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Efficiency of Horizontal and Vertical Well Patterns on the Performance of Micellar-polymer Flooding

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Abstract

There is increasing interest in micellar-polymer flooding because of the need to increase oil production from depleted and waterflooded reservoirs. Using horizontal wells for injection and production in a micellar-polymer flood process, higher sweep efficiency is expected compared with the use of conventional patterns by vertical wells. This paper presents an analysis of how the overall performance of a micellar-polymer flood process is influenced by the well pattern using horizontal injector and producer in different configurations. Results from the study have demonstrated that significant amount of oil can be recovered additionally and injectivity was remarkably improved by utilizing a combination of horizontal wells. The improvement of injectivity through a horizontal injection well was higher when it was combined with horizontal producer parallel to the injector.

Keywords: oil reservoir; micellar-polymer flood; horizontal well; injectivity

1. Introduction

The efficiency of this EOR process is dependent on a number of parameters that are specific to the field under study. Most of the micellar-polymer flooding projects use vertical wells as injectors and producers, however, horizontal wells promise greater injectivity and productivity characteristics. The higher injectivities allows surfactant-polymer slug and polymer solution to be injected at much higher rates or lower pressures in horizontal wells than in vertical wells, which leads to allowing oil to be recovered quicker or with less energy. The use of horizontal wells has been increasing very rapidly throughout the oil industry as advances in drilling techniques continue. Because the horizontal well technology is recently being applied to the production of crude oil by waterflooding or enhanced oil

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recovery methods, little information is available on the horizontal-well applications for chemical floods (Taber and Seright, 1992; Dakhlia *et al*., 1995; Westermark *et al*., 2006).

In this study, a comparison of the efficiencies of both horizontal and vertical wells in micellar-polymer flooding operations is performed. The influences of reservoir anisotropy coupled with various design parameters of well patterns are also studied. The study of these effects may assist the project design engineers in choosing the most optimal operating conditions that will maximize the efficiency of the process. With the goal of identifying these conditions, the effectiveness of the horizontal and vertical wells in micellar-polymer flooding projects is examined by simulating the process numerically.

2. Numerical Modeling

The numerical study was performed with the UTCHEM software, which is a general reservoir simulator. Among the most advanced chemical EOR simulators, UTCHEM has proved to be particularly useful for modeling multicomponent and multiphase transport processes (Center for Petroleum and Geosystems Engineering, 2000). UTCHEM has been extensively verified by comparing to analytical solutions and experimental measurements for its ability to predict the flow of fluids through the reservoir. Thus, UTCHEM will be used in this study for simulating multi-dimensional micellar-polymer flood processes for enhanced recovery of remaining oil in the reservoir.

To simulate the performance of the micellar-polymer flood processes, a hypothetical study site of one-quarter of an injection-well-centered five-spot is considered. The modeled system used in this study is a box-shaped reservoir with a horizontal area of 253×253 ft^2 and a vertical thickness of 25. Vertically, the simulation domain consists of five layers; and each layer is discretized into 23×23 grid blocks. The outer boundary is represented as a noflow. The reservoir investigated in this study was assumed to have already been waterflooded and is a potential candidate for micellar-polymer flood. The model assumes that the reservoir is originally saturated with oil and connate water. Initial saturation of water was assumed to be uniform spatially in the reservoir at 0.50. The uniform permeability of 250 md is assumed for both horizontal and vertical directions.

Micellar-polymer flooding process considered in this study involves the injection of a surfactant-polymer slug followed by a polymer drive and chase water injection. Fluids are pumped into the injection well at constant pressure of 650 psi over a simulation period of 1,000 days. The reservoir fluids are recovered from the production well operating at a sand face pressure of 500 psia, the same pressure as the initial reservoir pressure.

3. Results and Discussion

The model evaluated the flow of brine associated with surfactant and/or polymer and oil through a reservoir during the process. To understand the effects of various parameters on the oil recovery, simulation was performed with the injection sequence of micellar-polymer flooding followed by waterflooding. Volumetric fraction of surfactant in the injecting fluid is 0.03 during 0 to 180 days. Polymer concentration is 0.05% during 0 to 180 days, 0.025% during 180 to 360 days, and 0 % for remaining period in the chase water.

