Modeling the Interaction between Low Salinity Water and Sandstone Rock by Coupling Fluid Flow Equations with the PHREEQC Geochemical Model

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INTRODUCTION

Low salinity water (LSW) flooding is a promising enhanced oil recovery (EOR) method that has received more attention during recent years [1]. Previous experimental studies have revealed the EOR potential of LSW for producing incremental oil on top of conventional water flooding using high salinity water [2-3]. Moreover, different mechanisms were proposed to describe LSW performance among which rock wettability alteration toward more water wetness was believed to be one of the main underlying oil recovery mechanisms [4-5]. The latter was also experimentally supported that LSW could affect oil-water relative permeability function and make them more water-wet [6-7]. Although there is still no consensus on the dominant microscopic mechanisms leading to wettability alteration, it has been reported that geochemical reactions among low salinity water, crude oil and rock minerals could affect rock wettability [8-9]. The review of the previous studies shows that the core of the modeling procedure of LSW is mainly to modify oil-water relative permeability and capillary pressure as a function of brine salinity [10-11]. To this end, different interpolating parameters have been proposed to describe rock-fluid interaction induced by LSW injection [9, 11-12].

METHODOLOGY

In this paper, LWS injection in a sandstone oil reservoir was modeled by coupling fluid flow equations and PHREEQC geochemical model. The new concept of threshold salinity was used to describe oil-water relative permeability function in presence of water with different salinity. We considered ion exchange processes between injected water and rock surface and also calcite

dissoluton as the two main geochemical reactons in the LSW modeling. To this end, first, the fluid flow equations were discretized by using central finite difference scheme. Then, the ion transport equations in the aqueous phase were described to obtain water salinity through the model. It is worth to mention that the type of ions which are present in the aqueous phase and also ion concentration could be changed due to the occurrence of geochemical reactions between injected water and rock surface. Then, a threshold salinity of 3000 ppm in line with the previous experimental studies was used to describe the appropriate oil-water relative permeability function during water injection with different salinity [13-14]. Finally, the performance of LSW injection in the given reservoir conditions was discussed by describing the amount of calcite on the rock surface, cation equivalent fraction on the rock surface, evaluation of the pH of the aqueous phase, water saturation and oil recovery profile at different water salinity.

RESULTS AND DISCUSSION

The modeling results have shown that as LSW is injected, the initial equilibrium between reservoir aqueous phase and rock surface is disturbed because of the difference in salinity and composition of the injected low salinity water as compared to high salinity formation water. This leads to the calcite of the reservoir rock becomes dissolved in order to compensate the amount of Ca^{2+} cations in the aqueous phase. Also, due to the presence of CO_2 in the reservoir and its solubility in the aqueous phase, calcite dissolution reaction could be promoted, which leads to additional amount of Ca^{2+} cations in the reservoir. As a consequence, the produced Ca^{2+}

