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Screening of microemulsion properties for application in enhanced oil recovery

Achinta Bera, T. Kumar, Keka Ojha, Ajay Mandal *

Department of Petroleum Engineering, Indian School of Mines, Dhanbad 826004, India

HIGHLIGHTS

- Phase behavior of microemulsion was studied by water solubilization method.
- IFTs of crude oil and brine, surfactant and microemulsion system were determined.
- Effect of salinity on particle size distribution of microemulsion was analyzed.
- Flooding tests were carried out with microemulsion slugs at different salinities.
- Adsorption of surfactant on the sand particles at different salinities was studied.

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ABSTRACT

Microemulsion in enhanced oil recovery is an efficient tool because of its high level of extraction efficiency of residual oil from natural oil reservoir. In the present paper the effect of salinity on anionic microemulsion phase behavior has been investigated by water solubilization method. Interfacial tensions between crude oil and brine, surfactant solution and microemulsion have been measured and it was found that the microemulsion has high ability to reduce interfacial tension. Pseudoternary phase diagram has been established at optimum salinity and composition of single-phase microemulsion has been determined from the curve. Laser light scattering was used to monitor particle size of several microemulsion formulations at different salinities. A series of flooding experiments have been performed using the prepared microemulsions. The additional recoveries were calculated by material balance. Encouraging results with additional recovery more than 25% of original oil in place above the conventional water flooding have been observed. Adsorption characteristics of the surfactant on the sand particles (adsorbent) at different salinities have also been studied.

1. Introduction

The application of microemulsion in enhanced oil recovery (EOR) has been investigated with incorporation of new mechanism when the conventional techniques start to become unprofitable. Microemulsions are isotropic, transparent or translucent, thermodynamically stable dispersions of surfactant, alcohol, oil and water (brine), and have been used in various fields, such as EOR, pharmaceutics, nanoparticle synthesis, liquid–liquid extraction, cosmetic, detergency and other chemical engineerings, due to their very low interfacial tension (IFT), nanometer-sized droplets, and good solubilization capacity [1–4]. Along with these properties, particle size, interactions, and dynamics are of fundamental importance since they control many of the general properties of microemulsions. In particular, the size distributions of microemulsions give essential information for a reasonable understanding of the mechanism governing both the stability and penetration into porous media. Microemulsion in EOR is an efficient tool because of its high level of extraction efficiency of residual oil from natural oil reservoir [5–8]. Ultra low IFT can be obtained by creating a middle phase microemulsion using brine, oil, surfactant and cosurfactant. The phase behavior of surfactant–brine–alcohol–oil systems is of immense importance for surfactant flooding in EOR due to the well-established relationship between the IFT and microemulsion phase behavior [9–13]. The phase behavior of surfactant–brine–alcohol–oil system is one of the key factors in interpreting the performance of chemically EOR by microemulsion process [14]. The tertiary oil recovery is mainly dependent on the properties of oil–water-rock interfaces. These are capillary forces, contact angle, wettability, viscous forces and IFT. These properties are related to a dimensionless quantity, called Capillary number, N_C, that is a measure of the mobilization of the occluded oil to enhance the oil recovery and well represented by as:

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* Corresponding author. Tel.: +91 326 2235485; fax: +91 326 2296632.
E-mail address: mandal_ajay@hotmail.com (A. Mandal).

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$$N_C = \frac{\mu v}{\gamma} \qquad (1)$$

where μ is the dynamic viscosity of the liquid, v is the velocity, and γ is the IFT between oil and water phases.

In any enhanced oil recovery process the overall efficiency depends on both the macroscopic sweep efficiency and microscopic displacement efficiencies. While the gravity overrun and rock heterogeneity affect the macroscopic sweep efficiency, the microscopic displacement efficiency is influenced by the interfacial interactions involving interfacial tension and dynamic contact angles. Volumetric sweep is a macroscopic efficiency which is defined as the fraction of reservoir invaded by the injected fluid. Volumetric sweep efficiency of a displacement process is influenced by four factors like (a) the properties of the injected fluids, (b) the properties of the displaced fluids, (c) the properties and geological characteristics of the reservoir rock and (d) the geometry of the injection and production well pattern.

