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Development and Use of a Simulation Model for Mobility/Conformance Control Using a pH-Sensitive Polymer

I. Benson, SPE, Chevron Energy Technology Company; L.X. Nghiem, SPE, Computer Modelling Group; and S.L. Bryant, SPE, M.M. Sharma, SPE, and C. Huh, SPE, University of Texas at Austin

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Abstract

Injection of a pH-sensitive polymer has been proposed recently as a novel deep-penetrating mobility control method, and the development of a simulation capability for its scale-up is reported here. An aqueous dispersion of polymer microgel, whose swelling property shows a strong dependence on pH, preferentially flows into high-permeability zones under acidic conditions. Since the injected fluid viscosity is low, small injection pressures are needed to inject the polymer. Geochemical reactions increase the pH, causing the polymer-containing fluid to experience a viscosity increase of several orders of magnitude thereby altering the flow pattern of subsequently injected fluid. Because the viscosity of microgel dispersions can be controlled with adjustment of pH, this process can be employed both as a deep-penetrating mobility control method (with moderate polymer viscosity) and as a conformance control method (with immobile gel generation).

Polymer-bank placement design and process scale-up requires simulation of transport of microgel, acid-mineral geochemical reactions, pH changes, and the coupling between aqueous phase composition and viscosity. Such a capability has been implemented in a commercial reservoir simulator and preliminary simulations verify the operation and effectiveness of the complex new features, which can describe both the mobility and conformance control applications. Determination of reservoir mineralogy and mineral reaction rates is critical to modeling *in-situ* pH changes accurately. History matching of coreflood acid injection experiments was used to estimate geochemical reactions and reaction rates occurring in Berea cores. Linear and radial geometry floods in 2-layer reservoir models were carried out as preliminary scale-up simulations. Acidic fluids can be propagated farther into a reservoir in a low-pH state, using high injection velocity, an acid preflush, or weak acids. The Damkohler number was found to be a useful dimensionless quantity for characterizing acid floods with pH-sensitive polymer. Slugs of pH-sensitive polymer improve oil recovery better than continuous polymer flooding or waterflooding.

The simulator was successfully used to history match coreflood experiments, to model techniques to propagate low-pH fluids deep into reservoir, and to demonstrate the effectiveness of pH-sensitive polymer slug treatments for conformance control.

Introduction

Poor volumetric sweep or poor conformance, due to reservoir heterogeneity, reduces oil recovery and increases operating costs of mature waterfloods. Mobility improvement methods such as polymer flooding, and conformance control methods such as workovers and polymer gel treatments, aim to improve oil recovery by diverting injected fluid from high-permeability zones to low-permeability, unswept areas of a reservoir. Injection of a pH-sensitive polymer as a deep-penetrating mobility control or conformance control method has been developed earlier in our laboratory (Huh *et al*. 2005; Choi *et al*. 2006). A solution of pH-sensitive polymers such as polyacrylic acid hydrogel can exhibit an orders-of-magnitude viscosity increase when its pH increases from acidic condition to above a threshold value. Such polymers are commercially available at low cost in large quantities and are environmentally benign. A major strength of the proposed method is that the pH increase needed to induce the drastic viscosity increase *in situ* can occur naturally by geochemical reactions between acidic polymer solution and the reservoir rock. For the method to be effective, therefore, the ability to model the behavior of pH-sensitive polymer *in situ* in the reservoir environment is essential. Such a capability has been developed in a general-purpose reservoir simulator and is described in this paper.

As discussed in detail earlier (Choi *et al*. 2006), the controlled application of the proposed method requires a good understanding of its three sub-processes:

(1) dependence of polymer viscosity on ionic (pH) conditions in the reservoir;
(2) geochemical characterization of pH change in the rock; and
(3) polymer microgel transport in porous media.

The first of the above has been addressed in detail by Huh *et al*. (2005) and the second and the third by Choi *et al*. (2006).