Several cases were studied in which the sensitivity of oil recovery and injection rate to the well configuration (well type and length) was determined. Performance of micellar-polymer flooding with vertical wells was determined by comparing the oil recovery and injection rate from a base case with the oil recovered from the various micellar-polymer floods over production period.

Extensive simulations were undertaken to investigate the feasibility and compare applicability of micellar-polymer flood through vertical and horizontal wells. The objective of this parametric study is to investigate the effect of horizontal well orientation on the overall performance of micellar-polymer flooding projects using different injector/producer combinations. The ratio of horizontal well length to reservoir length was 0.52, which corresponds to well length of 132 ft. During this part of the investigation, the following nine injection and production well combinations are considered:

- first combination (VzIVzP): vertical injector and vertical producer (base case)
- second combination (VzIHxP): vertical injector and horizontal producer along the x-direction
- third combination (VzIHyP): vertical injector and horizontal producer along the y-direction
- forth combination (HxIVzP): horizontal injector along the x-direction and vertical producer
- fifth combination (HxIHxP): horizontal injector along the x-direction and horizontal producer along the x-direction
- sixth combination (HxIHyP): horizontal injector along the x-direction and horizontal producer along the y-direction
- seventh combination (HyIVzP): horizontal injector along the y-direction and vertical producer
- fifth combination (HyIHxP): horizontal injector along the y-direction and horizontal producer along the x-direction
- sixth combination (HyIHyP): horizontal injector along the y-direction and horizontal producer along the y-direction

Results of the calculations for isotropic reservoirs are shown and compared in Fig. 1 for various combinations of vertical and horizontal floods. As presented in the figure, the oil recovery and injection rate are highly influenced by the well patterns. It can be seen that the predicted values from the reservoir simulation illustrate higher oil production and lower water production from horizontal micellar-polymer flooding.

