

A Study on Enhanced Oil Recovery using Silica Nanofluids: Contribution of the Formation Water Salinity

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論 文 名 : A Study on Enhanced Oil Recovery using Silica Nanofluids: Contribution of the Formation Water Salinity (シリカナノ流体を用いた石油増進回収法における油層水中の塩濃度の影響に関する研究)

区 分 : 甲

論 文 内 容 の 要 旨

The enhanced oil recovery (EOR) techniques increase oil production from mature oil reservoirs by injecting thermal fluids, gases, chemicals, and other specific materials into oil reservoirs. The enhancement of oil recovery is brought by improving the properties of reservoir fluids and rock such as viscosity of oil and water, interfacial tension between oil and water, wettability of reservoir rock, the permeability of reservoir, etc. However, most conventional EOR techniques have not been practically used because they have still several challenges.

The EOR technique using nanoparticles (NPs) is now focused on because of its potential to overcome the challenges associated with the conventional EOR techniques while increasing oil production. Although the potential of NPs in EOR has been demonstrated by several previous studies, the mechanisms of the EOR has not been clarified yet. It is assumed that not only one mechanism but multiple mechanisms acting in combination bring the enhancement of oil recovery in this EOR. This study therefore focuses on the formation water salinity as an influential factor for this EOR. Moreover, this study aims to demonstrate the effectiveness of salinity control of formation water for this EOR.

The thesis consists of four chapters laid out as follows:

Chapter 1 introduces the overall view of the global conventional oil energy sources and literature reviews related to the topic of this study. The oil production methods, the application and mechanisms of NPs in EOR, and the research objectives are described in this chapter. According to the literature review, there are three types of NPs such as metallic and metal oxide NPs, organic NPs and inorganic NPs. A fluid in which NPs are dispersed in basefluid which is aqueous solution containing surfactant, polymer, alkaline and salt is known as nanofluids (NFs). Several mechanisms of NFs EOR has been proposed by previous studies. It has been reported that the enhancement of oil recovery is brought by the disjoining pressure, prevention of asphaltene precipitation, plugging of flow channels, alteration of rock wettability, reduction of interfacial tension between oil and water, and improvement of mobility ratio of oil/water phase in NFs EOR. In particular, Si-NFs in which silica NPs are dispersed is suggested to be one of the most effective NFs for enhancement of oil recovery and several studies on the application of Si-NFs for EOR have been reported. However, most of those previous studies fail to address the contribution of the formation water salinity, which is the concentration of NaCl in the formation water, for the enhancement of oil recovery by Si-NFs. Based on this literature review, this study which investigates the contribution of the formation water salinity for the Si-NFs EOR was conceived.

Chapter 2 describes the methodology for preparation of Si-NFs using the sonication technique and the

properties of Si-NFs in saline and non-saline environment, including dispersibility of Si-NPs, zeta-potential of Si-NPs, and the pH of Si-NFs. The dispersibility of Si-NPs in the NFs became lower by the increase in salinity. Si-NPs were agglomerated and sedimented in the saline environment. The sedimentation of Si-NPs in the saline water was gel-like material. The zeta-potential of Si-NPs was increased from -25.3 to -4.41 mV as the salinity increased from 0 to 4 wt%. The decrease in the absolute value of zeta-potential reduced the repulsion force of Si-NPs and it brought the decrease in dispersibility of Si-NPs in the NFs. The mean value of the particle size of Si-NPs in saline environment was larger than that in non-saline environment, therefore, the agglomeration of Si-NPs was stimulated in saline environment. Thus, it was demonstrated that the salinity was an influential factor for the dispersibility of Si-NPs in the NFs and agglomeration of Si-NPs was stimulated by increase in salinity in this chapter. These results suggested that the enhancement of oil recovery might be obtained by in-situ agglomeration of Si-NPs by controlling the salinity in oil reservoir.

Chapter 3 discusses the interaction between Si-NFs and reservoir materials such as oil and rock. Both wettability of rock surface and interfacial tension between oil and water were evaluated in saline and non-saline environment in this chapter. The interfacial tension between oil and Si-NFs in saline environment was low such as 8.2 mN/m while that in non-saline environment was 13.3 mN/m. The contact angle of oil droplet on the surface of sandstone plate which was saturated with oil was high such as 157° in saline environment while that in non-saline environment was 108° . These results indicated that NaCl enhanced the capacities of Si-NPs decreasing interfacial tension between oil and water, and altering wettability from lipophilic to hydrophilic, which were advantageous for oil recovery.

Oil displacement experiments were carried out using sandpack cores simulating oil reservoir in order to evaluate the potential of Si-NPs for enhancing oil recovery in this chapter. After the primary oil recovery based on the injection of original formation water, the injection of preflush water with different salinities was carried out before the Si-NFs injection in order to control the salinity in the sandpack. The effect of salinity on the Si-NFs EOR was thereby evaluated. The oil displacement efficiency by postflush after the Si-NFs injection was increased as the increase in salinity of the preflush water. 44 % of oil remaining after the primary recovery was additionally recovered by the postflush after the injection of preflush water whose salinity was 4 wt.% and Si-NFs. The additional oil recovery was assumed to be brought by the plugging of flow channels due to the agglomeration of Si-NPs in the sandpack. Si-NFs reacted with NaCl and agglomerated in the sandpack. The agglomeration of Si-NPs was plugged the flow channels whose permeability was high in the sandpack. Then, the postflush water flowed into poorly permeable zones which had not been swept and oil remaining in those zones could be recovered during the postflush. This mechanism was demonstrated through an oil displacement experiment using parallel sandpack model which was constructed by parallelly connecting two sandpack cores with different permeability. In primary oil recovery, preflush of 4 wt% NaCl solution and Si-NFs injection, oil was produced only from highly permeable core, however, the oil remaining in poorly permeable core was successfully recovered from poorly permeable core by the postflush after the Si-NFs injection in this experiment. This result indicated that Si-NFs had a combined effect with saline water to increase the oil recovery due to the plugging of highly permeable zones and improvement of the flow profile in heterogeneous oil reservoir.

Chapter 4 poses some concluding remarks of the present study. As final annotation, a few plausible directions for future works were provided therein, as well.