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Effect of laponite particles on the emulsion stability of produced water from polymer flooding

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ABSTRACT

In many oilfields, produced water from polymer flooding was more difficult to be treated than produced water from water flooding. The results of simulated experiment showed that the partly hydrolyzed polyacrylamide (HPAM) was present in the produced water, which stabilized the oil droplets in produced water. The addition of HPAM decreased oil–water interfacial tension and increased the viscosity of produced water, the emulsion stability was enhanced when the concentration of HPAM was below 500 mg/L. As the concentration of HPAM was high enough, the flocculating ability of the HPAM caused small oil droplets to coalesce into bigger ones. The addition of laponite particles to simulated polymer flooding water caused the zeta potential and interfacial tension of oil droplets to decrease rapidly, and the formation of stable oil–mineral aggregates (OMA) structures was observed when the concentration of laponite particles was below 150 mg/L. When the concentration of laponite particles was further increased, the zeta potential of oil droplets remained stable, the oil–water interfacial tension increased slightly, and large oil–mineral aggregates formed. These results caused the produced water to become unstable. The concentration of laponite particles determined the emulsion stability of the produced water. It was found that the synergetic effects of the laponite particles and the HPAM enhanced the emulsion stability of the produced water from polymer flooding. The electrostatic repulsion and steric stabilization effect are the main stabilization mechanisms in the polymer flooding water.

1. Introduction

With the reduction of oil resources most oilfields in China have reached the tertiary oil recovery stage (Deng et al., 2005). Polymer flooding as a topical technology of the tertiary oil recovery plays an important role in the exploitation of oil (Needham and Doe, 1987), and has been widely used in many oilfields in China (Han et al., 1999; Chang et al., 2006; Wang et al., 2009). Industrial experiences showed that polymer flooding can enhance oil recovery by up to 12%. However, the oilfields then face with new problems. With the development of polymer flooding, the amount of produced water increases greatly and the properties of the produced water become more complicated and more difficult to treat than that from water flooding (Taylor and Nasr-EL-Din, 1996; Nedjhioui et al., 2005). The produced water needs to be further treated for oil removal, and the treated effluent can be then injected into the strata again for reuse or discharge into the environment when it meets the emission standards (Fakhru'l-Razi et al., 2009). If the produced water from polymer flooding is not handled properly, the injection and efflux will risk harming both the oil wells and the environment (Deng et al., 2009).

Conventional technologies such as gravity settling, flotation, demulsification, membrane separation, high-speed flow hydrocyclonning, and biotechnology (Deng et al., 2002a; Qiao et al., 2008; Cha et al., 2010; Iglauer et al., 2010; Melo et al., 2010) are not able to meet the requirements for the treatment of water produced by polymer flooding in oilfields. It is therefore critical that effective technologies are developed for the treatment of polymer flooding wastewater; the development of such technologies depends on a comprehensive understanding of the stabilization mechanism.

The produced water from polymer flooding (a mixture of oil and water from oil wells) contains a large quantity of polymer (partly hydrolyzed polyacrylamide, HPAM) which is dissolved in water to increase the solution viscosity (Zhang et al., 2006). Due to the use of surfactant and polymer in the injected water in polymer flooding technology, the oil–water interfacial properties are changed and the oil droplets become more stable. However, the produced water is also continually contact with clay particles as crude oil flows through the underground reservoir, the solid

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Nomenclature

HAPM	partly hydrolyzed polyacrylamide
OMA	oil–mineral aggregates
WPS	weighted petroleum sulfonate
IFT	interfacial tension (mN/m)
D	diffusion coefficient
K	Boltzmann constant
T	thermodynamic temperature
η	viscosity
r	radius of particles
M_w	weight-average molecular weight

particles are an important factor affecting emulsion stability and carrying a series of problems in oilfields in recent years. The high concentration of clay particles in bulk phase may cause clogging of pipeline (Zhang et al., 2007; Deng et al., 2009), so the treating water has to reach the criterion before being re-injected into the underground. Moreover, clay particles and HPAM are simultaneously present in the produced water, the clay particles may interact with polymer and crude oil from produced water. To our knowledge, few studies in this aspect have reported the synergistic effects of HPAM and solid particles on emulsion stability of produced water.

