Numerical simulation study of uniform steam injection method for SAGD horizontal wells

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Abstract. Steam assisted gravity drainage (SAGD) has a better effect on heavy oil development than other thermal recovery methods. However, during the SAGD production practice, the problem of uneven temperature distribution of long horizontal well sections has appeared. In response to this problem, the reservoir numerical simulation software CMG is used to simulate different steam injection methods for SAGD horizontal well sections. The results show that the conventional steam injection steam cavity only develops at the heel end, the development length is 1/3 of the length of the horizontal section, and the steam suction profile is uneven. The double-pipe steam injection steam cavity develops at the heel and toe ends, and the steam suction profile is uniform. Improved, multi-point steam injection steam chambers are developed along horizontal wells, and the steam suction profile is the most uniform.

1. Introduction
Steam Assisted Gravity Drainage (SAGD) is one of the most effective development methods to exploit heavy oil reservoirs [1]. Production practice shows that SAGD technology is very helpful to improve the development effect of heavy oil. However, during the SAGD production practice, there have been problems such as low production and low recovery of the reservoir caused by uneven development of steam injection and steam absorption profiles in long horizontal well sections. Therefore, it is necessary to improve the uniformity of steam injection in SAGD horizontal well sections. The key research content to further improve the development effect of SAGD horizontal wells [2, 3].

In this paper, numerical simulation software is used to simulate and predict the development of steam profile experimental methods, to study the steam injection methods of different SAGD horizontal well sections, to clarify the development law of steam suction profiles along the horizontal well section, so as to optimize the optimal SAGD horizontal well Steam injection method. It has important practical significance for improving the development effect of SAGD horizontal wells in our country.

2. Establishment of numerical simulation model
Reservoir numerical simulation is an effective tool that combines physics, mathematics, reservoir engineering and computer programs to predict the performance of hydrocarbon reservoirs under various production conditions. The reservoir numerical simulation technology has been studied since the 1950s and has developed into a relatively mature technology. In the preparation and determination of oilfield development plans and the simulation of oilfield development process, it has gradually become an indispensable main research method [4].
Based on the actual reservoir data and development data of the SAGD experiment, the STARS simulator in the CMG reservoir digital simulation software was used to establish a numerical model to simulate the influence of different steam injection methods on the development effect of horizontal well SAGD.

2.1. Establishment of conceptual model
In order to accurately simulate the SAGD process of horizontal wells and the expansion of the steam absorption profile under different steam injection methods, the reservoir numerical simulation software CMG was chosen to establish a conceptual model. The model adopts LAB units and has a total of 7750 grid nodes (62×5×25). The horizontal, vertical and vertical grid steps are each 1cm, the top of the reservoir is buried at 0, and the reservoir thickness is 25cm. The established model is shown in Figure 1.

Other physical parameters used in the establishment of the geological model are shown in Table 1.

Table 1. Other physical parameters of geological model.

| Parameter name                              | Parameter value |
|---------------------------------------------|-----------------|
| Initial temperature of reservoir, °C        | 10              |
| Initial pressure of reservoir, kPa          | 220             |
| Volume heat capacity of rock, J/(cm³·°C)    | 2.39            |
| Thermal conductivity of rock, J/(cm·min·°C) | 3.125           |
| Thermal conductivity of crude oil, J/(cm·min·°C) | 0.055798       |
| Thermal conductivity of formation water, J/(cm·min·°C) | 0.384          |
| Crude oil density, kg·m⁻³                   | 1005.19         |
| Average porosity                            | 0.45            |

2.2. Establishment of fluid model
The crude oil is super heavy oil (natural bitumen) under the condition of reservoir temperature. The viscosity of crude oil decreases exponentially with the increase of temperature. This indicates that the viscosity of crude oil is very sensitive to the influence of temperature, which can indicate that the exploitation of heavy oil through SAGD has certain feasibility and inevitability. The relative permeability and absolute permeability can be used to calculate the effective permeability of each phase fluid when oil, gas, and water coexist. Effective permeability is an important parameter for the simulation of uniform steam injection in horizontal well SAGD.

2.3. Establishment of production dynamic model
In the model built, a pair of horizontal wells are used for SAGD development. The horizontal lengths of the annulus between the steam injection well and the production well are both 62 cm. The steam injection...
well is located above the production well, and the vertical distance between the two wells is 5 cm. The operating parameters of production wells and steam injection wells are shown in Table 1-1. Production will start on January 1, 2019, and the simulated production time will be 1,300 minutes.

