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MODELING OF LOW SALINITY EFFECTS IN SANDSTONE OIL ROCKS

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Abstract. Low salinity water has been reported as being capable of improving oil recovery in sandstone cores under certain conditions. The objective of this paper is the development and examination of a one-dimensional mathematical model for the study of water flooding lab experiments with special focus on the effect of low salinity type of brines for sandstone cores. The main mechanism that is built into the model is a multiple ion exchange (MIE) process, which due to the presence of clay, will have an impact on the water-oil flow functions (relative permeability curves). The chemical water-rock system (MIE process) we consider takes into account desorption and adsorption of calcium, magnesium, and sodium. More precisely, the model is formulated such that the total release of divalent cations (calcium and magnesium) from the rock surface will give rise to a change of the relative permeability functions such that more oil is mobilized. The release of cations depend on several factors like (i) connate water composition; (ii) brine composition for the flooding water; (iii) clay content/capacity. Consequently, the model demonstrates that the oil recovery also, in a nontrivial manner, is sensitive to these factors. An appropriate numerical discretization is employed to solve the resulting system of conservation laws and characteristic features of the model is explored in order to gain more insight into the role played by low salinity flooding waters, and its possible impact on oil recovery.

Key words. low salinity, multiple ion exchange, porous media, two-phase flow, convection-diffusion equations and wettability alteration

1. Introduction

In recent years, brine-rock-oil chemistry has generated a lot of interest in relation to improving oil production from reservoirs. In carbonate reservoirs, the brine constituents have been found to be important for oil recovery [37]. In sandstone reservoirs, the salinity and components of the brine have shown a lot of promise to improve recovery [34, 42, 44]. A number of requirements have been listed as being necessary for low salinity improved recovery. These include:

- Presence of clay [40] or some negatively charged rock surfaces;
- Polar components in the oil phase [35, 40];
- Presence of formation water [40];
- Presence of divalent ion/multicomponent ions in the formation water [24].

Despite meeting the above criteria, some experiments carried out have not shown positive low salinity effect [36, 48]. We also refer to [33] for experimental observations indicating that low salinity water injection as an EOR method appears very sensitive to a combination of several parameters.

1.1. Different mechanisms that have been proposed. Quite a number of different low salinity mechanisms have been put forward in the literature. Some of these mechanisms include:

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- *Multicomponent ion exchange (MIE) process* [24]: This mechanism describes the release of oil component previously bonded to the rock surface by divalent ion bridging. Low salinity is said to result in a double layer expansion that makes the desorption of the oil bearing divalent ions from the rock surface possible.
- *pH increase:* The authors of [40] describes a model, in which pH increase as a result of mineral dissolution, is the underlying mechanisms for low salinity induced improved recovery. Austad et al.[6] describe a model of local pH increase as a result of a chemical process involving the release of divalent ions from the rock surface.
- *Clay dispersion[40]:* This mechanism describes a model in which oil-wetted clays are dispersed from the rock surface in low salinity environment. The desorption of divalent ions can only aid such mechanism since divalent ions promotes clay flocculation.

1.2. Main objective of this work. As an attempt to develop some basic understanding of how such mechanisms possibly will have an impact on core flooding experiments in the context of low salinity studies, we will in this work formulate a Buckley-Leverett two-phase flow model where the wetting state, as represented by the relative permeability functions, has been coupled to a multiple ion exchange (MIE) process. In other words, in this work we have singled out MIE as the only mechanisms for taking into consideration possible low salinity effects. More precisely, according to the proposed MIE mechanism, we chose to link desorption of the divalent ions bonded to the rock surface to a change of relative permeability functions such that more oil can be mobilized. This will allow us to do some systematic investigations how different brine compositions can possibly have an impact on the oil recovery.

Hence, the purpose of this work is to, motivated by laboratory experiments with flooding of various seawater like brines, formulate a concrete water-rock chemical system relevant for sandstone flooding experiments with focus on low salinity effects. Main components in the proposed model are:

- Consider modeling of sandstone core plugs with a certain amount of clay attached to it that is responsible for the ion exchange process;
- Include a multiple ion exchange process that involve Ca^{2+}, Mg^{2+}, and Na^{+} ions;
- Implement a coupling between release of divalent ions (calcium and magnesium) from the rock surface and a corresponding change of water-oil flow functions (relative permeability curves) such that more oil can be mobilized.

The resulting model takes the form of a system of convection-diffusion equations:

$$
\begin{aligned}
s_t + f(s, \beta_{ca}, \beta_{mg})_x &= 0, \\
(sC_{na} + M_c\beta_{na})_t + (C_{na}f(s, \beta_{ca}, \beta_{mg}))_x &= (D(s, \phi)C_{na,x})_x, \\
(sC_{cl})_t + (C_{cl}f(s, \beta_{ca}, \beta_{mg}))_x &= (D(s, \phi)C_{cl,x})_x, \\
(sC_{ca} + M_c\beta_{ca})_t + (C_{ca}f(s, \beta_{ca}, \beta_{mg}))_x &= (D(s, \phi)C_{ca,x})_x, \\
(sC_{so})_t + (C_{so}f(s, \beta_{ca}, \beta_{mg}))_x &= (D(s, \phi)C_{so,x})_x, \\
(sC_{mg} + M_c\beta_{mg})_t + (C_{mg}f(s, \beta_{ca}, \beta_{mg}))_x &= (D(s, \phi)C_{mg,x})_x.
\end{aligned}
\tag{1}
$$

For completeness, since we are interested in flooding of seawater like brines (high salinity and low salinity), we have included chloride C_{cl} and sulphate C_{so}, despite that these will act only as tracers in our system. In other words, these ions are not