Modern Environmental Science and Engineering (ISSN 2333-2581)
April 2017, Volume 3, No. 4, pp. 231-236
Doi: 10.15341/mese(2333-2581)/04.03.2017/003
Academic Star Publishing Company, 2017
www.academicstar.us

A Sensitivity Study on Low Salinity Waterflooding

Barham S. Mahmood[1], Jagar Ali[2], Shirzad B. Nazhat[2], and David Devlin[2]

1. Department of Petroleum Engineering, Koya University, Kurdistan Region, Iraq

2. Department of Petroleum Engineering, Soran University, Kurdistan Region, Iraq

Abstract: It is widely accepted that different salinity brines injection may increase the oil recovery. However, the mechanisms by which low salinity flooding increases oil recovery are not yet fully understood. This work is to run simulation on ECLIPSE 100 simulator to show the effect of injecting low salinity into a reservoir. A three dimensional synthetic model was created to mimic a real reservoir. The effect of low salinity on oil recovery was observed by conducting sensitivity study on; injecting brine salinity, slug injection of low salinity, and endpoint saturations. A difference of 22% in oil recovery observed when the low salinity water is injected compared to the high salinity water only in the threshold range between 0 kg/m^3 to 5 kg/m^3.

Performing slug injection can reduce the requirement for low salinity water and recovers approximately the same percentage of oil. This can indeed give better cost saving when opting for low salinity injection.

The brine option in ECLIPSE 100 indicated to be very sensitive to the saturation endpoint and relative permeability. Thus, it is important to be aware of this during simulation of such augmented waterflooding, and input from experimental data is needed for accurate simulations.

Key words: improved oil recovery, low salinity waterflooding, Salinity, Slug injection, wettability

1. Introduction

The concept of injecting low-salinity water (LoSal) into the oil reservoir is not a new topic. The first observation of the LoSal effect on oil recovery goes back to Martin (1957) and Bernard (1967), who demonstrated that the injection of fresh water can improve the macroscopic sweep efficiency in sandstone containing clay due to mobilization of fine clay particles [1, 2]. However, this work did not draw the attention of the oil industries. Three decades later a new phase of research activities initiated to optimize the composition of injected water during waterflooding and its effect on oil recovery enhancement. The literature on low salinity waterflooding has increasingly become rich in last few year [3-13] are among the numerous studies which have been published during last 10-15 years. In these studies many different microscopic mechanisms behind low salinity waterflooding process have been proposed. However, there is not an agreement on the primary mechanisms that work to enhance oil recovery.

Tang and Morrow in their experiments on LoSal waterflooding identified the movement of fine clay particles. According to their understanding when contacted with low salinity brine, clay particles detach from the pore walls, as a result an intermediate wet phase becomes unstable and attains the ability to detach from the surface of the rock and expose the water wet. They also reported that when the salinity of the injected brine is less than 1550 TDS this causes a reduction in permeability [5]. However, in the experiment conducted by Lager et al. seems to have witnessed the low salinity effect even without fines migration or reduction in permeability [10].

The studies [8, 10-15] on LoSal waterflooding have demonstrated experimentally the low salinity effect on the pH value, claiming an increase of pH. This rise in

Corresponding author: Jagar Ali, Researcher, research areas/interests: reservoir simulation, history matching, petrophysics, reservoir characterization. E-mail: jagar.ali@soran.edu.iq.

the pH could be due to two chemical reactions: Carbon dissolution and cation exchange. This process leads to a reduction in the H+ ions in the liquid phase, resulting in a higher pH. Consequently, the low salinity waterflooding would start performing as an alkaline waterflood. In addition to the fact that LoSal flooding reduces the surface tension between the formation water and oil reservoir, also, it changes the wettability toward more water wet

Lager et al. claimed multi-component ion exchange (MIE) to be the major mechanism leading to the improved oil recovery by LoSal waterflooding. The same view is held by BP. After carrying out several experiments on the North Slope core samples, it has been observed that the interaction among the low salinity brine, the rock surface and the crude oil. This interaction resulted in a sharp reduction of the magnesium Mg^{2+} ions. Although both injected and connate brines contained a similar composition of Mg^{2+}, the Mg^{2+} ions was believed to be strongly adsorbed by the clay particles in the rock matrix [10].