cations along with initial Ca^{2+} cations present in the aqueous phase promote ion exchange processes through the exchange of divalent and monovalent cations on the clay exchanger sites on the rock surface. Based on Figure 1, the profile of equivalent fraction of cations on the clay exchanger sites in the grid block adjacent to the injection well shows that most of the exchanger sites are initially saturated by Na^+ cations. But due to higher tendency of the clay exchanger sites to adsorb divalent cations rather than monovalent ones, the equivalent fraction of Ca^{2+} cations (CaX_2) on the rock surfaces increases during LSW injection. Such above-mentioned ion exchange processes could promote wettability alteration toward more water wet conditions due to the release of hydrocarbon compound from rock exchanger sites. Also, based on Figure 1, the equivalent fraction of Mg^{2+} cations (MgX_2) continuously decreases on the rock surfaces during LSW injection. This is mainly due to fact that the clay exchanger sites have more tendency to adsorb Ca^{2+} than Mg^{2+} cations. Also, the Mg^{2+} concentration in the formation brine is much less than Ca^{2+}, and no Mg^{2+} is present in low salnity water. Thus, there is no additional source to generate Mg^{2+} cations and compensate the decreasing trend of MgX_2 during LSW injection. Geochemical analysis also revealed that calcite dissolution reaction was performed completely in the region near to the injection well leading to a significant reduction in pH of the aqueous phase. However, the rate of calcite dissolution reaction decreases far from the injection well most likely due to insufficient time to interact low salinity water with the reservoir rock and fluid.
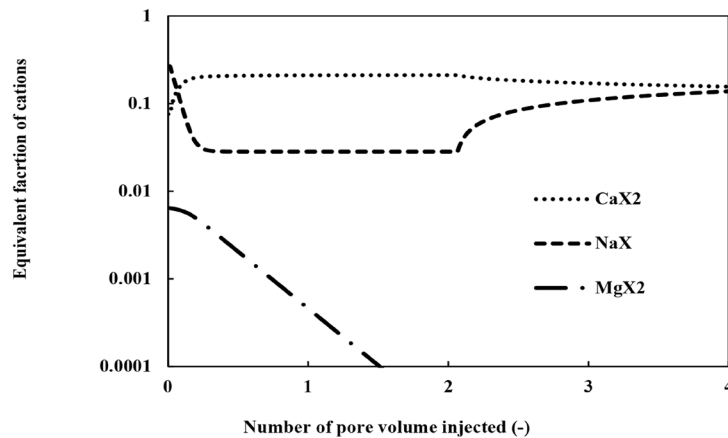
Figure 1: Equivalent fraction of cations on clay exchanger sites in adjacent grid block from injection well during LSW.

According to fluid flow analysis in Figure 2, it was found that two distinct water saturation shock fronts were evident during LSW injection. The first shock is related to oil displacement by high salinity water which is similar to the typical Buckley-Leverett displacement front. The second shock is related to the occurrence of geochemical reactions during LSW injection with a significant reduction of Na^+ concentration at production well. In terms of oil recovery, LSW injection increased oil recovery as much as 10 % of the oil initially in place on top of high salinity water injection under the given reservoir conditions, as seen in Figure 3.
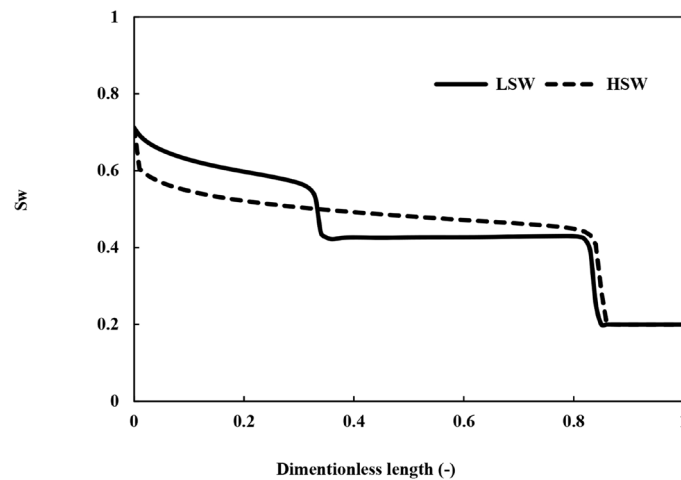

Figure 2: Water saturation profile during LSW and HSW injection at 0.25 pore volume injected.
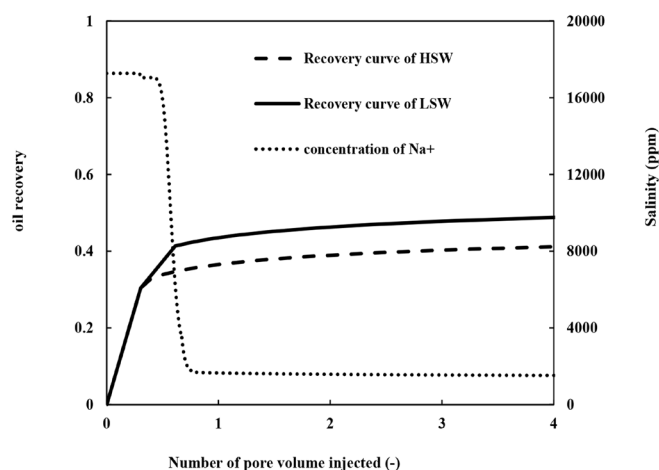
Figure 3: Oil recovery profile during LSW and HSW injection along with Na⁺ concentration profile during LSW injection in production well.

