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Full Length Article

Areal sweep efficiency improvement by integrating preformed particle gel and low salinity water flooding in fractured reservoirs

Ali K. Alhuraishawy[a,b], Xindi Sun[b], Baojun Bai[b,*], Mingzhen Wei[b], Abdulmohsin Imqam[b]

[a] Missan Oil Company, Amara, Missan 62001, Iraq

[b] Department of Geoscience and Geological and Petroleum Engineering, Missouri University of Science and Technology, Rolla, MO 65401, United States

A R T I C L E I N F O

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A B S T R A C T

The oil recovery from fractured reservoirs is usually low, which is usually caused by the existence of areal formation heterogeneity. Two existing enhanced oil recovery (EOR) technologies, low salinity water flooding (LSWF) and preformed particle gel treatment (PPG), have recently drawn great interest from the oil industry. We integrated both of these technologies into one process to improve both oil displacement and areal sweep efficiency. The objective of this study was to test how the integrated method could be used effectively to increase oil recovery and control water production. The semi-transparent five-spot models, which were made of sandstone cores and acrylic plates, were built. We investigated the effect of four parameters on the improvement of oil recovery and areal sweep efficiency of oil, including gel strength, water salinity, injection rate, and number of fractures. Two approaches were followed during core flooding, sequential mode and mixed mode. The result shows that PPG and LSW injected together as one mixture improved oil recovery factor more than the first approach. PPGs plugged the fractures and successfully improved areal sweep efficiency; however, they have little effect on displacement efficiency. LWSF increased displacement efficiency but had little or no effect on sweep efficiency. The integrated methods bypassed the limitations of each method when used individually and improved both displacement and sweep efficiency.

1. Introduction

Approximately two-thirds of the oil in place cannot be recovered by conventional technologies. Thus, enhanced oil recovery (EOR) methods are required to recover a sizeable portion of the remaining oil in a well. Mature wells are often abandoned due to low oil production rates as well as the formation of excess water. To recover this remaining unrecoverable hydrocarbon, two new EOR technologies are now being used: Micro-PPG conformance control and low salinity water flooding.

Within the past two decades, there has been an increase in the use of PPGs to improve the sweep efficiency of water flooding. PPGs are composed of a specialized superabsorbent polymer. PPGs can be as small as nanometer size or as large as millimeter size. The use of PPGs solves some problems inherent in an in-situ gelation system. These include a lack of gelation time control, gelling uncertainty due to shear degradation, chromatographic fractionation, or dilution by formation water [10,6,7]. PPGs are manufactured at a surface facility prior to injection. They are later injected into a reservoir. Therefore, gelation does not occur in the reservoir. These gels usually have only one component during injection. They are only slightly sensitive to a reservoir's physicochemical conditions (e.g., pH, salinity, multivalent ions, hydrogen sulfide, and temperature) [6,7]. Particle gels are available commercially in a number of sizes: micro- to millimeter-sized PPGs [12,6,7,38], microgels [42], pH-sensitive crosslinked polymers [4,15], and swelling submicron-sized polymers [27,14]. PPGs differ chiefly in their particle size, swelling time, and swelling ratio. The literature reveals that PPGs, microgels, and submicron-sized polymers are all cost-effective alternatives that reduce water production and improve oil recovery in mature oil fields. Zaitoun et al. [42] demonstrated that the microgels applied to about 10 gas storage wells were able to decrease water production. Cheung [11] effectively used submicron-sized particles in more than 60 wells. Millimeter-sized PPGs can preferentially penetrate into fractures or fracture-feature channels while diminishing gel penetration into unswept zones/matrices. Worldwide, PPGs have been employed in approximately 10,000 wells in water floods and polymer floods to decrease the permeability of fractures or of super-high permeability channels [8].

To improve displacement oil recovery, the use of LSWF has been researched extensively to decrease the residual oil saturation in swept areas. Martin [25] was the first to describe the effect of low salinity

* Corresponding author.
E-mail addresses: akak22@mst.edu (A.K. Alhuraishawy), baib@mst.edu (B. Bai).

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Nomenclature

E_A	areal sweep efficiency
E_D	displacement efficiency
F_{rrw}	water residual resistance factor
$P_{inj.a}$	injection pressure after gel placement
$P_{inj.b}$	injection pressure before gel placement
R.F	oil recovery factor
S_{oi}	initial oil saturation
S_{wi}	initial water saturation
S_{or}	residual oil saturation
WF1	first waterflooding (1.0% NaCl)
WF2	first waterflooding (1.0% NaCl)
LSWF1	first cycle of low salinity waterflooding (0.1% NaCl)
LSWF1	second cycle of low salinity waterflooding (0.01% NaCl)
PPG + 1.0% NaCl	PPG swollen in 1.0% NaCl
PPG + 0.1% NaCl	PPG swollen in 0.1% NaCl.
PPG + 0.01% NaCl	PPG swollen in 0.01% NaCl

