Pore scale simulations of wettability alteration during the low-salinity water flooding in carbonate rocks

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1. Introduction

The majority of the world's remaining oil resources are located in carbonate reservoirs, which are usually more difficult to produce than conventional sedimentary reservoirs. A possible mechanism that may improve the recovery of oil from carbonate reservoirs is the injection of low-salinity fluids. It has been proposed that this process alters the surface chemistry of the pores and hence changes the wettability, which leads ultimately to higher recovery.

In this project we will first develop a consistent physio-chemical theory for low-salinity water flooding in carbonates by using laboratory scale core-flooding experiments and pore-network simulations. Using continuum scale simulations it will then investigate how this process could impact oil recovery from a carbonate reservoir at the field scale.

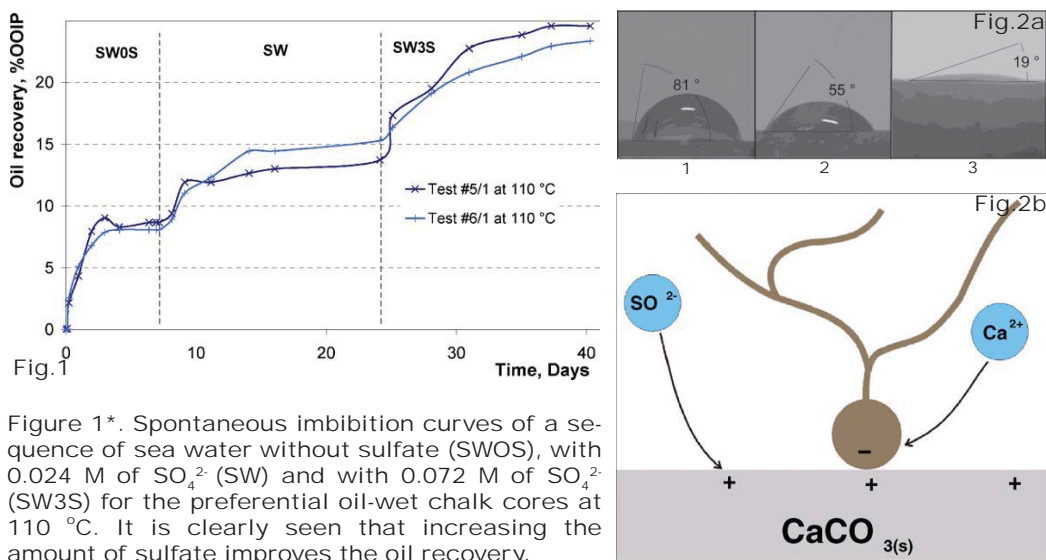## 2. Literature review on the wettability alteration in carbonates

Figure 1*. Spontaneous imbibition curves of a sequence of sea water without sulfate (SWOS), with 0.024 M of SO_4^{2-} (SW) and with 0.072 M of SO_4^{2-} (SW3S) for the preferential oil-wet chalk cores at 110 °C. It is clearly seen that increasing the amount of sulfate improves the oil recovery.

Figure 2. (a)** Advancing contact-angle measurements on magnesite surfaces after being exposed to (1) pure brine, (2) brine with 1.0 wt % $C_{12}TAB$ surfactant and (3) brine with surfactant and sulfate concentration of 1.7 g/l.
(b)* Suggested wettability alteration mechanism in chalk. The desorption of carboxylic materials from the surface involving both a change in surface charge by adsorption of SO_4^{2-} and the contribution from Ca^{2+} to release the carboxylic group.

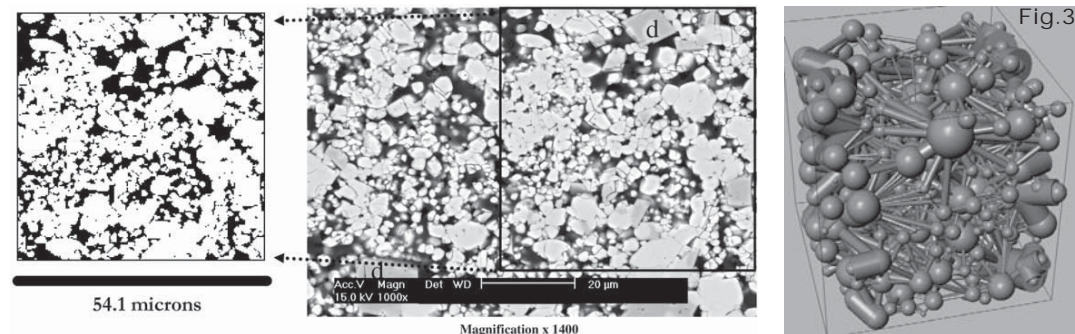## 3. Literature review on the pore network models

