Journal of Industrial and Engineering Chemistry 38 (2016) 200–210

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

Numerical studies on the effects of various complicated barrier configurations on sweep efficiency in surfactant/polymer flooding

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ARTICLE INFO

Article history:
Received 9 April 2016
Received in revised form 1 May 2016
Accepted 7 May 2016
Available online 13 May 2016

Keywords:
Surfactant flooding
Surfactant-polymer flooding
Barrier
Numerical simulation
Enhanced oil recovery
Five-spot

ABSTRACT

The effects of impermeable shale barriers on the performances of surfactant flooding and surfactant-polymer (SP) flooding are studied through numerical simulation by CMG (STARS) software. The barriers are assumed to exist in various configurations in a quarter five-spot pattern either by changing the location and size of a single barrier or by altering the number of barriers existing between two wells. The results show that small-type barriers exhibit positive effect on the enhanced oil recovery (EOR) process in surfactant flooding. In contrast, oil production is affected adversely in SP flooding when barriers are present in any types of configuration.

Introduction

Chemical flooding, which includes polymer flooding, surfactant flooding, surfactant-polymer (SP) flooding, and alkaline-surfactant-polymer (ASP) flooding, has been effectively utilized for the recovery of high volumes of trapped oil during the enhanced oil recovery stage [1–3]. Complete water flooding is not a further relevant method in the EOR stage since this method is not able to lower the residual oil saturation, as well as causes viscos fingering due to the improper control of the mobility ratio between the displacing and displaced fluids. On the other hand, appropriate design of the surfactant flooding process helps increase the capillary number and relative permeability of the fluid, thereby allowing for much higher oil production [4–6]. In order to control the mobility ratio between the displacing and displaced fluids, a properly designed polymer is added [7,8]. As a result, higher oil blobs are extracted, despite the slower flow rates [9,10]. Since the acid components in crude oil have been determined, alkaline components are injected for the *in-situ* generation of soap, which then easily removes the oil from the pores [11,12]. However, the application of the alkaline medium is limited to specific high-acid crude oil reservoirs. Therefore, generally, the use of alkaline chemicals must be considered carefully before application. Zhu et al. [13–15] has demonstrated that the combinations of chemical agents such as ASP or SP flooding perform the higher efficiency than single agent injection, particularly SP flooding might give the better results than that of ASP flooding in either technical or economic view point. Furthermore, they figured out the main factors affecting to the success of SP flooding process including connectivity between injector and producer, the designed properties of SP system, and the injected chemical volume. The experiment combined simulation works of Rai et al. [16] again confirmed the favorable uses of surfactant-polymer flooding with an achievement of additional 24% oil recovery, and the employments of surfactant or surfactant-polymer decreasing water cut substantially, which reflect the inverse relationship between water cut and chemical flooding. By using CMG (STARS) software for matching the experimental data of chemical flooding, Sinha et al. [17] concluded the good matching results between the simulator and laboratory data for SP flooding; however, the deviations of matching data are slightly higher for ASP flooding, which demonstrates the considerably complex mechanisms as well as the high level of uncertainty when simulating ASP flooding compared with SP flooding. In regard to the effect of barrier, 2D experimental work of Mohammadi et al. [18] pointed out the unstable front displacement with the presence of shale barriers and concluded that surfactant flooding is a good candidate for EOR processes in shaly oil reservoir. Numerical studies of Janssen and

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http://dx.doi.org/10.1016/j.jiec.2016.05.008

Bossie-Codreanu [19] on CO_2 injection also figured out that sweep efficiency is decreased according to the increase of shale fraction, and the shale positioning is the most important parameters for EOR or sequestration design optimization.

In this study, numerical work focuses on the performances of surfactant and SP flooding in the specific context of existing shale barriers between a producing and an injection well in quarter five-spot reservoir pattern. Various barrier configurations are assumed by altering the vertical size, longitudinal size, position, and the number of barriers. The EOR performances in various types of barrier are investigated and compared to those with no barrier case. The same injection strategies of surfactant and SP flooding are applied for all barrier cases and no barrier case in order to understand the effects of each barrier case clearly. Obviously, the work enhances the understanding of barrier effect on surfactant–polymer flooding processes that have not been fully covered by any of previous works; therefore, promisingly the results will give high impact to the industry.

All barrier cases are considered with the following assumptions:

- Permeability is nearly zero. This assumption is made in order to fully describe the obstruction level.
- Each barrier also contains fluids (oil and water).
- No reaction occurs between the fluids and barriers – this will avoid the corrosion and adsorption phenomenon at the bound.

