Study on Enhanced oil recovery by steam flooding in heavy oil reservoirs

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Abstract. With the development of social economy, the demand for energy is increasing day by day. Under this background, the development of conventional petroleum resources has been unable to meet the needs of social development, and the importance and necessity of exploitation of heavy oil reservoirs has become increasingly prominent. However, the viscosity of heavy oil is larger, the fluidity is worse than that of conventional crude oil, and it is more difficult to exploit. In this regard, in order to further improve the exploitation level of heavy oil reservoir, relevant enterprises and technicians need to strengthen the research on steam flooding exploitation technology, and improve the recovery efficiency of heavy oil reservoir by using the technical advantages of steam flooding. In view of this, this paper first briefly analyzes the mechanism of steam flooding to improve the recovery efficiency of heavy oil reservoirs, and then expounds the main factors affecting the recovery efficiency of steam flooding. On this basis, combined with specific cases, the feasibility of steam flooding to improve the recovery efficiency of heavy oil reservoirs is verified for reference.

Keywords: heavy oil; Steam drive; Recovery efficiency.

Steam drive oil recovery is a thermal recovery method adopted to further enhance oil recovery after steam huff and puff oil recovery. Under the background of the new era, in order to better cope with the problem of energy shortage and improve the recovery capacity of heavy oil reservoir, it is necessary for relevant enterprises to strengthen the understanding and research of steam flooding, identify the mechanism of improving heavy oil recovery and the main factors affecting it, so as to better use steam flooding oil recovery technology in actual production and promote the improvement of production efficiency and quality.

1. Mechanism analysis of enhanced oil recovery by steam flooding

Steam flooding is a kind of production mode based on the preferred development layer, development system and well pattern, which continuously intakes high temperature and wet steam into the reservoir from injection well to heat and displace the crude oil produced from production well. Its application in the production of heavy oil reservoir can significantly improve the recovery rate of the reservoir. Through scientific research, people realize that steam flooding can improve heavy oil recovery due to the following mechanism:

1.1 Viscosity reduction

The high viscosity and seepage resistance are the main reasons for the low production efficiency of heavy oil. Steam flooding will inject hot steam into the formation to raise the oil reservoir temperature. At this time, the viscosity of crude oil will decrease significantly and the fluidity will be greatly improved, thus reducing or even disappearing the starting pressure, playing a significant role in reducing viscosity and improving the recovery rate of heavy oil [1].

1.2 Thermal expansion

In the steam drive mining mode, the injection of a large number of high temperature and wet steam will increase the temperature of oil, water and rock in the formation, resulting in volume expansion. Under the same high temperature condition, the volume expansion of water phase and oil phase is significantly higher than that of rock. Therefore, under the influence of thermal

expansion, the flow rate of water and oil to production Wells will be significantly faster, which improves the mining efficiency. At the same time, the volume expansion of the oil phase is significantly higher than that of the water phase, which greatly reduces the residual oil saturation and improves the extraction quality [2].

1.3 Steam distillation

The core principle of this action is that the volatile components of a liquid mixture, when introduced directly to steam, can evaporate into a gaseous state at temperatures below their boiling point. In the process of steam drive mining, with the advance of the steam front, the remaining oil in the swept area of the condensation belt will be displaced and striped, and pushed to the steam front. During the process, the light hydrocarbon components and water vapor from the distillation once again encounter the cooler rocks in the condensation zone and condense into liquid water and light oil. These light oil and liquid water are miscible with the crude oil and will reduce the viscosity of the crude oil. With the continuous progress of steam drive mining, the above process repeats, which can significantly improve the fluidity of crude oil and thus achieve the effect of improving the recovery rate [3].

1.4 dissolving gas drive

The steam belt formed in the process of steam injection has a very high temperature. The area near the front of the steam belt at the back edge of the condensation zone is separated from the dissolved gas in the crude oil due to the decrease of solubility due to the large increase in temperature, and the volume expansion has a displacing effect on the crude oil, so the recovery rate can be improved.

1.5 Gravity separation

Due to the large density difference between crude oil, water and steam, the phenomenon of water and water separation occurs in the formation and the phenomenon of steam overlap occurs in the process of steam flooding and oil recovery. At this time, the steam condensate will advance from the lower part of the reservoir, and the upper crude oil will expand and become lighter under the heat of the high temperature steam, so that the flow is improved. Under the combined action of the above phenomena, crude oil will burst into the production well before the hot water zone, thus improving the recovery rate of heavy oil.

