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The dominant mechanism of enhanced heavy oil recovery by chemical flooding in a two-dimensional physical model

Xiaodong Zhou, Mingzhe Dong *, Brij Maini

Department of Chemical and Petroleum Engineering, University of Calgary, Calgary, AB, Canada T2N 1N4

HIGHLIGHTS

- ▶ Fourteen 2-D model tests are reported for enhanced heavy oil recovery.
- ▶ Contributions of chemicals to enhanced oil recovery have been identified.
- ▶ Correlation between tertiary oil recovery and pressure-drop build-up is found.

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ABSTRACT

The dominant mechanism of enhanced heavy oil recovery by chemical flooding is studied by conducting various chemical slug injections in a two-dimensional physical model. In this study, a total of seven single-chemical-slug tests and another seven two-chemical-slug tests are conducted to test the contribution of alkaline, surfactant, polymer, and their combinations to enhanced heavy oil recovery. The relationship between the tertiary oil recovery and the pressure drop of the seven single-slug floods is analyzed, and it is discovered that the two have a good correlation. Comparison of the tertiary oil recoveries of different chemical slug tests shows that the improved waterflood for the heavy oil used in this study is mainly due to the reduction of water mobility. The results of two-chemical-slug tests show that after regular alkaline/surfactant/polymer flooding, the second polymer slug injection can recover more oil, if a water slug injection is applied between the two chemical slugs.

1. Introduction

For heavy oil reservoirs, primary and secondary recovery methods, at their economic limit, leave 80% to 95% of the original oil-in-place (OOIP) behind [1]. The most important mechanism of the two most widely used enhanced oil recovery (EOR) methods, thermal and solvent techniques, is viscosity reduction. Many of western Canada's heavy-oil reservoirs are too thin to allow thermal recovery techniques [2]. As such, solvent-based processes for heavy-oil recovery, including Vapex [3], cyclic solvent injection [4] and emulsified-solvent [5], are attractive to the industry.

Many studies proved that chemical flooding is an alternative choice under the aforementioned circumstances. Alkaline flood tests conducted in heterogeneous sandpacks by Dong et al. [6] showed that the formation of water-in-oil dispersion could improve the displacement efficiency in the tertiary heavy oil recovery process. Polymer flooding is also a well-recognized technique for mobility control for conventional oils, which could be a potential method for enhanced heavy-oil recovery by improving the sweep efficiency. Laboratory studies and field tests of polymer flooding for heavy oils have been reported [7,8]. The application of horizontal wells for polymer flooding provided higher injectivity and lower shear rates at the injection sand face [9], which stimulated the application of polymer flooding. Wassmuth et al. [10] conducted laboratory studies of polymer flooding for several oils with viscosities ranging from 300 to 1600 mPa s. They also reported a field pilot design and implementation at East Bodo, Lloydminster, Canada [8]. Studies showed that oil recovery by polymer flooding could nearly double the waterflood recovery under suitable conditions.

Dong et al. [11] reported micromodel observations of two recovery processes of heavy-oil by chemical solutions: in situ dispersion of oil-in-water (O/W) and water-in-oil (W/O). It was shown that in the heavy-oil EOR process, in situ W/O dispersion can effectively increase water flow resistance in water channels to improve sweep efficiency, and in situ oil-in-water (O/W) emulsions use water to entrain and displace heavy oil out of oil sands. Many sandpack flood tests have shown that the in situ formed W/O emulsion can effectively block water channels, which leads to highly enhanced oil recovery [12].

* Corresponding author. Tel.: +1 403 210 7642; fax: +1 403 284 4852.
E-mail address: mingzhe.dong@ucalgary.ca (M. Dong).

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During past several years, a significant number of one-dimensional (1D) sandpack flood tests [1,2,6,12–15] for alkaline (A), polymer (P), surfactant (S), and their combinations, have been performed, with notable results. In this paper, a specially designed 2-D physical model is used to test the contribution of alkaline, polymer and surfactant to the improvement of heavy oil recovery, under two dimensional flooding conditions. By doing so, the dominant mechanism of enhanced heavy oil recovery is identified.

2. Experimental

2.1. 2-D Physical model

Fig. 1 shows the experimental set-up. It consists of the 2-D model, a digital pressure gauge, a pump (ISCO 500D Syringe Pump), a effluent collector and a computer for data acquisition. Fig. 2 shows the top view of the 2-D model. The stainless steel chamber of the model is 9 in. long, 6 in. wide and 1 in. high. The model has a two-inch-thick plexiglass cover. As shown in Fig. 2, two horizontal wells were installed near the two short sides of the model, one of which is used as the injector, and the other as the producer.

The plexiglass cover can withstand up to 500 psi stress. This thickness will prevent any deformation of the plates during the flooding process. The wells are 3/8 in. (0.375 cm) in diameter, which were perforated on their circumference (44 holes in four different directions, each 1/10″ in diameter) and covered with metal screens that guard against any flow of sands.

