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Waterflood Surveillance and Control: Incorporating Hall Plot and Slope Analysis

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Abstract

Waterflood automation at a field scale is a complex coupled problem. In our analysis, data from injecting and producing wells, as well as satellite differential interferograms (InSAR) are used as the inputs. Some information processing is carried out on-line automatically, and other needs personnel expertise. Dynamic adaptive control is performed in the mixed open-loop-feedback mode. Our surveillance-control system is being implemented in Sections 32 and 33 of the Lost Hills diatomite field, CA, USA.

Introduction

Automation of waterflood surveillance and control helps to make oil recovery operations more efficient and reduce the costs related to early water breakthrough and well failure. Early warnings about possible trouble spots help to make corrective actions in a timely manner. Automation is an attractive, but challenging task¹. Automated data acquisition and storage technologies have made impressive advances over the past decade². However, it is insufficient to only collect and store the exponentially growing volumes of often meaningless data. The focus should be shifted to the development of robust on-line data analysis and quality control. In waterflood operations, this analysis should result in injection set points that can be sent to the wellhead controllers to close the control loop.

The paper is organized as follows. First, the principles of dynamic adaptive control are discussed. Then, several on-line and off-line methods of monitoring performance of an injection well are reviewed and evaluated. After that, examples of simultaneous analysis of the InSAR subsidence maps³ and maps based on performance analysis of the individual wells in the project are presented. Two Appendices include brief background material related to the Hall plot,

slope analysis, and the frequency-domain asymptotic estimates of time-dependent formation properties.

Dynamic adaptive control

Waterflood projects affect reservoir dynamics over large portions of oilfields. However, oil is produced and water is injected locally through individual wells. Therefore, it is natural to control an entire waterflood project by adjusting injection rates and pressures individually at each well. Clearly, the injection rates and pressures are coupled parameters: An increasing injection pressure results in an increased rate, and vice versa. In a moving car, the driver adjusts the accelerator pedal to increase or decrease the torque passed from the engine to the wheels to maintain the desired speed. Similarly, the force driving a waterflood, the injection pressure, is regulated to maintain the desired injection rate. In a car, the engine power is regulated by opening and closing a fuel throttle. At a well, the pressure is regulated by a valve installed at the wellhead. Therefore, the objective of the control at each individual well is to set up the pressure in such a way that the injection rate is maintained at the desired level. How to select the target rates for each well depends on an analysis of performance of a group of wells or the entire field. This analysis includes oil, water, and gas rates at producing wells, subsidence and consequent well failure, rock mechanics and physics, oil prices, etc. Below, a subsidence case is analyzed using satellite InSAR images³; see also Ref. 3.

The formation conditions near the wellbore change in the course of operations. Especially, this is the case when the reservoir rock is low-permeability, soft, and prone to damage, like the diatomite^{4,5}. The injection pressure must be adjusted according to these changing conditions; therefore, control must be dynamic. There are two major types of regulation: open-loop and closed-loop control. The former means that the control set points are planned in advance for a substantial period of time, whereas the latter one means that the set points are generated from the current measurements of available parameters. In fact, for injection control, neither of these two modes is suitable in its pure form. The open-loop control requires a reliable model of the process with accurately specified parameters that are almost never available for subsurface fluid flow. The closed-loop control or, otherwise, the feedback regulator, is also not suitable because the current injection conditions are the result of the history of well

³ InSAR images are produced by Vexcel Corporation.

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