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Microemulsion flow in porous medium for enhanced oil recovery

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ABSTRACT

Injection of microemulsion is a chemical technique of enhanced petroleum recovery. With the implementation of this technique, oil recovery is enhanced by increasing the viscosity of the microemulsion systems, and reducing the interfacial tension between oil and water in a porous medium. In this work, injection assays have been carried out with fluids comprising microemulsion-based commercial anionic surfactants, oil from the Quiambina Field (mature field in the Brazilian State of Bahia) and brine (2% KCl). The experiments basically consisted of the injection of fluids into cylindrical plug samples from the Botucatu formation by means of conventional (injection of water or brine) and enhanced (injection of microemulsion) recovery techniques. During water and microemulsion flooding, samples were collected as a function of time, after which the volume of oil recovered was obtained. Parameters like mobility ratio, volume of displaceable oil, volume of displaced oil and displacement efficiency have been obtained as results. It was verified that lower mobility ratios were acquired with the injection of microemulsion than with injection of water, thereby favoring oil recovery. The volume of oil displaced by the microemulsion corresponded to 75% of the total displaceable oil, which is a much higher yield than that observed in conventional recovery procedures. The results showed that, when microemulsion flooding is applied, the displacement efficiency is 21.5%, whereas with the conventional method the efficiency is 41%. It could be concluded that the use of microemulsion in enhanced oil recovery is efficient to provide higher levels of extraction due to the higher viscosity of the microemulsion and to the decrease in the interfacial tension between the fluids in the porous medium.

1. Introduction

Enhanced oil recovery (EOR) techniques are used in physical situations where conventional methods fail, or would fail if they were to be implemented. Three categories are commonly known for general EOR techniques: thermal, miscible and chemical methods. Such classification is not unique, and there are a number of processes that may be included in more than one category.

This work particularly focuses on chemical methods, with the use of microemulsions as a recovery fluid. In chemical methods, it is assumed that the processes occur with a certain extent of chemical interaction between injected fluid and reservoir fluid, by injecting solutions of polymers or surfactants, microemulsions, and alkaline systems into the reservoir.

The first attempt to displace petroleum from reservoir rocks by microemulsion injection was carried out in 1963 by the *Marathon Oil Company*, which designed a process known as *Maraflood*® (Gurgel et al., 2008). The microemulsion contained brine, hydrocarbons, cosurfactant and a high concentration of surfactant. Later, Healy and Reed (1973) studied some properties of microemulsions by constructing ternary phase diagrams. Specially, viscosity, surface tension and resistivity were assessed for three different types of microemulsion systems in EOR. As a result, the authors could completely describe the phase regions for three distinct micellar configurations and demonstrated the consistency of the data based on the concepts proposed by Winsor (1948).

In microemulsion injection, a high concentration of surfactant is required to produce self-assembled structures, such as spherical droplets similar to micelles, that are able to solubilize or dissolve the oil in a reservoir. This process occurs by incorporating a certain amount of oil in the core of the droplets, thereby promoting miscibility in the overall system (Shindy et al., 1997). Surface tensions between oil and water are then reduced with the microemulsion injection into the reservoir, improving the oil recovery efficiency, also because of the relatively high viscosity of microemulsions (Glover et al., 1979; Austad and Strand, 1996; Shindy et al., 1997; Wellington and Richardson, 1997; Santanna et al., 2009).

Li et al. (2009) proposed a new type of flooding system, involving wormlike micelles, formed by the anionic surfactant sodium oleate (NaOA), in sodium phosphate (Na_3PO_4) solutions. Laboratory simulation flooding experiments were performed to

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investigate the effects of flooding with the wormlike micelle system. The results showed that the oil recovery was as high as 32.7%.

The mobility (λ_i) of a given fluid is defined by the ratio between its effective permeability (k_i) and its viscosity μ_i. For example, the mobility of oil samples (displaced fluid) can be given by Eq. (1) (Dake, 1998).

$$\lambda_o = k_o/\mu_o \quad (1)$$

The mobility ratio (M) can then be defined as

$$M = \lambda_i/\lambda_o \quad (2)$$

where λ_i is the mobility of the displacing fluid.

It is known that the oil recovery efficiency decreases with increasing mobility ratio, because the injected fluid tends to displace the oil banks due to its higher mobility. Preferential paths are then created between injected and producing wells (Ahmed, 2006). When $M<1$, a favorable condition is established and the displacement is little different from the case when $M=1$. However, if $M>1$, the mobility ratio becomes unfavorable, and instabilities on the displacement front promote the appearance of viscosity “fingers” or channeling, considerably changing the nature of the displacement phenomenon (Salama and Kantzas, 2005).

