# Experimental Investigation of Wettability Alteration in Carbonates: Interactions between Low Salinity, Surfactant and Polymer

**Maissa Sassi Souayeh**

## Abstract

Numerous studies showed that injecting water with lower salinity than the formation connate water or water with modified ions composition would result in improvement in oil recovery. The combination of low salinity water with chemicals such as surfactants and polymers has been recently considered as it is believed that it would result in considerable high oil recovery compared with low salinity water alone. Among the reported studies, only a small fraction was dedicated for carbonate reservoirs. Therefore, more understanding of the dominant mechanisms of oil recovery in such combined system is needed.

In this study, combinations of low salinity, surfactant and polymer were considered. The extent of each combined system in altering the wettability of oil-wet carbonate and its contribution to oil recovery was evaluated. Commercial polyethoxylated nonionic surfactants were selected as the main surfactant in this study. As for the polymer, a commercial sulfonated polyacrylamide was selected. The first screening tool was the cloud point ($T_{cp}$) measurements of the low salinity surfactants systems in order to test their compatibility at operating temperature of 75 °C. Only clear and stable surfactants systems were considered for further analysis. The interfacial tension (IFT) was measured against crude oil for the clear systems as a function of time. For wettability alteration investigation, contact angle (CA) and spontaneous imbibition were utilized. Further tests: zeta potential, pH, Fourier transform infrared (FTIR) analysis and Thermogravimetric analysis (TGA) were conducted to understand the mechanism of wettability alteration. The IFT measurements revealed that there is a trend of reducing the IFT with increasing salinity and decreasing the ethylene oxide (EO) units in the hydrophilic part of the surfactant. The minimum IFT obtained was when the surfactant system was 1 °C below its $T_{cp}$. Wettability alteration induced by nonionic surfactant was thoroughly investigated. A mechanism supported by evidence of CA, zeta potential, pH, TGA and FTIR analysis was proposed for the first time for polyethoxylated nonionic surfactant. In addition to that, a relationship between the oil recovery by spontaneous imbibition, IFT reduction, $T_{cp}$ and salinity was systematically identified. Increasing salinity to a level close to the $T_{cp}$ of the surfactant would result in a reduction of its adsorption on the surface which is associated with enhancing IFT reduction and less wettability alteration. In addition to that, the synergistic effect of nonionic/anionic surfactants was studied. It was found that the number of EO units would have a major role on the overall performance of the mixed system as it would improve or demote the oil recovery performance compared with the single nonionic system. Possible interactions between the two surfactants supported by CA and zeta potential measurements were proposed considering the different factors of salinity, $T_{cp}$ and IFT. Furthermore, the combined effect of modified low salinity water and nonionic surfactant was tested. Results showed that improved oil recovery was not associated with increasing $Mg^{2+}$ and $Ca^{2+}$ to high levels. A slight

enhancement of the ratio of either of $Mg^{2+}$ or $Ca^{2+}$ to $Na^{+}$ at low salinity would results in improvement of wettability alteration toward strong water-wet state. Also, the best performing systems were very close to their $T_{cp}$ and resulted in the lowest IFT values among all the tested systems in this study. This $T_{cp}$ dependent effectivity of the nonionic surfactant would provide more understanding and a novel implementation of surfactants for the different conditions.

The combined low salinity polymer was evaluated. The polymer was able to alter the wettability at all the studied salinity range as provided by the CA and zeta potential measurement. Oil recovery from spontaneous imbibition by low salinity polymer increases with decreasing salinity. The best performing systems from low salinity surfactant and low salinity polymer were combined and resulted in higher oil recovery compared with each of the two systems alone. These findings confirm the success of the systematic approach followed in this study to capture most of the possible parameters of the combined systems and evaluate its effect on the overall performance in enhancing oil recovery in carbonates.

Petroleum and Chemical Engineering Department-College of Engineering-Sultan Qaboos University