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Micro Scale Investigation of Enhanced Oil Recovery Using Nano/Bio Materials

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Abstract

Recently application of nano/bio materials for enhanced oil recovery (EOR) has been examined by few researchers, but there exists ambiguous concepts about simultaneous injection of nanoparticles/biomaterials. Therefore, in this study the heavy oil displacement mechanisms using simultaneous injection of nanosilica/biosurfactant have been investigated in a glass micromodel. In order to better illustrate the influence of nano/bio material different flooding scenarios containing distilled water, nanosilica/distilled water, biosurfactant/distilled water and nanosilica/biosurfactant/distilled water have been conducted. Experimental results indicate that simultaneous presence of nanoparticles and bioproducts have synergy on each other and because of IFT reduction, improving the mobility ratio and increasing the injected fluid viscosity; the oil recovery can be achieved about 58%. Furthermore, nanoparticles can play as an inhibitor to avoid asphaltene precipitation.

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Keywords: Enhanced oil recovery; Micromodel; Nanoparticle; Biosurfactant; Nano/Bio Material.

1. Introduction

Recently, interest is devoted to new techniques for enhanced oil recovery (EOR) to overcome limitations and problems of current methods. Microbial enhanced oil recovery (MEOR) is one of the new technologies that can increase the oil recovery by applying microorganisms and their metabolites such as biosurfactants, bioacids, biopolymers, biosolvents and biogases, Amalia et al. (2015). Shabani Afrapoli et al. (2011) mentioned that the main

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mechanisms understood for MEOR methods are decreasing the interfacial tension (IFT), selective plugging, wettability alteration and sweep efficiency improvement. It is worthy to note that between different bioproducts, biosurfactants via the IFT reduction have a considerable effect on the oil recovery factor, Shabani (2015). Beside biomaterials recent studies illustrate that nanoparticles can also improve the oil recovery by different mechanisms such as IFT reduction, decreasing the oil viscosity, wettability alteration, improving the mobility ratio and avoiding asphaltene precipitation. Mohebbifar et al. (2014) conducted a series of flooding tests in a shaly system and simultaneously injected biomaterials including bioemulsifier, biopolymer and biosurfactant in the presence of SiO_2 nanoparticles at 3000 ppm concentration. They observed that shales decrease the oil recovery factor and nano/bio materials via different mechanisms can improve the oil recovery. As literature indicates there is a serious lack of information about mechanisms involved in simultaneous injection of nano/bio materials and there exists ambiguous and unknown concepts about this matter. Therefore, in this study the influence of nanosilica/biosurfactant flooding on displacement of the heavy oil has been investigated in a glass micromodel.

2. Materials and Methods

2.1. Materials

The heavy oil with 19 °API supplied from one of Iranian reservoirs, nanosilica (3 wt%)/distilled water as the nanofluid and *Acintobacter calcoaceticus* (PTCC: 1318), isolated from the contaminated soil in Masjed Soleyman, for biosurfactant production were used in this study. It is worthy to mention that for minimizing the side effects of water impurities distilled water was utilized for preparation of the injected fluids. For biosurfactant production *Acintobacter calcoaceticus* was cultured in a liquid growth medium with compositions listed in table 1.

Table 1. Composition of the growth medium (g/lit).

Peptone	Meat Extract	Agar	ManganeseII Sulfate Monohydrate)
5	3	15	10

Properties of nanosilica with more than 98% purity supplied from US Research Nanomaterial Inc. is presented in table 2. In order to avoid grains aggregation the consumed nanoparticles are spherical and also the particles diameter is small enough. In addition, for making the nanofluid and nano/bio fluid, silica nanoparticles sequently were mixed with distilled water and biosurfactant/distilled water and the suspensions were stirred using a magnetic stirrer for 15 minutes at 400 rpm. Then for production of stable solutions they were placed in a programmable ultrasonic bath for 40 minutes.

Table 2. The nanoparticle properties.

