Research on A Novel Foaming Agent for Low Permeability Reservoir with High Temperature and Salinity

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Abstract: Foam has been widely used in oilfield to enhance oil recovery as a mobility control agent in EOR, especially for low permeability reservoir with high temperature and salinity. A novel foam system stabilized by a hydrophobically modified polyacrylamide was researched by Ross-Miles method and its foaming ability, stability and plugging performance was evaluated. Dodecyl dimethyl betaine (BS-12) showed good foaming ability while hydrophobically modified polyacrylamide (HMPAM) showed good foam stabilization performance. The new foaming agent of BS-12/HMPAM compound exhibited both good foaming ability and high stability under high temperature and salinity conditions. The foam generated by the alternate injection of the new foaming agent solution and air had good plugging performance under reservoir conditions with high temperature and salinity.

Keywords: foam, hydrophobically modified polyacrylamide, high temperature, high salinity, plugging performance.

1. INTRODUCTION

Foam is a kind of dispersion of gas in liquid which is stabilized mainly by polymer, surfactant and alkali, etc. Foam has been widely used in the field of oilfield chemistry such as mobility control in EOR [1-4], recovery of wastes in environmental remediation [2] and forest and coal mine fire prevention [3].

As a mobility control agent in heterogeneous reservoirs, foam can increase the apparent viscosity of the gas phase and thus can reduce gas-fluid mobility in high permeability reservoirs which can improve the profile control and sweep efficiency in heterogeneous reservoirs to enhance oil recovery in heterogeneous reservoirs [4].

Foam is thermodynamically unstable and it is necessary to improve its stability [5]. Water soluble polymers such as HPAM can enhance the stability the stability of foam by increasing the bulk viscosity of the foam system and the interfacial viscosity of the gas/water interfacial film [5]. But in reservoirs with high temperature and high salinity, HPAM is not suitable in these reservoirs as HPAM will hydrolyze in high temperature and undergo a viscosity reduction in high salinity. Hydrophobically modified polyacrylamide (HMPAM) have received
increasing attention due to their unique rheological characteristics and applications, in oil recovery, drilling fluids, coatings or cosmetics [6]. When the polymer concentration is above the critical aggregation concentration (CAC), inter-molecular association occurs between the hydrophobic groups and network structure can be formed in the solution which can significantly increase the viscosity of polymer solution. Besides, HMPAMs show better temperature and salt resistant performance compared with HPAM and thus can be used in high temperature and high salinity reservoirs [6].

In this study, a novel foaming agent with the main component of dodecyl dimethyl betaine and the stabilizer of a hydrophobically modified polyacrylamide was researched by Ross-Miles method and its foaming ability, stability and plugging performance was evaluated to explore a new method to enhance oil recovery for the reservoirs with high temperature and high salinity.

2. EXPERIMENTAL

2.1 Materials.

The crude oil from Xifeng oilfield has a water content of less than 0.5%, and density and viscosity of 857 kg.m⁻³ and 11.2 mPa·s (at 50 °C), respectively. The ions of the Xifeng simulation formation water was mainly composed of NaCl and CaCl₂ with the total salinity of 50000 mg/L and the Ca²⁺ concentration of 2000 mg/L.

The main foaming agent used in this paper is dodecyl dimethyl betaine (BS-12) and the foam stabilizer is hydrophobically modified partly hydrolyzed polyacrylamide (HMPAM) of Poly(acrylamide-sodium acrylate-N-dodecylacrylamide) (abbreviated as P(AM-NaA-C₁₂AM) synthesized as reported in my previous study [7].

2.2 Measurement of foaming ability.

Ross-Miles method was employed to evaluate the foaming ability according to GB/T 7462-94 “Surface active agents-Measurement of foaming power-Modified Ross-Miles method”. The initial foam volume and foam height was recorded to describe the foaming ability and foam half-life was used to describe the foam stability. The experiment was conducted at a condition of high temperature (70 °C) and high salinity (Xifeng simulation formation water).

2.3 Plugging performance of foam system.

Foam resistance factor is regarded as an important index to evaluate the Plugging performance of foam system among all parameters. The resistance factor R can be determined according to Petroleum industry standard SY/T5672-93 “Evaluation method of high temperature foaming agent for steam injection” and the resistance factor R is calculated through Equation 1.

$$ R = \frac{\Delta P}{\Delta P_0} $$

Where R is the resistance factor, ΔP₀ is the pressure difference between two ends of the core during water injection while ΔP is the pressure difference between two ends of the core during foam injection.

