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An Experimental Investigation of Nanofluid Flooding and Mechanisms Affecting Enhanced Oil Recovery through Glass Micromodels

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Abstract

Injection of nanofluids in oil reservoirs is one of the new methods for increasing oil recovery. The stability of these fluids in reservoir conditions and negligible formation damage, along with the significant increase in oil recovery are the factors which influence the selection of suitable nanofluids for increasing oil recovery in harsh reservoir condition. In this study, the efficiency of three nanostructures: nano-gamma-alumina, iron(III) oxide and silica with concentrations of 200, 500 and 600 ppm and with two different mixture ratios of formation water and reservoir injected water in a brine with a salinity of 106000 ppm to 234000 ppm, and a temperature of 90°C in oil extraction from oil-wet, media has been studied. In this part of the study, by conducting two-dimensional flow experiments in a glass micromodel at ambient temperature and atmospheric pressure, the displacement of oil by injecting fluid was studied, and the mechanisms of the performance of nanofluids were investigated for enhancing oil recovery. Zeta potential of the fluids was measured for the reservoir pressure and temperature (T= 90°C, p=2700 psi) to insure stability of the fluids. The results of these experiments showed that injection of all three nanofluids can enhance oil recovery up to 20% in comparison to that for the injection of brine. The highest amount of recovery was recorded for alumina nanostructure and then for iron oxide and silica respectively. Due to the slight change in the viscosity of nanofluids compared to water injected, and also the negligible change in the interfacial tension of the aqueous-oil phase for alumina and silica nanofluids, and the results of static tests for determining the contact angle, the mechanism change of wettability to water wet condition seems to be the dominant mechanism for alumina and silica nanofluids for this increase in oil recovery. Considering the slight change of iron (III) oxide nanofluid and results of pendant drop test for interfacial tension measurement of the nanofluid, the reduction of interfacial tension of water-oil phase for iron (III) oxide nanofluid may be reported as the dominant mechanism of enhanced recovery. The formation process of emulsion with iron (III) oxide nanofluid and oil is a confirmation of this mechanism for iron (III) oxide nanofluid.

Keywords: Enhanced Oil Recovery, Immiscible Injection, Nanofluid, Micromodel, Contact Angle, IFT.

Introduction

Recently, with the development of nanotechnology and the revealing of the properties of these materials, the use of nanoparticles in various sectors of the oil industry has been studied [5, 6]. In this regard, the use of nanoparticles as an agent for enhanced oil recovery has also been of great interest to researchers in this field [7]. Most studies that investigate the effect of nanofluid injections on enhancement of oil recovery in different porous media, including glass micromodels, have resulted in a significant increase in recovery due to the injection of these fluids under the mechanisms of wettability alteration to more water-wet condition, reducing interfacial tension and creating disjointing pressure which leads to creation of a wedge film [9-11]. In this study, a glass micromodel with direct injection pattern was used as a porous medium to observe the oil displacement pattern by nanofluids alumina, silica and iron (III) oxide in three concentration and two salinities 106000 ppm and 234000 ppm. The potentially engaged mechanisms including wettability alteration and IFT reduction were conducted.

Experimental setups and Procedure

Materials and setups

In this study, a glass micromodel with direct flow pattern similar to the considered carbonate rock was used for injection tests. The injection was done with a syringe pump with a minimum injection rate of 0.0005 cc/hr. A digital camera with a macro lens which was connected to a computer was used to capture photographs of the model at specified time intervals. In this study, pendant drop equipment was used to determine interfacial tensions and contact angles.

In this experimental study, nanoparticles of gamma-alumina, iron (III) oxide, and silica were used to prepare nanofluids. The aqueous phases used to prepare nanofluids were two mixtures from seawater from the Persian Gulf and formation water of the studied reservoir with total salinities of about 106,000 and 234,000 ppm. Dead oil from one of the Iranian oil fields was used as the oil phase.

Methods

Before the start of the injection tests, the physical and hydraulic properties of the micromodel were calculated. In order to make the micromodel oil-wet 2% solution of chlorotrimethylsilane was injected into the model. The model was then saturated with oil. 20 injection tests were carried out in the micro model for oil displacement study. Moreover, the injection flow rate in all tests was fixed at 0.0005 cc /hr and 25°C. The contact angles were calculated by measuring the angle of contact by the formation of a drop of oil on the surface of the glass in the presence of an aqueous phase. The pendant drop test was also used to study the interfacial tension between the aqueous phase-oil and the effect of the nanoparticles on it. All the tests were carried out with 3 concentrations of 3 nanofluids in 2 salinities.

Results and Discussion

The results of these experiments showed that injection of all three nanofluids could increase oil recovery by up to 20% in comparison to that for the injection of brine. The highest amount of recovery was recorded for alumina nanostructure and then for iron oxide and silica, respectively. It was also observed that the more the concentration of nanofluid the higher the recovery factor. Furthermore, the recovery was enhanced at higher salinity which may be due to the higher viscosity of more concentrated brine. The underlying mechanisms of these recovery enhancements were determined to be the wettability alteration toward more water-wet for alumina and silica and IFT reduction for Iron (III) oxide. The microscopic pictures also showed the effect of nanofluid injection on phase distribution and wettability of the surface as that shown in Figure 1.

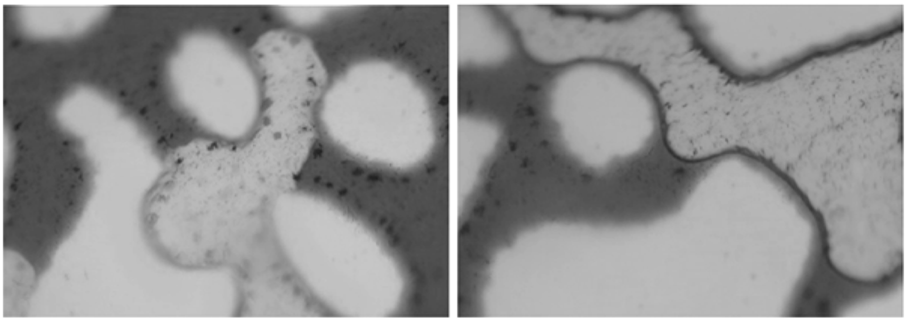

Figure 1: Phase distribution while injecting nanofluid (left) and brine (right).

Conclusions

According to the results of the micromodel tests and the mentioned pieces of evidence, stable nanoparticles are considered as suitable fluids for oil recovery. This enhancement in recovery, which generally occurs under the mechanisms wettability changes due to the adsorption of nanoparticles (for gamma-alumina and silica) into the wall of pores and the reduction of interfacial tension (for iron (III) Oxide), increased the recovery by up to 20% in micromodel tests. In addition, based on the results of these experiments, we can state the following:

- Due to the remarkable change in the interfacial tension of iron oxide and oil nanofluids, the reduction of interfacial tension is the main factor behind the recovery of oil in the injection of iron oxide nanofluid.
- Contact angles determine the effect of gamma alumina and silica nanoparticles on the change in wettability toward a more water-wet state.
- Microscopic photographs of micro-model pores determine the effect of nanofluid flow on phase distribution. Therefore it could be a sign of a change in the wettability of nanoparticle-treated surfaces.

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