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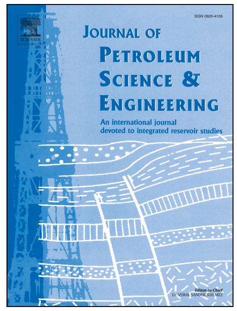

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Evaluation of Combined Low-Salinity Water and Microgel Treatments to Improve Oil Recovery Using Partial Fractured Carbonate Models

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Abstract

Combining two methods in one process to enhance oil recovery represents a needed cost savings in the oil industry. Microgels are used as conformance control agents to improve oil sweep efficiency and control excess water production. Low-salinity waterflooding (LSWF) is used as a wettability alteration agent in carbonate reservoirs and improves displacement efficiency. This paper offers a comprehensive understanding of the combined technology through laboratory experiments. The focus of this study is to see how microgels and low water salinity perform in porous media by creating flow resistance to injected fluid thereby changing the wettability and enhancing the sweep and displacement efficiency. This study elucidates the influence of swelling ratio, fracture width, microgel-placed pressure, and wettability on the oil recovery factor and water residual resistance factor (Frrw). A set of carbonate cores from Indiana Limestone was used to evaluate the performance of the combined method in partially open fracture. Oil recovery factor increases with swelling ratio and microgel placed pressure but decreases with the increase of fracture width. It was shown that oil recovery improved by 10% when the swelling ratio increased from 40% to 160% and improved by 9% when fracture width decreased from 0.8 cm to 0.2 cm. Also, the combined method shows larger effect in the oil-wet core when compared to the water-wet core. Frrw increases with the increase in swelling ratio and microgel-placed pressure but decreases with the increase of fracture width. The water-wet core showed a higher Frrw than the oil-wet core due to wettability alteration by low salinity water, which resulted in a higher swelling ratio.The combined method can improve both the displacement and the sweep efficiency.

Introduction

EOR methods offer promising approaches to recover a significant portion of remaining oil which is about two-thirds of the oil in place and cannot be recovered by conventional technologies. Excess water production and low oil production rates are two major issues that lead to early well abandonment and unrecoverable hydrocarbon in mature wells. Preformed particle gels (PPG) control conformance, and low salinity water flooding are two novel EOR technologies that have recently gained favorable attention from the oil industry.

Preformed particle gels have recently been developed and applied to improve the sweep efficiency of water flooding. PPGs are a specific kind of superabsorbent polymer. Their size can be controlled in nano-meter, micro-meter and also millimeter ranges. PPGs are able to overcome some drawbacks inherent in an in-situ gelation system such as lack of gelation time control, gelling uncertainty due to shear degradation, chromatographic fractionation, or dilution by water formation (Chauveteau et al., 2003; Bai et al., 2007a, 2007b). Preformed gel is formed at a surface facility before injection, and is then injected into a reservoir; thus, no gelation occurs in the reservoir. These gels usually have only one component during injection, and little sensitivity to physico-chemical conditions in a reservoir, such as pH, salinity, multivalent ions, hydrogen sulfide, and temperature (Bai et al., 2007a, 2007b). Current commercially available particle gels come in various sizes, including micro- to milli-meter sized preformed particle gels (PPGs) (Coste et al., 2000; Bai et al., 2007a, 2007b, Wu & Bai, 2008), microgels (Zaitoun et al., 2007), pH sensitive crosslinked polymers (Al-Anazi et al., 2002; Huh et al., 2005), and swelling submicron-sized polymers (Pritchett et al., 2003; Frampton et al., 2004). Their major differences lie in the particle size, swelling time, and swelling ratio. Published documents show that PPGs, microgels, and submicron-sized polymers have been economically applied to reduce water production and improve oil recovery in mature oil fields. Microgels were applied to about 10 gas storage wells to reduce water production (Zaitoun et al., 2007). Submicron-sized particles were applied to more than 60 wells (Cheung, 2007). Millimeter-sized PPGs can preferentially enter into fractures or fracture-feature channels while minimizing gel penetration into unswept zones and matrixes when millimeter-sized particle gels are used, and they have been applied in nearly 10,000 wells in water floods and polymer floods worldwide to reduce the permeability of fractures or super-high permeability channels (Bai et al., 2013; Peirce et al, 2014).

Low salinity water flooding has been widely investigated to reduce the residual oil saturation in swept areas and thus improve oil recovery. The encouraged effect of low salinity water on oil recovery can be traced back to Martin (1959). He observed an increase in oil recovery by injection of fresh water compared to sea water injection in sandstone core samples. However, its EOR potential was not recognized until Morrow and his co-workers published a series of related works from 1991 to 1999 (Jadhunandan and Morrow, 1991, 1995; Yildiz and Morrow, 1996; Tang and Morrow, 1997, 1999). Since then, many companies and research organizations have investigated how water salinity and compositions affect oil recovery and their mechanisms for sandstone and carbonates. Extensive laboratory experiments have demonstrated that low salinity water can improve oil recovery for both sandstone and carbonate reservoirs (Sheng, 2014). Zhang et al. (2007) reported that high salinity water injection into chalk formations increased oil recovery up to 40% of the original oil in place (OOIP). Lager et al. (2008) and McGuire and Chatham (2005) reported that low salinity water-floods could increase recovery up to 40% OOIP. In sandstone formations, a few field applications have also demonstrated the technology can further reduce residual oil