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Study on organic alkali-surfactant-polymer flooding for enhanced ordinary heavy oil recovery

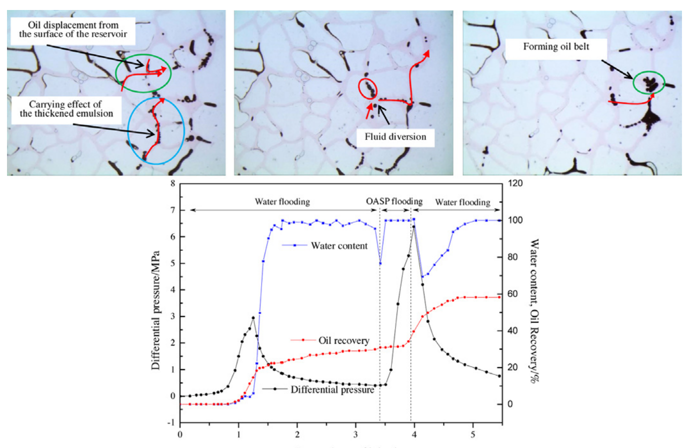
Lipei Fu, Guicai Zhang*, Jijiang Ge, Kaili Liao*, Haihua Pei, Ping Jiang, Xiaqing Li

College of Petroleum Engineering, China University of Petroleum, Qingdao 266580, China

HIGHLIGHTS

- The organic alkali/surfactant/polymer flooding system was established.
- It is suitable for the reservoir with high content of high-valent metal ions.
- During the OASP flooding the additional oil recovery was 20%.
- The recovery increases with the increase in organic alkali concentration.
- The mechanisms for OASP flooding in normal heavy oil are proven.

GRAPHICAL ABSTRACT



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ABSTRACT

With regard to ordinary heavy oil reservoirs which are not suitable for thermal methods, alkaline-surfactant-polymer (ASP) flooding exhibits great potential for enhancing heavy oil recovery. But for the formation water with high content of Ca^{2+} and Mg^{2+} ions, conventional ASP flooding always causes precipitation of a large amount of Ca and Mg salts which are damage to reservoirs. In this study, organic alkali-surfactant-polymer (OASP) flooding system is established, which exhibits good compatibility with the brine containing high-valent metal ions. The interfacial tension tests show that the combination of Shengli petroleum sulfonate (SLPS) and ethanolamine exhibits a good synergistic effect, and acquires an ultralow interfacial tension. Based on micromodel flooding tests, the mechanisms of OASP flooding system are studied as follows: the organic alkali in OASP system reacts with the acidic component of heavy oil and promotes the formation of water-in-oil (W/O) emulsion in heavy oil, thus increasing the flow resistance of flooding liquid and improving the sweep efficiency of normal ASP system. The generated surface active materials and surfactant can decrease the interfacial tension to an ultralow level, which could easily initiate the emulsion dispersion of crude oil, form the O/W emulsion, and improve the oil displacement efficiency. The sandpack flood results demonstrate that the oil recovery is increased by about 20%, and the recovery increases with the increase in organic alkali concentration. Therefore, the organic alkali-surfactant-polymer flooding technology can be developed into a new type of economically and technically feasible compound flooding technology suitable for ordinary heavy oil reservoirs with

* Corresponding authors.
E-mail addresses: 13706368080@vip.163.com (G. Zhang), lkl123@163.com (K. Liao).

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high content of Ca^{2+} and Mg^{2+} ions. Moreover, OASP flooding technology shows broad application prospects in improving the recovery of ordinary heavy oil reservoirs in Shengli Oilfield.

1. Introduction

The reserves of heavy oil reservoirs is 15×10^8 t in China, and they are mainly distributed in Liaohe, Xinjiang, Shengli, and Henan Oilfield [1]. In China, there are two main methods for ordinary heavy oil production. Water flooding is usually employed to develop the reservoirs in which the viscosity of underground crude oil is less than 5000 mPa s, and this method contributes to 18% of the total ordinary heavy oil production. Thermal methods are used for the reservoirs with the viscosity more than 5000 mPa s, which contributes to 82% of the total ordinary heavy oil production. Due to the high viscosity of the crude oil, the recovery of water flooding is usually less than 25%. Thermal methods are very effective in thick reservoirs or bottom-water reservoirs [2]. However, for the oil sheet reservoirs (less than 10 m), or deep reservoirs (more than 1000 m), or bottom-water reservoirs, thermal methods show poor effect because of the serious loss of heat [3]. In this case, the non-thermal methods are needed to further improve the ordinary heavy oil recovery. Many studies have shown that using chemical flooding after water flooding is an effective method to increase oil recovery for ordinary heavy oil [4,5].