Expansion of the electrical double layer is another possible mechanism to improve oil recovery by LoSal waterflooding. Ligthelm et al. discussed the double layer effect, which is the expansion of the ionic electrical double layer between the clay and oil interfaces; increases in the absolute level of the zeta potential. This in turn yields increased electrostatic repulsion between the clay particles and the oil, leading to a desorption of oil components from the surface and an increase in water wetness [14].

Hence, this research will use ECLIPSE 100 Black Oil Simulator. A different sensitivity case will be tested and recorded. The inputs based on previous research work and this will help to run the simulations in a logical manner.

2. Synthetic Model and Properties

Three dimensional simulations were performed using ECLIPSE 100. The synthetic model is sectorized by 50×50×6 grids. Each grid measures 3 m × 3 m × 3 m in X, Y and Z directions, respectively. The model is heterogeneous, the permeability range is between 275 to 525 mD and the porosity range is between 0.23 to 0.305. Two active wells; a producer and an injector, have been added to the model and they are located diagonally with respect to each other (Fig. 1). Both wells are completed from the top to the bottom and they are set to be controlled by the reservoir fluid volume rate (RESV), with a flow rate of 100 m^3/day.

The active phases in the reservoir model are oil and water. The salinity of connate water was set to be 35 kg/m^3 (TDS), this is approximately the same salinity as for regular sea water. When the LOWSALT keyword is activated, two different sets of relative permeability curves should be assigned with respect to the two different salinities; high and low salinity. The LSALTFNC keyword is automatically used to choose a constant that represents the assigned specific salinity. The value of the weighting factor ranges from 0 to 1 with a constant weighting fraction of "0", indicating high salinity properties to be assigned. A corresponding constant of "1" represents the other extreme of low salinity floods. Interpolation is made for any fraction ranging between 0 and 1, and a weighting factor is used, respectively. In this study, the relative permeability profile for high and low salinity were taken from Kossac Chuck, Schlumberger advisor (Fig. 2) [16].

3. Sensitivity Analyses

The main sensitivity studies that have been performed in this paper are the injection of brine with

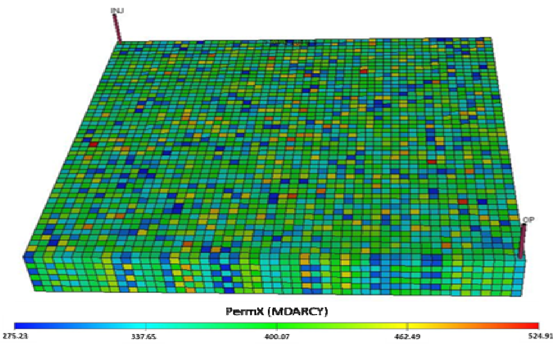

Fig. 1 Permeability distribution and well placement in synthetic model.

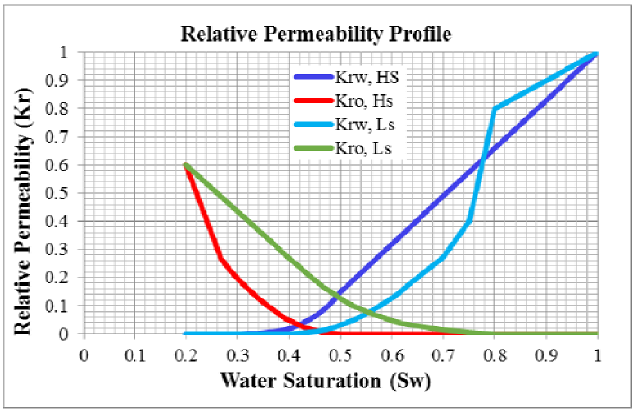

Fig. 2 Relative permeability profile for high and low salinities [16].

different salinities, the effect of slug size, the effect of endpoint saturations and the relative permeability interpolation.