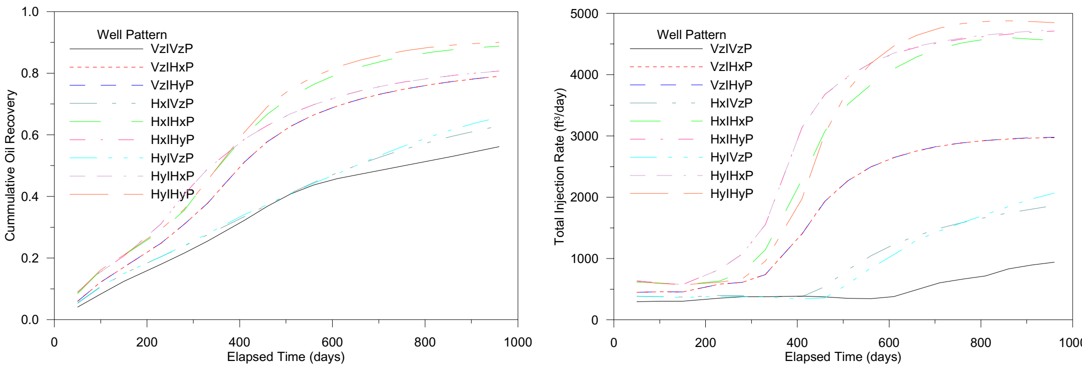


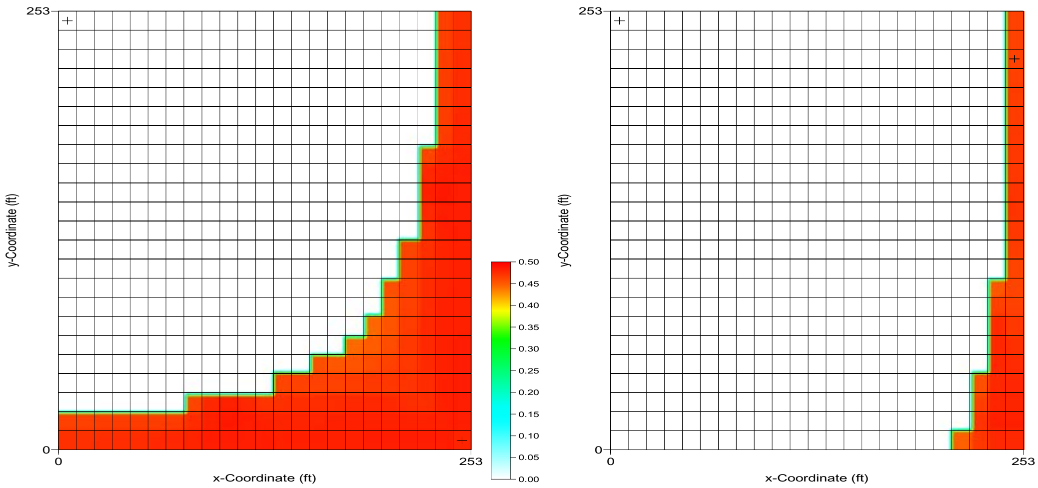
Fig. 1. History of production and injection wells obtained from simulations for isotropic reservoirs (a) Cumulative oil recovery; (b) Injection rate

The fifth and ninth combinations yield the highest additional production to the base case. This is expected since these combinations adopted only horizontal wells for injection and production and the producer and the injector have the same orientation. With horizontal wells aligned to the same orientation, areal sweep patterns are a lot closer to line-drive geometry the production will be maximized during the early injection period. The other combinations including horizontal wells also show markedly better performances than the base case as presented in Fig. 1. The improvement of oil recovery can be attributed to the higher injection rate and larger area open to flow and resulting improved sweep efficiency in horizontal wells than that of vertical wells.

Fig. 1(b) compares the results of injection rate for different injector-producer combinations, against the performance of the first combination which is considered as the base case. This comparison indicate that horizontal well floods result in the much higher rate compared to an equivalent five-spot flood at the same pressure. At early time, the presence of horizontal injectors seems to be more beneficial than the presence of horizontal producers. Conversely, the presence of horizontal producers is more beneficial than the presence of horizontal injectors after water breakthrough.

The combination of horizontal injector and producer shows the highest injection rate. The injection rate in HyIHyP at the same operating pressure would be about 6.1 times higher than that for the base case, which represents a significant improvement in injectivity and high effectiveness to sweep the reservoir oil over values attained by the model of vertical wells. The result implies that the same volume of fluid can be injected at much lower pressure, in turn. The higher injectivities allowed by horizontal injection wells can help to alleviate substantially less injectivity of a vertical injection well. The higher injectivity associated with horizontal wells can also help to mitigate the effects of chemical and thermal degradation of injecting fluids.

Fig. 2 depicts oil saturation of the middle layer for five different well patterns including VzIVzP, VzIHxP, HxIVzP, HxIHyP, and HxIHxP after 410 days of injection. The sweep efficiency advantage of horizontal well flooding patterns would be observed best for horizontal injector and horizontal producer aligned to the same orientation. Analyzing the results presented in Fig. 3, the swept region did not cover the entire area of the layer with vertical injector or producer. In cases of horizontal injector and producer, the flood front covered almost the entire region. The pore volumes injected for the well patterns are 0.43, 0.79, 0.49, 1.36, and 1.08 for VzIVzP, VzIHxP, HxIVzP, HxIHyP, and HxIHxP, and cumulative oil recoveries are 0.32, 0.51, 0.33, 0.59, and 0.60, respectively. The highest sweep efficiency was obtained for a pattern HxIHxP in which injected fluid and the produced fluid are flowing by two parallel horizontal wells. This type of well pattern is called inverted line drive pattern and has the advantage of using the entire length of the horizontal section for sweep. As compared to the sweep patterns that developed between vertical wells, areal sweep patterns are closer to line-drive geometry in horizontal wells.