Due to capillary effects, only part of the oil can be displaced. This fraction is called displaceable volume or mobile oil (Ahmed, 2006), and is given by the following expression:

$$V_{DL} = V_p(S_o - S_{or}) \quad (3)$$

where V_{DL} is the volume of displaceable oil, V_p is the porous volume, S_o is the oil saturation and S_{or} is the residual oil saturation.

Considering the convention water injection technique, the volume of water that invades the porous medium must be equal to the volume of displaced or produced oil. As a result, the volume of oil displaced by the conventional method (V_{DCM}) can be given by

$$V_{DCM} = V_{pinvw}(S_w - S_{wi}) \quad (4)$$

where V_{pinvw} is the volume of the porous medium that is invaded with water, S_w is the water saturation and S_{wi} is the initial water saturation.

When microemulsions are used in EOR applications, the volume of microemulsion that invades the porous medium must be equal to the volume of both oil and water that are displaced and consequently produced. In this case, the volume of water displaced by the enhanced method (V_{WDEOR}) can be given by

$$V_{WDEOR} = V_{pinvmicro}(S_w - S_{wi}) \quad (5)$$

where $V_{pinvmicro}$ is the porous volume that is invaded with microemulsion. Similarly, the volume of oil displaced by the enhanced method (V_{ODEOR}) is

$$V_{ODEOR} = V_{pinvmicro}(S_o - S_{or}) \quad (6)$$

Fig. 1 shows a typical curve of oil recovery by water injection into a reservoir, with a plot of recovered oil volume versus injected water volume. The linear section of the curve reflects the fact that the amount of injected water can displace the same volume of oil in the reservoir. The inflexion point indicates the transition from a linear to a non-linear behavior, and is commonly referred to as the *curve inflexion* or *breakthrough* (Ahmed, 2006). From this point on, the volume of produced oil is not proportional to the amount of injected water, and a fraction of the oil is retained within the reservoir. Ultimately, some water also starts to be produced together with oil.

The displacement efficiency is a measure of the reduction in oil saturation in the region that is invaded by the displacing fluid. One of the methods used in the study of fluid flow in porous medium is the complete displacement model or piston-like displacement. In this model, it is assumed that only the displacing fluid moves in the region of the reservoir that it invades. Therefore, the displacing fluid expels the fluid that was originally stored in the reservoir as it flows, like a piston, and the displacement efficiency (DE) is the ratio between the displaceable oil volume and the porous volume, as in Eq. (7) (Ahmed, 2006).

$$DE = V_p(S_o - S_{or})/V_p = S_o - S_{or} \quad (7)$$

2. Materials and methods

2.1. Chemicals

The chemicals used to prepare the microemulsion systems were a commercial anionic surfactant (soap) derived from fatty

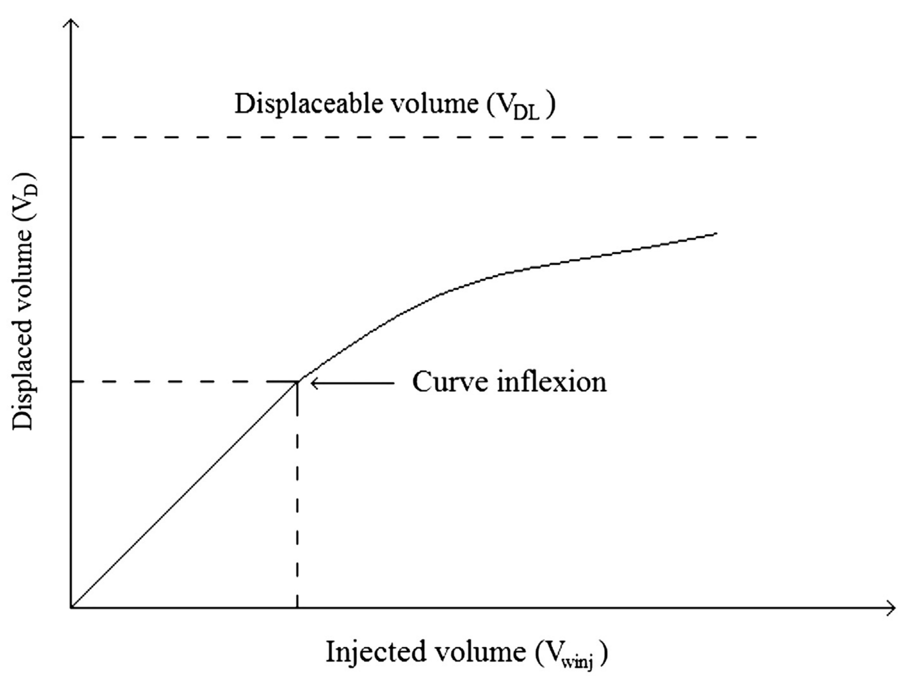

Fig. 1. Volume of displaced oil as a function of volume of water injected.