4. Results and Discussions

4.1 Injection of Brine with Different Salinities

To study the effect of brine salinity on improving oil recovery, eight different cases were examined. Initially, injection of brine with 35 kg/m^3 TDS was carried out to set a base case oil recovery. Subsequently, the injection of brines with 10, 5, 4, 3, 2, 1, and 0 kg/m^3 TDS were undertaken. The results are displayed in Table 1 and Fig. 3. As expected, there was no observed incremental oil recovery for the injection of brines above 5 kg/m^3 TDS. This is because the low salinity effects were set to start at salinities less than 5 kg/m^3 TDS. An increase in recovery is experienced, when LoSal water is injected mainly due to the reduction in water production (Fig. 4). In other words, low salinity brine injection creates a net wettability shift that minimizes the residual oil saturation (Sor) and water relative permeability that result in a more efficient oil displacement by water-flooding, hence, slower development of water cut is observed.

4.2 Effect of Slug Size

During the LoSal process, it is important to consider the amount of water injected into a reservoir. Injecting LoSal water for the entire production life is cost prohibitive and has the potential to affect company profits. In this sensitivity study, the effect of different slug sizes on oil recovery was conducted. Fig. 5 demonstrates the results of different scenarios of

Table 1 Effect of Brine salinity on oil recovery.

Brine salinity (Kg/m^3)	0	1	2	3	4	5	10	35
Oil recovery (%)	59	56	51.7	47	42	37	37	37

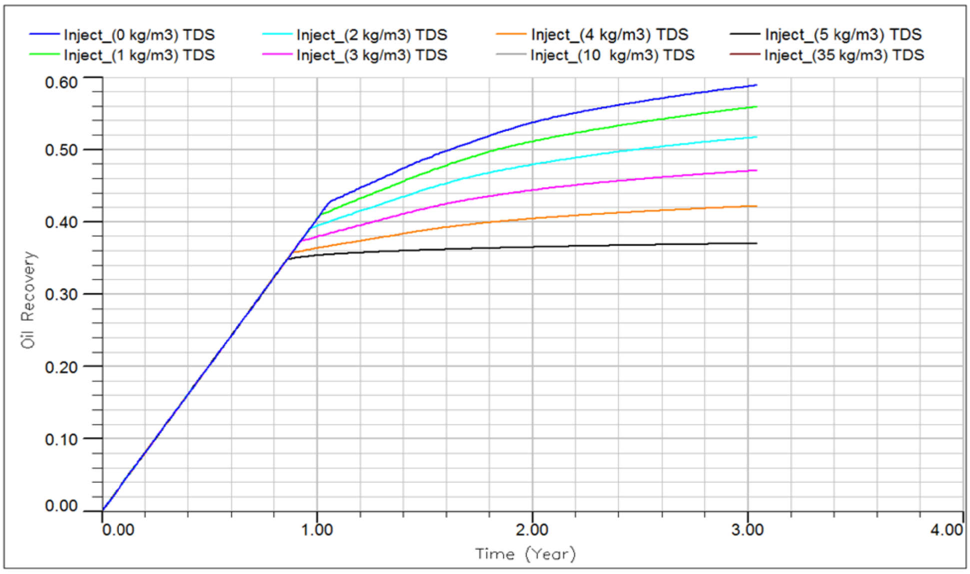

Fig. 3 Field oil efficiency (FOE) with brine salinities of 35, 10, 5, 4, 3, 2, 1, and 0 kg/m^3.

