Scale-Dependent Models for Modified Salinity Waterflooding

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SCALE-DEPENDENT MODELS FOR MODIFIED SALINITY WATERFLOODING

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Summary

Numerous attempts have been made to model the effect of modified salinity water flooding that leads to additional oil production in both sandstone and carbonate reservoirs. Since there is no consensus on the physicochemical mechanisms of modified salinity water flooding, it is challenging to develop a physics-based model and simulate the complete system. Therefore, a simple model based on linear interpolation between two sets of high salinity and low salinity relative permeability curves is widely used in the industry. This work investigates the impact of grid size and hysteresis effects on the numerical modelling of modified salinity water flooding. In order to include the hysteresis effect, we modify two different interpolation approaches, which are commonly used in commercial software, to switch from high salinity to low salinity relative permeability and capillary pressure curves. The results show that the grid-block sizes heavily influence the response time of the reservoir to the injection of low-salinity water and the final oil production, but to different extents for the two different interpolating approaches. It was also found that only a small discrepancy can be observed between two approaches by refining the grid.

Introduction

Water flooding is extensively applied to improve the oil recovery factor due to its availability, affordability, and environmental-friendliness. The laboratory and field experiments show that lowering or modifying brine salinity leads to incremental oil production (Morrow *et al.*, 1998; Webb, Black and Al-Ajeel, 2003; McGuonire *et al.*, 2005). These observations triggered the investigation of the effect of salinity on the oil recovery in both carbonate and sandstone reservoirs.

Many experimental studies (Strand, Standnes and Austad, 2006; Zhang, Tweheyo and Austad, 2006; Romanuka *et al.*, 2012) have been conducted to investigate the effect of modified salinity water (MSW) flooding. In spite of considerable research studies of MSW flooding, there is no consensus on the underlying mechanisms. Therefore, devising a representative mathematical model that can help in the design and optimization of the salinity and ionic composition of the injected brine is still a challenge in the field-scale implementation of the MSW flooding (Derkani *et al.*, 2018).

Numerous modelling studies (Jerauld *et al.*, 2008; Dang *et al.*, 2013; Qiao *et al.*, 2015; Eftekhari *et al.*, 2017; Taheri *et al.*, 2019) have been developed to describe modified salinity effect, ranging from empirical to mechanistic models. The simplest way of modelling MSW flooding is broadly used based on linear interpolation between two sets of relative permeability and capillary pressure curves (high and low salinity curves) resulting from wettability change, using the total salinity as the interpolating parameter. This approach, although simple and somewhat effective, dramatically suffers from the large artificial diffusion that smears out the salt concentration front leading to a poor estimation of the relative permeability values. Moreover, this simple interpolation technique falls short when hysteresis is included in the model. Additionally, none of the experiments conducted to date has been able to show systematically at which level a significant change in salinity is required to trigger the effect. Morrow *et al.* (1998) reported that a 10% reduction of the connate water causes a substantial increase in the oil recovery, whereas lowering further to 1% only gives a little increase in oil recovery. It is stated that the modified salinity effect is not dependent on high salinity as significant modified salinity effects have been seen for salinities in the range of 1000 to 2000 ppm (Jerauld *et al.*, 2008). These observations have risen the interest to compare the different approaches in switching from high to low salinity.

To find an answer to the above questions, this paper provides a comparison of the modelling of MSW flooding using different interpolations between high salinity and low salinity curves and grid sensitivity analysis under the effect of hysteresis.

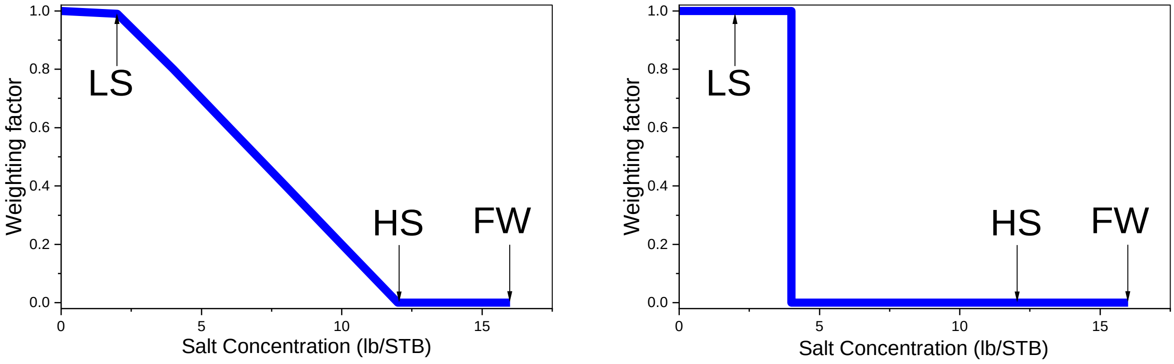
Method and Assumptions

In field-scale simulations, considerable errors can appear by ignoring the hysteresis effect, particularly in a gas reservoir with a strong water drive (Larsen and Skauge, 1998). The hysteresis model allows both relative permeability and capillary pressure curves to change between imbibition and drainage (bounding curves) via the intermediate curves, which are called scanning curve (Killough, 1976). In MSW flooding, the scanning curves change profoundly with the salt concentration, which has an enormous impact on the prediction of oil recovery. In this work, we suggest two simple methods of relating the imbibition curve directly to salinity by taking into account the effect of hysteresis.

