REPEATABILITY OF SPONTANEOUS IMBIBITION PROCESSES IN HELE-SHAW CELLS

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ABSTRACT

Spontaneous cocurrent imbibition experiments were accomplished in glass Hele-Shaw cells. Water was used as displacing fluid and oil (Soltrol 170) as displaced fluid. The wettability restoration of the internal surfaces of the cell was observed; internal surface waviness and its influence in the spontaneous displacement was evaluated. The reproducibility of the spontaneous displacement patterns of oil by water was obtained; the behavior of the displacement speed of fluids and the inlet and outlet effects were accounted for and the evolution of the water-oil interface and its relation to the displacement of fluids were found.

INTRODUCTION

Spontaneous imbibition is defined as the spontaneous displacement process through which two immiscible fluids compete for places in a capillary or porous media, driven by a wettability difference. In the oil industry spontaneous imbibition plays a very important role, particularly for naturally fractured reservoirs in water-wet rocks. These reservoirs can be visualized as a network of large matrix rock blocks surrounded by fractures. In a waterflooding process, water invades fractures at first and then spontaneously penetrates into the matrix rock, expelling oil towards the fractures. The spontaneous imbibition is a natural waterflooding process which can be used to take advantage for the secondary oil recovery technologies. The exchange of water and oil from and towards fractures is known as the matrix-fracture interaction. Some modeling expressions for the matrix-fracture interaction have been found from Aronofsky[1] and Kazemi *et al*[2].

The experimental research on spontaneous imbibition has been devoted to study the process in reservoir rock samples. Most of them consider the rock as a "black box" and experiments have been conducted to obtain information about displacement rates and sweep efficiencies[1-9]. More information has been procured by gamma-ray absorption[10], X-ray scanning[11], microwave scanning[12] and, more recently, X-Ray tomography methods[13]. However, there are still several aspects where research is needed in order to improve secondary oil recovery technologies. In particular, a better understanding of the spontaneous waterflooding mechanisms, which determine that a non-wetting fluid may be displaced or trapped inside the capillary or porous media, is needed.

Visualization of the spontaneous imbibition process is an important way to study the behavior and mechanisms of the phases inside the capillary or porous media. However, real porous media present many difficulties for *in situ* observation of fluid motion. Taking porous media as the initial system may be an inconvenient starting point for a basic research study on the governing mechanisms of these processes. Notwithstanding this fact it is possible that simple models of capillary media may provide relevant basic information that contributes to the understanding of these processes in real porous media[14]. Furthermore, information is still needed on spontaneous imbibition in 2D capillary media[15-16]. An approach to remedy this drawback may be by designing *ad hoc* experimental models for the study of spontaneous displacement characteristics and mechanisms. For this reason, in this work a 2D experimental model was built, in order to visualize the spontaneous displacement of oil by water. These simple physical models are known as Hele-Shaw cells and are constructed using two flat parallel transparent sheets with a thin gap between them.

In preliminary experiments, several important aspects of the spontaneous displacement of oil by water in rugged Hele-Shaw cells went apparent. The fingering size was found to be of the order of the cell size[15] (10 cm X 10 cm). Inlet and outlet effects also influenced the displacement rate of the fluids[16].

EXPERIMENTAL DEVICE

Hele-Shaw cells were built from 0.9 mm width, 20X20 cm length and wide glass sheets. Three different gaps: 0.005, 0.015 and 0.075 cm were set for the cells. Cocurrent flow was established for the cell operation, two parallel cell sides were closed with epoxi glue and the other two were outfit as inlet and outlet.

EXPERIMENTS

In order to study the experimental reproducibility, the same pair of glass sheets were used for each experiment and its repetition, once an experiment was finished the glasses were unassembled and cleaned following a previously established technique[17].

At the beginning the cell was saturated with colored oil, the cell inlet was then waterflooded without imposing a pressure drop. The water spontaneously invaded the cell capillary space by the inlet and simultaneously the oil was expulsed cocurrently by the outlet. Experiments were accomplished at atmospheric pressure and room temperature.

Cell lighting was provided from below and a video camera was set above the cell. A set of representative images were selected and processed, measuring the oil area and the water-oil interface length as functions of elapsed time.

Each couple of glass sheets was used for seven experimental runs. Three of them for 0.015 cm gap, two for 0.075 cm gap and two for 0.005 cm gap. Once an experimental run was finished, the glass sheets were unassembled and cleaned for a further use in another experimental run. Three couples of glass sheets were used in the way described above for repetitions of the whole set of experimental runs in order to observe the influence of the local wettability heterogeneity, giving a set of 21 experimental runs.

RESULTS

The structures and regions appeared in the spontaneous displacement were identified in order to quantify the oil areas and the water/oil interfacial lengths by image digital processing. The experimental outcomes can be resumed in four fundamental aspects.

Repeatability

This aspect was analysed following a qualitative approach as well as a quantitative one. The fluid displacement pattern, defined by the observed local structures was qualitatively determined. A further quantitative analysis was performed by comparison of the displacement speed of the fluids.

Waviness analysis

The waviness of the cell internal surfaces was evaluated with a Fizeau interferometer. Using this information and the displacement evolution, the conclusion that there was not an apparent relation between the surface waviness and the time evolution of waterflooding inside the cell could be established.

Interfacial dynamics analysis

The fluid spontaneous displacement was governed by the growing up of the interfacial water-oil length. Moreover, the *Total oily area/Total water-oil interfacial length* ratio vs *elapsed time* behavior shaw a linear decreasing plot section in a semi-logarithmic scale, with a characteristic slope value which depended on the gap. The wider the gap the smaller the slope value.

Flow dynamics analysis

Three consecutive displacement speed stages were observed: the first one at the beginning was named *initial stage*, followed by the second one named *development stage*, further followed by the third one named *final stage*. Entrance and exit effects happened at the first and the last stages, respectively. The final stage was not considered in this analysis since the complex flow dynamics observed requires more study. The initial and development stages shaw characteristic speeds and interfacial shapes which depended upon the gap. For 0.005 and 0.015 cm gap, the initial stage advance occurred as a uniform-like front and the development stage advance occurred as a viscous fingering front. For the 0.075 cm gap the initial stage advance was also in the way of a uniform-like front, instead the development stage advance was a uniformly decaying event up to a whole stop, without the interface reaching the cell outlet. The capillary number ($Ca = \mu V / \sigma$) was estimated from the mean speed (V) at each stage. For initial stage, Ca was around a constant from 0.015 cm gap up. However, for the development stage Ca was a decreasing function as the gap was increased. The interfacial power density was also estimated. This quantity was defined as the work done for the oil displacement by one squared centimeter of interface.

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