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Modeling Low-Salinity Waterflooding

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Abstract

Low salinity waterflooding is an emerging EOR technique in which the salinity of the injected water is controlled to improve oil recovery over conventional higher salinity waterflooding. Corefloods and single well chemical tracer tests have shown that low salinity waterflooding can improve basic waterflood performance by 5 to 38%. This paper describes a model of low salinity flooding that can be used to evaluate projects, shows the implications of that model, demonstrates its use to represent corefloods and single well tests as well as field scale simulations, and gives insight into the reservoir engineering of low salinity floods.

The model represents low salinity flooding using salinity dependent oil/water relative permeability functions resulting from wettability change. This is similar to other EOR modelling and conventional fractional flow theory can be adapted to describe the process in one dimension for secondary and tertiary low salinity waterflooding. This simple analysis shows that while some degree of connate water banking occurs it need not hinder the process. Because mixing of injected water with in situ water delays the attainment of low salinity, potentially preventing attainment of low salinity all together if very small slugs of low salinity water are used, care must be taken in representing mixing appropriately in interpreting data and in constructing models. The use of numerical dispersion to represent physical dispersion in 1D, radial and pattern simulations of this process is demonstrated, i.e. coarse simulations are shown to give the same result as fine grid simulations with appropriately large physical dispersion. In many applications, the fine grid simulation necessary to represent appropriate levels of dispersion is not practical and pseudoization is necessary. We demonstrate that this can be done by changing the salinity dependence and shapes of relative permeability curves.

Introduction

Waterflooding is widely used to improve recovery from oil reservoirs but, except to avoid formation damage, is largely

designed without regard to the composition of the brine injected. Yildiz and Morrow¹ showed that changes in injection brine composition can improve recovery, thereby, introducing the idea that the composition of the brine could be varied to optimize waterflood recovery. Tang and Morrow²⁻⁵ built on this idea by demonstrating the benefit lowering brine salinity has on oil recovery. BP has carried out an extensive research programme on low salinity injection which has thus far included more than 20 reservoir condition core floods on a range of sandstone reservoirs from its global portfolio both in secondary and tertiary mode, more than 10 single well chemical tracer tests (SWCTT), and a log inject log test. This program has resulted in a series of publications⁵⁻⁸ and the registration of the LoSal™ EOR process trademark. These tests have shown improvements of waterflood process efficiency by 5% to 38% by using low salinity water, or corresponding reductions in residual oil saturation of 3 to 17% pore-volume. The purpose of this work is to present a simple extension to waterflood simulators that can be used to translate corefloods or SWCTT into field scale estimates of low salinity waterflood oil recovery and demonstrate this with examples from a sandstone reservoir.

Mechanism

A recent summary of the understanding of the mechanism involved in the liberation of additional oil by low salinity flooding has been given by Lager et al.⁸. Results of the work of Tang and Morrow² suggest that it is a wettability change towards water wet with increasing waterflood recovery corresponding to greater rates of spontaneous imbibition of brine. This is also indicated by the direction of change of the relative permeability in that there is a lower water relative permeability and a higher oil relative permeability at a given water saturation. While residual oil saturation is lower, water relative permeability at residual oil is roughly the same. Several studies have been undertaken to investigate potential mechanisms^{2-4, 7}, and the results from these studies have been used to infer potential mechanisms for increased oil recovery with low salinity waterflooding. Results from these studies showed that:

- Initial water saturation required- if no connate water saturation is present no benefit is seen.
- Crude oil is required- no impact is seen with refined (depolarized) oils. This is also consistent with wettability change because crude oils contain naturally occurring surface active agents, acids and bases, which change the wettability away from water-wet.