Salinity Dependence. Several approaches are tried to simulate MSW flooding. The conventional approach is to change the shape of the relative permeability and capillary pressure curves as a function of salinity. Jerauld *et al.* (2008) assumed that the oil and water permeability and capillary pressure curves can be obtained using the salinity value to interpolate between low salinity and high salinity curves. Therefore, the final relative permeability and capillary pressure values at a specific saturation are obtained through the weighted average of low salinity and high salinity curves. Mahani *et al* (2011) proposed a model where wettability changes suddenly from oil-wet to water-wet at a specific salinity (estimated below 10% of high salinity). Figure 1 shows the two approaches of applying the salinity effect on relative permeability and capillary pressure curves. Here, it is assumed that the capillary pressure of low salinity is the same as high salinity.

Relative Permeability. It is presumed that the primary drainage curve is constant, and the primary imbibition curve changes over time as the salinity changes. Moreover, the residual oil saturation is reduced by the factor of 5% to take into account the effect of the MSW flooding effect (Figure 2).

Conceptual model. The model has one horizontal injector and producer, 600 ft apart from each other (Figure 3). All simulations had been performed by coupling between MATLAB and Eclipse 100.



a (Linear interpolation) b (Step function)

Figure 1 *Two approaches of interpolating between high salinity and low salinity curves based on the value of total salt concentration*

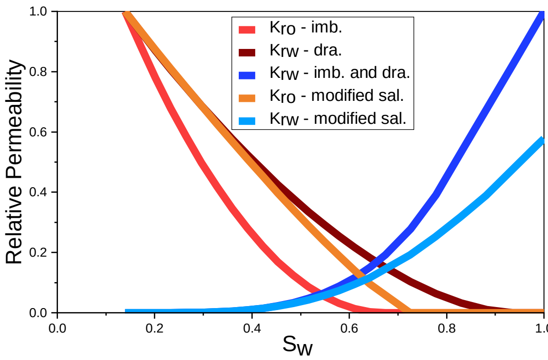


Figure 2 *Residual saturation of the imbibition relative permeability curve has been shifted to the right by 5% to capture the effect of MSW flooding*

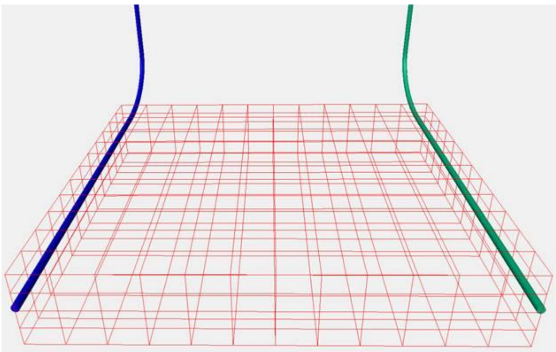
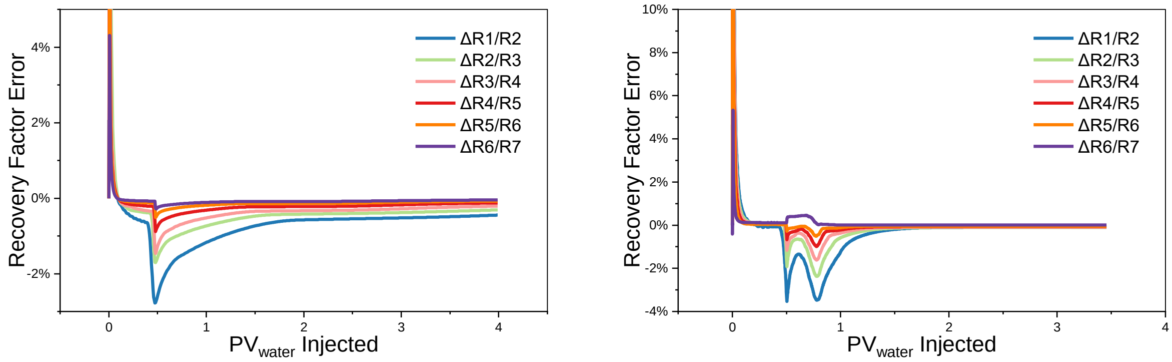


