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FULL LENGTH ARTICLE

Investigating the role of polymer type and dead end pores' distribution on oil recovery efficiency during ASP flooding

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Abstract Although alkaline-surfactant-polymer flooding is proved to be efficient for oil recovery from petroleum reservoirs, effects of existence of dead end pores on this process need more discussions. In this work, several ASP flooding tests constituted from 4 polymers, 1 surfactant and 1 alkaline were performed on micromodels designed in four various dead end pore distributions initially saturated with crude oil. The results showed that although using ASP solution constituted from hydrolyzed polymers at high molecular weights significantly increases oil recovery factor due to increasing apparent viscosity of the solution, using sulfonated polymers in ASP solution increases oil recovery much more because of their capability to increase viscosity even in saline solutions. In addition, it was concluded that the number of dead end pores as well as their distribution with respect to the flow direction are two main characteristics that identify the efficiency of brine and ASP floods in dead end porous media. Moreover, although in ASP flooding, since the viscosity is higher and the front is flatter, the role of the number of dead ends on the recovery efficiency is more identifiable than the role of dead ends' distribution, in waterflooding, since the mobility ratio is not low enough, the role of dead end direction with respect to the flow direction plays a more significant role in recovery process. So, considering the efficient direction of injection is too important during waterflooding and chemical EOR especially in reservoirs that have a remarkable percentage of dead end pores in their geological structure.

1. Introduction

Chemical flooding, in particular alkaline-surfactant-polymer (ASP) flooding, has attracted remarkable interests because of current high oil prices and the need to increase oil production.

Surfactant flooding is a common chemical EOR which improves oil recovery significantly because of its crucial effect on decrease in IFT (interfacial tension) even in dilute solutions; however, it does not have good sweep efficiency. Although it

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could have good sweep efficiency in high concentrations which causes micelle flow, reaching to those concentrations of surfactant solution is not economical. Thus, it is better to add a relatively cheap co-surfactant as well as a viscosity improving agent in those surfactant solutions to make operations economical.

The alkaline flooding method relies on chemical reactions between chemicals such as sodium carbonate and sodium hydroxide (most common alkali agents) and organic acids in crude oil to produce in situ surfactant (soaps) that can lower interfacial tension. So, in heavy oil reservoirs which have high acid contents, using alkaline as co-surfactant is economical and can provide lower IFT seriously.

The main concept of polymer flooding is affecting the sweep efficiency. Sweep efficiency is defined as the ratio of oil volume contacted by displacing agent to initial volume of oil in place [1]. Sweep efficiency is affected by mobility ratio, pore structure, reservoir rock wettability, reservoir heterogeneity, fractures and properties of fractures [2]. Polymer solution increases oil recovery in three ways: (1) by affecting fractional flow, (2) by reduction of water–oil mobility ratio, (3) by diversion of injected water toward swept zones [3]. Although polymer flooding also in a common EOR method increases oil recovery by improving water viscosity and sweep efficiency, it does not improve oil recovery in dead end pores significantly. This method implied displacement mechanisms of visco-elastic polymer flooding such as pulling and stripping. Since much residual oil remains cohesive to tiny and dead end pores, using an IFT reduction agent is essential. The IFT reduction agent is surfactant; however, it may not be economical singularly. So, adding alkaline to the polymer and surfactant solution increases recovery by applying all displacement mechanisms of polymer flooding, surfactant flooding and alkaline flooding.

Surfactant whether synthetic or in situ surfactant generated by alkaline reaction with crude oil's acids, reduces IFT between water and oil [4]. Reduction in interfacial tension can result in capillary number which reduces residual oil to a low value in swept regions [5]. In addition to the use of alkaline and surfactant, polymers should be used to provide mobility control to the displacement process [6]. So, ASP flooding can increase oil recovery considerably.

Many surfactant-polymer flooding works were performed in 1970s [7,8]. Co-surfactant enhanced alkali flooding [9] was introduced which allowed increasing the optimal salinity of the alkali slug high enough for its satisfactory propagation. The phase behavior of oil-brine-surfactant systems would often be accompanied by viscous emulsion, gels or liquid crystals [10,8]. Most of the surfactant flooding in 1970s and 1980s were limited to sandstones with low salinity. Recent research has led to the development of surfactant systems suitable for high salinity and carbonate environments [11–14]. Sedaghat et al. [14] did many ASP experiment in fractured media but they did not survey it in dead end media. In addition, several ASP field tests have confirmed that residual oil can be displaced by the use of alkaline-surfactant-polymer [15,16]. The most famous tests have been done on Daqing oil field in which oil recovery has been increased 20% more than waterflooding [17]. Despite, numerous studies reported in this field, a little attention has been paid on the efficiency of ASP flooding in systems with dead end pores, especially when the models have different numbers and distributions of dead ends.

In this work, several ASP solutions constitute from 4 polymers, 1 surfactant and 1 alkaline type were used in flooding tests. And the effects of chemical type as well as effects of dead end distribution on oil recovery efficiency were investigated. To apply the defined distributions of dead end pores to the porous media, micromodel system was selected and used.

2. Experimental facilities

The micromodel set-up is composed of a micromodel holder placed on a platform. It includes: a camera with a video recording system, a pressure transducer and a precise low rate pump. Fig. 1 illustrates a schematic of the experimental setup.

2.1. Pumps

A "Quizx" pump with a high accuracy and low flow rate was used. This pump can inject the fluid with an accuracy of 10^{-5} to 10 ml per minute. In addition, a vacuum pump also was used to wash and clean the micromodel by distilled water and toluene.

2.2. Optical system

In these experiments a high quality camera which had the zooming ability up to 200 times was used. This camera is attached to computer by a line. During the experiments, pictures are taken in specified periods of time.

2.3. Image analysis

To analyze the results of experiments in micromodel, the saturation of fluids should be measured. In order to calculate the oil saturation in porous media, the fluids should have distinct colors. In this project we used Photoshop software to analyze the pictures and calculate the saturation of fluids by calculating oil pixels of image. To consider brownish parts of porous media which represent alkaline diffusion, a range of brownish colors were considered for saturations 0.25, 0.5 and 0.75. Average saturation of porous area is used to calculate oil recovery.

2.4. Micromodel preparation

First, the patterns which are synthetic porous media with defined characteristics were designed by Corel software and then were engraved by laser tool on glass. Schematics of micromodel patterns are shown in Fig. 2. Then the patterns of micromodel for acquiring proper depth were fused throughout the model.

Four models with different dead end distribution patterns were engraved on glass and then another glass was placed over it and covered the engraved pattern and created porous media. That glass which covers the surface of porous media has input and output holes which were drilled on it and injection and production of fluids flow through these holes. This set was placed in a special furnace that its heat flux was controlled automatically. Then furnace started from ambience temperature to 724 °C slowly and after that the furnace was cooled down to the ambience temperature. This heat process is called fusing which causes two glass plates of micromodel adhere to each other.