In microemulsion systems, a variety of phases can exist in equilibrium with another phase, with each phase having different structure. Microemulsion phases are changed from Winsor type I to Winsor type II through Winsor type III by systematic variation of salinity at a particular temperature and pressure [15,16]. The commonly observed Winsor-type systems indicate that the microemulsions can remain in equilibrium with excess oil, excess water, or both. The factors that affect the phase transition between different types of systems and physicochemical properties include salinity, temperature, molecular structure and nature of the surfactant and cosurfactant, nature of the oil and the water–oil ratio (WOR) [17–20]. Under adequate conditions, the microemulsion system is miscible with both oil and water. Optimum salinity and the amounts of solubilized oil and water contained in a microemulsion play important roles in obtaining low IFTs and higher oil recoveries in chemical EOR. Since IFTs are having minimum value at optimal salinity and solubilization parameters are related to IFT, estimation of both properties is of great importance in designing economical microemulsion flooding [21,22]. The use of microemulsions is of high interest in many aspects of crude oil exploitation, but none more so that in EOR. In cases where the pressure exerted by gushing sea water on the oil phase is not able to overcome capillary forces sufficiently, microemulsions are the key to extracting more than just a minor portion of crude oil. Properly balanced microemulsions are able to do so by drastically reducing the IFT to the magnitude of 10^{-2}–10^{-3} mN m^{-1}. This decrease in IFT allows spontaneous emulsification and displacement of the oil [23,24]. In microemulsion flooding a small chemical slug (5–30% pore volume) is injected into oil reservoir during the process. This slug is displaced through the reservoir by a polymer bank, which in turn is displaced by drive water.

Adsorption of surfactants from aqueous solutions in porous media is very important in EOR of oil reservoirs because surfactant loss due to adsorption on the reservoir rocks impairs the effectiveness of the chemical solution injected to reduce the IFT of oil–water and render the process economically unfeasible [25–27]. Surfactant adsorption at solid/liquid interface has been studied for several decades. A number of studies have been conducted on the adsorption of ionic and nonionic surfactants [26,28–34]. The solid surfaces are either positively or negatively charged in the aqueous medium by ionization/dissociation of surface groups or by the adsorption of ions from solution onto a previously uncharged surface. Microemulsion flooding prefers a high concentration of surfactant solution to form micelles that can solubilize or dissolve the reservoir oil and the process takes place via incorporation of small oil droplets in micelle core, effectively causing miscibility in the system [35]. Some researchers carried out flooding experiments with microemulsions and they observed a linear relationship between the values of injected pore volume (PV) and the oil recovery, typically reaching 40–50% of residual oil recovery by injecting 5–10 PV of microemulsion [5,36,37].

The objectives of the present study are the formation and characterization of microemulsion that are stable at the reservoir conditions. The formation of stable microemulsion using minimum amount of surfactant is the biggest challenge for its use in EOR. Thus, a complete study on phase behavior and physicochemical properties of microemulsion comprising of sodium dodecyl sulfate, brine, propan-1-ol and heptane have been investigated as a function of salinity. Relative phase volumes of different components in microemulsions are very sensitive to the salinity. IFTs between crude oil, and brine, surfactant solution and microemulsion have been studied as a function of time. Effect of salinity on IFT has also been investigated. Pseudoternary phase diagrams have been drawn to identify the microemulsion region. Laser light scattering was used to monitor particle size of several microemulsion formulations at different salinities. A series of flooding experiments have been performed using the prepared microemulsion. The additional recoveries were calculated by material balance. Encouraging results with additional recovery more than 25% of original oil in place above the conventional water flooding have been observed. Another series of batch experiments were carried out to determine the adsorption isotherms of surfactants on the sand particles (adsorbent) at different salinity. The results of the adsorption study show that as salinity of the solution increases adsorption capacity of adsorbent also increases.

2. Experimental section

2.1. Materials

Anionic surfactant, Sodium dodecyl sulfate (SDS) of 98% purity was purchased from Fisher Scientific, India. Sodium Chloride (NaCl) with 98% purity procured from Qualigens Fine Chemicals, India, was used for preparation of brine. Reverse osmosis water from Millipore water system (Millipore SA, 67120 Molshein, France) was used for preparation of solutions. Propan-1-ol (98% pure) was used as cosurfactant. In formation of microemulsion, cosurfactant (medium chain alcohol) is used for improving microemulsion property. Cosurfactant increases the solubility of the solid surfactant which is less soluble in the system hence makes the microemulsion formation very feasible. Cosurfactant improves the viscosity of microemulsion which is important in flooding purpose. Cosurfactant also helps to reduce interfacial tension with combination of surfactant. Addition of cosurfactant reduces the adsorption of costly surfactant on reservoir rock. It was supplied by Otto-kemi Pvt. Ltd., India. In this study *n*-heptane (with purity >99%) was used as oil and purchased from MERCK, India. The entire chemicals were used without further purification.

2.2. Experimental procedures

2.2.1. Determination of water solubilization and phase boundary

The solubilization of water in the microemulsion region was determined by conventional titration method of microemulsion with brine or water under satisfied conditions until the opaqueness of the microemulsions was obtained. Here the opaqueness is especially defined as the turbid, densed milky appearance of that system through which nothing can be seen. For different cases different colored translucent mixture was not considered the required opaqueness of the system. However, the end point of the titration was considered the actual transition point of the clear, transparent and isotropic microemulsions to a birefringent phase where the boundary was determined as the onset of the cloudiness