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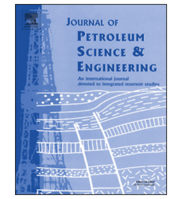

The effect of heterogeneity and well configuration on the performance of hot water flood

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ABSTRACT

This study investigated the performance of hot water injection in several stochastically-generated permeable media using different well configurations and initial oil viscosity. The reservoir investigated is typical of a Middle Eastern heavy oil reservoir with heterogeneity and fluid properties that differ significantly from one location to another. The reservoir is a candidate for a thermal recovery method. However, due to the lack of fresh water to conduct steam flooding, only hot water flooding is considered in this study. Several three-dimensional heterogeneous permeability fields were generated geostatistically using the matrix decomposition method, to cover a wide range of permeability variation and correlation structure. Initially, simulations of hot water displacement were performed in all these permeable media with a multilateral horizontal well injector and a vertical producer. These results were then compared to those obtained with unheated conventional water flood. Investigations were then carried out to study the sensitivity of the displacement performance to the initial oil viscosity and to other well combinations. These well combinations consisted of vertical producer-vertical injector in a five-spot pattern and horizontal injector-vertical producer in a line-drive pattern. Results show that the performance of hot water injection is strongly affected by the degree and structure of reservoir heterogeneity. Regardless of the permeability variation and the correlation structure, the use of vertical wells in a five-spot pattern was found to be the most suitable well configuration to develop this reservoir. The combination of high permeability variation and high correlation length significantly reduces the displacement performance of horizontal or multilateral wells.

1. Introduction

The expansion of industry and increase in world population make the world oil consumption continuously increasing. Oil primary recovery can only recover around one-third of the world oil reserves. This fact forces the oil producing countries to find and search for methods to recover more oil. Mahroos (2005) highlighted the future challenges for producing Middle East oilfields during the maturation stage. In the Middle East, there are about 93 giant oil fields each of them holding oil reserves of one billion barrels and above. The total reserves of these fields are 600 billion barrels. In his paper, he illustrated the challenges in maintaining oil production and provided directions toward possible solutions. Farouq Ali (2003) emphasized that the heavy oil resources are on the order of 8 trillion barrels in place located in many countries. In his paper, he reported that the current world production of heavy oil is around 3.5 million barrel per day. The continuous growth in world oil demand stimulates oil producers to develop these resources. For example, Heavy oil resources will be major contribution to meet the requirement in delivering the 2030 strategic production targets in Kuwait (Sanyal and Al-Sammak, 2011). The Middle East region contains large amount of heavy oil deposits (Madhava et al., 1983; Milhem and Ahmed, 1987; Rice, 1991; Sivakumar, 2001). In Southern Oman, Rice (1991) stated that 12.6 billion STB of medium to heavy oil are originally in place.

Heavy oil deposits occupy large percent of the world oil reserves. This unconventional oil requires unconventional methods of recovery. Thermal recovery techniques are one of the common EOR methods that usually used to improve recovery from reservoirs containing heavy oils. The basic process concept involved in thermal recovery processes is to generate hot fluid on the surface or in situ and inject it through an injection well into an oil bearing formation. The hot fluid will heat the oil and reduce its viscosity to flow toward the producing well, where it is pumped to the surface.

Hot water flooding is the least expensive thermal recovery techniques and it is similar to conventional water flooding (Farouq Ali, 1974). Although heat carrying capacity of water is less than steam, hot water offers displacement force advantages than for

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steam (Diaz-Munoz and Farouq Ali, 1975). Martin et al. (1968) presented a case study of a hot water flood pilot test in the Loco field in southern Oklahoma. The main objective of the pilot was to obtain technical information and operating experience in a reservoir containing oil with 600 cp. Hot water flood was carried out after the conventional water flood was well past its economic limit. The hot water flood showed an increase in oil recovery.

Experimentally, Bousaid (1991) presented a laboratory work, where hot-water and steam flood experiments were conducted in a five-foot linear cell. The effect of injection rate of 240 °F water and steam was studied for the Kern River viscous oil (13° API) using a fine graded silica sand. It was found that hot water floods can mobilize the oil effectively at 205 °F and above. A residual oil saturation of 18% can be expected near the injection well using hot water with 240 °F temperature. Okasha et al. (1998) investigated the displacement and dispersion of tarmat by combining solvent and hot water injection to improve aquifer support. They concluded that the gain in recovery for hot water over cold water is substantial in the presence of tarmat.