Type	Average size (nm)	Density (g/cm^3)	Specific Area (m^2/gr)
Silica	11-14	2.4	600-785

2.2. Experimental Procedure

In order to investigate the effects of nano/bio materials in the oil recovery four different tests including water, nanofluid, biosurfactant and nanosilica/biosurfactant flooding were performed using the micromodel setup (Fig . 1). The main equipment used in the experimental setup are the injection and vacuum pumps, glass micromodel, optical source and a professional camera that takes the process pictures in 1 minute time interval. Then captured images are analyzed with Adobe Photoshop CS6 software and the oil recovery can be calculated.

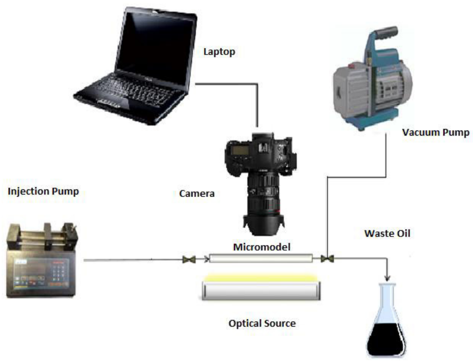

Fig. 1. Schematic of the experimental setup.

A glass micromodel (Fig. 2) was prepared for direct monitoring of the fluid flow through the porous medium. This model is a two dimensional flow channel network etched in a glass to simulate the fluid behaviors in oil reservoirs. The plate has an inlet and outlet port drilled at either end. A second glass plate was then placed over the first side and fused together in a programmable Oven. Fusing is the last stage in preparing the micromodel. Thickness, dimension and porosity of the used model are 60 micrometer, 3.2×11 centimeter and 51%, respectively.

It is worthy to mention that for elimination of the gravity effect the glass micromodel was placed horizontally in all flooding tests. In addition, experiments were done at ambient pressure and temperature and before start of each experiment the micromodel was washed with toluene to be completely cleaned. Then the porous medium was fully saturated by the heavy oil and after that the fluid was being injected at flow rate 5 ml/hr.

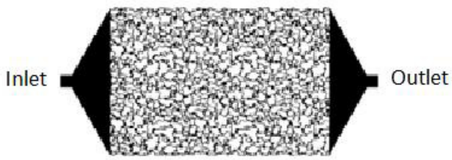

Fig. 2. Schematic of the glass micromodel.

3. Results and Discussion

In order to study the effect of simultaneous injection of biosurfactant and nanoparticles on the oil recovery factor, flooding tests were conducted and results were compared to the common EOR method, water flooding (Fig .3). It is clear from the figure that the amount of ultimate oil recovery in the nano/bio material flooding is the maximum (58%), and in order to better investigate the influence of nano/bio fluid; captured photos during the experiments have been analyzed carefully.

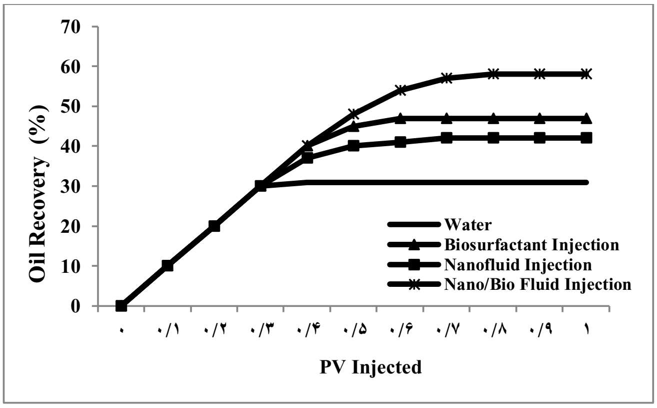

Fig. 3. The heavy oil recovery versus pore volume of injected fluids.

