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The comparison study of IFT and consumption behaviors between organic alkali and inorganic alkali

Donghai Xie [a,b,c,*], Jirui Hou [a,b,c], Fenglan Zhao [a,b,c], Ankit Doda [d], Japan Trivedi [d]

[a] Enhanced Oil Recovery Institute, China University of Petroleum, Beijing 102249, China
[b] Laboratory of Basic Theory for Application of EOR in Low Permeable Oil Fields, CNPC Key Laboratory of EOR, China University of Petroleum, Beijing 102249, China
[c] MOE Key Laboratory of Petroleum Engineering, China University of Petroleum, Beijing 102249, China
[d] School of Mining and Petroleum, University of Alberta, Edmonton, Alberta, Canada T6G 2W2

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ABSTRACT

Alkali plays an important role in alkali/surfactant/polymer (ASP) technology. The mechanisms of alkali were reviewed in this paper and the advantages were significant. In this study, three main steps were conducted. Firstly, ethanolamine was selected from four organic alkalies (ethanolamine, diethanolamine, triethanolamine and triethylamine) by interfacial tension (IFT) tests. Then the selected organic alkali, ethanolamine, was compared with inorganic alkali (sodium carbonate) by IFT performance. The results showed that ethanolamine had low IFT like inorganic alkali and it has lower IFT than sodium carbonate when concentration was higher than 0.8%. Secondly, alkali consumption experiment was conducted to compare organic alkali and inorganic alkali. The results indicated that ethanolamine had lower consumption than inorganic alkali, which maintained the efficiency of ASP flooding. Finally, the concentrations of silicon and aluminum in solution were measured to evaluate the reservoir damage caused by alkali. The results found that ethanolamine system had the lower concentrations of silicon and aluminum than inorganic alkali, which means it caused less reservoir damage. Thus, ethanolamine may be a potential alkali which can replace inorganic alkali in ASP technology.

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1. Introduction

There are thousands of successful experiences in the alkali/surfactant/polymer (ASP) technology application, especially in US and China. La Salina Field, on the eastern coast of Maracaibo Lake in Venezuela, is ASP pilot project with an estimate of 19.0% was considered as the incremental recovery factor for reservoirs of Miocene with the injection of ASP according to previous studies to optimal ASP formulation (Guerra et al., 2007). Daqing Oil Field in China has successful experience in applying ASP with 16–17% OOIP incremental recovery over 100% water cut by water flooding (Demin et al., 1998). Another research showed that Daqing Oil Field had completed 5 ASP flooding pilot field tests from 1993 to 1996. All have gotten high displacement efficiency from 19.24–25% OOIP (Hongfu et al., 2003). Since 2000, several industrial ASP flooding tests have been carried out successfully which have shown a satisfied effect of higher oil production (Berger et al., 2006).

Alkali, as a component of ASP flooding, has some mechanisms of enhancing oil recovery. First of all, alkali can react with acids present in crude oil to form in-situ soaps which act as surface active agents. These surface active agents have synergistic effect with added surfactant and then reduce interfacial tension (IFT) between oil and water (Peru et al., 1990). Alkali can also overcome the surfactant depletion due to the adsorption. Secondly, alkali can improve the wettability of rocks in reservoir. Wettability is an important factor in oil recovery which affects relative permeability characteristics by capillary pressure and the fluid distribution. Some reservoirs are oil wet which means the capillary pressure has a resistant effect on oil recovery. Alkali is applied to alter the wettability from oil wet to water wet reservoir which is beneficial to oil recovery (Dehghan et al., 2015). Finally, alkali can emulsify oil into droplets. The small oil droplets transport with injected solution, which is called entrainment. The large oil droplets are entrapped by pore and then improve sweep efficiency, which is called entrapment (Tong et al., 1998).

Although there are some successful ASP cases in some oil fields, the ASP flooding has not been widely applied. To some extent, the reason is related to the application of alkali, although it has some advantages for oil recovery. Alkali can react with divalent cations in reservoir and then form precipitation which blocks pore and decreases the permeability. A paper by Hou Jirui addressed the

* Corresponding author at: Enhanced Oil Recovery Institute, China University of Petroleum, Beijing 102249, China.

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corrosion and scale problems that occurred during the ASP flooding at Daqing. He pointed out that the use of alkali resulted in reduction of injectivity and sharply shortened period of checking pump (Hou et al., 2001). To overcome the problems, the effective anti scale agent was a possible solution. But the costs of the agent is so high that limits the application of alkali in ASP technology. In addition, alkali dissolves rock minerals and also reacts with rock minerals and then forms new minerals. The newly formed minerals are some particles which will also result in reservoir damage. Low concentration of alkali is used to avoid the negative effect, but the low concentration also limits the advantages of alkali.

In this paper, organic alkali was used in ASP solution to compare with inorganic alkali in some properties. The IFT test was conducted to screen the best organic alkali and then the performance of IFT was also compared between organic alkali and inorganic alkali. Alkali consumption, as a factor which affects the efficiency of alkali, was compared in both alkali systems. Finally, the reservoir damage comparison was performed to investigate the difference between organic alkali and inorganic alkali. Based on the studies, some results were found that Organic alkali has lower IFT than inorganic alkali when concentration is over 0.8%. In addition, Organic alkali has lower alkali consumption and weaker reservoir damage than inorganic alkali.

