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Surfactant flooding characteristics of dodecyl alkyl sulfate for enhanced oil recovery

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ABSTRACT

Surfactant-enhanced oil recovery is a type of enhanced oil recovery (EOR), a method to produce residual oil by injecting surfactant solution into the reservoir. The application of surfactant EOR requires knowledge of the phase behavior for more efficient production of residual oil.

In this study, the relationship between dodecyl alkyl sulfate and some specific crude oils was examined through phase behavior test. It was found that the branched surfactant was more effective than the linear surfactant. The system was stable at salinities <3 wt%. On adding a small amount of co-surfactant, the emulsion activity was increased.

The gravity drainage flooding test (GDFT) was performed to determine the potential of dodecyl alkyl sulfate to produce residual oil in porous media. It was found that the solution could be flooded at temperatures of 60 °C or higher. In the core flooding test, injecting one pore volume of 2 wt% surfactant solution with 3 wt% salinity produced 26.6% more oil after water flood. With the addition of only 0.01 wt% co-surfactant, oil production increased by 1.6%. Contrary to the phase behavior test, the linear surfactant produced 1.3% more oil than the branched surfactant in the core flooding test.

1. Introduction

Enhanced oil recovery (EOR) is a general term for any technique used to increase oil production after the primary and secondary production periods. EOR has been receiving much more attention since the last decade [1], mainly because of the increasing price of oil and the massive market value of the residual oil in reservoirs. The petroleum industry has typically used mechanical (steam/CO_2) and chemical (polymer/surfactant) EOR processes to increase production in oil and gas reservoirs [2]. Polymer injection helps in propagating the oil bank formed by surfactant injection by increasing the sweep efficiency [3]. Heavy oil recovery by alkali-polymer flooding using polyacrylamide (HPAM) solution with the addition of NaOH could be more effective in improving sweep efficiency than polymer flooding [4]. Bo et al. showed the potential of utilizing Gemini surfactants in harsh reservoir conditions for EOR applications. Gemini surfactant molecules have excellent aqueous stability even in high salinity and properties that are lower maximum adsorption densities than the conventional single chain surfactants [5].

In this study, surfactant EOR, one of the chemical EOR processes, was investigated. The application of surfactant EOR improves the recovery of residual oil from known deposits by using a surface-active agent to reduce interfacial tension (IFT) to mobilize the residual oil. The surfactant needed to obtain good phase behavior and ultra-low IFT varies greatly with oil characteristics and reservoir conditions [6]. Low IFT can be obtained with a wide variety of surfactants, but the best surfactant depends on the crude-oil and reservoir conditions and must also satisfy several other stringent requirements [7]. When water is injected into the reservoirs during the secondary production period, the capillary forces gradually become larger as compared to the viscous forces. Generally, 50–70% residual oil is still trapped in the reservoir by the capillary forces [8].

Four primary mechanisms are used to enhance oil recovery with the help of surface-active additives: (1) the generation of very low IFT ($<10^{-3}$ mN/m) between the oil and the water flooding solution, (2) the spontaneous emulsification or microemulsification of the trapped oil, (3) the reduction of the interfacial rheological properties at the oil–aqueous solution interface, and (4) controlling the wettability of rock pores to optimize the oil displacement [9].

Abbreviations: ASP, alkaline-surfactant polymer; CMC, critical micelle concentration; EOR, enhanced oil recovery; GDFT, gravity drainage flooding test; IFT, interfacial tension; PV, pore volumes; SEAR, surfactant-enhanced aquifer remediation.

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This study was primarily conducted to design an alkaline-surfactant-polymer (ASP) process for application in a reservoir at >60 °C. A screening method that utilizes the knowledge of the surfactant structure and the results of the phase behavior test was used to understand the complexities of ASP. The information obtained from the phase behavior test was then used to design and optimize a laboratory-scale flood. Laboratory tests were described by Levitt et al. which starts with the screening and optimization of surfactant formulations by phase behavior experiments incorporating co-surfactants, alkali and then advances to core flood testing with the most promising formulations [10,11]. These techniques were built on the enormous amount of information accumulated from research conducted over the past 40 years, because of the well-established relationship between the micro-emulsion phase behavior and IFT. It is common in the industry to screen surfactants and their formulations for low IFT through laboratory-based oil/water phase behavior tests [10,12]. Particularly the research on surfactant-enhanced aquifer remediation (SEAR) by Jayanti et al. at the University of Texas at Austin [13] and the chemical EOR research by Levitt et al. [14] and Jackson et al. [15].

