An Overview of Low Saline Water Flooding to Improve Oil Recovery

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Abstract: Low saline water injection has recently gained a wide interest from researchers, oil companies, and governments, who are evaluating the economical and the most effective method to improve the recovery of oil. While field tests laboratory work have pointed out that water flooding with low-salinity can have positive results on oil recoveries. Up-to-date, researchers have conducted numerous core flood tests in order to determine the effects of low-salinity water flooding over rock wettability. The general phenomena accepted is that low-saline water injection effects are caused by rock wettability modification, however the methods involved in this process are static or not fully understood. The aim of this study is to provide information effectively that will help to accelerate the efforts to investigate this effect. In this study, different laboratory observations including the benefits under reservoir conditions, operating conditions to have a positive result of low saline and effects of low-saline water flooding and its different proposed mechanisms have been analyzed.

Keywords: *Low Saline water flooding, Wettability alteration, Enhance oil recovery*

1. Introduction

Low salinity water flooding is committed to a sound technique that improves additional recovery of oil by reducing injected brine salinity [1]. When low saline water is injected into the formation, it alters the wettability of rock from oil wet towards more water wet. This can be indicated that residual oil saturation is reduced and relative permeability curves will be changed, as a result oil recovery improves because of production acceleration [2]. In oil industry, low salinity water flooding is widely practiced because of easily available of water sources, low operation prices and other operational advantages. The potential of low salinity water injection for Enhanced Oil Recovery (EOR) was not acknowledged until a scientist named Morrow witnessed from their laboratory work that higher recovery of oil relies on the composition of flooding water. After this discovery, numerous core flood experiments have been done and published in order to determine the effects of low salinity water on EOR. Not all, but most of the results indicated that higher recovery of oil can be obtained when the injection water salinity is below than the salinity of formation water. In addition to core flood experiments, researchers have also proposed different mechanisms that explain the effects related to low-salinity water flooding. Among the scientists, there is no unanimity about leading mechanisms of low salinity water injection. In fact, it is believed by the researchers that water injection with low salinity can drain higher recovery of oil from the reservoir. Only few are uncertain, because their core flood tests did not indicate beneficial result [3-7].

The objective of this paper is to analyze and examine the laboratory observations. Moreover, the effects of low salinity water flooding with its different proposed mechanisms that explain the interactions of crude oil brine rock (COBR) have been studied.

2. Laboratory observations

Morrow's group in 1991 conducted many experimental core flood experiments and concluded the additional recovery of oil from low-salinity water flooding. It was observed that numerous core flood experiments indicated positive response. Only in few experiments, no increased recovery of oil was witnessed [8]. In this section, the following typical observations are presented.

2.1.Typical behavior of water flooding with low salinity

The behavior of injecting low saline water may be explained with the following main observations.

- ❖ If the salinity of flooding brine is below the salinity of initial brine inside the reservoir, this causes additional oil to be recovered.
- ❖ During the process of stage injection, salinity value of brine is decreased which causes greater drop in pressure. Tang and Morrow explained this phenomena in 1999. Further, Zhang et al. also observed same phenomena in 2007.
- ❖ When the injection water with minimum salinity is flooded inside the reservoir, maximum observed values of pH are 9 and below [9, 10].

2.2. Benefits of low salinity under reservoir conditions

British Petroleum in order to conduct experiment on low salinity water injection. They used a core flood facility

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which contained live oil. In addition, reservoir conditions were also simulated in the facility to have actual results. Two cases were investigated i.e. secondary and tertiary water flooding. For secondary water flooding case, the salinity of formation water was set to be 28,000 ppm and the salinity of flooding water was set at 1400 ppm. Results obtained showed that oil recovery improved from 69.5% to 83.5% of the original oil in place (OOIP). For similar case, another experiment was conducted and a higher recovery of oil was achieved. For second case, in tertiary recovery, water injection salinity of 1500 ppm was followed by salinity of 15,000 ppm secondary water flooding. The recovery of oil improved from 63% to 71% and from 75% to 84% respectively. These experiments concluded that in order to get the benefit from a low-salinity water flooding, the salinity of water must not be above 4000 ppm [11].

