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Modeling Particle Gel Propagation in Porous Media

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Abstract

Gel treatments are a proven cost-effective method to reduce excess water production and improve sweep efficiency in waterflood reservoirs. A newer trend in gel treatments uses particle gel (PG) to overcome some distinct drawbacks inherent in *in-situ* gelation systems. In this paper, we present a conceptual numerical model, based on laboratory tests and analyses, to simulate PG propagation through porous rock. In particular, we use a continuum modeling approach to simulate PG movement and its impact on isothermal oil and water flow and displacement processes. In this conceptual model, the PG is treated as one additional "component" to the water phase. This simplified treatment is based on the following physical considerations: (1) PG is mobilized only within the aqueous phase by advection in reservoirs; (2) PG, once retained in the porous media, will occupy pore space in pore bodies or pore throats and therefore reduce the permeability to bypassing water or oil; and (3) PG mobilization may not occur through pores or pore throats until some thresholds in pressure and/or pressure gradients are achieved and these threshold conditions are described by analogy to non-Newtonian fluid or non-Darcy flow in porous media, i.e., by a modified Darcy's law. The model is able to predict and evaluate the effects of PG as a conformance control agent to improve oil production and control excess water production.

Introduction

Excess water production has become a major problem for oilfeld operators to deal with, as more and more reservoirs, subject to long-term water flooding, become mature. In addition to rapid reduction in oil recovery, high rates of water production also create many problems from corrosion and fluid-handling facility to waste water handling and eventually lead to well shut-in. Consequently, many producing zones are often abandoned in an attempt to avoid water contact, even when the formations still contain large volumes of remaining hydrocarbons. Controlling water production has become more and more important to both the oil industry and environmental protection.

Gel treatments, if used properly, are very effective to improve reservoir conformance and to reduce excess water production during oil and gas production. Traditionally *in-situ* gels have been widely used for these purposes. The mixture of polymer and crosslinker, called gelant, is injected into target formation and reacts to form gel to fully or partially seal the formation at reservoir temperature (Sydansk, 1992; Jain, 2005). Thus the gelation occurs in reservoir conditions. A new trend in gel treatments is applying preformed gels, because the preformed gels are formed at surface facilities before injection, no gelation occurs in reservoirs, so they can overcome some distinct drawbacks inherent in *in-situ* gelation systems, such as lack of gelation time control, uncertainness of gelling due to shear degradation, chromatographic fractionation or change of gelant compositions, and dilution by formation water. The preformed gels include preformed bulk gels (Seright, 2004), partially preformed gels (Sydansk, 2004 and 2005), and particle gels which include mm-sized preformed particle gel (PPG) (Li, 1999; Coste 2000; Bai, 2004 and 2007), microgels (Chauveteau, 2001 and 2003; Rousseau 2005; Zaitoun 2007) and pH sensitive crosslinked polymer (Al-Anazi, 2002; Huh, 2005), mm-sized swelling polymer grains which is a similar product with PPG (Pyziak et al., 2007; Larkin and Creel, 2008; Abbasy et al., 2008), and Bright Water® (Pritchett, 2003; Frampton, 2004). Their major differences are in their sizes and swelling times. Published documents indicate that several particle gels were economically applied to reduce water production in mature oilfields. Microgel was applied to one gas storage well to reduce water production (Zaitoun, 2007). Bright water was used for more than 10 wells treatments with BP and Chevron (Cheung, 2007). PPGs were applied in about 2,000 wells to reduce fluid channels in waterfloods and polymer floods in China (Liu, 2006; Bai, 2008). Recently, Occidental Oil Company (Pyziak et al., 2007) and Kinder-Morgan (Larkin and Creel, 2008) used the mm-sized swelling polymer grains to control CO_2 breakthrough for their CO_2 flooding areas and promising results have been found.

To understand particle gel transport through porous media, Bai et al. (2007) reported their experimental results of PPG