2. the main factors affecting the recovery rate of steam drive

2.1 Reservoir permeability

Scientific research shows that the greater the permeability of the reservoir, the smaller the resistance of the fluid in the reservoir, and the stronger the flow capacity of crude oil. Taking common heavy oil as an example, scientific tests show that when reservoir permeability increases from 200mD to 300mD, the net oil production curve changes most obviously, and the recovery efficiency of horizontal well steam flooding is significantly improved. When the permeability exceeds 300mD, the permeability of the reservoir is further improved, and the change amplitude of the net oil production curve is slowed down, which has little influence on the recovery efficiency of steam flooding. It can be seen that reservoir permeability is a major factor affecting the recovery rate of steam flooding. For common heavy oil, when the reservoir permeability reaches 300mD, steam flooding can obtain the best recovery rate [4].

2.2 Crude oil saturation

Scientific research shows that increasing oil saturation can reduce the heat loss of steam flooding, improve the heat utilization rate of steam, so that more heat is used for heating of crude oil, so as to

obtain better thermal expansion effect and maximize the fluidity of crude oil. Relevant research data show that no matter what type of reservoir, when the crude oil saturation increases, its net oil production and well group recovery will also increase accordingly. For common heavy oil reservoirs, the oil saturation limit measured by scientific tests is 35%[5].

2.3 Formation dip Angle

The results show that with the increase of formation dip, the effect of steam huff and puff in the process of crude oil production will become worse. Therefore, formation dip Angle is also an important factor affecting the recovery rate of steam flooding. Specifically, when the dip Angle increases, the recovery rate of horizontal well steam flooding pattern parallel to the structure and perpendicular to the structure decreases, and the change trend of the pattern pattern perpendicular to the structure is more obvious. Scientific research data show that when the formation dip is not more than 5°, the variation range of well pattern recovery efficiency is obvious. When the dip Angle exceeds 5°, the variation range of well pattern recovery efficiency decreases. Considering the influence of formation dip Angle on the recovery rate of steam flooding, technicians should reasonably set the well spacing ratio between the lower, middle and higher parts of the production well according to the formation dip Angle during the technical design, so as to obtain the best recovery rate of steam flooding [6].

3. Case verification of enhanced oil recovery by steam flooding in heavy oil reservoirs

3.1 Reservoir overview

Reservoir A consists of seven vertically developed formations. The case study is the d1III and d2I formations buried between 1450m and 1650m. The average monolayer thickness of the above reservoirs is 2.8m and the maximum monolayer thickness is 5m ~ 9m, belonging to the delta front deposits. The connectivity coefficient of the main layer is 83%, the average connectivity coefficient is 68%, the average permeability is 1364mD, the crude oil density is 0.98g /cm3 at 20℃, and the viscosity of the crude oil is 253-1307mpa • s at 50℃. By the end of 2022, the reservoir is developed by steam huff and puff, of which d1III stage recovery degree is 12.4%, oil recovery rate is 1.4%; The stage recovery degree of d2I is 11.6% and the oil recovery rate is 1.3%. Considering the development difficulties of the reservoir, such as dispersed pay, large inclination and irregular well pattern, the technicians decided to change the development mode and use steam flooding to improve the oil recovery.

3.2 Steam drive oil recovery technology design

3.2.1 Determination of development layer

Only when the thickness and reserves meet the standard, can meet the demand of oil production speed and stable production period, and the reservoir oil properties, physical properties and distribution patterns are similar, and the temperature and pressure are unified, can the reservoir be identified as a set of independent development layers. In this case, the d1III and d2I reservoirs have the characteristics of thin thickness (maximum single layer thickness ≤5m, total layer thickness ≤21m) and concentration of well segments, which meet the setting criteria for independent development of formations, so they are suitable for the development of one set of formations.