2.2. Sandpacking procedure

The sand used in this study is Granusil sand (Industrial Minerals Inc., Calgary, Canada). The size of 76.3% of the sand is between 50 and 100 mesh.

For each test, fresh sand was packed to ensure the same wettability for all the tests. The sandpacks were packed as follows: the model, filled with brine water (with a NaCl concentration of 2.5 wt%), was positioned horizontally and the sand was added to fill the container. After the sand was poured in, it was stirred to make sure there was an even packing. Then, when it was almost full, the model was covered with the plexiglass plate and fixed with bolts. Next, it was vertically installed on the vibrator. While on the vibrator, sand was added into the model to fill any space created by the vibration. This process was continued for one hour, before the vibration stopped. The porosity of each sandpack was approximately 38.5–39.8%, and the absolute permeability was approximately 5.8–8.9 Darcies.

Before each test, the model and the wells were thoroughly cleaned with Varsol, rinsed with hot water, and finally air-dried. In the experiments, the model was placed horizontally.

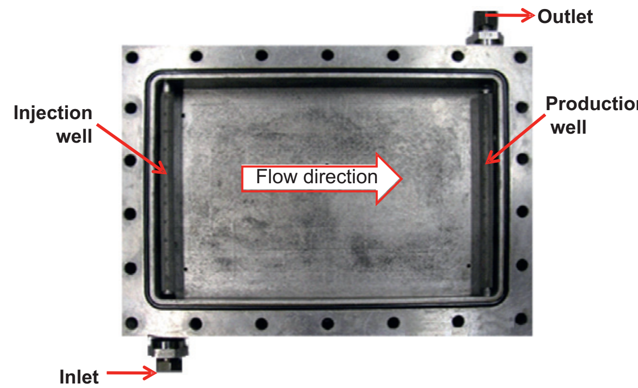

Fig. 2. Top view of the 2-D sandpack flood (The plexiglass cover was removed for clear view).

2.3. Materials

Heavy oil and water: A heavy oil with a viscosity of 1202 mPa s and an acid number of 1.07 (mg KOH/g-oil) from a heavy oil reservoir in Alberta was used in this study [12]. Based on the composition of the formation brine produced from the heavy oil reservoir, synthetic brine was prepared and used in the flood tests.

Alkaline: From the preliminary screening tests, Na_2CO_3 and NaOH were chosen as the alkaline agents [2] for the self-dispersion process for the target oil. Based on the results of tests with different concentrations and various combinations of the alkaline, the following alkaline formula was adopted in alkaline flooding: 0.15 wt% Na_2CO_3 + 0.45 wt% NaOH.

Surfactant: Based on previous study results [1] and numerous screening tests, alkyl ether sulfates CS-460 (Stepan, Canada) were used, and the concentration was set as 450 ppm.

Polymer: Also based on previously completed research [12], AN923PGO polymer (SNF Floerger, France) was used in the flooding tests. The hydrolysis degree and molecular weight of AN923-PGO are 25 mol% and 18×10^6, respectively.

The viscosities of polymer solutions were measured using the Brookfield DV-II+ Programmable Viscometer (Brookfield Engineering Laboratories Inc., USA) in conjunction with a water bath. Polymer solution was prepared by slowly adding polymer into brine which was being stirred. After that, the solution was stirred for approximately 24 h until it became completely transparency. When the solution is transparency, no filtration is needed. According to literature [15], shear rates in most of oil formations are between 0.01 and 10 s^{-1}. In this study, polymer solution viscosity was measured under a shear rate of 0.31 s^{-1} (6 rpm) at 22 °C.

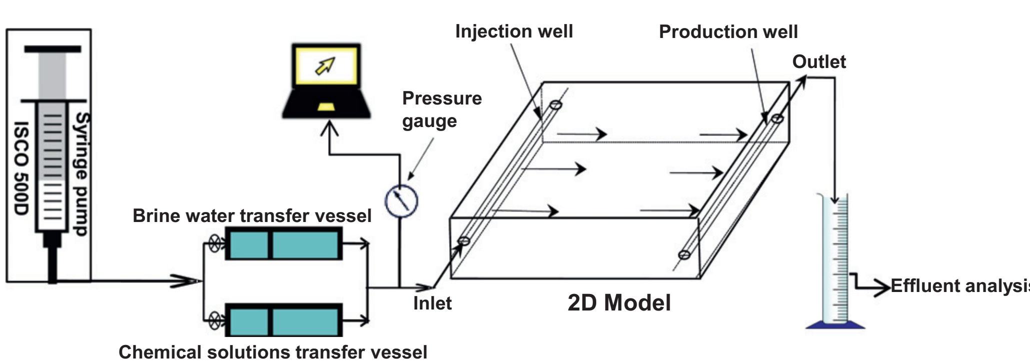

Fig. 1. 2-D sandpack flood test set-up.