Figure 3***. Various stages of pore model construction workflow. Left: Two-dimensional SEM image of the carbonate sample from which a thresholded 2-D digitized image is extracted (black areas denote pore spaces). Right: This 2-D image is then used to construct a digitized 3-D image (not shown) from which one finally extracts a 3-D pore network.
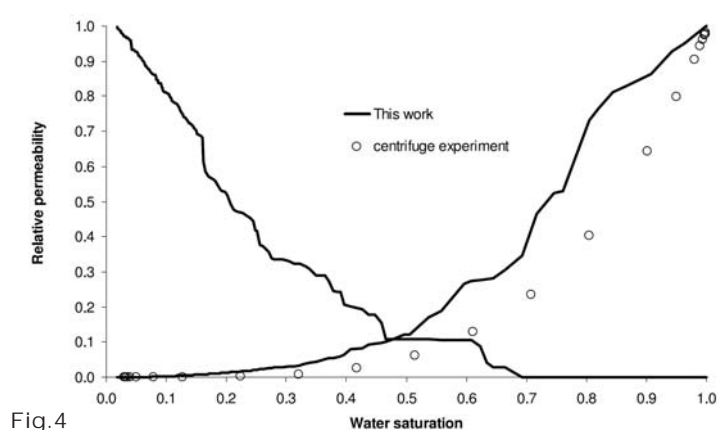

Figure 4***. An example of comparison of network-predicted versus measured relative permeability during waterflood.

Benefits of pore scale modeling compared to laboratory measurements:
1. Can be used to understand the measurements and their associated uncertainties and explain them in a clear physical manner.
2. Can then be used to predict transport properties outside the range of parameters studied experimentally. For instance one can extend the results on rocks with different wettability types.

References:
* Picture taken from: Strand, S., Hognesen, E. J., and Austad, T., Colloids and Surfaces A: Physicochem. Eng. Aspects 275, 1-10 (2006).
** Picture taken from: S. Strand, D.C. Standnes, T. Austad, Energy Fuels 17 (2003) 1133–1144.
*** Picture taken from: Al-Kharusi, A. S., and M. J. Blunt (2008), Water Resour. Res., 44, W06S01.

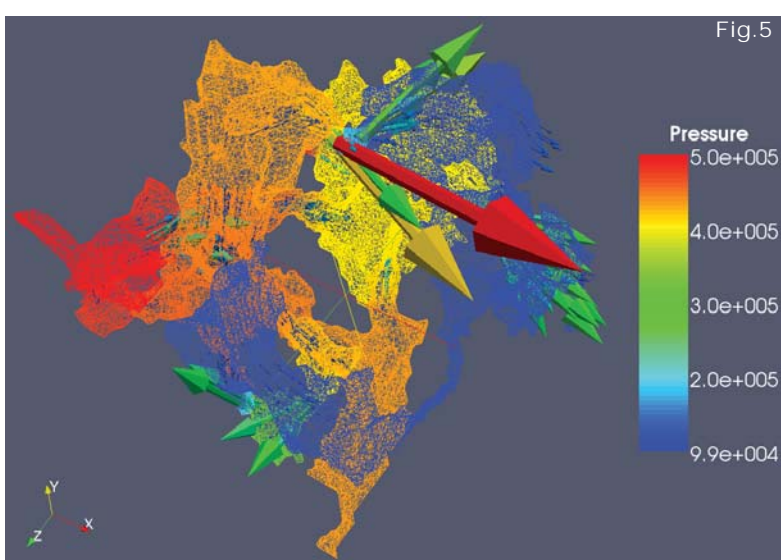## 4. Pore scale modeling of a scanned porous sample using CSMP++

Figure 5. Simulation of single-phase flow due to an applied pressure gradient in a real pore geometry. It was acquired experimentally via CT scanning, the resulting volumetric mesh was constructed and read into the CSMP++ finite element analysis package. Then, the Stokes equation for incompressible fluid flow was solved and the corresponding pressure and velocity profiles were obtained. This approach allows us to estimate the a priori values of permeability, dispersivity and other sample characteristics as well as to calculate any chemical reactions that can occur on the grain surface.

5. Future work

1. Carry out theoretical investigations of interactions occuring between ions present in the water and organic functional groups of the oil phase.
2. Use chemical reactions modeling at the pore scale to develop an appropriate physio-chemical theory for low-salinity water flooding in carbonates.
3. Validate it using the laboratory experiments.
4. Amend the theory based on the experimental results by additional pore scale simulations.
5. Upscale the derived theory to continuum scale (jointly with Karen Schmid)