2. Experimental procedure

In this study, an experiment was performed to analyze the oil recovery by using dodecyl alkyl sulfate through phase behavior analysis and core flooding system. The core flooding system was set horizontally to simulate oil recovery after injecting the surfactant into the system (Fig. 1). Two 500-mL syringe pumps were used to inject the fluids (brine, oil, and surfactants); a 1000-mL syringe pump was used to maintain the overburden pressure inside the core holder. The water circulating around the core holder was heated using the heat circulator to establish the required testing conditions.

The experimental temperature and pressure data were collected from the core flooding system with the help of a computer. The effluent fluids were collected in the separator. The amount of the recovered oil was measured 30 h after the collection of the effluent fluids began.

2.1. Microemulsion phase behavior

A microemulsion phase behavior test was performed to investigate the performance of the surfactant formulation with the specific crude oil. Due to the complexity of the crude oil composition, the surfactant had to be tested with specific crude oil to find the one that could be used to generate a microemulsion system. The commonly observed Winsor type system indicates that the microemulsion can remain in equilibrium with excess oil, excess water, or both and that affect the phase change between different types of system and physicochemical properties include salinity, temperature, molecular structure and water–oil ratio [16–19].

The procedure of the microemulsion phase behavior test is simple, similar to that of aqueous solubility tests. The test consists of combining and blending crude oil, brine, the surfactant, and electrolytes, and then waiting for a phase change depending on the concentrations of the surfactant and the brine. The surfactant and the brine were blended beforehand so that the surfactant was completely dissolved in the brine. The volume of the aqueous solution was recorded and the crude oil was blended into the solution. Small amounts of aqueous components were gradually poured into a glass tube, which was then kept at room temperature in order to observe the phase change of the microemulsion. Microemulsion phases are changed from Winsor type I to Winsor type II through Winsor type III by variation of salinity at a certain temperature and pressure [20,21].

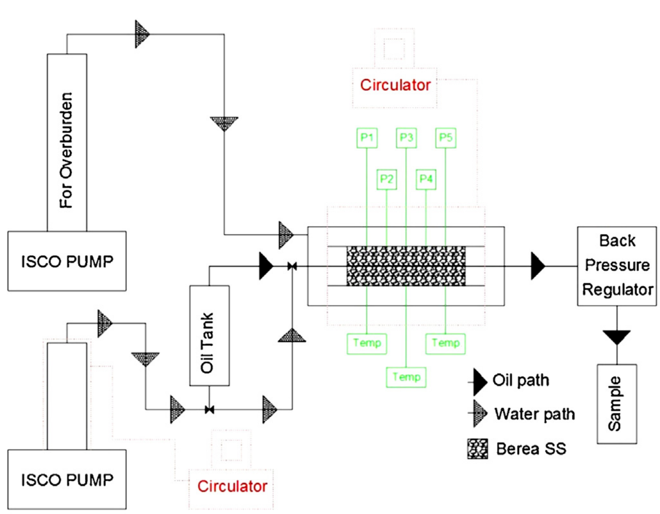

Fig. 1. Schematic design of the system for core flooding experiment.

2.2. Core flooding

The core flooding procedure included core preparation, assembly, saturation, and aging with brine or crude oil; brine flooding, oil flooding, water flooding, and surfactant flooding; collection and analysis of the effluent samples for cumulative oil recovery; and surfactant retention and adsorption [22].

2.2.1. Brine flooding

After core preparation, core flooding assembly, and aging, the core was flooded with brine. The main purpose of this brine flooding was to determine the absolute permeability. About two pore volumes (PV) of brine were injected into the core at a flow rate of 0.5–1.0 mL/min until the pressure stabilized. The pressure drop was recorded to determine the average absolute brine permeability of the core.

2.2.2. Oil flooding

After the brine flooding, oil flooding was conducted at 60 °C. The main purpose of the oil flooding was to determine the initial water saturation, effective oil permeability, and relative oil permeability. The oil flooding was conducted under a constant pressure to saturate the pores with oil and to accurately obtain the initial water saturation. Considering the different densities of oil and water approximately 1.5 PV of the oil was injected into the top end. The effluent fluids were collected in a separator, and the volume of the displaced water was acknowledged as the volume of oil retained in the core. The oil flooding was continued until the water cut reached <1% and the pressure stabilized. The pressure drop was recorded during oil flooding to determine the oil permeability.

2.2.3. Water flooding

Water flooding with filtered brine was performed after oil flooding to determine the residual oil saturation, effective water permeability, and relative water permeability. Approximately 0.8 PV of brine was injected into the core at a low constant flow rate of 0.4–0.5 mL/min to achieve natural residual oil saturation after the water flooding. The effluent fluids were collected in a separator. The water flooding was stopped when the water cut reached 99% and the pressure was stabilized. The residual oil saturation was estimated by the oil volume in the separator. The effective brine permeability was calculated from the pressure drop across the core.