A large amount of movable residual oil still remains in heavy oil reservoir after water flooding [6,7]. To conduct a chemical flooding in heavy oil reservoir after water flooding, following points should be ensured: first, the flooding system should come in contact with the oil-rich zone; and second, the flooding system in oil-rich zone should have higher sweep efficiency [8,9]. The alkaline-surfactant-polymer (ASP) flooding technology can not only increase the viscosity of displacement fluid, improve the water-oil mobility ratio, and further enhance the sweep efficiency, but also significantly reduce the oil/water interface tension and increase the oil displacement efficiency [10]. Therefore, ASP flooding technology is one of the most effective ways for improving the water flooding recovery of heavy oil reservoirs currently [11,12]. However, the inorganic alkali in the ASP flooding system can react with the high valence metal ions present in the formation water, resulting in problems, such as scaling [13]. Therefore, development of an organic alkali system with good compatibility with the brine containing high valence metal ions (i.e., calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions) is highly desirable [14,15].

Inorganic alkali is sensitive to the divalent ion; therefore, Ca^{2+} and Mg^{2+} ions in alkali solution can cause the scaling of both the injection system and the near-well zone of the injection well. Jennings et al. concluded that the hardness of the water in the form of Ca^{2+} ions could deactivate the in-situ formed surfactants. Therefore, removal of Ca^{2+} ions from the prepared alkaline solution was highly desirable [16]. Organic alkali is a type of good chelating agent, capable of efficiently complexing with the Ca^{2+} and Mg^{2+} ions in the injected water. Berger and Lee studied the effect of replacing the inorganic alkali in ASP flooding with the organic alkali; investigated the effects of organic alkali on the interfacial tension, viscosity, and adsorption of OASP system (Organic alkali-Surfactant-Polymer); and compared them with those of the conventional ASP system. The results indicated that the organic alkali was not affected by the hardness of water, and it strengthened the ability of polymer toward increasing the viscosity of the displacing water to decrease the W/O mobility ratio [17]. The overall effect was better than the conventional ASP flooding. Lakatos et al. used the organic alkali like organic amine as the pH regulator for preventing scaling [18]. The research results showed that addition of organic alkali not only improved the descaling effect, but also reduced the damage to the formation permeability caused by the injected liquid. Sharma et al. used ammonia instead of sodium carbonate to form ASP flooding system. The research results revealed that ammonia water and formation water exhibited good compatibility, and the addition of ammonia did not lead to the precipitation of divalent ions [19]. In addition, organic alkali-surfactant-polymer flooding system significantly improved the recovery of Berea sandstone oil reservoir.

Formation water of Shengli Oilfield contains higher content of Ca^{2+} and Mg^{2+} ions; therefore, flooding system prepared using inorganic alkali, in general, results in the precipitation of a large amount of Ca and Mg salts. These salts interfere with the injected oil displacement agent, causing serious alkali consumption, and thus limiting the technology application for this type of reservoir. Therefore, establishing and developing the organic alkali system, instead of the conventional inorganic alkali system, with a good compatibility with the brine containing high valence metal ions (i.e., Ca^{2+}, Mg^{2+}), can solve the problem of Ca and Mg precipitation in the injection system. Further, it can result in the development of a new type of economically and technically feasible compound flooding technology suitable for the ordinary heavy oil reservoirs, thus exhibiting a broad application prospect in increasing the recovery of the ordinary heavy oil reservoir in Shengli Oilfield.

2. Experimental

2.1. Materials

The oil sample was collected from the Zhuangxi heavy oil reservoir in Shengli oilfield. The is 1550 mPa s at 50 °C and its acid value is up to 2.14 mg KOH/g. The solution used in the experiment was prepared according to the formation water in the field (Shengli Oilfield, China). The content of formation water is shown in Table 1. Five types of surfactants were used in the experiments in order to find the surfactant system suitable for the interfacial tension of heavy oil from Shengli Oilfield. They are Shengli petroleum sulfonate (SLPS, with a purity of 35%, Provided by Shengli oilfield, China), Anqing petroleum sulfonate (WPS, with a purity of 40%, Provided by Sinopec Anqing Branch, China), Xinjiang petroleum sulfonate (XJPS, with a purity of 40%, Provided by Xinjiang oilfield, China), Heavy alkyl benzene sulfonate (NJPS, AR, provided by Nanjing Shihao Chemical, China), α-olefin sulfonate (KAS, AR, Aekyuan Chemical CO., LTD, South Korea), Sodium dodecyl benzene sulfonate (SDBS, AR, Sinopharm, China). Ethanolamine was selected as the organic alkali, which was analytical-grade and purchased from Sinopharm, China. Hydrolyzed polyacrylamide (HPAM, 1000 ppm) with a molecular weight of 12 million was selected as the polymer component (Shengli Oilfield, China). Chemicals applied in the

Table 1
Ionic Composition of the formation water.

Ion content (mg/L)					total salinity (mg/L)
Cl^-	HCO_3^-	Ca^{2+}	Mg^{2+}	Na^+	13659.9
8118.5	248.2	146.7	49	5097.5	