the physics, such as matrix density, can vary significantly. Consequently, we