Title:
“Characterization of Controlled Salinity Waterflooding in Carbonates Using Streaming Potential Measurements”

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Abstract:
The impact of brine composition on rock wettability and oil recovery in carbonates has been an area of active research in recent years. Many studies have reported contradictory results and the underlying mechanism(s) are poorly understood. The zeta potential, which is a measure of the electrical charge at the mineral surface, is highly variable in carbonates, depending on the ionic composition of the pore water. The zeta potential controls the magnitude and polarity of the electrostatic interactions between the mineral surface and polar species in the brine and oil; it also controls the magnitude and polarity of the streaming potential, an electrical potential which arises in response to pressure gradients across saturated rocks. Here we report the use of streaming potential measurements to determine key controls on zeta potential at mineral-brine and oil-brine interfaces, and characterise wettability and optimize injection brine composition during controlled salinity waterflooding in carbonates at reservoir conditions of salinity and temperature.

The zeta potential is controlled by the concentration-dependent adsorption of the lattice ions Ca, Mg and CO$_3$ within the Stern layer. A Nernstian relationship between zeta potential and pCa or pMg is observed over the range of typical natural brines. Addition of SO$_4$ can affect zeta potential by moderating Ca in solution. The temperature dependence of the zeta potential can be correlated with the temperature dependence of pCa and shows a Nernstian linear relationship. The zeta potential in intact carbonate samples decreases with temperature at low ionic strength and independent of temperature at high ionic strength irrespective of brine composition. Thus, for a given carbonate type, zeta potential measurements in natural brines (e.g. saline aquifers, formation waters or seawater; ionic strength ≥0.5M) at laboratory conditions may be applied in situ.

The zeta potential at both the mineral-water and oil-water interfaces must be determined when characterising wettability and designing the optimum brine composition for controlled salinity waterflooding in carbonates. The experimental method presented here allows this to be done using intact core samples saturated with the crude oil and brine of interest. We find a monotonic relationship between zeta potential and wettability expressed in terms of the Amott water index ($I_w$). Thus, measurements of streaming potential can be used to characterise wettability more quickly and cheaply than existing laboratory methods. Results reported here demonstrate for the first time that the oil-water interface can be positively charged at the high pH and ionic strength relevant to the formation brines found in many carbonate reservoirs. It is usually assumed that the oil-brine interface is negatively charged. Improved recovery during controlled salinity waterflooding in carbonates is observed if the change in brine composition yields a zeta potential at each interface that has the same polarity, such that a repulsive electrostatic force acts between the interfaces and stabilizes a water film on the mineral surface. These results have broad application and significance in allowing oil companies to design water injection strategies that yield improved oil recovery from carbonate reservoirs.
Short Bio:

2013 – Present  PhD student in Imperial College
2008 – 2013  Reservoir Engineer in the waterflood carbonate reservoir, Petroleum Development Oman (PDO), Oman
2007 – 2008  Msc in Petroleum Engineering from Curtin University, Perth, Australia
2003 – 2006  BEng in Chemical Engineering from Nottingham University, UK