water on oil recovery. Using sandstone core samples, he compared an injection of seawater to that of freshwater, finding that oil recovery rose more after the injection of freshwater. However, the potential of LSWF was not established until the work of Morrow et al., published from 1991 to 1999 [19,20,39,36,35]. After that seminal work, research has been conducted by numerous corporations and other groups to discover the relationship between water salinity and oil recovery, especially as it relates to sandstone and carbonate. Numerous laboratory studies have confirmed that LSWF can increase oil recovery in sandstone and carbonate reservoirs [30]. A study by Zhang et al. [43] found that injecting low salinity water into chalk formations led to oil recovery of up to 40 percent of OOIP. Similar data were found by Lager et al. [21] and [26], who discovered that LSWF could increase recovery up to 40 percent OOIP. LSWF can further decrease residual oil saturation when compared to normal water flooding in sandstone formations [26,29,23,40]. The percentage of oil recovery improvement is dependent upon a number of considerations. These include multicomponent ion exchange, clay content, formation water composition, oil

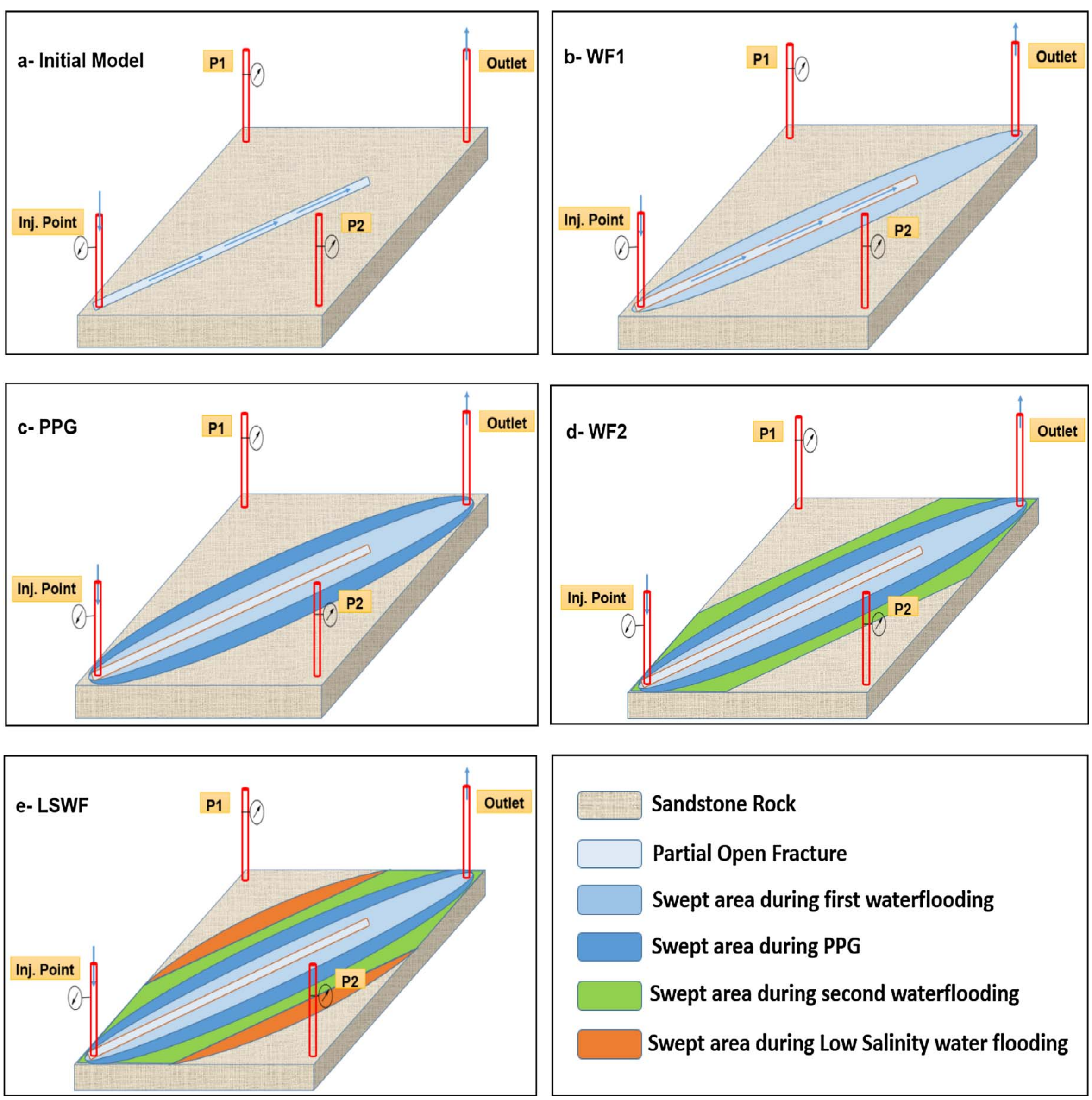

Fig. 1. Schematic showing the PPGs mechanism's injection in the partial open fracture.