CONCLUSIONS

In this paper, the performance of LWS injection in a sandstone oil reservoir by coupling fluid flow equations with the PHREEQC geochemical model is investigated. We considered the salinity threshold concept along with calcite dissolution reaction and ion exchange processes to describe geochemical reactions between low salinity water and reservoir rock surface. The results showed that as LSW was injected into the given reservoir pre-equilibrated by formation brine, calcite dissolution and cation exchange occurred due to the difference between salinity and composition of injected water compared to reservoir aqueous phase. These geochamical processes promote the exchange of divalent and monovalent cations on the clay exchanger sites on the rock surface. This causes to break cation bridging between hydrocarbon compound and rock surface that can make the rock water-wet and increase oil recovery as much as 10% of the oil initially in place as compared to high salinity water injection.

REFERENCES

[1]. Robertson E. P., *"Oil recovery increases by low-salinity flooding: Minnelusa and Green River formations,"* SPE Annual Technical Conference and Exhibition, Florence, Italy, 2010.

[2]. Zhang Y. and Morrow N. R., *"Comparison of secondary and tertiary recovery with change in injection brine composition for crude-oil/sandstone combinations,"* SPE/DOE Symposium on Improved Oil Recovery, Tulsa, Oklahoma, USA, 2006.

[3]. Skrettingland K., Holt T., Tweheyo M. and Skjevrak I., *"Snorre low salinity water injection—core flooding experiments and single well field pilot,"* SPE/DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma, 2010.

[4]. Austad T., RezaeiDoust A. and PunterVold T., *"Chemical mechanism of low salinity water flooding in sandstone reservoirs,"* SPE improved oil recovery symposium, Oklahoma, USA, 2010.

[5]. Farooq U., Asif N., Tweheyo M. T., Sjöblom J. and Øye G., *"Effect of low-saline aqueous solutions and pH on the desorption of crude oil fractions from silica surfaces,"* Energy & Fuels, Vol. 25, pp. 2058-2064, 2011.

[6]. Mohanty K. K. and Chandrasekhar S., *"Wettability alteration with brine composition in*

high temperature carbonate reservoirs," SPE Annual Technical Conference and Exhibition, Dubai, UAE, 2013.

[7]. Emadi A. and Sohrabi M., "Visual Investigation of oil recovery by lowsalinity water Injection: formation of water micro-dispersions and wettability alteration," SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, 2013.

[8]. Fjelde I., Asen S. M. and Omekeh A. V., "Low salinity water flooding experiments and interpretation by simulations," SPE Improved Oil Recovery Symposium, Tulsa, Oklahoma, USA, 2012.

[9]. Kazemi Nia Korrani A., Jerauld G.R. and Sepehrnoori K., "Coupled geochemical-based modeling of low salinity waterflooding," SPE Improved Oil Recovery Symposium, Tulsa, Oklahoma, USA , 2014.

[10]. Dang C. T. Q., Nghiem L. X., Chen Z. J. and Nguyen Q. P., "Modeling low salinity waterflooding: ion exchange, geochemistry and wettability alteration," SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, 2013.

[11]. Lager A., Webb K. J., Collins I. R. and Richmond D. M., "LoSal enhanced oil recovery: Evidence of enhanced oil recovery at the reservoir scale," SPE Symposium on Improved Oil Recovery, Tulsa, Oklahoma, USA, 2008.

[12]. Vledder P., Gonzalez I. E., Carrera Fonseca J. C., Wells T. and Ligthelm D. J., "Low salinity water flooding: proof of wettability alteration on a field wide scale," SPE Improved Oil Recovery Symposium, Oklahoma, USA, 2010.