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Experimental Investigation of the Performance of Low Salinity Water Flooding as a Novel Enhanced Oil Recovery

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Abstract

Previously, we examined the potential formation water (FW) Mg2+ for low-salinity (LS) EOR effect, where the incensement in divalent cations in FW was lowering the effect of LS water. In this paper, we demonstrate the importance of the same divalent cations in the injected water (both FW and LS water). We also try to relate the percentage of the divalent cations in the injected water to that in the FW to engineer the optimum concentration of the injected water and obtain the maximum oil recovery from sandstone reservoirs. Berean sandstone cores were successfully flooded with FW and LS water at 70°C. While injecting both brines, samples of the effluent were analyzed for pH. Oil recovery experiments with a double Ca2+ and Mg2+ concentration showed a lower LS water effect, meaning that the cores became more water-wet; however, the LS water effect was much greater when the amount of Ca2+ and Mg2+ in the HS water was decreased by half. The results of this work relate oil recovery with LS water chemical compositions, temperature, ion exchange, and pH.

Keywords: Enhanced oil recovery, LS water flooding, Petroleum geochemistry.

Introduction

The improved oil recovery from using LS water flooding was 2-40% of the original oil in place (OOIP) [1,2]. The experimental observations of Tang and Morrow [3] for LS water flooding set out conditions for how LS water works. The conditions were: (1) the crude oil must contain acid and base numbers and (2) sandstone should contain clay such as illite and kaolinite. After several years, McGuire [4] and Lager and Web [5] added another condition, which was that divalent cations must be present in the FW. The second condition of Tang and Morrow was no longer valid after the investigations of Al-Saedi and Brady [6] and Sohrabi [7]. The observations from chromatographic columns of quartz showed an increase in the acetate detachment from the quartz surface [6]. The oil recovery observations from the quartz column supported the proposed mechanism [8]. Lager and Webb [5] examined the effect of LS water during brine injection into a sandstone oil reservoir that had an identical amount of Mg2+ in the injected brine and formation water. The objective of this study is to identify the important role of the divalent cations in the injected water for secondary and tertiary flooding.

Materials and Methods

Materials: The brines were prepared by dissolving the salts in deionized water. The brine compositions are listed in Table 1. Crude oil was delivered by Colt Energy from one of the Kansas oil fields. The

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viscosity of the oil was 14 cp at 20°C, the density is 0.815 gm/cc at 20°C. The experimental setup is shown in Figure 1. A syringe pump was used to injected water into the accumulators which contain the FW and LSW. The injected brines flow into the core mounted in the core holder and the effluent was collected from the other side. The whole system installed inside an oven.

Core flooding: The Berean sandstone cores were flooded with 2 PV FW (96,100 ppm) as a secondary flooding, and then 2 PV LS water (4000 ppm) was injected for the tertiary stage at a constant rate. While injecting brines, samples of the effluent were analyzed for pH. The experiments were conducted as follows:

1. Core1 was saturated with FW containing 90 mmole/l Mg2+, and then flooded with the same FW followed by LS water containing 3 times diluted Mg2+ of the Mg2+ in FW.
2. Core2 was saturated with FW containing 90 mmole/l Mg2+, and then flooded with the same FW followed by LS water containing 10 times diluted Mg2+ of the Mg2+ in FW while keeping the salinity of the LS water the same as in Core1 by adding NaCl.

Results and Discussion

In previous work [1], we investigated the role of the divalent cations (Ca2+ and Mg2+) in the FW on the LS EOR and found that the role of the Mg2+ in FW is more effective than the Ca2+ even at high concentrations. As the concentration of the divalent cations increases in the FW, the sandstone turned more water-wet and less LS EOR effect was observed. In the present study, the focus was on the divalent cations in the injected LS water. The oil recovery results have been discussed in relation to the concentrations of the injected divalent cations.

The outcrop core1 was successively flooded with FW and LS water at 70°C. No increased oil recovery was observed during LS water flooding (d3Mg2+) after core1 was flooded in secondary stage with FW. The ultimate oil recovery remained constant at 52.5% OOIP (Figure 2a). The measurements of the pH were logged for the FW and LS water. The pH reading for FW effluent was 6.8 (Figure 3a), which must be sufficiently low to promote adsorption of polar components onto the sandstone surface. The injection pressure was 41 psi during the FW flood. The LS water injection pressure increased to 47 psi (Figure 4a).

When switching from FW to LS water, the pH of the LS water effluent increased to 7.3 (Figure 3), which was small pH increment due to the high concentration of Mg2+ in the injected LS brine demonstrating very low wettability alteration. According to Lager and Webb [5] and Brady and Morrow [9], the difference in upward shift in effluent pH between HS and LS water is traditionally ascribed to the exchange of H+ for divalent cations on clay surfaces. Our previous work showed a similar attitude on both free-clay sandstone and rich-clay sandstone [6]. More water-wet sandstone would be introduced due to that pH jump. It seems the core wet ability has not been altered by the injected LS water because of the high concentration of the Mg2+. Mg2+ was responsible for the low pH in the LS water effluent, an in turn, no additional oil recovery was obtained (Table 2).

