

Real-Time Waterflood Reservoir Management using Key Performance Indicators in Smart Fields

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Abstract

Optimization of waterflooding operations, whether reducing water cut (WCUT) or increasing ultimate oil recovery, has been a great challenge. With advancing technology, intelligent wells with controllable down-hole chokes have provided the petroleum industry with efficient tools. Several techniques originating from different industries have been applied within the petroleum industry to address such challenges. This paper presents the advantages of using intelligent well valves compared to the base case of conventional wells with simultaneous use of a next-generation reservoir simulator and a user-friendly, robust optimization tool by maximizing net present value (NPV) and cumulative oil production.

Recovery has been enhanced using dynamic and smart control of interval control valves (ICVs) (Brouwer et al. 2002). ICVs provide more control and real-time action than that of inflow control devices (ICDs). Integrating a thorough understanding of reservoir physics expressed in analytical terms as key performance indicators, it is now feasible to use smart field technology proactively, rather than reactively. The additional recovery as a result of integrating key performance indicators with ICVs is presented through reservoir simulation. The difference between static and dynamic optimization methods used to date within the industry is also outlined. This paper additionally demonstrates the pros and cons of using intelligent well chokes for various optimization and uncertainty scenarios using a model of wells under rate and pressure-constraint simulations and parameters of uncertainty.

Waterflooding is the most commonly used secondary recovery method that uses water injection to increase oil production. Water injection helps increase reservoir pressure, thereby increasing oil production rates and, ultimately, oil recovery. The effectiveness of waterflooding depends on various factors, including oil viscosity, mobility ratio between oil and water, and rock characteristics. It is a dynamic process, and its performance can be improved by applying appropriate strategies at the correct time. Continuous monitoring and data analysis are fundamental components of modifying and improving waterflooding techniques.

During waterflooding, the injected fluids can reach the producers through channels and can leave parts of the reservoir untouched. Intelligent wells are equipped with sensors to monitor downhole pressure and saturation changes and with downhole valves to control the fluid flow from the reservoir to the well. Intelligent well technology is an enabler for proactive control that begins previously, before water breakthrough, to pre-vent or delay it. Short-term control optimizes the valve settings based on current and forecasted well performance. The long term approach uses the reservoir model and NPV techniques. The primary problem when applying an effective control strategy is an un-certain or outdated reservoir model. The key enabler for proactive control is better knowledge of the reservoir and an updated reservoir model based on measured data (Brouwer and Jansen 2004; Saputelli et al. 2005; Awasthi et al. 2008; Saputelli et al. 2009).

Intelligent well technology has been one of the most significant breakthroughs in terms of production technology during recent years. An intelligent well has downhole measuring and controlling equipment that can be adjusted to optimize production based on particular key performance indicators. The ability to monitor and use ICVs for controlling inflow from multiple zones can result in improved production and oil recovery. Intelligent wells aim to accelerate production and increase reserves. Ebadi et al. (2005) demonstrated that intelligent well technology is more effective in heterogeneous reservoirs because varying permeability and porosity create the type of fluid front that ICVs can best exploit. In deepwater formations, waterflooding is the primary recovery mechanism used; remotely operated valves can be used effectively to help pre-vent early water breakthrough and achieve desirable oil sweep.

Kahn et al. (2014) describes the use of smart work-flows for waterflooding optimization and the effect of injection pattern optimization on production. The key performance indicator in this study was real-time data, including pump intake pressure, flowline pressure, WC, flowing bottomhole pressures, static bottomhole pressure, production log results, and production flow test data. Goel et al. (2013) investigated the use downhole ICVs in intelligent well completions to control early water breakthrough, enhancing reservoir sweep efficiency.

The challenge of waterflooding notwithstanding, the oil and gas industry has encountered major challenges maximizing profitability in dynamic and uncertain environments. Improvements to oilfield operations, new technology, and appropriate business processes have helped companies address these challenges. A recent approach has been to adopt proven and successful technology from downstream (oil refining) and other affiliate industries to help solve similar problems encountered in upstream processes. Although this approach involves promising technologies, such as real-time optimization, some of the processes must be adapted to suit the needs of the oil and gas industry. Current practices in terms of real-time optimization often involve combining mathematical models, field data, and experience to help make better decisions regarding optimal production scenarios. Often, practical field realities can make the selected scenario un-feasible; in this case, feedback of the deviation and unfeasibility must be provided to dynamically reoptimize under the most current production constraints. One approach is to continuously update the numerical reservoir model with new field data through history matching. Despite its obvious advantages, the vast volume of data associated with this approach makes it a labor-intensive task.

In recent literature (Chu 1990; Sankaran et al. 2010; Corre et al. 2000; Damsleth et al. 1992; Egeland et al. 1992; Dejean and Blanc 1999), several proxy modeling techniques have been proposed in which the out-put variables are modeled as a function of input variables. These methods are purely data-driven; they capture the nonlinear effects in the dataset on which they are trained, which has been helpful to the performance of real-time optimization. These methods, however, fail to adequately model reservoir phenomena unseen in the past (i.e., water breakthrough) or operating regimes outside of the training data set.

It is in light of these limitations that the work of Brouwer and Jansen (2004) is groundbreaking. They presented a vector-matrix representation of the reservoir model to use optimal control and continuous model updating. Because this model was derived from reservoir physics, it was suitable for extrapolation outside of the training data set while providing the quick calculations necessary for a real-time optimization setup. This paper proposes the use of this approach to help identify the best possible scenarios under uncertainty conditions.