The fluid flow displacement in water flooding is shown in Fig. 4 and as this figure indicates, the mobility ratio is not favorable and because of the fingering phenomenon water tends to pass through the shortest and the most permeable path. Water does not flow in areas with higher flow resistance, so poor or zero recovery is achieved in these areas. This causes to the low oil recovery in water flooding. Another reason of the little ultimate oil recovery (31%) is the high IFT between oil and water that leads to low capillary number.

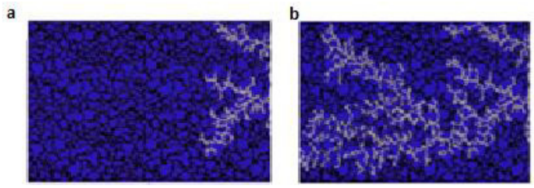

Fig. 4. Oil displacement during water flooding after (a) 20 minutes; (b) 75 minutes.

The fluid flow pattern during the biosurfactant injection (100 mg/lit) is demonstrated in Fig. 5. It is clear that amount of finger compare to water flooding has been reduced and width of the area covered by the injected fluid is increased. In other words, in this case the injected fluid contacts with more bypassed oil, mobilize more residual oil and consequently more oil is produced and this is mainly due to a considerable reduction in IFT (about 87%) by the produced biosurfactant at the critical micelle concentration (100 mg/lit).

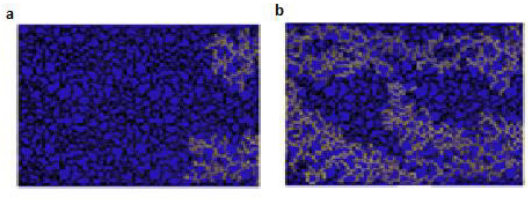

Fig. 5. Oil displacement during biosurfactant flooding after (a) 20 minutes; (b) 75 minutes.

The fluid distribution in the nanofluid injection is illustrated in Fig. 6. Nanoparticles similar to biosurfactant performance decrease fingers and the width of area covered by the injected fluid compare to water flooding is increased. This leads to enhance the sweep efficiency and the ultimate oil recovery is computed about 42%. Increasing the injected fluid viscosity and IFT reduction are the main mechanisms in the presence of nanoparticles.

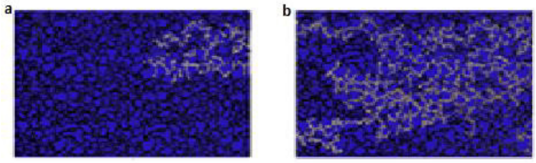

Fig. 6. Oil displacement during nanofluid flooding after (a) 20 minutes; (b) 75 minutes.

The effect of simultaneous injection of nanosilica/biosurfactant is demonstrated in Fig. 7. It is clear from the figure that the area covered by the injected fluid is more than previous tests. It means that the sweep efficiency is in the maximum and the ultimate oil recovery is 58%. In injection of the nano/bio material, benefits of both methods (IFT reduction, improving the mobility ratio and increasing the injected fluid viscosity) act in the same direction. Therefore, it is valuable to find the best combination of nano/bio materials for enhancing the oil recovery.

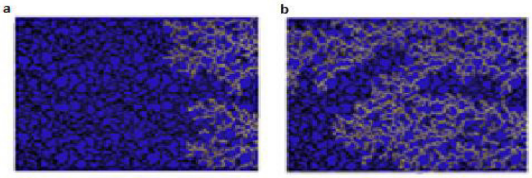

Fig. 7. Oil displacement during nano/biosurfactant flooding after (a) 20 minutes; (b) 75 minutes.

4. Conclusion

This work demonstrates the success of simultaneous injection of nanosilica/biosurfactant flooding and referring to the experimental results, it has been obtained that both nanosilical and biosurfactant decrease the IFT, increase the injected fluid viscosity and also improve the mobility ratio. As these materials have interactions on each other, the amount of ultimate oil recovery in the nano/bio material flooding is the maximum (58%) and it is valuable to obtain the best nano/bio material for the EOR process.

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