



Investigation of wettability alteration through relative permeability measurement during MEOR process: A micromodel study

Hamideh Khajepour^{a,b,*}, Maziyar Mahmoodi^b, Davoud Biria^a, Shahab Ayatollahi^c

^a Department of Biotechnology, Faculty of Advanced Sciences and Technologies, University of Isfahan, Hezarjarib Street, Isfahan, Iran

^b Enhanced Oil Recovery Research Center, School of Chemical and Petroleum Engineering, Shiraz University, Shiraz 71348-51154, Iran

^c Department of Chemical and Petroleum Engineering, Sharif University of Technology, Azadi Avenue, Tehran, Iran

ARTICLE INFO

Article history:

Received 25 December 2013

Accepted 26 May 2014

Available online 4 June 2014

Keywords:

Microbial Enhanced Oil Recovery

Enterobacter cloacae

wettability alteration

relative permeability

micromodel

interfacial tension

ABSTRACT

Microbial Enhanced Oil Recovery (MEOR) as a tertiary process employs microorganisms and their metabolites to reduce the residual oil saturation of the reservoir mainly through interfacial tension (IFT) reduction and wettability alteration. In spite of its great potential and the mentioned advantages, application of MEOR has been limited because of the lack of practical convincing experimental results. In this study, the effects of MEOR process on wettability changes and the reduction of residual oil saturation have been examined by providing microscopic visualization of two phase flow in transparent glass micromodels. Biosurfactant producing bacterial strain (*Enterobacter cloacae*) was utilized to investigate the impacts of both the biofilm and biosurfactant on wettability of the micromodel pore walls by measuring the relative permeabilities before and after microbial treatment. Results indicated that wettability of the pores was altered towards more water wetness which was also supported by visual observation of the oil/water phase saturations in the glass micromodel. Moreover, the oil recovery was increased up to 24.5% of the original oil in place (OOIP) during the MEOR process. At last, Biofilm formation was found to be more responsible for the wettability alteration process.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Continuous rising of the worldwide energy demands and depletion of the conventional oil reserves are considered as the main motivations to explore the effective methods to increase oil recovery efficiency (the percent OOIP recovered) from the depleted reservoirs (Kianiye and Donaldson, 1986). In fact, conventional oil recovery techniques recover up to 45% of the original oil in place (OOIP) of the petroleum reservoirs (Leonard, 1986; Van Hamme et al., 2003; Belyaev et al., 2004; McInerney et al., 2005; Al-Sulaimani et al., 2011). Microbial Enhanced Oil Recovery (MEOR) as a cost-efficient (Sunde et al., 1992; Desai and Banat, 1997) and environmental friendly process of tertiary oil recovery (Poremba et al., 1991; Desai and Banat, 1997; Al-Sulaimani et al., 2011) has attracted many attentions during the last decades (Lazar et al., 2007; Sen, 2008). The recovery improvements induced by the application of microorganisms have been justified by a plethora of mechanisms such as gas production (Bryant, 1987), acid production (Volk and Hendry, 2010), oil viscosity reduction, modification of the fluids mobility ratio in the reservoir, relative

permeability improvement, enhancing the sweeping efficiency of water flooding process (Raiders, 1986; Bryant and Burchfield, 1989; Li et al., 2011), interfacial tension (IFT) reduction (Deng et al., 1999; Crecente et al., 2005; Hiorth et al., 2007; Lazar et al., 2007; Gray et al., 2008; Sen, 2008), and wettability alteration (Bryant and Burchfield, 1989; Kowalewski et al., 2005; Crecente et al., 2006; Gautam and Tyagi, 2006; Sen, 2008; Heidari et al., 2011; Aparna et al., 2012; Vaz et al., 2012). Among the studied mechanisms, the IFT reduction and wettability alteration which are related to the biosurfactant production capability of the microorganisms have been considered as the most effective ones especially in oil wet carbonate reservoirs (Crecente et al., 2005; Crecente et al., 2006; Gandler et al., 2006; Biria et al., 2007; Hiorth et al., 2007; Afrapoli et al., 2009; Amani et al., 2010; Zargari et al., 2010).

Pore scale wettability is considered as one of the most important parameters responsible for the performance of enhanced oil recovery (EOR) processes because at the micro scale, the fluid flow is usually controlled by surface-based forces (Raza et al., 1968; Anderson, 1986; Buckley, 2001; Probstein, 2005). Numerous studies on the effect of wettability in multiphase flow through porous media have been published which demonstrate the strong effect of wettability on waterflooding efficiency (Anderson, 1987c; Jadhunandan and Morrow, 1995; McDougall and Sorbie, 1995), relative permeability (Anderson, 1987a; Graue et al., 1999; Masalmeh, 2003) and capillary

* Corresponding author. Tel.: +98 711 6474602; fax: +98 711 6474619.

E-mail address: hamideh.khajepour@gmail.com (H. Khajepour).

pressure (Anderson, 1987b; Bradford and Leij, 1995; Graue et al., 1999; Masalmeh, 2003). The performance of waterflooding is strongly affected by the reservoir rock wettability; for example in an oil-wet porous media more water must be injected to recover oil compared to water wet condition (Anderson, 1987a, 1987c; Morrow, 1990; du Petrole and Rueil Malmaison, 1991). There are many published results in the literature dealing with wettability changes because of chemically treated EOR techniques (Austad and Milter, 1997; Austad et al., 1998; Standnes and Austad, 2000a, 2000b; Chen et al., 2001; Standnes et al., 2002; Seethepalli et al., 2004; Rao et al., 2006; Seiedi et al., 2010). However, few of them have discussed the effects of bacteria on wettability alteration (Kianiyepey and Donaldson, 1986; Afrapoli et al., 2010; Zargari et al., 2010; Armstrong and Wildenschild, 2012a, 2012b; Karimi et al., 2012; Sarafzadeh et al., 2013). Wettability alteration critically depends on the initial wetting properties of the medium which showed that surface wettability was more likely to alter toward water-wetness from initially oil-wet systems (Mu et al., 2002). Conversely, the water-wet systems were found to be altered toward a more intermediate state when the system was initially at a strongly water-wet condition (Polson et al., 2002).

