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The effect of ultrasonic waves on the phase behavior of a surfactant–brine–oil system

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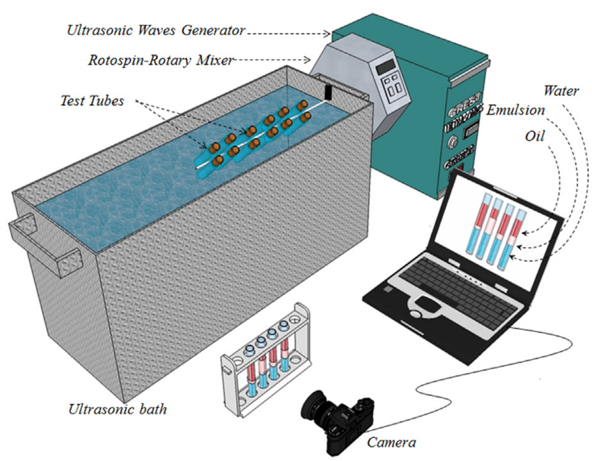
HIGHLIGHTS

- Ultrasonic effect on phase behavior of surfactant–brine–oil was investigated.
- Solubilization parameter and optimal salinity changes under ultrasound were studied.
- Rotary mixer was put inside the ultrasonic bath.
- Short-period radiation of ultrasound yields more volume of microemulsion.
- Integrated ultrasound-surfactant flooding caused surfactant consumption to decrease.

GRAPHICAL ABSTRACT



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ABSTRACT

In recent years, most of the mature oilfields in the world have needed enhanced oil recovery (EOR) techniques to maintain their production level. Nevertheless, each EOR technique suffers from a number of limitations. Surfactant flooding, which is a conventional EOR method, can cause emulsification and displacement of the trapped oil in the reservoir. Surfactants are the most expensive components in a microemulsion. Therefore, selecting a proper surfactant formulation which can mobilize oil without considerable surfactant adsorption is very important. The application of ultrasound is one of the unconventional EOR methods. This causes emulsification of oil and water in the reservoir. Integration of surfactant flooding and ultrasound has the potential to decrease surfactant consumption. Therefore, in the case of integrated ultrasound-surfactant flooding, the phase behavior of surfactant–brine–oil, herewith referred to as the SBO system, is crucial and needs to be investigated. In this study, the effect of ultrasonic stimulation duration on the phase behavior of an SBO system was investigated, and changes in solubilization parameters and optimal salinities are discussed. By comparing the results of the phase

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behavior of SBO under short and long durations of ultrasonic stimulation, it was concluded that a short duration of stimulation (15 min) yields more volume of microemulsion compared to cases using no ultrasound and a longer duration of ultrasound stimulation. Therefore, by using short durations of ultrasonic stimulation in the integrated ultrasound-surfactant flooding process, the interfacial tension remains low and the surfactant consumption decreases.

1. Introduction

In the oil and gas industry, the decline in oil production is a significant concern, as global demand for oil increases. Therefore, developing new enhanced oil recovery (EOR) techniques to mobilize residual oil left in the reservoir and make best of the original oil in place (OOIP) is crucial. Surfactant flooding is a promising EOR method, which can cause the oil/aqueous interfacial tension (IFT) to drop, thus allowing emulsification and displacement of the trapped oil in the reservoir. Surfactants are the principal agents that enable oil and water to mix and are often the most expensive component in a microemulsion. Due to the high cost of surfactants, application of surfactants for EOR can be categorized as follows: (a) high-volume low-concentration slugs, i.e. various pore volumes (PV) of 0.1–0.3% surfactants and (b) low-volume high-concentration slugs, i.e. a fraction of PV of 1–3% surfactants [1]. In EOR, formulating a system comprised of surfactant–brine–oil (SBO) which shows desirable phase behavior is a crucial stage in improving microemulsion systems' performance for EOR purposes [2,3]. The ideal microemulsion formulation can be achieved by analyzing the phase behavior of the system comprised of SBO. An optimum condition for the oil recovery is observed when the middle phase contains the added surfactant and equal amounts of oil and water [2]. Therefore, estimation of solubilization parameters, volume of oil solubilized in microemulsion divided by volume of surfactant in microemulsion, V_o/V_s and volume of water solubilized in microemulsion divided by volume of surfactant in microemulsion, V_w/V_s, are important design factors in the economical applications of microemulsion flooding compositions. One hundred percent of the surfactant is assumed to be in the microemulsion phase [4]. The surfactant concentration in the oil phase increases with increasing salt concentration in the aqueous phase. The point at which the solubilization parameters are equal and the volumes of oil and brine solubilized in the micromeulsion phase are approximately equal is called optimal salinity. Healy et al. [5] have demonstrated that the phase behavior of SBO systems is the main parameter in analyzing the oil recovery factor by microemulsion processes. By manipulating salinity, they observed that low interfacial tension (IFT) and high oil and water solubilization in the microemulsion phase take place in the vicinity of the salinity ranges giving three phases. There is an overall agreement about the strong dependency of microemulsion on IFT, and therefore it is common practice in industrial applications to monitor surfactants and their formulations for low IFT through conducting phase behavior tests on oil–water [6,7]. In 2011, Bera et al. [8] studied the oil and water solubility in a microemulsion phase by changing the salinity. The proper surfactant composition for EOR was forecasted by elucidating the behavior of the middle-phase microemulsions in oil–brine system. They concluded that the solubilization parameter, V_o/V_s, is strongly affected by salinity, while V_w/V_s decreases as salinity increases. In addition, the IFT between microemulsion and oil phase is highly affected by surfactant concentration and salinity.

