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Improving polymer flood performance in high salinity reservoirs

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ABSTRACT

The application of Enhanced Oil Recovery (EOR) techniques is encouraged by the current oil price and the growing global demand for oil. Optimizing oil production from current resources becomes a main strategy target for many oil producing companies around the world. Among EOR processes, polymer flooding is an attractive option in many reservoirs. The objective of polymer flooding is to control water mobility inside oil reservoirs to ensure high oil recovery factors. Several design parameters are critical for the success of polymer flooding applications. In many reservoirs, high salinity of formation's water imposes a challenge on polymer flood applicability. Therefore, improving polymer flood performance in high salinity conditions may unlock these resources which in turn will have enormous positive impact on oil reserves. Injection of a water slug (preflush) ahead of polymer, to condition the high salinity reservoir, is a promising technique to minimize the effect of salinity on polymer slug. In this work, a series of lab experiments were conducted to explore the performance of sequential injection of preflush-polymer-water on oil recovery factor. The effects of several design parameters are investigated including polymer concentration and polymer slug size, preflush salinity, and preflush slug size. The results indicate that preflush and polymer characteristics have various degrees of influence on oil recovery factor.

1. Introduction

Polymer flooding is one of the most promising EOR processes in many reservoirs because of its relative lower capital cost (Da Silva et al., 2007). In order to ensure favorable oil displacement front, polymers are used to reduce mobility ratio between water and oil. Polymers basically increase the viscosity of the injected water which allows for an increase in the vertical and areal sweep efficiency and consequently an increase in oil recovery factor. Generally, there are two types of polymers which are used in EOR applications: synthetic material polyacrylamide in its partially hydrolyzed form (HPAM) and the biopolymer Xanthan (Sorbie, 1991).

Polymer flooding technique has been used for more than 30 yr with an ultimate recovery expectation of 50% and incremental oil recovery of 10–15% over water flooding technique. There are several examples of field implementations of polymer flooding in the literatures (Seright 2010; Thakuria et al., 2013). In China for example, Liu et al. (2007) conducted a simulation study for an oil reservoir in Daqing field which indicates that polymer flooding might reach an oil recovery factor of 61% OOIP. In another work, Fulin et al. (2006) presented a case study for two pilot projects in Daqing oil field which indicates that an incremental oil recovery, over water flood, of 19.8–22.9% can be achieved for the first pilot and around 19.4% for the second pilot. Fulin et al. (2006) showed that before implementing these pilots, the results from core flood experiments resulted in an incremental recovery factor over water flooding of more than 20% OOIP which can be achieved by early time injection of high molecular weight, high concentration polymers. Moreover, Tielong et al. (1998) investigated the feasibility of polymer flooding in a pilot test conducted in Shuanghe reservoir located in the southeast Henan oil field which is known to be an elevated-temperature reservoir. At the end of the pilot, a total of 9.8% incremental oil recovery was achieved. They concluded that polymer with extra-high molecular weight can successfully control the mobility ratio and modify the permeability profile. Furthermore, Chang et al. (2006) presented an overview of polymer flood applications in Daqing and Shengli oil fields which stated that up to 14% of incremental oil recovery factor was obtained by implementing chemical EOR processes. Besides polymer floods in China, Da Silva et al. (2007) presented an economic analysis of PETROBRAS's experience with polymer flooding projects. They concluded that polymer flooding can be justified economically and environmentally under the current oil market conditions. Littmann et al. (1991) showed a case study where a reservoir with a salinity of 220,000 ppm was flooded with polymer. They stated that the performance of the polymer flooding could reach an oil recovery of 8% OOIP over waterflood. A study by Wyatt et al. (2004), which shows other examples of polymer flooding implementations, compares the performance of core

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flood experiments with the performance of field implementations of four polymer flooding pilots: 2 in Canada, 1 in USA and 1 in China. They concluded that core flooding experiments can be used to predict the performance of polymer flooding.

Conducting lab investigations is a crucial task toward a successful implementation of EOR projects. Lab studies narrow the risks associated with the application of EOR techniques on oil reservoirs. Before polymer flooding implementation, several lab experiments are advised such as polymer injectivity, polymer thermal and chemical stability, polymer retention in porous media, and effective viscosity measurements. Furthermore, a number of key parameters which play crucial roles in polymer flooding performance should be determined such as inaccessible pore volume, screen factor, and resistance factor (Jennings et al., 1971). Castagno et al. (1987) shows a case study in which discouraging outcomes from lab results prevent the implementation of polymer flooding project. They found that the viscosity of the proposed polymer solution was low and lack microbial control in near wellbore region. Moreover, Kleinitz and Littmann (1996) showed four cases of polymer flooding in Germany in which two of four pilots failed due to the loss of controlled displacement front.