Wettability can be measured by quantitative methods such as contact angle, Amott, USBM index, as well as qualitative methods like imbibition, microscopic examination, and relative permeability method. Qualitative methods are more preferred to compare different wettability conditions (Anderson, 1986).

Relative permeability is defined as a direct measurement of flow ability of one fluid in a porous system in the presence of other immiscible fluids (Craig, 1993). This crucial parameter for evaluating oil recovery performance is influenced by pore geometry, fluid distribution in porous medium, and pore wall wettability. In a strongly wetted system, the wetting fluid is in the small pores and as continuous thin film over the entire surfaces (Anderson, 1986). The flow of non-wetting phase is mainly through the large pores; however, is also affected by the wetting phase saturation and the extent of surface wettability (Anderson, 1986). It is known that at constant saturation as the system becomes more oil-wet, the relative permeability of water increases and the oil phase relative permeability decreases (Anderson, 1987a). The effect of system wettability on displacement of immiscible fluids has been investigated in previous studies (Mungan, 1966; Owens and Archer, 1971). Craig (1993) has presented general rules to verify the wettability status of porous media through relative permeability measurement. These rules are given in Table 1.

The relative permeability measurement in the core is restricted because of difficulties associated with the monitoring of different phases saturation distributions. Therefore, more visualization is needed to increase the spatial and temporal resolution of immiscible fluid phases inside the porous media. The use of glass micromodels as representations of porous media has provided promising approach to the determination of pore-scale fluid distribution to identify the enhanced oil recovery mechanisms.

Few MEOR investigations have been carried out in micromodels, most of which have used microscopic images as an indication of

bacterial influence on fluid distribution and oil recovery (Soudmand-asli et al., 2007; Shabani Afrapoli et al., 2008; Afrapoli et al., 2009; Amani et al., 2010; Armstrong and Wildenschild, 2012a). No experimental results have been reported in the literatures to confirm wettability alteration in micromodel during MEOR process using relative permeability measurements. The objective of this study is to apply a new injection protocol in glass micromodels in order to investigate the effect of bacteria and bacterial by-products on oil recovery, IFT changes and wettability alteration through both visualization and changes in relative permeability curves.

2. Materials and methods

A brief overview of the materials used in the experiments and a description of the experimental set-up is given here. The techniques used for determining the recovery efficiency, investigating wettability alteration and measuring relative permeability are also described in detail.

2.1. Crude oil and brine

Crude oil used in this study was supplied from Masjed Soleyman oil field which is located in the south of Iran. This crude oil has a density of 845.1 kg/m³ and viscosity of 5.6 cp at the experiment temperature, 25 °C. Brine was synthesized according to Masjed Soleyman Asmary formation brine with the composition of (g/l) Na₂SO₄: 1.26, NaHCO₃: 0.051, NaCl: 0.75, CaCl₂: 9.2, MgCl₂: 7.6, KCl: 0.61. This field was previously screened for MEOR process because of its unique fluid and reservoir properties (Rabiei et al., 2013).

2.2. Bacterial medium

Enterobacter cloacae strain used in this work is a facultative anaerobic Gram-negative bacterium, which was isolated from a heavy oil contaminated soil in the south of Iran (Zargari, 2009). This strain was already reported to be a good candidate for MEOR processes because it tolerates the reservoir extreme conditions up to 70 °C, 15% NaCl salinity and 6000 psia, producing high amount of biosurfactant (Darvishi et al., 2011). The microorganism was first cultured on Brain Heart Infusion (BHI) growth medium for 24 h at 37 °C and 150 rpm to enrich the bacterial medium. Then mineral salt solution was inoculated with 1% (v/v) of the cultivated BHI medium and incubated in 37 °C and 150 rpm for 24 h to produce biosurfactant. The obtained solution (which is in early stationary phase) was used directly as the bacterial solution or it was centrifuged (4000 rpm, 20 min) for cell removal to be utilized as crude biosurfactant solution during the flooding tests.

2.3. Micromodel fabrication and properties

The fabrication process included three main steps: patterning; etching and fusing. The etch quality (Stjernström and Roeraade, 1998) and bonding procedure is sensitive to glass plate quality (Petersen et al., 2004). Therefore, float glass plate with high optical clarity was utilized in fabrication process which was coated with a 0.02 mm thick acid-resist adhesive layer. The flow pattern was designed using CorelDRAW Graphics Suite X6 and exposed to a Speedy 100 Laser engraving machine, selectively removing the acid-resist layer. The glass plate was then etched in a solution composed of NH₄F (98%, Merck, Germany), HCl (38%, Merck, Germany), HF (39%, Merck, Germany) and distilled water for 40 min to reach the desired pore depth. Ports for the inlet and outlet of the porous model were drilled through the etched glass plate. This patterned plate was sandwiched with another flat glass

Table 1
Craig's rules for wettability determination.

Criterion	Water-wet	Oil-wet
Interstitial water saturation, S_{wi}	> 20–25% PV	< 10–15% PV.
Water saturation at cross-over point which oil and water relative permeabilities are equal	> 50%	< 50%
End-point relative permeability to water at S_{or}	< 30%	> 50% and approaching 100%

Download English Version:

<https://daneshyari.com/en/article/1755027>

Download Persian Version:

<https://daneshyari.com/article/1755027>

[Daneshyari.com](https://daneshyari.com)