On the other hand, the ultrasound technique is another unconventional EOR method which mobilizes the oil droplets trapped in the reservoir. In 2012, Hamidi et al. [9] performed experiments to study the effect of various wave frequencies (20, 40 and 68 kHz) on oil recovery. These frequencies are obtainable by the majority of commercial transducers. It was concluded that the oil recovery increases with increasing frequency. In addition, in 2015, Hamidi et al. [10] conducted some experiments to study the effect of ultrasound radiation duration on emulsification and demulsification of paraffin oil and surfactant solution/brine using Hele–Shaw models and they obtained desirable results using a frequency of 40 kHz. They avoided using frequencies more than 100 kHz because dissipation becomes large at these frequencies [11]. There are probable mechanisms that increase oil production under ultrasound stimulation such as increasing temperature, oil viscosity reduction, emulsification, oil detachment due to Bjerknes forces and cavitation. These have been investigated in the work of Simkin [12], Naderi [13], Mohammadian et al. [14] and Hamidi et al. [15]. Numerous macromodel studies of the emulsification of oil and water have demonstrated that the microemulsion has been generated at the interface of two immiscible fluids under the influence of ultrasonic waves [14,16–22]. However, each EOR technique has its own limitations. Some of them are expensive to use, need a wide range of surface apparatus, generate dangerous environmental conditions and have technical limitations [23]. Integration of the EOR methods might decrease these limitations and could be beneficial. Therefore, the phase behavior of an SBO system in the case of using ultrasound-surfactant flooding (integration of ultrasound and surfactant flooding) is crucial and should be investigated. The findings could answer the question of whether integration of ultrasound and surfactant flooding techniques can decrease the consumption of surfactant. Therefore, in this study, the effect of ultrasonic waves on phase behavior of an SBO system was investigated, and changes in solubilization parameters and optimal salinities were discussed. In addition, the effect of short and long duration of ultrasonic stimulation on IFT between microemulsion and oil/water was also investigated.

2. Experimental set-up and procedure

2.1. Equipment

In this research, ultrasonic waves were generated using a Genesis^{TM} XG-500-6 generator and supplied to a bath through an immersible transducer. The generator produces ultrasonic waves at a frequency of 40 kHz and with a power of 500 W. The bath (W: 21 cm × L: 50 cm × H: 30 cm) was built to provide an appropriate surrounding for ultrasound application. The bath efficiency was measured by the calorimetric method [24] as 35.4% which shows that the actual power dissipated in the bulk solution is 176.9 W. The properties of the ultrasonic bath are shown in Table 1. The Rotospin^{TM} rotary mixer (Tarsons Products Pvt. Ltd., Kolkata) was put on the holder and immersed into the water bath at a 15 cm distance from the immersible transducer (Figs. 1 and 2). A digital camera was used to take high-resolution pictures of the proportion of the phases inside the test tubes. The schematic diagram is shown in Fig. 1. The interfacial tensions between micromeulsion and oil/water were measured by a Spinning Drop Tensiometer SITE100 (KRUSS GmbH).