3.2.2. Selection of well pattern form

In the process of reservoir production by steam drive, five-point method, reverse seven-point method and reverse nine-point method are usually used to determine well pattern. However, in this case, the reservoir geology is complicated and the well inclination is large, so it is difficult to plan a relatively regular well pattern. Therefore, in the planning and design stage of well pattern pattern,

technicians simulated and analyzed different well pattern patterns such as steam flooding in directional Wells, steam flooding in directional Wells and steam flooding in directional Wells by numerical simulation method based on existing Wells. The results showed that the well pattern pattern using directional well steam flooding had the highest degree of reservoir recovery. In view of this, technicians decide to adopt the well pattern of directional well injection-production steam flooding and suggest that non-condensate gas should be continuously injected into the postharmine low pressure area during the mining process to increase formation pressure and improve the mining rate of steam flooding .

3.2.3 Setting of injection and production parameters

In order to achieve the best recovery efficiency of steam flooding in heavy oil reservoir, the following key injection and production parameters should be set rationally in technical design: (1) steam injection efficiency. Relevant scientific research results show that there is a close relationship between steam injection speed and steam flooding recovery efficiency, and the greater the steam injection speed, the greater the possibility of steam flooding success. In view of the characteristics of d1III and d2I formations, such as small reservoir thickness and large spacing of steam drive injection and production Wells, technicians believe that the steam drive production quality can be better guaranteed by using larger steam injection efficiency. Through the numerical simulation calculation, the technical staff set the steam injection efficiency to 1.8~ 2.0t/(d • hm2 • m); (2) Production and injection ratio. In the steam flooding stage, the setting of this parameter will directly affect the formation and development of the steam chamber. For example, if the production/injection ratio is too low, it will lead to continuous fluid accumulation at the bottom of the well. If it is too high, the bottom pressure will drop too fast, and the pressure gradient between the production well and the steam injection well will increase, which is not conducive to the development of the steam chamber. If the development of steam chamber is not good, the stability of reservoir pressure will be affected, and then the effect of mining mode conversion and the recovery rate of steam flooding will be affected. Therefore, it is necessary to scientifically calculate and set the production and injection ratio. In this case, the technical personnel proposed that the production/injection ratio should not be more than 1.2 after scientific numerical calculation based on the actual situation of the reservoir, and the specific values of each stage are shown in Table 1 . (3) Bottom hole steam dryness. As an important parameter to reflect the quality of steam entering the reservoir, the setting of the dryness of steam at the bottom of the hole will have a decisive influence on the heat carrying of steam, the stability of steam zone expansion, and the ability of displacement and sweeping of the reservoir. Relevant scientific research results show that the higher the dryness of injected steam, the better the exploitation effect of oil Wells. Especially for the thin oil reservoir, the dryness of steam at bottom hole should be increased as much as possible. However, there is an inverse relationship between steam dryness and implementation cost. Therefore, in order to maximize the economic benefits of reservoir production, factors such as steam drive recovery rate and steam dryness improvement cost must be considered comprehensively when setting steam dryness parameters. In this case, through digital and analog calculation, the technical personnel proposed that, based on the actual situation of the research object, the dryness of steam at the bottom of the well could be guaranteed to reach 40%, which could achieve the best balance between the mining rate and economic benefits .

Table 1 Set values of production and injection ratio for each stage of the study object

Stage	production and injection ratio
Hot connectivity phase	0.8
Displacement phase (initial)	1.0
Displacing phase (late stage)	1.2
Denudation adjustment stage	1.0

3.3 Effect analysis

10 steam flooding groups were deployed based on the above technical solution. Combined with the production data of nearly one year, the following results can be obtained through the digital simulation calculation: the recovery rate of the control group (huff and puff mining) is 30.2%, and that of the observation group (steam flooding mining) is 45.7%, which is 15.5% higher than that of the traditional huff and puff mining. The conclusion that conversion from huff and puff production to steam drive production can improve recovery efficiency of heavy oil reservoir is verified.

4. Conclusion

In summary, in the process of steam drive oil recovery, the oil recovery efficiency of the reservoir will be significantly improved due to the effects of viscosity reduction, thermal expansion, steam distillation, dissolved gas drive and gravity separation. Therefore, using steam flooding technology to recover heavy oil reservoirs can obtain better production results. In the specific production process, the relevant technical personnel should pay attention to the consideration of reservoir permeability, oil saturation, formation dip and other factors, as well as the determination of development strata, well pattern selection, injection and production parameters setting and other key links to ensure that the steam drive to achieve the best recovery.

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