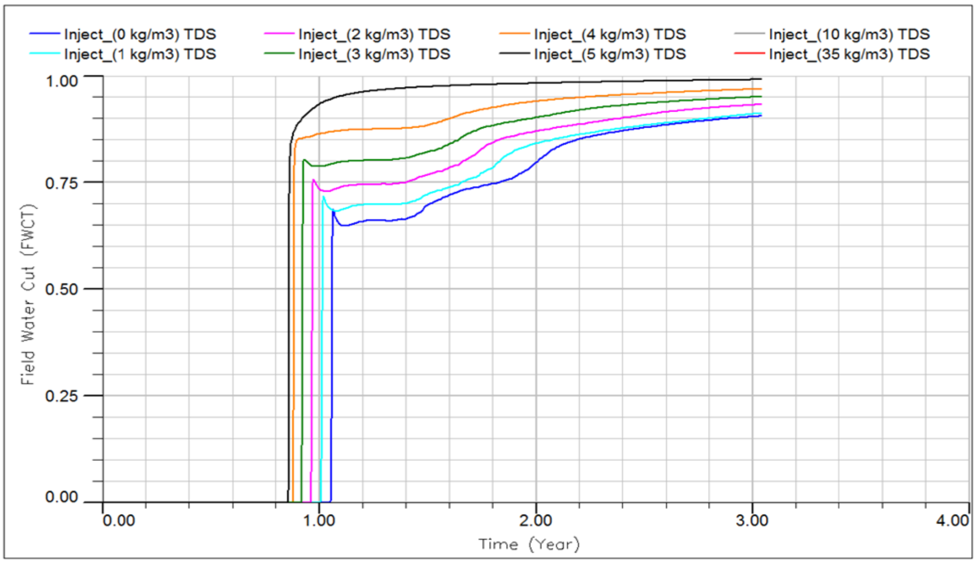

Fig. 4 Field water cut (FWCT) with different brine salinities injection.

injecting low salinity brine with 0 kg/m^3 TDS for 6, 10, 11, 12, 13 and 15 time steps of 30 days each, followed by injecting brine with a salinity of 35 kg/m^3 TDS. The results demonstrate a strong dependence of incremental oil recovery on slug sizes. However, there is no clear indication on the relationship between the oil recovery and the amount of fluids being injected. Therefore, it is better to illustrate it by volume calculation as shown in Table 2.

When the injected brine volume rose from 17471 to 37613 Rm^3, the incremental oil recovery recorded an approximate value of 8.8%. Whereas, when the injected brine volume increased from 37613 to 39580 Rm3, the incremental oil recovery was only 1.2%.

4.3 Effect of Endpoint Saturations and Relative Permeability Interpolation

Table of low-salt weighting factors versus salt concentration (LSALTFNC) indicates the amount of the high salinity and low salinity saturation profiles and relative permeability that have been used for different injected brine salinities. In this sensitivity study, in addition to of the base case, two other LSALTFNC were made, as shown in Table 3. Case one was conducted

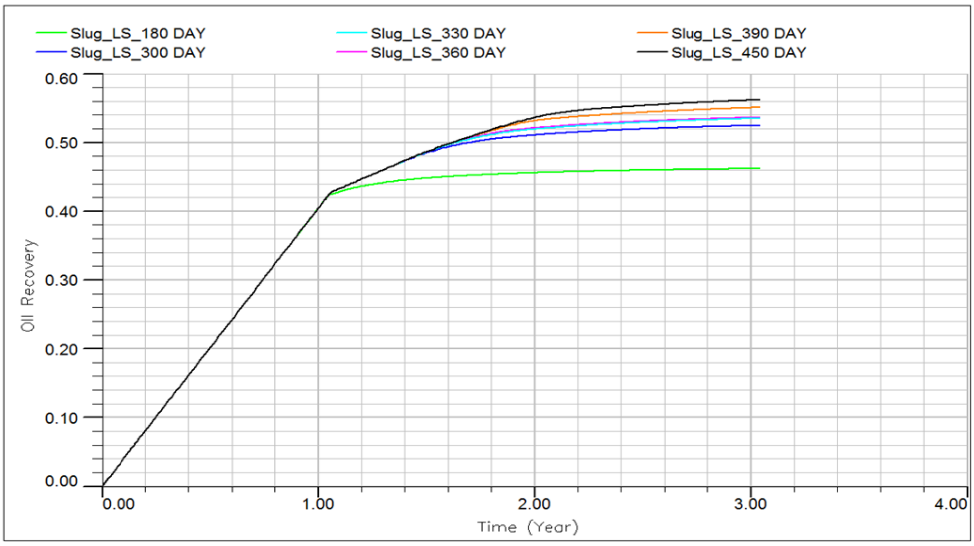

Fig. 5 Oil recovery for different slug sizes during low salinity injection with brine salinity of 0 kg/m^3 TDS.

such that when a salinity below 5 kg/m^3 occurs, only data from the low salinity profiles were used, yet using high salinity profiles when salinity of brine above 5 kg/m^3. In case two, less data from low salinity profiles is used when injected different brine salinity compare to the base case.