The core2 was flooded the same way as in core1 but with d10Mg2+ LS water. As pointed previously, core1 and core2 were saturated with FW containing 90 mmole Mg2+.The oil recovery during FW forced imbibition reached a plateau at 51.5% OOIP (Figure 2b). The oil recovery was similar to core1 because of both alike in petrophysical properties and the core preparations. Upon switching to LS water, the incremental oil recovery was 2.65% of OOIP (Figure 2b). Diluting the Mg2+ 10 times in the injected LS water improved the oil recovery from 0% to 2.65%. The initial pH of the FW was 6.9, and the pH increased to 7.9 when switching to LS water (Figure 3b), which was significantly higher than for the core1. The pH during FW flooding providing a favorable environment for creating mixed-wet media. The pressure profile had similar behavior to that in core1 (Figure 4a and 4b). In our previous work we conducted the same experiments under the same conditions but at 90°C. The results were quite similar for secondary oil recovery but it was greater for the LS water flooding when the Mg2+ was diluted 10 times in the LS water [10].

Conclusions

1. When Mg2+ exists in the LS water, there is no oil recovery improvement during LS water flooding. There is no pH jump. It seems Mg2+ disrupts LS water EOR effect.
2. The experiments showed that Mg2+ is favorable for secondary oil recovery when the Mg2+ is presented in the

Table 1: Core properties and water description.

Core	Quartz, %	Kaolinite, %	Diameter, cm	Length, cm	K, md	Porosity, %	Mg^{2+} in FW, mM	Mg^{2+} in LSW, mM
Core#1	95	5	2.54	14.77	~100	~21	90	30
Core#2				14.67			90	9

Table 2: Oil recovery results for both FW and LS water flooding.

Core	Ca^{2+} in FW & LSW (mM)	Mg^{2+} in FW (mM)	Mg^{2+} in LSW (mM)	Secondary Oil Recovery by FW, %	Secondary Residual Oil Saturation S_{or}, %	Tertiary Oil Recovery by LSW, %	ΔS_{or}, %
Core#1	0	90	30	52	48	0	48
Core#2	0	90	9	51.5	48.5	2.63	45.87