2.3. Initial water saturation effects

Two researchers Tang and Morrow in 1999 witnessed that recovery of oil obtained from high-salinity water flooding is same as that of low salinity water i.e. 1% of the high-salinity water injection, when initial saturation of water is zero [9]. Similarly another researchers, Zhang and Morrow in 2006 also observed that for secondary recovery, the recovery of oil generally increase with increased initial saturation of water by injecting low salinity. In simple words, in order to observed effect from water injection with low salinity, connate water saturation is required [12].

2.4. Connate water salinity effects

Two scientists Sharma and Filoco in 1998 observed that the prime factor that controls the recovery of oil is the salinity of connate water. When connate water salinities are 0.3%, 3% and 20% NaCl while the salinity of injection water is 3% NaCl, the recovery of oil will be greater for lower salinity of connate water. During drainage process, they endorsed this reliance to change wettability of rock from water-wet to intermediate wet states. Intermediate states witnessed lower residual oil saturations than oil-wet or more water-wet cores [5].

2.5. Injection water salinity effect

The effect of low salinity was observed when the water injection salinity is essentially lower than the formation water, thus a higher recovery of oil was obtained in most of the published cases. A study was conducted in which 10% of connate water salinity was used [9]. But the effect was not observed when the concentration of saline was higher than 7 kg/m^3 (7,000 ppm) in the single well chemical tracer test [13]. The concentration of brine was used between 1000-4000 ppm (1-2 kg/m^3) which was lower than 5% of formation total dissolved solids (80 kg/m^3) [11]. It was witnessed that water injection with brine concentration of 15000 ppm which was approximately 5% salinity of connate water caused in the differential pressure and tertiary oil recovery was observed. When Ca^{+2} and Mg^{+2} (divalent ions) were added to the low saline water injection of 15000 ppm as a result 4% additional recovery of oil was obtained [10]. In the laboratory and field practices, it was suggested that the concentration of brine must be 1000-2000 ppm or 10-25% of formation water salinity. It could be a good start when connate water salinity of 10% may be used [14].

2.6. Wettability Effect

In the cores, it was found that wettability of rock associated with initial water saturation (Swi). The cores be evidence for strongly water-wet together with higher Swi and the recovery of oil improved from strongly water-wet towards neutral wet state. The aim of that research was not to compare recovery of oil with salinity of water. However the cores data with lower ionic strength (or calcium concentration) showed more water-wet condition. The effect of low saline may be associated to rock wettability. Water injection with low saline will cause the cores in the state of more water-wet Instead of the cores with high initial salinity as a result higher recovery of oil was observed [5, 15].

3. Operating conditions for low salinity effects

The environment required to have a positive effect with low saline water flooding are encapsulated as follows:

- In the reservoir, Clay fraction is essentially present
- Oil must be present containing polar components (acidic or basic)
- Formation (initial/connate) water must be present
- Divalent cations (Ca^{2+} and Mg^{2+}) is essentially present in the formation water
- Injecting water with low salinity must be lower than 5000 ppm to observe a positive effect. The salinity of low brine composition range in between 0-5000 ppm is called “threshold salinity”. Water injection with low salinity is essentially lower than the salinity of connate water [16, 17, 12, 18, 19].

4. Suggested Mechanisms for low salinity water injection effects

A number of labortary work and field experiments showed to have a constructive results for low saline water injection. There are various mechanisms suggested by many researchers that interpret the interfaces of crude oil brine rock (COBR) during water injection with low salinity indicating additional recoveries of oil, but contradictory effects survive for each of it [14]. The suggested mechanims are as follows:

- Fines Migration
- pH alteration
- Multicomponent Ionic Exchange (MIE)

4.1 Fines Migration

It was conducted an experiment in order to describe the mechanism for low saline water injection. During water injection with high salnity, clay particles was observed to be uninterrupted therefore creates oil-wet state that causes lower displacement efficiency.

