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Low-Salinity Waterflooding to Improve Oil Recovery—Historical Field Evidence

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Abstract

Waterflooding is by far the most widely applied method of improved oil recovery. Crude oil/water/rock interactions can lead to large variations in the displacement efficiency of waterfloods. Laboratory waterflood tests and single-well tracer tests in the field have shown that injection of low-salinity water can increase oil recovery, but work designed to test the method on a multi-well field scale has not yet been undertaken. Historical waterflood records could unintentionally provide some evidence of improved recovery from waterflooding with lower salinity water. Numerous fields in the Powder River basin of Wyoming have been waterflooded using low salinity water (about 1000 ppm) obtained from the Madison limestone or Fox Hills sandstone. Three Minnelusa formation fields in the basin were identified as candidates for waterflood comparisons based on the salinity of the formation and injection water and reservoir characteristics. Historical production and injection data for these fields were obtained from public records. Field waterflood data were manipulated to display oil recovery in the same format as laboratory coreflood results. Recovery from fields using lower salinity injection water was greater than that using higher salinity injection water—matching recovery trends for laboratory and single-well tests.

Introduction

Almost without exception, at the start of a waterflood, water from the cheapest source (usually different in composition than the initial formation water) is used as the injection water, provided injectivity is not adversely affected by formation damage. Historically, little consideration has been given in reservoir engineering practice to the effect of the composition of the salt in the injection water on waterflood displacement efficiency or to the possibility of increased oil recovery through manipulation of the injection water composition. Most laboratory relative permeability tests and displacement tests are done using synthetic formation water as both the for-

mation and injected water rather than using formation water and the actual field injection water for these tests.

It has been shown that different wetting states of crude oil, water, and rock ensembles can yield widely different oil recoveries during laboratory waterflood tests. The wetting state, or wettability, of a rock and fluids system can be altered in a number of ways. For example, wettability can be altered in the laboratory by changing the crude oil composition, changing the temperature while aging the rock and crude oil, or by changing the temperature during water displacement.¹ It has also been observed that the composition of the water can have a significant impact on wettability and oil recovery.^{1,2,3,4} It follows that there may be cases where attention to injection water composition could lead to increased oil recovery and a likely increase in the economic profitability of a waterflood.

There may be an optimal composition of the dissolved solids in the injection water that would yield the highest oil recovery. The composition could involve many variables with respect to ionic composition and concentration but current knowledge of how and when water composition can be manipulated to increase oil recovery is limited. Several examples of improved recovery by injection of low ionic strength brine have been reported for both outcrop and field core samples by Tang and Morrow.^{4,5} Of the many possibilities that need to be further explored, laboratory results showing increased recovery resulting from injection of dilute brine appear the most promising with respect to near term field application. Tang and Morrow showed that oil recovery increased markedly with injection-brine dilution for recovery of several types of crude oil and sandstones. **Fig. 1** is an example of the potential for increased oil recovery from low-salinity waterflooding.⁶ The corefloods depicted in this figure were done using two different cores from the CS reservoir under identical conditions with the exception of the composition of the injected water.

Robertson et al. have also discussed examples of laboratory work showing increased recovery from low salinity waterfloods.⁷ Average recovery curves from seven corefloods are plotted in **Fig. 2** and show a clear increase in recovery from low-salinity waterfloods under simulated reservoir conditions.

The conditions necessary for improved recovery, such as the type of crude oil and rock, composition of the formation and injected water, and initial water saturation are still far from understood. The crude oil/water/rock interactions that determine displacement efficiency are highly complex. Nevertheless, laboratory observations such as those discussed above were sufficiently encouraging to justify further studies aimed at field application.