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Investigation on the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group in the tight oil reservoir

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Abstract. Water huff-n-puff is one of the effective energy supplement methods for the development of tight oil reservoirs by horizontal wells. However, the oil production performance of water huff-n-puff severely decreases after several cycles. Available researches indicate that the inter-fracture asynchronous injection-production technology for the horizontal well is an efficient method for improving the oil production performance of water huff-n-puff. However, considering the object of the inter-fracture asynchronous huff-n-puff is the single horizontal well, the study for a horizontal well group is less. Therefore, the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group was investigated in this paper. The oil productions of the horizontal well group for different huff-n-puff modes were compared and analyzed first. After that, the oil recovery mechanisms of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group were revealed. Finally, the influence of operating parameters on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group was studied by the numerical simulation method. The results show that compared with the water huff-n-puff, the accumulative oil productions for the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group increased by 5134.8m3, and the increased amplitude is 36.86%. The imbibition, the inter-fracture displacement, and the inter-well displacement are the main oil recovery mechanisms of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group. The accumulative oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff increases first, and then declines, finally tend to be stable with the increase of injection rate. Both the injection volume and the soaking time show a positive correlation with the accumulative oil production. The accumulative oil production of the horizontal well group decreases with the increase of production rate due to the aggravation of water channeling in the production stage. This work could provide certain theoretical guidance for the effective development of similar reservoirs by the horizontal well group.

1. Introduction

Tight oil reservoirs have been proven to be an important alternative oil resource in the future due to the abundant geological reserve1-4. Considering the extremely low formation permeability, tight oil reservoirs are generally developed by multi-stage horizontal wells under natural depletion5-7. However, horizontal wells face the problems of rapid production decline and low primary oil recovery owning to the no effective energy supplement8, 9. Therefore, looking for an effective energy supplement method is critical to the efficient development of tight oil reservoirs by multi-stage horizontal wells.

Waterflooding is the worldwide used energy supplement method for the conventional reservoir. Due to the large fracture networks scale in horizontal wells, water breakthrough tends to occur during the waterflooding affecting the development effect of horizontal wells10-12. Although the cyclic waterflooding technology was proposed to solve this issue, it achieved a limited effect13. To mitigate this issue, the water huff-n-puff was proposed to supply formation energy and improve the oil production of multi-stage horizontal wells in tight oil reservoirs. The water huff-n-puff refers to that water is injected into the formation through production well firstly, then the well is shut-in for some time, finally, the well is opened for production14-17. Imbibition is the main oil recovery mechanism of the water huff-n-puff18, 19. Field tests indicated that the oil production of horizontal wells for water huff-n-puff decline rapidly after several cycles. Therefore, it is imperative to find an effective method for improving the development effect of water huff-n-puff. In

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this connection, the inter-fracture asynchronous injection-production technology was proposed to improve the production performance of horizontal wells for water huff-n-puff. Currently, many numerical simulation research and experimental researches were carried out on the inter-fracture asynchronous injection-production technology, which confirmed the superiority of the inter-fracture asynchronous injection-production technology on the energy supplement20-23. The inter-fracture asynchronous injection-production technology refers to that one fracture is used for water injection, and the adjacent fractures are used for production, the injection and production are asynchronous. Imbibition and inter-fracture displacement are the main oil recovery mechanisms of the inter-fracture asynchronous injection-production technology. Furthermore, Kang et al. and He et al. investigated the influence of operating parameters and fracture parameters on the oil production of horizontal wells for the inter-fracture asynchronous injection-production technology, providing certain theoretical guidance for the technology wide implementaion24, 25. However, available studies on inter-fracture asynchronous injection-production technology focus on the single horizontal well, the study on the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group is limited.

In this work, the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group was investigated via the numerical simulation method. Firstly, the oil production performances of the horizontal well group for different huff-n-puff modes were compared and analyzed. On this basis, the oil recovery mechanisms of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group were revealed. Finally, the influence of operating parameters on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group was studied by the numerical simulation method. This work could provide certain theoretical guidance for the effective development of similar reservoirs by the horizontal well group.