As shown in Fig. 6, case one gave the highest oil recovery compared to both the base case and case two. This can be predicted as the effect of the LoSal water-flooding performance is high when the optimum profile is used. A reduction in the amount of the LoSal profiles the oil recovery was found to decrease, but not to the same degree as in case one.

Table 2 Oil recovery and pore volume (PV) injected for different slug sizes with injection brine salinity of 0 kg/m^3 TDS.

Total PV	112942	(Rm^3)				
Injection time	**Time**	**Total time**	**Rate**	**Inject vol.**	**Inject PV**	**Total recovery**
(time steps)	(day)	(day)	(Rm^3/day)	(Rm^3)		(%)
6	30	180	100	17471	0.15	46.2
10	30	300	100	29117	0.26	52.5
11	30	330	100	32029	0.28	53.5
12	30	360	100	34940	0.31	53.7
13	30	390	100	37613	0.33	55
15	30	450	100	39580	0.35	56.2

Table 3 Different tables of low-salt weighting factors versus salt concentration for the synthetic model.

Base case			**Case I**			**Case II**		
Salt concentration (kg/m^3)	**F1**	**F2**	**Salt concentration (kg/m^3)**	**F1**	**F2**	**Salt concentration (kg/m^3)**	**F1**	**F2**
0	1	1	0	1	1	0	1	1
1	0.8	1	1	1	1	1	0.6	1
4	0.2	1	4	1	1	4	0.4	1
5	0	0	5	0	0	5	0	0
35	0	0	35	0	0	35	0	0
45	0	0	45	0	0	45	0	0

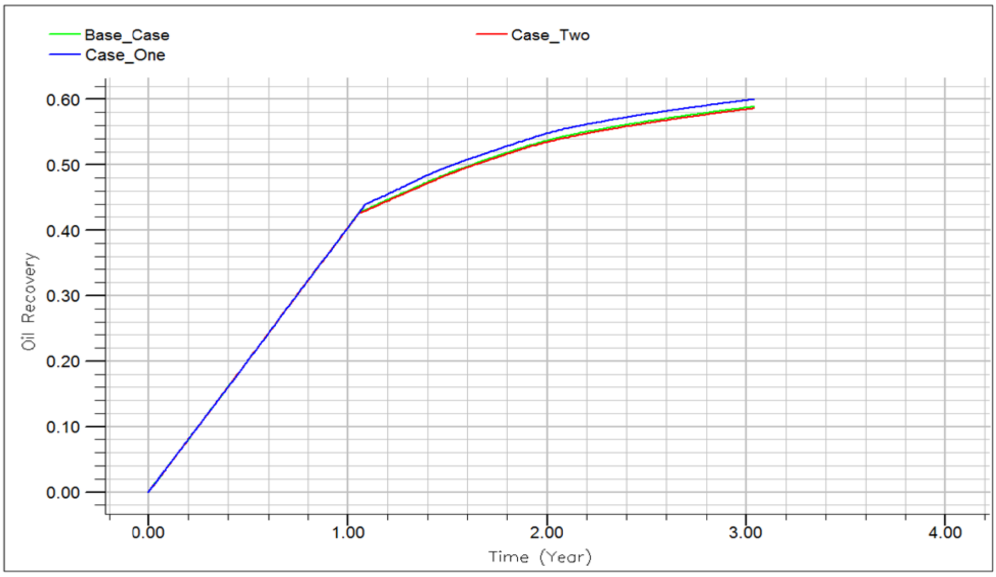

Fig. 6 Illustrates the oil recovery for different low-salt weighting factors versus.

5. Conclusions

Sensitivity studies of LoSal water-flooding on a synthetic model were carried out using ECLIPSE 100. The obtained results are based on the properties used in the simulation model, clearly showed a significant salinity dependence. An increase in oil recovery can be observed in conjunction with a reduction in the salinity of injected brine, where only in the threshold range between 0 kg/m^3 (0.0 ppm) to 5 kg/m^3 (5000 ppm). Furthermore, continuous LoSal injection gives higher oil recovery. However, when economic aspects were considered, slug injection can reduce the requirement for LS water and approximately recovers, the same percentage of oil. Moreover, the simulation results, also, indicate that the potential recovery in low salinity waterflooding was very sensitive to endpoint saturation. Therefore, it is important to be aware of such input data in order to obtain accurate simulation results.

