Contribution ID: **892** Type: **Oral 20 Minutes**

Micromodel study of low salinity water flood and wettability alteration

Tuesday, 15 May 2018 10:26 (15 minutes)

Low salinity water flooding is an effective and cost-efficient improved oil recovery method. Wettability alteration is believed by many to be the primary reason for the observations of increased recovery. However, the causes of the wettability alterations and approaches for optimization are not fully understood. We conduct experiments in micromodels by injecting brine at different salinities in these oil-saturated micromodels and observe distinct changes in the contact angle and wettability. Meanwhile, we observe water droplets form and grow with time inside the oil phase when low salinity water was injected. Additionally, significant improvements in oil recovery is observed when high-salinity brine is followed by low-salinity brine, but the response is delayed by hours or even days.

We fabricated glass, water-wet micromodels (homogeneous porous medium and single channel with dead-end) using the method we developed in Ke et al. [2017]. The micromodels are unique in that pores and throats are of different depths, thereby having three-dimensional features that allow oil snap-off behaviors. We conduct dead-end micromodel experiments and homogeneous micromodel experiments to see the oil recovery. For the dead-end micromodel experiments, visualization was conducted under microscope. Micromodels were initially saturated by crude oil (120 cp heavy Middle Eastern oil) and then flooded at very low rate by low salinity water (500 ppm) or high salinity (34000 ppm) water. For the homogeneous micromodel experiments, visualization was conducted under a digital camera. Micromodels were initially saturated by crude oil and then displaced by a high salinity sea water (34000 ppm) at 2 ft/day into micromodels until no additional oil was recovered. Then, low salinity (0-5000 ppm) water was injected at 2 ft/day into the micromodel for at least 2 days.

The dead-end experiments show that the micromodel was initial oil wet and gradually altered to more water wet after the low salinity water injection. We also observed water droplets forming and growing in the crude oil phase and oil swelling. This swelling appears to provide an additional mechanism for recovery.

From the homogeneous micromodel experiments, we observed up to 30% incremental oil recovery using the low-salinity brine after the high-salinity brine. Importantly, a time delay of hours even days was required. For zero-salinity (DI water) case we observed a more than 10 hours of flooding was required before production re-started, and more than 20 hours of delay for 5000 ppm brine.

Our conclusion is that the wettability alteration is a time dependent process caused by the redistribution of negative charged polar compounds within the crude oil. When low salinity water is injected, the polar compounds migrate from the surface to the inside of the oil and form micelles. The lack of polar compounds on oil surface leads to wettability alteration, and the water molecules accumulate around these micelles to form water droplets. The growing of water droplets leads to oil swelling which also contribute to the incremental oil recovery. The wettability alteration and the oil swelling are both consequences of the redistribution of the polar compounds, and both contribute to the additional oil recovery by both wettability alteration and oil swelling.

References

Ke, et al. A 2.5-D glass micromodel for investigation of multi-phase flow in porous media, Lab Chip, 2017, 17, 640-646

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Session Classification: Parallel 3-F

Track Classification: MS 1.01: Multi-scale Particulates Transport through Porous Media Saturated with Multi-Phase Fluids