The performance of polymer flooding is a function of several parameters that can be studied in the lab. Szabo (1975) studied the effect of polymer concentration on the performance of polymer flood in unconsolidated sand packs. He found that there are lower and upper limiting values for polymer concentration beyond which the performance of polymer flooding decreases. He also studied the effect of polymer slug size on oil recovery factor under various polymer concentrations from which he determined the optimum slug size and polymer concentration for different sands. Furthermore, Szabo (1975) studied the effect of salinity on the performance of polymer flooding and found that the salinity reduces oil recovery factor at low polymer concentrations and has a little effect at high polymer concentrations. Ryles (1988) studied the effect of temperature and divalent ion on the chemical stability of some water-soluble polymers used in EOR and showed the degree at which these polymer start to degrade under anaerobic conditions. These polymers were polyacrylamide, xanthan, scleroglucan, cellulose sulfate, and a heteropolysaccharide. Moreover, Doe et al. (1987) evaluated several copolymers of vinylpyrrolidone (VP) and acrylamide (AM) for EOR applications in hostile environments. They found that a range of VP/AM copolymer compositions was found to tolerate the harsh environment of 250 °F. The performance of these copolymers was evaluated by extensive coreflooding experiments. The results show that these copolymers can be easily injected into porous media and can be used for EOR applications in hostile environments. Kulicke et al. (1990) conducted a detail investigation about various Xanthan samples in term of viscosity, molecular weight, flow behavior, NMR and enzymatic analysis. They found that the various Xanthan solutions differ from one another with respect to their viscosity and injectability. In another work, Kleinitz et al. (1989) conducted a screening study of eight commercially available Xanthan solutions for a reservoir with a salinity of 220,000 ppm and they found that only four Xanthan solutions passed the injectivity test under saline conditions.

The two main concerns associated with polymer flooding applications are the effects of salinity and temperature of formation's water on the stability of polymer solutions and hence oil recovery factor. Stability of polymer solutions in high salinity and high temperature reservoirs is challenged; therefore, implementing polymer flood requires critical evaluations (Levitt et al., 2013). The recent advancements in polymer flood technology indicate that new families of polymers can sustain harsh environment, however, they are still in the development phase and no known field application have been documented.

Despite the lab experiments mentioned previously, investigations are still needed to improve the performance of polymer flooding in high salinity reservoirs. In the Middle East, many oil reservoirs are characterized with high salinity of 200,000 ppm and more. Thus, improving the performance of polymer flooding under high water salinity conditions may unlock these resources and hence dramatically increase oil reserves. One possible way to improve polymer flooding performance is to condition the reservoir by injecting a slug of water (preflush), with specific characteristics, ahead of polymer. In this work, a series of lab experiments were conducted to investigate the effects of several design parameters on the performance of preflush-polymer-water flood under high salinity conditions. The investigated parameters include polymer concentration, polymer slug size, preflush salinity, and preflush slug size. The objective of the work is to evaluate the functional relationships between these parameters and oil recovery factor.

2. Methodology

In order to reach the objectives of this study, a series of lab experiments were conducted to investigate the performance of preflush-polymer-water flooding in high salinity oil reservoirs. A sandstone reservoir, which is currently under waterflooding operations, was selected for this study. The high salinity of formation water, around 150,000 PPM, and the high temperature are the main challenges that prevent applying polymer flooding on this reservoir after waterflooding. Fig. 1 shows the relationship between oil viscosity and temperature for an oil sample taken from the considered reservoir.

The average reservoir temperature is around 175 °F; therefore, the oil has an in situ viscosity of 10 cp. Consequently, the viscosity of the injected fluid should be at least 10 cp in order to provide a favorable viscosity ratio to sweep oil during core flooding experiments.

The design of polymer solutions requires controlling four parameters: temperature, flow shear rate, salinity of water, and polymer concentration in order to have a prescribed viscosity. During core flooding experiments, the temperature is kept at reservoir conditions of 175 °F. The effect of shear rate on polymer viscosity is an important factor to be considered during the design of polymer solutions. Several correlations are available in the literature to calculate the expected average shear rate during polymer flooding experiments. Jennings et al. (1971) presented the following equation:

$$\dot{\gamma}_w = \frac{3n+1}{4n} \times \frac{4q}{A[8k\theta]^{1/2}}$$

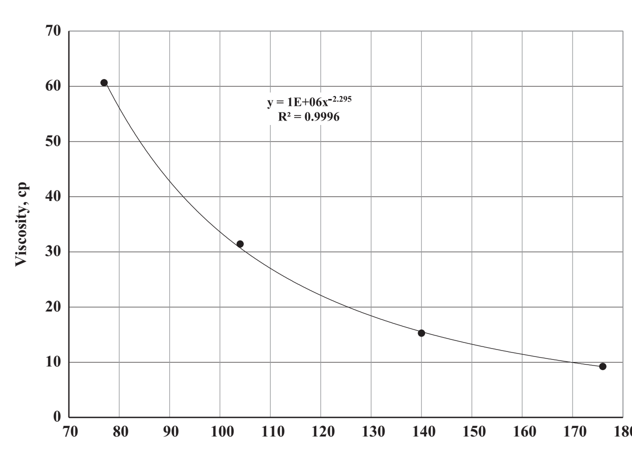

Fig. 1. Crude oil viscosity versus temperatre.