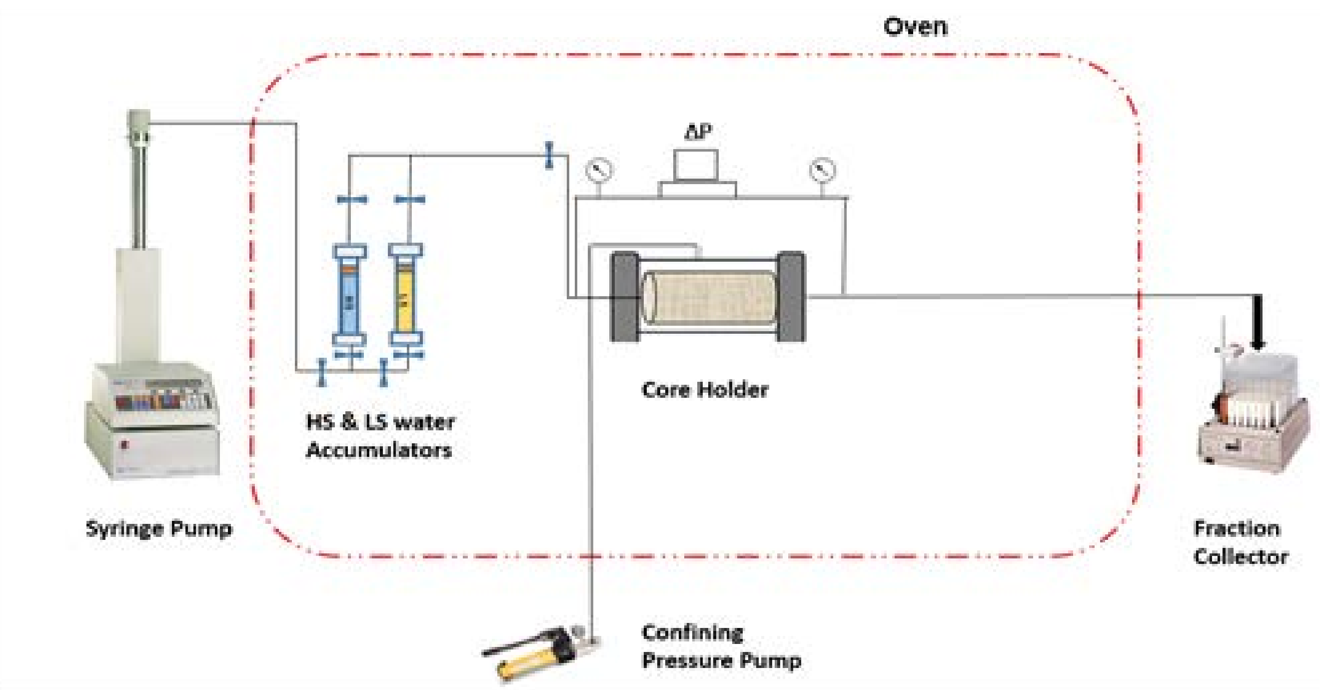

Figure 1. CoreFlood setup.

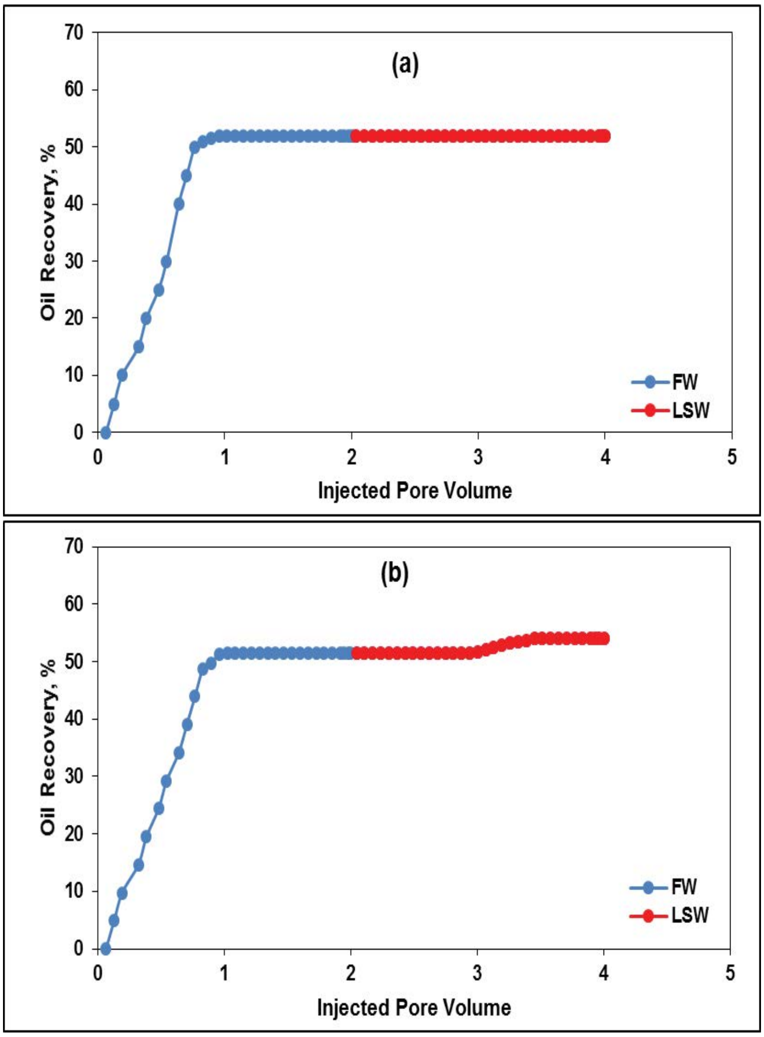

Figure 2. Oil recovery results for (a) core1 and (b) core2.