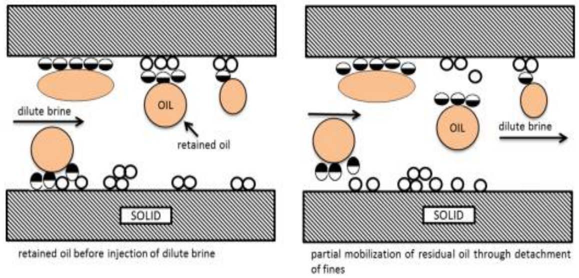

Figure. 1 Mobilization of residual oil through detachment of clay particles.

It was observed in low saline water injection, clay particles mostly kaolinite fine particles were permitted to release from the rock surface. The interpretation of fines mobolization and underlying rock surfaces affect the system will be more water-wet as shown in Fig. 1. Moreover, the detachment of clay fines may distract the flow of water towards the area which is not swept as a result improved sweep efficiency [9].

4.2 pH Alteration

A recovery mechanism was proposed by researchers that low sainity water injection based on the surfactants production from residual oil (higher pH ranges). In reference to the interpretations upon the transformations in rock/fluid interactions will cause wettability alteration and changes in reservoir fluids. When low saline water is injected into the core, the chemical reaction is drastically accelerated between low saline water and clay minerals occur in the reservoir generates hydroxyl ions, therefore improving the ranges of pH upto 9 or more and recovery of oil is observed [13].

As water is injected with low salinity into the reservoir, the chemical reaction takes place between low saline water and clay minerals as shown below [13].

Ca^{2+} - Clay + H_2O = H^{+} - Clay + Ca^{2+} + OH^{-}(Cation Exchange)

4.3 Multicomponent Ionic Exchange (MIE)

In order to investigate fundamental reasons of choosing low salinity water flooding for enhanced oil recovery, it is imperative to study the brine and rock chemistry. The Multi component Ionic Exchange (MIE) is one of the fundamental theory which studies the chemical interaction between the injection brines and reservoir brines. Sandstone reservoirs, specifically oil-wet in nature, also consists of an amount of clay particles having their surfaces negatively charged. The divalent cations i.e. Ca^{2+} and Mg^{2+} are responsible to keep the oil molecules on the surface of these clay particles.

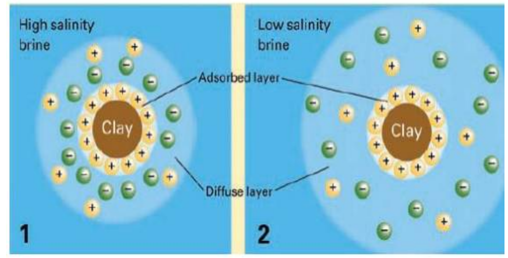

Figure. 1.2 The concept of the double layer.

This causes the formation of polar organic compounds of complex nature. In this condition, if more brine comes in contact with such oil bearing reservoirs then it will result in the formation of a diffuse layer around the formation as evident in Fig 1.2. The stability and thickness of these layers depend upon the brine salinity in which the reservoir is submerged. It is also affected by the concentration of active ions in place [20].

Since the diffuse layer depends upon the salinity of brine therefore the injection of low saline brine (whose salinity is comparatively lesser than formation brine) in the reservoir results in the change of grain chemistry and causes the expansion of diffuse layer. The injection of high saline brine has an opposite effect i.e. the diffuse layer reduces in thickness. The chemical replacement of free cations from the injected brine with the divalent ions in the diffuse layer might take place. For instance, the Na^{+} ions from the injected brine may exchange with Mg^{2+} and Ca^{2+} causing the release of oil from negatively charged clay surface [20].