References

[1] J. C. Martin, The effect of clay on the displacement of heavy oil by water, in: *Venezuelan Annual Meeting*, Caracas, Venezuela, 14-16 October 1959.

[2] G. G. Bernard, Effect of floodwater salinity on recovery of oil from cores containing clays, in: *SPE California Regional Meeting*, California, USA, 26-27 October 1967.

[3] P. Jadhunandan and N. R. Morrow, Effect of wettability on waterflood recovery for crude oil/brine/rock systems, *Society of Petroleum Engineering* 10 (1995) (1) 40-46.

[4] G.Q.Tang and N.R. Morrow, Wetting behavior of selected crude oil/brine/rock systems, 1997,available online at: http://www.osti.gov/scitech/servlets/purl/772382.

[5] G. Q. Tang and N. R. Morrow, Influence of brine composition and fine migration on crude oil/brine/rock interaction and oil recovery, *Petroleum Science and Engineering* 24 (1999a) (2) 99-111, doi: 10.1016/S0920-4105(99)00034-0.

[6] G. Q. Tang and N. R. Morrow, Oil Recovery by waterflooding and imbibition — Invading brine cation valency and salinity, in: *International Symposium of the Society of Core Analysts*, Colorado, USA, 1-4 August 1999.

[7] K. J. Webb, C. J. J. Black and H. Al-Ajeel, Low salinity oil recovery — Log-Inject-Log, in: *SPE 13th Middle East Oil Show & Conference*, Bahrain, 5-8 April 2003, pp. 1-8.

[8] P. L. McGuire, J. R. Chatham, F. K. Paskvan, D. M. Sommer and F. H. Carini, Low salinity oil recovery: An exciting new EOR opportunity for Alaska's North Slope, in: *SPE Western Regional Meeting*, California, USA, 30 March-1 April 2005, pp. 1-15.

[9] G. R. Jerauld, C. Y. Lin, K. J. Webb and J. C. Seccombe, Modeling low-salinity waterflooding, in: *SPE Annual Technical Conference and Exhibition*, Texas, USA, 24-27 September 2006, pp. 1-12.

[10] A. Lager, K. J. Webb, C. J. J. Black, M. Singleton and K. S. Sorbie, Low salinity oil recovery — An experimental investigation, in: *International Symposium of the Society of Core Analysts*, Trondheim, Norway, 12-16 September 2006.

[11] Y. Wu and B. Bai, Efficient simulation for low-salinity waterflooding in porous and fractured reservoirs, in: *SPE Reservoir Simulation Symposium*, Texas, USA, 2-4 February 2009, pp. 1-13.

[12] S. Berg, A. W. Cense, E. Jansen and K. Bakker, Direct experimental evidence of wettability modification by low salinity, *Petrophysics* 51 (2010) (5) 314-322.

[13] A. Aladasani and B. Bai, Investigating low-salinity waterflooding recovery mechanisms in Sandstone Reservoirs, in: *SPE Improved Oil Recovery Symposium*, Oklahoma, USA, 14-18 April 2012, pp. 1-16.

[14] D. J. Ligthelm, J. Gronsveld, J. P. Hofiman, N. J. Brussee, F. Marcelis and H. A. Van der Linde, Novel waterflooding strategy by manipulation of injection brine composition, in: *SPE EUROPEC/EAGE Annual Conference and Exhibition*, Amsterdam, the Netherlands, 8-11 June 2009. pp. 1-22.

[15] S. Rivet, L. W. Lake and G. A. Pope, A coreflood investigation of low-salinity enhanced oil recovery, in: *SPE Annual Technical Conference and Exhibition*, Florence, Italy, 19-22 September 2010.

[16] C. Kossack, *Eclipse Black Oil Simulator Advanced Options: Low Salinity Water Flooding*, Denver, Colorado, 2012.