Numerically, Goodyear et al. (1996) used a sector model of a high permeability reservoir containing oil with 400 cp, underlain by a large aquifer. Their study showed that hot water flooding can recover significant quantities of incremental oil, up to 18% of the original oil in place. A risk management study was also reported in which sensitivities to parameters such as vertical to horizontal permeability ratio, heterogeneity, and relative permeability were investigated. The optimal choice of the injection well position was considered for cold and hot water flooding and was shown to be strongly determined by the vertical to horizontal permeability ratio. Al-Shatti et al. (2006) presented a simulation study to evaluate the performances of steam and hot water floods in exploiting heavy oil deposits from a Middle Eastern reservoir. They concluded that the effect of enhancing the displacement efficiency is more pronounced than the effect of reducing oil viscosity in terms of oil recovery for this reservoir. Therefore, they suggested applying hot water flooding instead of steam flood in developing this heavy oil deposits. Furthermore, Alajmi et al. (2005) presented a study in which they investigated the heavy oil recovery by hot water flooding under different patterns (line drive and 5-spot) with different well configurations at different injected water temperature in homogenous reservoirs. They concluded that injection well length had a significant effect on heavy oil recovery.

Technology plays a major role in increasing the world oil reserves and recovering more oil. The use of horizontal wells in oil industry has increased rapidly during the last decades. The employment of horizontal wells instead of vertical wells is thought to improve the oil production and increases the sweep efficiency. Therefore, the utilization of horizontal wells, instead of vertical ones, in enhanced oil recovery processes became attractive for the oil industry. Algharaib and Gharbi (2005) studied the advantages of Horizontal/Multilateral wells over the conventional vertical wells. They compared the performance of four Horizontal/Multilateral well configurations to that of the vertical wells in waterflooding operations. Their study shows that the pattern used has a significant effect on the displacement performance. At the high oil prices, the application of horizontal wells in thermal recovery methods received an increasing interest at present time. El-Abbas and Shedid (2001) conducted a number of laboratory experiments to investigate the recovery of heavy oil using steam flooding through horizontal wells. The experimental setup used a well configuration in which a horizontal well is used as a steam injector while a vertical well is used as a producer. In addition, their investigations involve the addition of some chemical to steam to further enhance the recovery of heavy oil. They concluded that well configuration that they used in their experiments substantially improved oil recovery. Bernd and WinterShall (2001) presented a study in which horizontal wells were used to enhance hydrocarbon recovery from a reservoir that underwent a number of thermal recovery processes. In the study, three horizontal wells, which are utilized as producers, surround a vertical steam injector well. This well configuration showed a significant improvement in the performance as compared to the earlier production history where only vertical wells were utilized.

The reservoir condition has great impact on the performance of EOR techniques. For example, reservoir heterogeneity can be a factor to influence the EOR technique performance efficiency in the oil displacement. Ellison and Clayton (1995) used reservoir simulation tools to understand the performance of steam flood applications in a heterogeneous reservoir. They concluded that steam flood performance improves as reservoir quality and oil saturation improves, clay content decreases, and dip becomes more pronounced. Steam flood performance found to be related directly to the reservoir quality in which the path of steam flow was significantly influenced by reservoir heterogeneity. Gharbi et al. (1997) investigated the performance of enhanced oil recovery processes with horizontal and vertical wells in heterogeneous reservoirs. They studied the sensitivity of the displacement performance to the horizontal well length and the ratio of horizontal to vertical permeability using various well combinations. They showed that the degree and the structure of the reservoir heterogeneity have a significant effect on the efficiency of EOR processes with horizontal wells. Alajmi et al. (2009) studied the hot water flood performance in recovering heavy oil using single lateral horizontal injection well and vertical producer (line drive well pattern) in heterogeneous reservoirs. They concluded that regardless of the degree of reservoir heterogeneity, hot water flood showed better performance compared to conventional water flood.

The evaluation of multilateral well configuration (well with branches) and the effect of reservoir heterogeneity on the heavy oil recovery by hot water are yet to be investigated. In this work, the recovery of heavy oil by hot water under different well configurations is presented. The reservoir heterogeneity effect on the oil recovery is also presented and evaluated.

The reservoir investigated in this study is a Middle Eastern heavy oil reservoir with oil viscosity of 500 cp at reservoir temperature of 85 °F (Al-Qabandi et al., 1995). The reservoir has been long recognized as being a strong candidate for thermal recovery methods such as steam injection or hot water flood. However, due to the lack of fresh water for steam generation, hot water injection becomes the most suitable method to develop this reservoir.

Therefore, the primary objective of this study was to investigate and evaluate, through a systematic simulation study, the performance by hot water injection with multilateral wells that expected in this reservoir with several geostatistically-generated permeable media. For comparison purposes, unheated conventional water flood was also studied in this work. Since there is variation in the reservoir fluid properties, a secondary objective was to examine the effect of initial oil viscosity on the process performance.

The results of this study can be useful in determining whether the use of hot water with multilateral wells in this reservoir is suitable or not as compared to conventional water flood with vertical wells. The commercial black oil simulator, ECLIPSE®, was used for the purpose of this study.

2. Discussion and results

2.1. Simulated permeable media

When the permeability field is spatially varying, then the field is said to be heterogeneous. A collection of a set of continuous layers, each representing different values of permeability and