2. Comparison between the horizontal well group production performance for different huff-n-puff modes

The horizontal well group production performances for the water huff-n-puff and the asymmetric inter-fracture asynchronous huff-n-puff were compared based on the geological model of the horizontal well group with ECLIPSE software. The geological parameters of the model are consistent with that in the BT block, as shown in Table 1. The geological model of the horizontal well group is shown in Fig. 1. The two horizontal wells are parallel, well spacing is 800m, fracturing stage is 6, fracture spacing is 100m, fracture half-length is 200m, and fracture conductivity is $2250\times10^{-3}\mu m^2$ m. The water huff-n-puff began after two years of depletion development

Table 1 Geological parameters of the horizontal well group model

Parameter	Value	Parameter	Value
Porosity/fraction	0.08	Water compression coefficient /MPa^{-1}	4.1
Effective thickness/m	15	Oil viscosity/mPa s	17.42
Wellbore radius/m	0.1	Water viscosity/mPa s	0.3
Permeability of matrix/mD	0.08	Oil volume factor/ Dimensionless	1.02
Oil saturation/%	50	Water volume factor/ Dimensionless	1.02
Oil compression coefficient /MPa^{-1}	7.5	Initial formation pressure/MPa	5.4

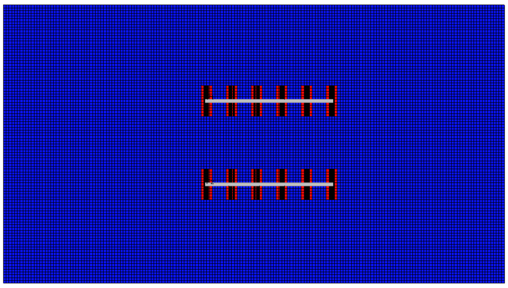

Fig. 1. The geological model of the horizontal well group

Keeping other parameters as the same in these schemes, three cycles were simulated to evaluate the horizontal well group production performances for different huff-n-puff modes. The accumulative oil productions of the horizontal well group for different huff-n-puff modes are shown in Fig. 2. From Fig. 2, the accumulative oil production for the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group increased by 5134.8m^3 that that of water huff-n-puff, with an increase of 36.86%. Based on the analysis above, the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group has been proven an effective method for improving the production performance of the horizontal well group.

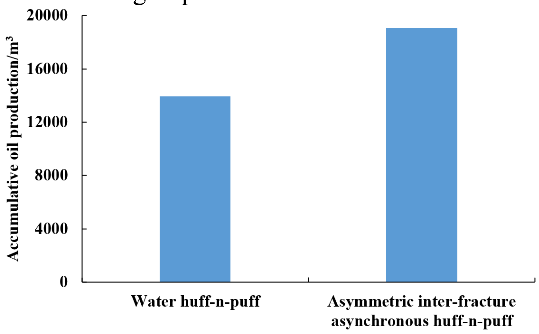

Fig. 2 The accumulative oil productions of the horizontal well group for different huff-n-puff modes

3. Oil recovery mechanisms of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group

Imbibition and inter-fracture displacement are the main oil recovery mechanisms of the inter-fracture asynchronous huff-n-puff technology for the horizontal well. From Fig. 3, the effective inter-well displacement effect could be formed due to the employment of asymmetric inter-fracture injection for the horizontal well group. Under the pressure difference between symmetric fractures, water injection could displace the oil between wells to the symmetric fractures, which could reduce the oil seepage resistance and facilitate the extraction of oil. Comparison between the horizontal well group production performances for different huff-n-puff modes showed that the accumulative oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff technology is 19069.4 m^3, increasing by 36.96% than that of water huff-n-puff. As a result, the inter-well displacement effect could not be ignored during the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group. Therefore, The imbibition, the inter-fracture displacement, and the inter-well displacement are the main oil recovery mechanisms of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group.

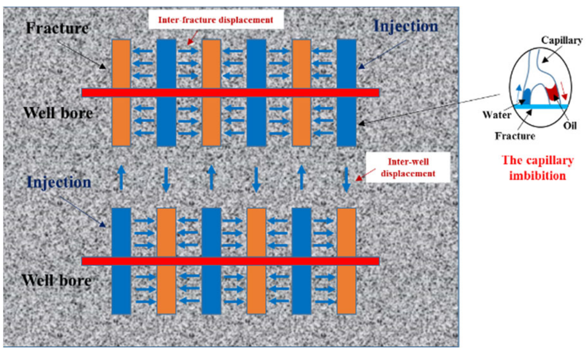

Fig. 3. Schematic of mechanism of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group

4. The influence of operating parameters on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff

By using the geological model of the horizontal well group, the influence of operating parameters, such as injection rate, injection volume, soaking time, and production rate, on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff was studied.

