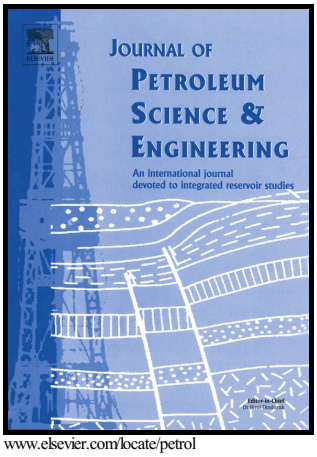


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# A Framework for Assisted History Matching and Robust Optimization of Low Salinity Waterflooding under Geological Uncertainties

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**Abstract**

Low Salinity Waterflood (LSW) is an emerging Enhanced Oil Recovery (EOR) method that is simple to implement and has been shown to yield a substantial increase in oil recovery over conventional waterflood, especially in oil-wet sandstone reservoirs. The major mechanism for increased oil recovery is a wettability change from oil-wet to water-wet, which is induced by ion exchange between the injected fluid and the clay surface.

This paper presents a framework for field scale modeling, assisted history match, and robust optimization of LSW under geological uncertainties that has rarely been discussed in the past. To handle this complex recovery process, a comprehensive ion-exchange model has been implemented, fully coupled with geochemistry specially designed for the modeling of LSW physical phenomena in an EOS reservoir simulator. This model is capable of accounting for the critical role of the properties, quantity, and distributions of clay minerals.

A systematic study was performed to evaluate the critical effects of geology on large scale LSW performance. Numerous geostatistical realizations of a five-spot LSW pattern were generated to evaluate the effect of clay on LSW. The numerical simulation results indicate that LSW's performance depends critically on the reservoir geological characteristics. Based on the integrated modeling approach presented in this paper, multiple geological realizations can be automatically generated from a big-loop approach that is needed for fast and accurate HM and optimization of LSW. The key parameters for successful field scale LSW HM include: clay distribution/quantity associated with different facies, relative permeability modification, wettability alteration thresholds, reservoir minerals, geochemical reactions, and operating conditions. More importantly, LSW HM by tuning reservoir parameters may only lead to poor prediction results, while the integrated modeling approach provides much better forecasting results to true history data.

Finally, a new concept for LSW robust optimization under geological uncertainty is introduced and demonstrated with reservoir simulation. As there are uncertainties associated with the geological modeling of the clay distribution, this paper shows how robust optimization can be applied to reduce uncertainties in the LSW optimization through well placement.

**Keywords:**

Low Salinity Waterflooding, Enhanced Oil Recovery, Assisted History Matching, Robust Optimization, Geological Uncertainties.

## Nomenclature

| | |
|---|---|
| $a_i$ | Activity of the species i |
| $\hat{A}_m$ | Reactive surface area of reactant mineral m |
| $[Ca - X_2]$ | Equivalent fraction of $Ca^{++}$ |
| $[Na - X]$ | Equivalent fraction of $Na^{+}$ |
| F | Global objective function |
| $\mathcal{F}_i$ | Objective function for representative realization i |
| $k_m$ | Reaction rate constant of mineral reaction m |
| $K_{eq}$ | Chemical equilibrium constant |
| $K_{Ca\backslash Na}$ | Selectivity coefficient for ion exchange |
| $m_i$ | Molality of the species i |
| N | Number of geological realization in robust optimization |
| $Q_m$ | Activity product of the mineral m |
| RF | Recovery Factor |