3. Comparison of results of three steam injection methods

3.1. Comparison of temperature distribution

Figure 2 shows the temperature distribution of three steam injection methods. The heel end and the toe layer of the heel end begin to develop in the conventional steam injection method. As the steam injection process progresses, the steam cavity is still located at the heel end of the horizontal well section and the length accounts for 1/3 of the total length of the horizontal well section. The temperature at the toe end of the horizontal well is only about 80°C, much lower than the temperature of the steam chamber. To the later stage of SAGD production, with the continuous suction of steam along the bottom of the well, the length of the steam chamber was only 2/3 of the total length of the horizontal well, but the height was close to the top of the model and the temperature reached above 200°C, which caused serious steam overriding. Easy to produce a single point of steam breakthrough.

The numerical simulation results of the dual-tube steam injection method show that the overall uniformity of the horizontal well section is greater than that of the conventional steam injection method, and the steam suction profile develops at the heel end and toe end at the same time. Compared with conventional steam injection, the toe end area can be used effectively; improve the uniformity of the steam suction profile development of horizontal wells. The steam suction profile at the heel and toe ends is well developed, but the middle section is still unevenly developed. From steam injection to the middle of SAGD, the suction profile is still at the heel and toe ends of the model. The suction profile along the well height accounts for 1/2 of the total length of the horizontal well section, but the toe part of the model is unevenly developed. At this time, the temperature in the middle of the horizontal well It is only about 100°C. As the production time increases, the steam suction profile develops vertically upwards at the heel end and toe end, and horizontally develops toward the middle of the model. Finally, the development gradually slows down in the middle of the model, forming a "dumbbell"-shaped temperature field.

Due to the small interval between the steam injection points, the multi-point steam injection method has a similar development of the steam cavity along with the conventional steam injection, but the temperature gradient decline is significantly better than the conventional steam injection method, showing a "decreasing concave function". In the middle of SAGD, the suction profile has grown to the middle of the model, and its length is 1/2 of the total length of the horizontal well section. At this time, the temperature gradient along the well of the entire reservoir is relatively gentle compared to conventional steam injection. By the end of SAGD production, the steam suction profile had grown to the toe end of the horizontal well, covering almost the entire horizontal well section. In the entire SAGD process, the average temperature of the toe part of the reservoir does not exceed 100°C. Compared with the conventional, double-tube steam injection method, it effectively solves the problem of steam overlap. In the actual SAGD production process, according to the formation permeability distribution and the development of the steam absorption profile, the downhole supporting tools can be used to rationally allocate the steam injection volume along the horizontal well to make the steam absorption profile more uniform.

Comparing the temperature distribution patterns of the three steam injection methods, it can be found that the multi-point steam injection method has the most uniform temperature field distribution along the well direction, which is the best steam injection method.
3.2. Comparison of remaining oil distribution

Figure 3 shows the remaining oil distribution in the model after the development is stopped. It can be seen from the figure that due to the increase in reservoir temperature due to the injection of steam, the viscosity of the crude oil decreases, and the fluidity is enhanced, and it is produced by the production well. Therefore, the steam absorption profile is well developed. The remaining oil saturation is low, and as the steam absorption profile continues to expand, the remaining oil saturation in the reservoir continues to decrease. The steam in the toe and the upper half of the reservoir is not affected, resulting in more remaining oil and affecting the development effect.

Compared with the conventional steam injection method, the double-tube steam injection method produces a higher degree of heel and toe recovery. The middle and upper oil reservoirs of the horizontal section are not affected. However, the overall recovery degree is greater than that of conventional steam injection.

The multi-point steam injection method distributes the remaining oil evenly along the entire horizontal well. The part along the well has a higher degree of recovery, and the toe is lower than the heel, but the recovered part still accounts for 1/2 of the height of the reservoir. The overall uniformity is greater than the conventional, double-pipe steam injection method.

4. Conclusion

The steam suction profile of the conventional steam injection method gradually decreases from the heel end to the toe end. The steam injection profile at the heel end of the steam injection well is well developed, and the steam suction profile of the horizontal well gradually deteriorates along the way. The toe end of the horizontal well and the upper half of the formation are poorly produced. The production length accounts for about 1/3 of the total length of the horizontal well.

The heel and toe steam suction profiles of horizontal wells with double-tube steam injection are well developed, but the middle section develops unevenly. The production length occupies about 1/2 of the total length of the horizontal well.
The multi-point steam injection method can be used along the steam injection well; it can effectively improve the uniformity of the horizontal well steam suction profile development. The production length accounts for about 2/3 of the total length of the horizontal well.

Comparing the three steam injection methods, the multi-point steam injection steam cavity is developed along the horizontal well, and the steam suction profile is the most uniform.

Acknowledgments
This work was financially supported by National Science and Technology major projects (No.2016ZX05031-002) fund.

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