In this work, we used well-defined laponite particles as model solid particles as its structure and composition approximate to the natural clay particles. The produced water from polymer flooding was prepared, and the effect of the HPAM was studied in conjunction with laponite particles on emulsion stability of produced water in terms of interfacial tension, zeta potential and viscosity. The synergistic effects of HPAM and laponite particles on the stabilization mechanism for polymer flooding were discussed. To find an effective method to treat the produced water from polymer flooding, the stabilization mechanisms of produced water from polymer flooding were discussed.

2. Experimental materials and methods

2.1. Materials

The crude oil used in this study was obtained from Shengli oilfield in China; it had a water content of less than 0.5%, a density of 865 kg/m^3, and a viscosity of 60 mPa s (at 45 °C). Partly hydrolyzed polyacrylamide (HPAM) was purchased from East Asiatic Company (Japan); the HPAM had an average molecular weight (M_w) of 5.0×10^6, and a degree of hydrolysis of approximately 25–30%. The laponite particles were provided by the Xinjiang Technical Institute of Physics and Chemistry (CAS) with composition as follows: SiO_2 66.2%, MgO 30.2%, Na_2O 2.9%, Li_2O 0.7%. The diameter of laponite particles was 25–30 nm and the layer thickness of laponite particles was 1 nm. The weighted petroleum sulfonate (WPS) was provided by Shengli Engineering and Consulting Co., Ltd. Other materials were analytical regents.

2.2. Preparation of simulated produced water

Brine was prepared according to constituents of the underground water in Shengli oilfield. Salts contained in the brine were as follows (mg/L): NaCl 1600, $NaHCO_3$ 2600, Na_2CO_3 300, Na_2SO_4 40, $CaCl_2$ 40, $MgCl_2$ 40. The mineralization degree of brine was 4620 mg/L. WPS (1 g) was solubilized into 1 L brine to obtain a stock solution with 0.1% WPS. Then the brine was used to prepare simulated produced water from polymer flooding with preparation process as follows: First, 300 g brine with 0.1% WPS and 100 g crude oil were added to a 500-mL beaker and the mixture was heated to 45 °C in water bath for 1 h. Then the mixture was emulsified for 5 min at 15,000 rpm with an emulsifier to obtain a 25% oil-in-water emulsion. We studied the emulsifier effect of the oil-in-water emulsion, immediately after the emulsion preparation and after kept for 24 h at room temperature, by measuring the changes in emulsion volume with time. The stability of emulsion was characterized by the relative volume of emulsion constituents, defined as the ratio of oil-in-water emulsion volume after 24 h to the total volume of water, oil and surfactant were used together to prepare the emulsion. If the volume of emulsion does not change with time, then the emulsion doesn't emerge oil–water separation, the emulsion can be used to conduct following experiments. Next, 0.4 g 25% oil-in-water emulsion was added to 99.6 mL brine with different concentration of HPAM and laponite particles, the brine was shaken uniformly to get the simulated produced water with oil concentration of 1000 mg/L.

2.3. Determination of the oil concentration

The oil concentration in the water samples was determined as follows: 100 mL of the produced water was placed in a 100-mL beaker, and was then left to settle for 4 h at 45 °C in water bath. A 2-mL sample of the liquid was then taken from below the surface of the sample. The pH of the water was adjusted to 2.0 using HCl (1:1, v/v), and then the sample water was extracted twice with petroleum ether. The adsorbance of the extract was determined using a TU-1810 type UV–vis spectrophotometer (Beijing Purkinje General Instrument Co., Ltd.) operated at 254 nm (Wang et al., 2012). The oil content in the water was calculated according to a standard curve. The oil concentration provided an insight of the oil–water separation properties of the simulated produced water.

2.4. Determination of the zeta potential of the oil droplets

The zeta potential measurements were conducted on a Zeta-plus zeta apparatus (Brookhaven Company, USA). In this case, 100 mL of the model produced water was allowed to settle for 4 h at 45 °C, and a 5-mL sample was then removed and tested.

2.5. Oil–water interfacial tension measurement

A K12 Tensiometer (Kruss Company, Germany) was used to determine the oil–water interfacial tension. This instrument determines the interfacial tension by using the ring method. The temperature was maintained at 45 °C, and oil/double distilled water without any added chemicals was used as the reference interface for all measurements.

2.6. Viscosity measurement

A CS-Rheometer RS75 (with a double-gap sensor DG400) from HAAKE Company (Germany) was used to determine the viscosity of the produced water. In the measurements, the temperature of the produced water was maintained at 45 °C, and the shear rate used was 10 s^{-1}.