2. Experimental

2.1. Fluids and chemicals

Oil and formation brine samples were from VI reservoir in Nanyang oilfield in China. The density of oil was 0.85 g/cm^3, and its viscosity was 1.7 mPa s at 92 °C, the reservoir temperature. The water type of injection brine was sodium bicarbonate whose salinity was 10884 ppm, it contained 3009 ppm chloridion (Cl^-), 17 ppm calcium ion (Ca^{2+}), 4 ppm magnesium ion (Mg^{2+}).

The chemical agents used in this study included alkali, surfactant and polymer. The alkaline agents used in this study were organic alkali (ethanolamine, diethanolamine, triethanolamine and triethylamine) and inorganic alkali (sodium hydroxide, sodium carbonate). The surfactant was SH-6 which was provided by Nanyang oilfield with a purity of 50%. The polymer was HPAM which was provided by Nanyang oilfield.

2.2. Measurements of Interfacial Tension (IFT)

The IFT between oil and water was measured by the SVT20N spinning drop interfacial tensiometer at 92 °C. During the measurements each sample was rotated at a speed of 6000 rpm. Equipped with an image-capture device and image-acquisition software, this instrument could automatically measure and record the dynamic IFT. Each measurement was stopped until the equilibrium was established.

2.3. Alkali consumption

The sands and different solution systems were mixed in polyethylene bottles with tight polypropylene lids. Sands and solutions were preheated to 92 °C. Appropriate amounts of the solutions and sands were weighed and kept in constant-temperature oven. For each reaction time, a separate bottle was used. Distilled water should be added to bring the solution back to the original weight if there is vaporization loss of water. The liquid/solid ratio was 50 ml/10*g*, 50 ml/5*g* and 50 ml/2.5*g*, the concentration of alkali was 0.6%, 0.8%, 1.0%, 1.2%, the reaction time was 4 h, 24 h, 120 h, 480 h. After reaction, the mixture in the bottle was centrifuged. The supernatant was used to measure the concentration of alkali, silicon, aluminum.

2.4. Concentration measurement of silicon

Prepared a series of silicon solution with the range of concentration from 1 ppm to 18 ppm in 50 ml volumetric flasks by the silicon standard solution. Litter distilled water was added into the volumetric flasks. Then 1.5 ml aqua fortis and 5 ml ammonium molybdate with concentration of 5% were added. The volumetric flasks were shocked and filled in distilled water to the scale mark. Let them stand for 10–15 min. Each concentration of silicon solution was scanned by ultraviolet spectrophotometer at the wavelength $\lambda = 410$ nm. Each concentration corresponded an absorbancy. Then the relationship between concentration and absorbancy will be built. The absorbancy of the supernatant was measured by the method above. Then the concentrations were calculated by the standard curve.

2.5. Concentration measurement of aluminum

Prepared a series of aluminum solution with the range of concentration from 0.2 ppm to 0.8 ppm in 50 ml volumetric flasks by the silicon standard solution. Litter distilled water was added into the volumetric flasks. A drop of methyl orange was followed. The hydrochloric acid was added until the color of solution turn to red. Then 1.5 ml ascorbic acid (1.0%) and 2.5 ml chromazurine (0.2%) were added, followed by acetic acid-sodium acetate buffer solution. The volumetric flasks were shocked and filled in distilled water to the scale mark. Let them stand for 5–10 min. Each concentration of aluminum solution was scanned by ultraviolet spectrophotometer at the wavelength $\lambda = 587$ nm. Each concentration corresponded an absorbancy. Then the relationship between concentration and absorbancy will be built. The absorbancy of the supernatant was measured by the method above. Then the concentrations were calculated by the standard curve.

3. Results and discussions

3.1. Organic alkali screening

3.1.1. Dynamic IFT comparison

The IFT behavior was studied to find out which organic alkali was best. Fig. 1 shows IFT between oil and different chemical solutions at 92 °C. The chemical solution contained organic alkali with concentrations ranging from 0.6 to 1.2% and surfactant with a constant concentration, 0.3%. The results indicated that dynamic IFT of each system decreases first and reach the equilibrium value after decreasing to the minimum value. It was due to adsorption property of organic alkali, surfactant and in situ soap on the oil/water interface. There was adsorption and desorption on the interface. At primary stage, the adsorption was faster, so the IFT decreased quickly as the adsorption of organic alkali, surfactant and in situ soap, then reached the minimum value. As the amount of adsorption increased, desorption was accelerated. So desorption was faster and IFT increased. At last, the rate of adsorption and desorption was equal and then the IFT became stable.

The IFT of triethylamine system had high value (>0.01 mN/m), even if the concentration was 1.2%. The IFT values of diethanolamine and triethanolamine systems were low (0.001 mN/m-0.01 mN/m) when the concentrations were at high level (1.0%, 1.2%). The ethanolamine system had the best performance on IFT behavior. The IFT values of ethanolamine system were all lower than 0.01 mN/m, even lower than 0.001 mN/m when the concentration increased to 1.0%. Obviously, ethanolamine had a better synergy

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