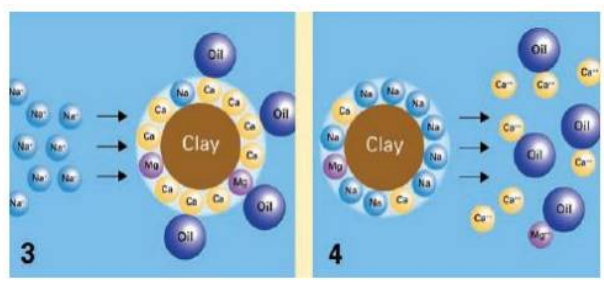

Figure. 1.3 MIE and wettability alteration

The MIE theory describes this particular behaviour. When the Na^{+} ions encounters Mg^{2+} and Ca^{2+} already present on the negatively charged surface, the divalent ions holding oil releases from the diffuse layer. These "new" free ions are then transported away from the reservoir with produced hydrocarbons and water. It then now causes an increase in concentration of free ions in the produced water as shown in Fig 1.3. After the production of all Mg^{2+} ions, the formation will absorb Mg^{2+} ions of the injected brine and concentration of Mg^{2+} ions in the produced water would disappear. This behaviour is not only limited to Mg^{2+} ions but also valid for other divalent ions. The initial ions may start to produce again if the formation gets fully saturated with the divalent ions [21].

Herthone discussed that that oil adheres to rock (specifically sand) and water may flow easily. However, after injection of low salinity water, the rock changes to water-wet. It means that more water adheres to the surface of rock which in turns causes the oil to be released from the surface and move freely. Hence the alteration of wettability is one of the methods to produce more oil from reservoir hence decreasing residual oil saturation. The water-oil-rock interaction is depicted in fig 1.4 [22].

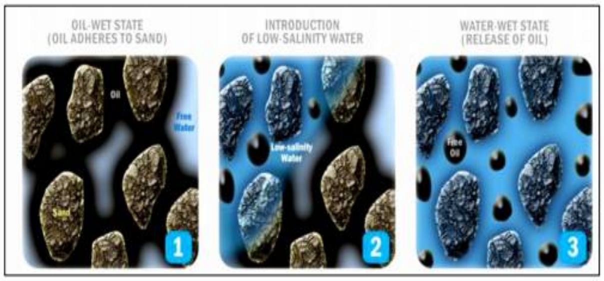

Figure. 1.4Water-Oil-Rock interfacial characteristics

The results obtained from the experiment conducted in core flood is shown in fig 1.5. These results specifies that by reducing seawater salinity to 20% (approximately to 5,600 ppm) results in a small increment in oil recovery, however by reducing the seawater salinity to 5% (approximately to 1,400 ppm) results in high oil recovery [14].

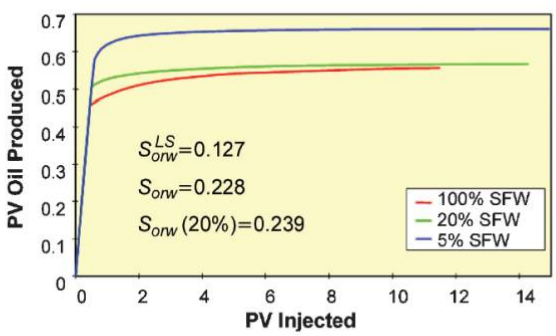

Figure. 1.5 Recovery of oil in secondary low salinity water flooding (SFW=salinity).

5. Conclusion

It can be observed from the literature that there's no agreement regarding which suggested mechanisms work in the environment of low-saline water flooding. Including the suggested mechanism, the most suitable mechanism is rock wettability alteration. In this mechanism, wettability of rock can be modified from oil wet towards water wet state, or from water-wet to mixed-wet condition. In either way, equivalent recovery of oil could be improved. However the mechanism of low-salinity brine requires more investigations to be completely determined. Nevertheless, a few of the most significant contributors are migration of fines/mineral dissolution, pH increase, and wettability alteration or MIE.

It is determined from the laboratory results that water flooding with low-salinity brine gives a positive response or benefit towards oil recovery. Even though, the magnitude of additional recovery of oil would not be anticipated as high as laboratory observation. In laboratory, many pore volumes of low-saline water were injected, which is impractical in the actual field of water flooding projects. Since the effect of low-salinity brine reflects to be positive. In addition, low saline water flooding is a friendly environment approach and doesn't require significant investment in facility.

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