The experiment was conducted in artificial quartz sand core (the porosity was 21.35 % and the water measurement permeability was 11.76×10⁻³ μm²) and the temperature was 70 °C.
3. RESULTS AND DISCUSSION

3.1 Optimization of the foaming agent.

The initial foam height and the foam height after 3 min and 5 min was recorded to describe the foaming ability as shown in Fig. 1. The main foaming agent of dodecyl dimethyl betaine (BS-12) showed good foaming ability in high temperature and high salinity condition. The initial foam height increased with the increasing surfactant concentration dramatically at low surfactant concentration and then gently at a surfactant concentration above 0.25%. The foam height after 3 min and 5 min was much smaller than the initial foam height which showed that the foam was not stable in high temperature and high salinity conditions.

![Fig.1 Influence of surfactant concentration on foaming property.](image)

To better enhance the stability of foam, a kind of HMPAMs of P(AM-NaA-C_{12}AM) was employed in the foaming system. As reported in my previous study, the molecular weight of P(AM-NaA-C_{12}AM) is 4.8×10^6 with a degree of hydrolysis of 28% and the critical aggregation concentration (CAC) of P(AM-NaA-C_{12}AM) is about 800 mg/L. P(AM-NaA-C_{12}AM) has a good thickening property and shows good temperature and salt resistant performance. Fig. 2 showed the influence of polymer concentration on foaming property. P(AM-NaA-C_{12}AM) showed good foam stabilization performance in high temperature and high salinity conditions. The initial foam height increased with the increasing polymer concentration dramatically at low polymer concentration and then gently at a polymer concentration above 0.15%. The foam height after 3 min and 5 min decreased a little compared the initial foam height which showed that the foam stabilized by HMPAM had a good stability in high temperature and high salinity conditions.
Based on the above results, a novel foaming agent of BS-12/HMPAM compound was proposed, and the mass fraction of HMPAM (the total concentration is 0.25%) on foaming property was studied as shown in Fig. 3. The results showed that the surfactant BS-12 and the polymer P(AM-NaA-C12AM) produced good synergistic effect both in foaming ability and foam stability compared with the surfactant BS-12 itself. The optimal HMPAM mass fraction of BS-12/HMPAM compound is 0.7 which meant HMPAM concentration was 0.175 %.

3.2 Property evaluation of BS-12/HMPAM foaming agent.

The temperature and salinity resistant performance of BS-12/HMPAM foaming agent was studied and the results were shown in Fig. 4 and Fig. 5. Fig. 4 showed that the foaming ability increased with the increasing temperature but the half-life decreased. The half time of the foam generated by BS-12/HMPAM was still above 60 min at 90 °C. Fig. 5 showed that the foaming ability decreased with the increasing Ca2+ concentration especially when Ca2+ concentration was above 6000 mg/L. Generally, the foaming agent of BS-12/HMPAM showed good temperature and salinity resistant performance which can be used to enhance the oil recovery in high temperature and high salinity reservoirs.
Fig. 4 Influence of temperature on foaming property of BS-12/HMPAM compound.
(Xifeng simulation formation water)

Fig. 5 Influence of Ca2+ concentration on foaming property of BS-12/HMPAM compound.
(70 °C, the total salinity was 50000 mg/L)

3.3 Plugging performance of BS-12/HMPAM foaming agent.
As shown in Fig. 6, with the increase of the cumulative injected volume in pore volumes, the resistance factor increased. The results showed that the foaming agent solution and air alternately injected in the cores can generate foam and thus increased the bubble number and foam volume which can increase the plugging performance compared with alternate injection of air and water. The results showed that foam had good plugging performance under reservoir conditions with high temperature and salinity.
Fig. 6 Resistance factor as a function of cumulative injection volume in pore volumes.

4. CONCLUSION

A novel foam flooding agent stabilized by a hydrophobically modified polyacrylamide was researched by Ross-Miles method and its foaming ability, stability and plugging performance was evaluated. Dodecyl dimethyl betaine (BS-12) showed good foaming ability while hydrophobically modified polyacrylamide (HMPAM) showed good foam stabilization performance. The new foaming agent of BS-12/HMPAM compound exhibited both good foaming ability and high stability under high temperature and salinity conditions. The foam generated by the alternate injection of the new foaming agent solution and air had good plugging performance under reservoir conditions with high temperature and salinity.

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