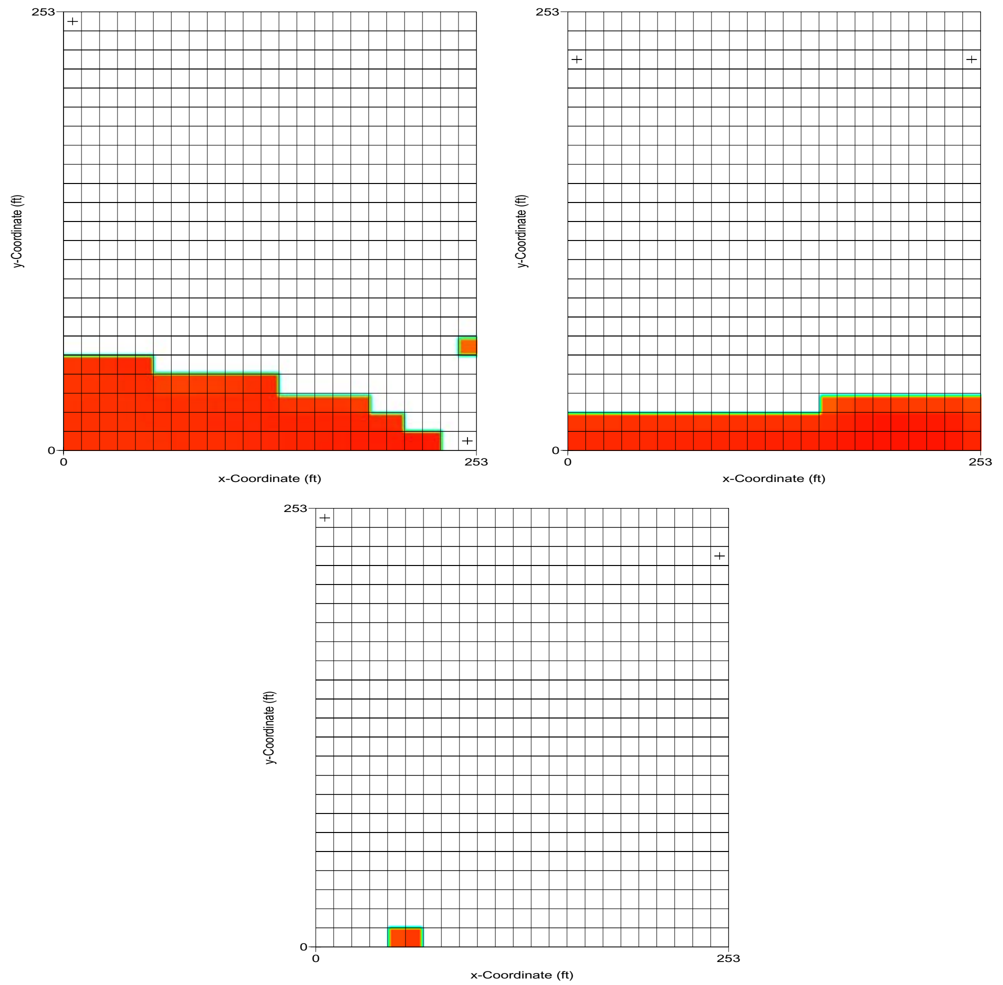


Fig. 2. Areal distribution of oil saturation for different well combination at 410 days (a) VzIVzP; (b) VzIHxP; (c) HxIVzP; (d) HxIHyP; (e) HxIHxP

4. Conclusions

Based on the studies carried out in this work in order to evaluate the oil recovery efficiency of a micellar-polymer flooding process with various combinations of horizontal and vertical wells, the following conclusions are drawn. Because of the improved injectivity and the potential for increased recovery by better sweep efficiency, the use of horizontal wells during micellar-polymer flooding could offer remarkably significant benefits as compared to the results obtained in a conventional pattern processed by vertical wells. It is essential to place the horizontal producers and injectors parallel to each other to obtain better performance efficiency than the vertical well combination. A very favorable injectivity and sweep occur when two opposed horizontal wells parallel in the pattern are used for injection and production. Compared to five spot patterns with vertical wells, the combination of parallel horizontal wells can increase oil recovery by 40% and injectivity by as much as a factor of two.

Acknowledgments

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