4.1 Injection rate

To investigate the influence of injection rate on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff, schemes with different injection rates (12 m^3/d, 24 m^3/d, 50 m^3/d, 72 m^3/d, and 120 m^3/d) were simulated while keeping other parameters as the same in these schemes. The injection volume was 1800 m^3, the soaking time was 6 months, and three cycles were simulated.

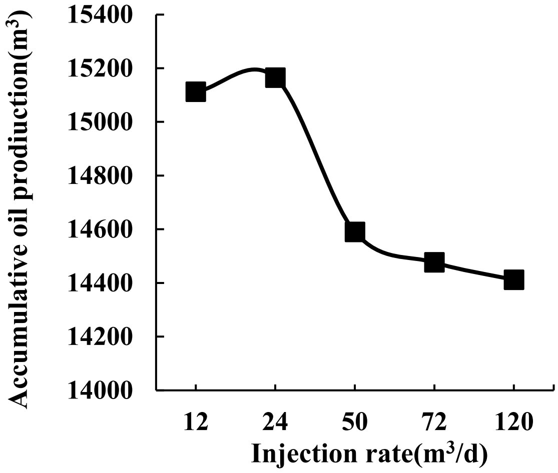

Fig. 4. The influence of injection rate on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff

Fig. 4 shows the influence of injection rate on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff. From Fig. 4, under the same injection volume, with the increase of injection rate, the accumulative oil production increases first, and then declines, finally tend to be stable. The reason is owing that with the increase of injection rate at the beginning, the inter-fracture displacement and the inter-well displacement gradually play their roles, increasing the accumulative oil production. After that, with the further increase of injection rate, the probability of water breakthrough occurring between fractures and wells increases. As a result, the swept volume of injection water decreases, and the imbibition probability decreases, so the accumulative oil production decreases. Finally, when the injection rate increases beyond a certain value, the phenomenon of water breakthrough occurs between fractures and wells is obvious, the inter-fracture displacement and the inter-well displacement can be ignored, and the imbibition plays a dominant role. In this condition, the swept volume of injection water no longer changes with the increase of injection rate, so the accumulative oil production tends to keep stable.

4.2 Injection volume

To investigate the influence of injection volume on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff, schemes with different injection volumes (1000m^3, 1400 m^3, 2200 m^3, and 3600 m^3) were simulated while keeping other parameters as the same in these schemes. Consistent with the above research, three cycles were simulated.

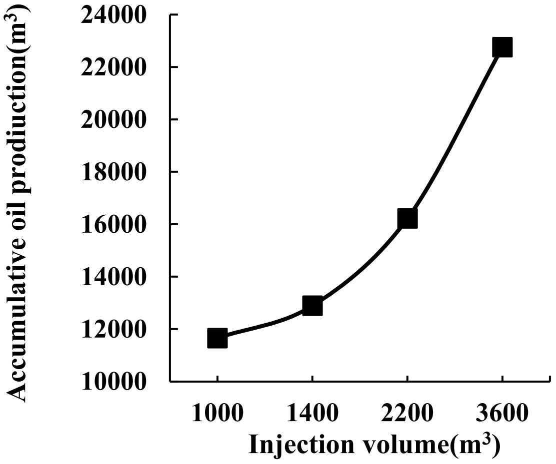

Fig. 5. The influence of injection volume on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff

It can be seen from Fig. 5 that with the increase of injection volume, the accumulative oil production of the horizontal well group increases. The reason can be concluded as that, on the one hand, the increase of injection volume increases the swept volume of injection water, increasing the imbibition probability. On the other hand, the increase of injection volume improves the net pressure in the fracture, enhancing the imbibition. Moreover, with the increase of injection volume, inter-fracture displacement and inter-well displacement are more sufficient. Therefore, the accumulative oil production of the horizontal well group increases with the increase of injection volume.

4.3 Soaking time

To investigate the influence of soaking time on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff, schemes with different soaking times (8 months, 12 months, 18 months, and 24 months) were simulated while keeping other parameters as the same in these schemes. A total of three cycles were simulated.