Figure 3 *location of injector and producer in the conceptual model*

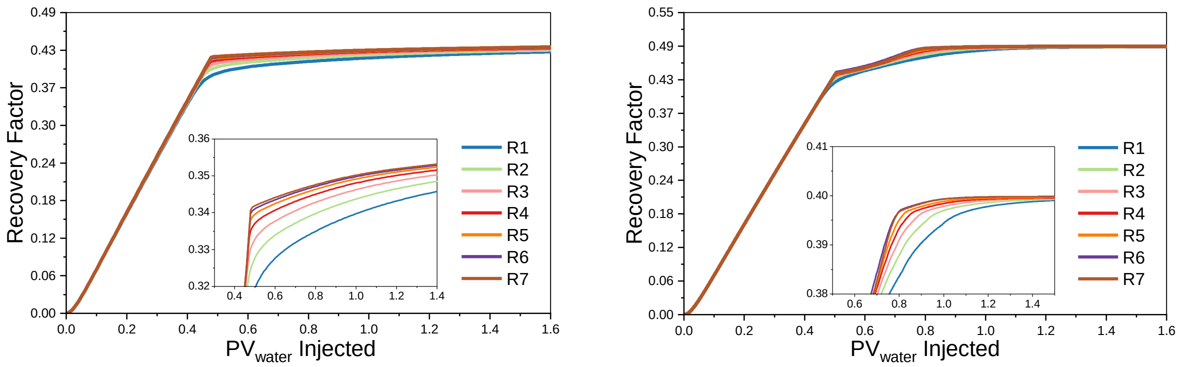
Results

The impact of grid refinement on seawater and MSW flooding is shown in Figure 4. The grid size is reduced from 50 ft (R1) to 0.39 ft (R7) until no change in oil production is observed. Clearly, the results of simulations are dependent on the grid size due to the high numerical dispersion for the larger grid sizes. In the finite volume (or finite difference) scheme, the low salt concentration front that reaches a new grid cell is "numerically mixed" in a large volume of formation water in a finite volume (finite difference) cell. This diminishes the wettability-change effect of the injected low salinity water and causes an unrealistic predicted delay in the oil production. This also has a crucial impact when matching the core-flooding data curve because the level of physical dispersion is different in the laboratory and the field. Therefore, the right level of dispersion must be considered in the simulations. An early increase in total oil production appears by reducing the grid size, as shown in Figure 5.



a (Seawater flooding) b (MSW flooding)

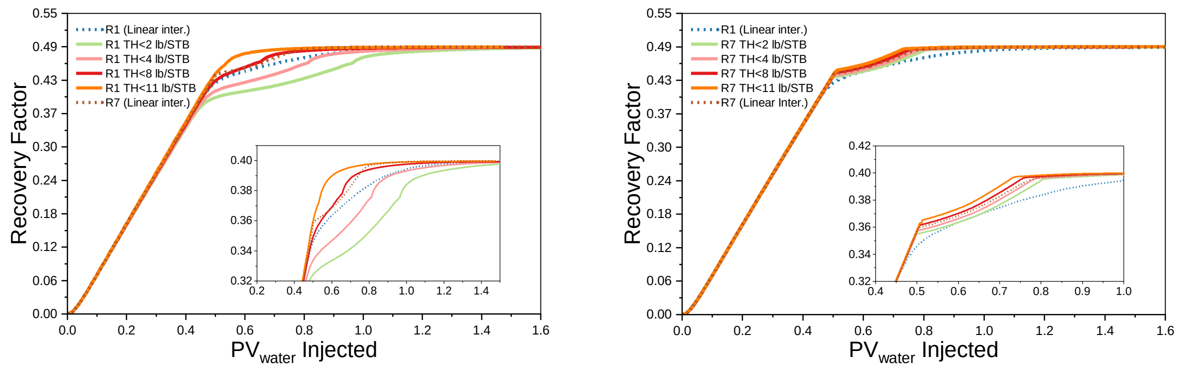
Figure 4 *The error of recovery factor (subtraction of oil production from the fine grid-sizes resolution) as a function of pore volume (PV) injected*



a (Seawater flooding) b (MSW flooding)

Figure 5 *Recovery factor for various grid sizes (R1= coarse grid-sizes, R7 = fine grid-sizes)*

Figure 6 shows the impact of different methods of interpolation between high and low salinity relative permeability curves. It shows that the grid size strongly influences the oil recovery when using the step function compared to the linear interpolation approach. The impact varies depending on the threshold salinity level (seawater salinity assumed to be 12.7 lb/STB), as illustrated in Figure 6.



a (coarse grid-sizes) b (fine grid-sizes)

Figure 6 *Recovery factor for coarse and fine grid-sizes for two different interpolation approaches*

Conclusions

- Large discrepancy occurs in the predicted oil recovery factors by using different MSW interpolation approaches.
- It was found that the accuracy of the two approaches is nearly the same for the fine grids.
- The step function approach strongly depends on the grid size compared to the linear interpolation approach.
- Step function predicts a considerable delay of oil production in coarse grid sizes at small threshold salinity. Pseudothreshold salinity can be used to approximate fine grid results.

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