Practically, the performance of an enhanced oil recovery project is significantly influenced by the complicated heterogeneity of the reservoir system [20,21]. Therefore, the process designs have to cover all of the potential contexts that can affect overall the performance, such as the conditions of the reservoirs, geological issues, fluid injectivity, and so on, with the assistance of a useful simulator [22].

Theoretically, the existence of a pertinent barrier will change the conventional fluid flow by altering the direction and efficiency of the swept areas. However, the nature of the effect (positive or negative) will depend on the type of obstruction levels including their size and location within the reservoir. Taking into account, the existence of barriers at the beginning of a project enables the operator to minimize the risk of EOR processes. In addition, unexpected barriers can also affect conventional performance metrics during the operation of projects.

Building model

Reservoir description

In order to consider the effects of barriers on oil production, a base reservoir model as shown in Table 1, with no barrier, is built in the STARS simulator of Computer Modeling Group (CMG) under conventional conditions. In this case, no barriers exist within the reservoir. Basic reservoir properties have been partly referred from the work of Naijaifabadi [1].

Table 1
Reservoir input parameters.

Reservoir parameters	Values
Grid	15 × 15 × 8
Porosity	0.2
Horizontal permeability	500 md
Vertical permeability	50 md
Initial oil saturation	0.5
Depth	396.34 m
Reservoir pressure	MPa
Reservoir temperature	93.3 °C
Oil viscosity (at reservoir condition)	4.5 cp
Oil gravity	31°API

A base model consisting of a 15 × 15 × 8 grid block with each block having a reasonable size of 12.2 × 12.2 × 2.59 (m^3) is defined to represent a field scale reservoir model. Two vertical wells are assumed to be present throughout all the layers and are located in a quarter five-spot pattern. One of the wells is the injector, whereas the other is the producer. The average porosity of the reservoir is 0.2, whereas the horizontal and vertical permeability are relatively high and 500 and 50 md, respectively. Reservoir formation is assumed with strongly water-wet rock condition with the relative permeability curves are expressed in Fig. 1.

After the base reservoir model is built, the shale barriers are introduced between the injector and producer. Three cases are considered by changing the width of the barrier. In addition, three multi-barriers are also considered by changing the number of barriers. Furthermore, vertical bypass-flow is also considered by changing the thicknesses and locations of each of the single barriers.

In the case of single barriers, three widths, namely small, medium, and large, are considered. In addition, three vertical sizes are also considered for the single barriers, corresponding to different ratios of the thickness of the barrier to net-pay. These three vertical sizes are denoted as "half-height," "2/3-height," and "entire-height" and correspond to the ratios of 1/2, 2/3, and 1, respectively. The thickness of each vertical size for various cases is illustrated in Table 2.

Only two locations are assumed for each barrier. In the first case, the barrier is suspended in the middle of the reservoir (vertical direction), whereas in the second case, the barrier is located at the bottom of the reservoir (denoted as "bottom"). Fig. 2 shows how the barriers change according to the vertical and horizontal sizes, as well as the locations.

In order to distinguish between the various barriers during the analysis, the following nomenclature is utilized: "width-location-thickness". For example, a "medium-bottom 2/3-height" barrier refers to a barrier of medium width located at the bottom of the reservoir with a 2/3-height thickness ratio. Similarly, a "small half-height" barrier refers to a barrier that has a small width, with a half-height thickness ratio, and is suspended in the middle of the reservoir (this type of location is not named).

Multi-barrier are assumed to lie in different locations and layers, in order to describe in more detail the complicated geological structure of reservoirs, with each barrier occupying four layers. There are three different assumed barriers existing in layers two to five and five to eight, as illustrated in Fig. 2d.

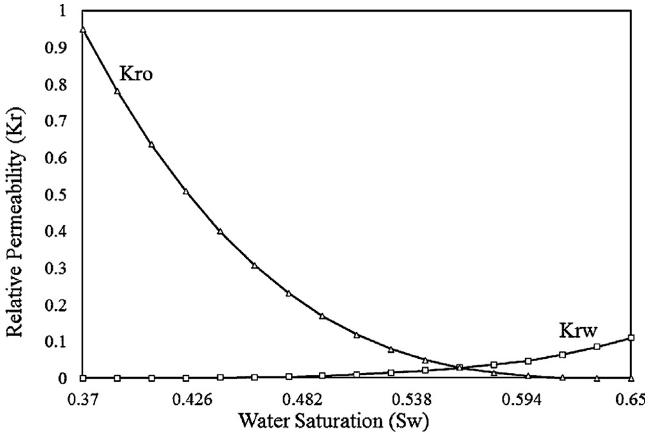

Fig. 1. Relative permeability curves at low trapping number.