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Model Updating and Optimum Control for Water Coning: an Application of Ensemble Kalman Filter

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Abstract

Recent advances in downhole data acquisition facilitate continuous updating of the reservoir model and optimum control of well operations. Ensemble Kalman Filter is a model updating algorithm that permits rapid assimilation of production response in reservoir models and thus renders the process feasible in a real time setting. This paper demonstrates the feasibility of implementing a feedback optimum control procedure for controlling water production due to coning. Optimal production rate setting for a reservoir with strong bottom water influence is demonstrated.

The critical rate at which a well can be produced without inducing coning is strongly influenced by the reservoir permeability in the vicinity of the well. Since there is uncertainty in the reservoir permeability distribution, there is uncertainty in the prediction of critical rate. Continuous updating of the reservoir model reduces the uncertainty in critical rate estimates. This paper demonstrates the worth of periodic model updating in terms of optimized production and oil recovery. A synthetic reservoir with a horizontal well over an active aquifer is first presented. Continuous updating of the permeability field using the ensemble Kalman Filter results in better prediction of production profile. The approach is then implemented in a laboratory setting using a sandpack with the main features of the synthetic reservoir, and monitoring production pressure and rates that were used for updating sandpack permeability. A novel feedback control scheme for efficient operation of wells is demonstrated with an example of a vertical well affected by water coning.

Introduction

The productive life of a well completed over an active aquifer is strongly affected by water coning. The evolution of the water cone is driven by non-uniform drawdown pressure near the wellbore. The irreversibility of water coning mandates its early detection, modeling and control before and/or during water breakthrough. Recent development in technologies for in situ monitoring using pressure and temperature distributed sensors allow acquisition of real-time production data that carry valuable information about reservoir properties and the water coning process in the vicinity of the well. The acquired data can be used to maximize oil-water ratio through model based dynamic optimal control of pressure drawdown along a production well and/or inflow allocation among the wells draining the same reservoir.

Water coning is a local phenomenon governed by the gradient of the flow potential in the vicinity of the well. Since the flux variations in the far-field have a relatively insignificant influence on the characteristics of coning, a full reservoir model is not required to control this local phenomenon. Muskat (1935) presented an analytical solution for the critical flow rate of a well in a homogeneous and isotropic reservoir below which a stable water cone is formed. The velocity of cone propagation is partially determined by reservoir permeability as shown by Eq. (1).

$$\frac{\partial h}{\partial t} \propto \Delta P_{tot} = \frac{\mu}{2\pi kD} \ln \left[\frac{r_o}{b(1-h)} \right] - \Delta \rho g b h - 2P_c \quad (1)$$

h is the cone height from original water-oil contact; ΔP the pressure difference from the tip of the cone to the wellbore; μ oil viscosity; k rock Permeability; b distance from the well to original WOC; $\Delta \rho$ fluids density difference; g gravity force; P_c capillary pressure.

Several analytical and numerical correlations that predict water coning performance accounting for more complex geometries and heterogeneity have been developed. A comprehensive literature survey on water coning was published by Alikhan and Ali (1977). Despite the extensive work done on water coning, most of the existing models for this process are