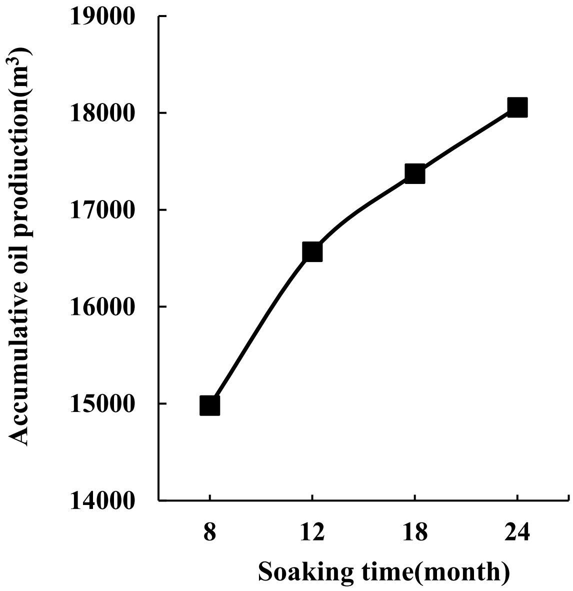

Fig. 6. The influence of soaking time on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff

Fig. 6 shows the influence of soaking time on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff. It can be seen from Fig. 6 that the accumulative oil production of the horizontal well group increases with the increase of soaking time, but the increased amplitude decreases gradually. That is because the increase of soaking time leads to the full play of the imbibition of injected water. As a result, the imbibition production increases. Besides, with the increase of soaking time, the formation pressure distribution gradually equalizes. Correspondingly, the inter-fracture displacement and inter-well displacement are enhanced gradually. Therefore, the accumulative oil production increased. However, with the further increase of soaking time, the imbibition oil absorbed on the fracture wall inhibits the subsequent take place of imbibition in the soaking stage, resulting in the slow increase of the imbibition oil production. Moreover, the further increase of soaking time no longer improves the enhancements of the inter-fracture displacement effect and the inter-well displacement effect. Therefore, the accumulative oil production increase rate decrease with the increase of soaking time.

4.4 Production rate

To investigate the influence of production rate on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff, schemes with different production rates (2 m^3/d, 4 m^3/d, 6 m^3/d, 8 m^3/d, and 10 m^3/d) were simulated while keeping other parameters as the same in these schemes. A total of three cycles were simulated.

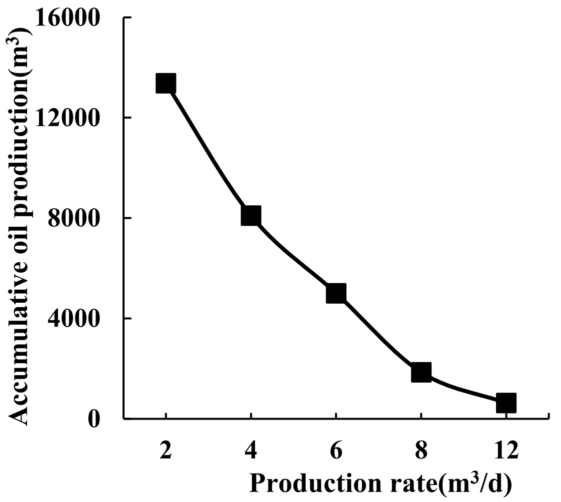

Fig. 7. The influence of production rate on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff

The influence of production rate on the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff is shown in Fig. 7. From Fig. 7, with the increase of production rate, the accumulative oil production gradually decreases. The reason is that the phenomenon of water channeling in the production stage is more obvious with the increase of production rate, which decreases the swept volume of injected water. Therefore, the oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff decreases with the increase of production rate.

5. Conclusion

(1) Comparison between the horizontal well group production performances for the water huff-n-puff and the asymmetric inter-fracture asynchronous huff-n-puff indicates that the accumulative oil productions for the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group increased by 5134.8m^3 than that of water huff-n-puff, with an increase of 36.86%.
(2) The imbibition, the inter-fracture displacement, and the inter-well displacement are the main oil recovery mechanisms of the asymmetric inter-fracture asynchronous huff-n-puff technology for the horizontal well group.
(3) The accumulative oil production of the horizontal well group for the asymmetric inter-fracture asynchronous huff-n-puff increases first, and then declines, finally tend to be stable with the increase of injection rate. That is because the dominant role of the inter-fracture displacement, the inter-well displacement, and the imbibition are different in different injection rate ranges. The accumulative oil production of the horizontal well group increases with the increase of injection volume. The reason is that with the increase of injection volume, the swept volume of injected water and the net pressure in fracture increases. Moreover, inter-fracture displacement and inter-well displacement are more and more sufficient. With the increase of soaking time, the imbibition, the inter-fracture displacement, and the inter-well displacement are enhanced gradually, increasing the accumulative oil production. The accumulative oil production of the horizontal well group decreases with the increase of the production rate. That is because of the aggravation of water channeling in the production stage.

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