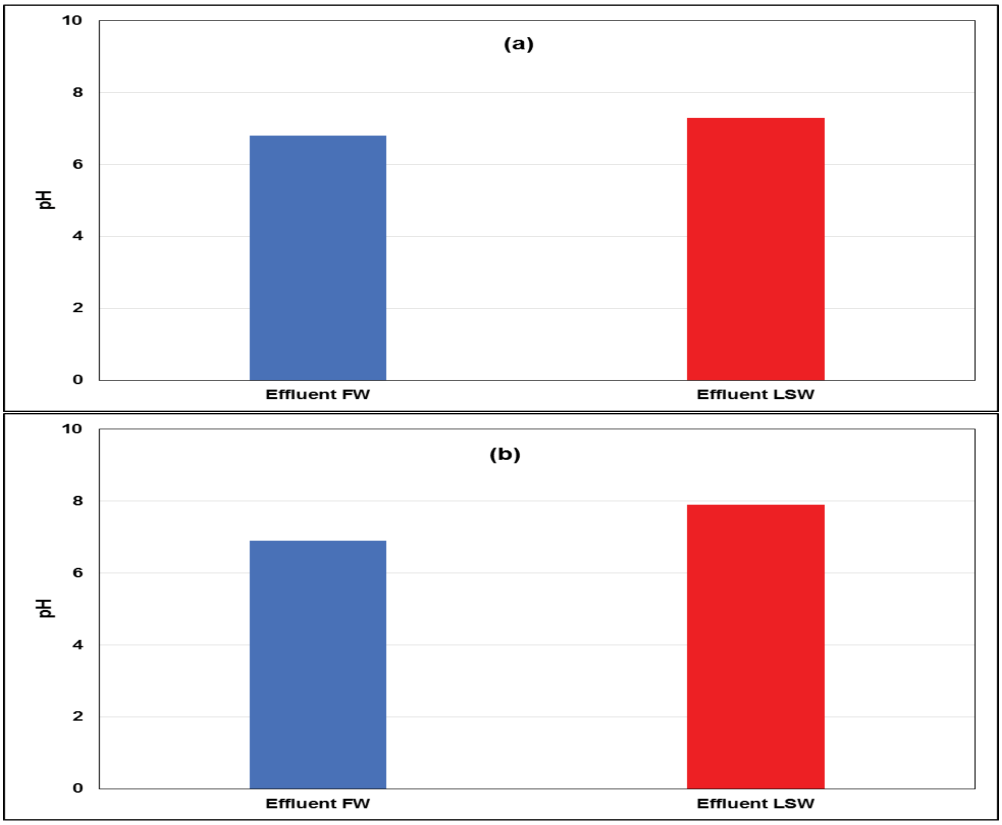

Figure 3: Measurements of the effluents pH for (a) core1 and (b) core2.

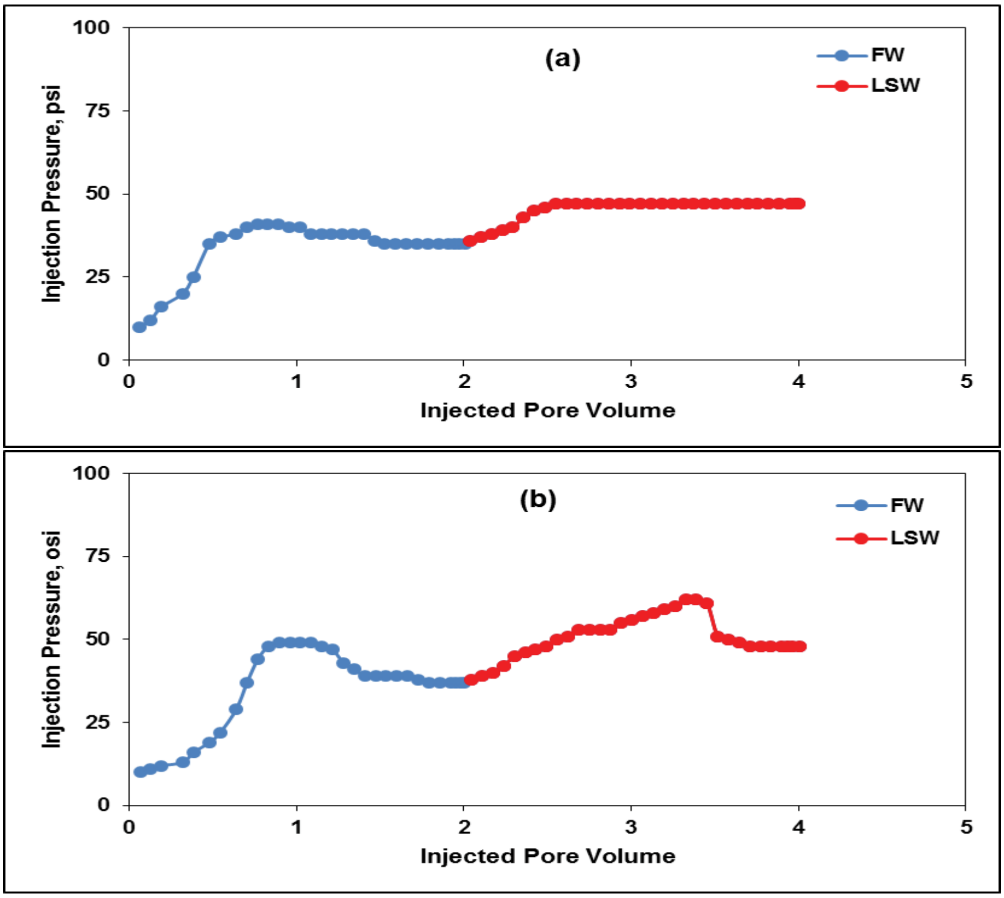

Figure 4: Injection pressure readings for (a) core1 and (b) core2.

FW and the injected FW during secondary flooding.

3. Abundance of Mg2+ in the injected LS water could provide 0% in oil recovery improvement, but diluting the Mg2+ to 10 times could improve the oil recovery.

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