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COMPREHENSIVE ANALYSIS AND IMPROVEMENT METHOD FOR HEAVY OIL RECOVERY OF DIP RESERVOIR USING SAGP THERMAL METHOD BASED ON NUMERICAL SIMULATION

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ABSTRACT

Steam-assisted gravity drainage is one of the most efficient thermal methods to develop heavy oil and bitumen accumulations. However, SAGD requires a large amount of steam injection especially in long production time, which may make the process uneconomical. As an improvement of SAGD technology, steam and gas push (SAGP) has attracted more attention due to its better performance. This method involves the addition of a non-condensable gas such as carbon dioxide co-injected with steam, which reduces the total amount of steam needed and improves energy efficiency. Due to the geological tectonic movement, heavy oil reservoirs with dip angles are widely distributed around the world. The influence of reservoir dip angle on SAGP method must be seriously considered. In this paper, the development effects of SAGP and SAGD methods for heavy oil reservoir with dip angle are compared based on the basic production parameter SOR and cumulative oil production by CMG-STARS. Secondly, the steam chamber evolution of dip angle reservoir with time is analyzed. Finally, we improve the low production caused by reservoir dip angle by optimizing well pair location. The well pair should be placed close to the side boundary in downdip zone, not in the center of the reservoir by numerical simulation. The results show that SAGP process is more suitable for dip Angle reservoir development than SAGD process. In addition, carbon dioxide injection in SAGP process is also conducive to reducing greenhouse effect and contributing to environmental protection This paper has a certain guiding significance for the development of widely distributed dip angle heavy oil reservoir.

Keywords: heavy oil recovery, dip angle, thermal recovery, SAGP method, SOR

NONMENCLATURE

Abbreviations	
SOR	steam oil ratio
SAGD	steam assisted gravity drainage
SAGP	steam and gas push

1. INTRODUCTION

With the continuous development of reservoir resources, more and more people pay attention to the precious heavy oil resources[1]. Because of its high viscosity, the oil will not flow in the initial formation conditions. There are many methods to develop heavy oil reservoirs, and thermal recovery is generally considered to be the most direct and effective method[2]. Steam assisted gravity drainage is developed by Butler, which is one of the most effective thermal recovery methods[3]. A typical SAGD process is illustrated in Fig. 1. This process mainly relies on the gravity effect of steam, utilizing a pair of horizontal wells whose distance is approximately 5 meters. Steam is injected into the formation by the top well injector. This leads to the formation and fluid heat up, resulting in a significant decrease in oil viscosity. Then SAGD process have been used around the world, which brings significant benefits to the oil industry[4].

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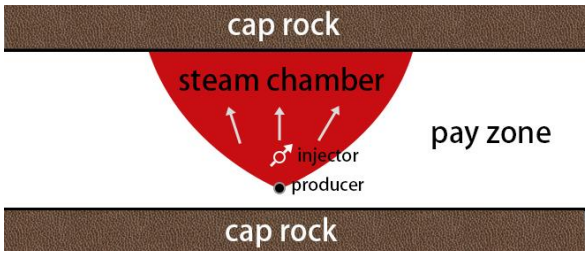

Fig. 1 Configuration of SAGD well

Although SAGD is efficient in producing heavy oil, it requires a large amount of steam to heat the rock and fluid. In addition, the heat loss to the overburden rock is large[5]. So SAGD process may become uneconomic in some reservoirs. A new method called steam and gas push (SAGP) was developed to overcome these disadvantages[6]. This new method involves the addition of non-condensable gas such as carbon dioxide or nitrogen co-injected with steam [7]. As a result, the steam requirement is reduced and steam oil ratio is decreased. This improved method has attracted wide attention.

Due to the geological tectonic movement, heavy oil reservoirs with dip angles are widely distributed all over the world[8]. Steam is easier to move towards the updip zone because of its low density. In most of the published literature, dip angle is ignored by simplification, which may be unreasonable for predicting oil production. Whether SAGP is more effective than SAGD method in dip-angle reservoirs development must be seriously considered. In this paper, the development effects of SAGP and SAGD methods for heavy oil reservoir with dip angle are compared based on the basic production parameter SOR by CMG-STARS. Finally, we give some advice to improve the low production caused by reservoir dip angle such as optimizing well spacing. This paper has a certain guiding significance for the development of widely distributed dip angle heavy oil reservoirs.

2. NUMERICAL RESERVOIR SIMULATION

2.1 model description

A simple homogenous numerical model was developed by CMG-STARS to investigate the development effects of SAGP and SAGD methods for heavy oil reservoir. The reservoir simulation model was derived from a detailed Athabasca reservoir geological model as described by Robinson et al[9]. The size of this numerical model was 310m × 210m × 32m and the size of each grid was 10m × 5m × 1m. The dip reservoir has an angle of 10°, and the injector was 2m above the producer, and the well length was 270m. The other data of reservoir parameters for CMG are shown in Table 1. The relative permeability and viscosity temperature curves are shown in Fig. 2 and Fig. 3 respectively.

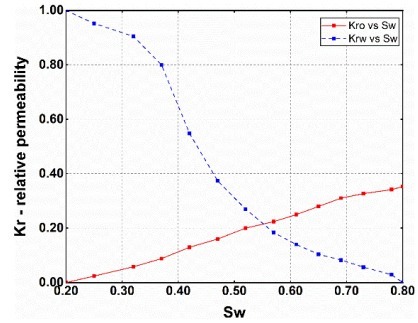

Fig. 2 Oil-water relative permeability curves

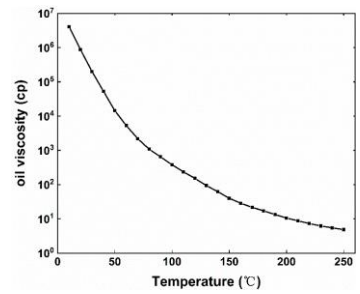

Fig. 3 Oil viscosity as a function of temperature

Table 1 Main reservoir and fluid properties used in CMG-STARS simulation

Properties	Value
Absolute permeability	3400×10^{-3} μm^2
Depth	200 m
Kv/Kh	0.8
Oil density	0.98 g/cm^3
Thermal diffusivity	5.8×10^{-6} m^2/s
Initial oil saturation	0.8
Heat capacity	1648 kJ/(m^3°C)
Porosity	0.25
Reservoir temperature	31 ℃

2.2 operating condition

To initialize SAGD, using heater wells and preheating was performed for two months to build heat connectivity, after which steam continued to be injected into the formation and the chamber gradually expanded. In our numerical simulation, the constant pressure production was used for the numerical simulation. In the SAGP and SAGD processes, steam is injected at 300 ℃, with a quality of 90%. The steam is injected with a rate of 500 m^3/day in SAGD process and in SAGP process, steam is injected 450 m^3/day and carbon dioxide is injected 50 m3/day at the same time. and the simulation time is 4years for these two processes.

3. RESULT AND DISCUSSION

In this section, the production performance of SAGD and SAGP processes were compared and analyzed.

3.1 Steam chamber evolution comparison

Numerical simulation results show that formation dip has an effect on the development of steam cavities in both SAGD and SAGP process. Fig. 4 shows steam chamber evolution for SAGD and SAGP processes. It can be found that the steam chamber developed in both processes is asymmetrical on the injection well. The explanation for this phenomenon is that the steam is easier to migrate to the updip zone due to its low density. In addition, the co-injection of carbon dioxide makes formation temperature rise faster, the area of steam chamber is also larger in SAGP process. The co-injection increases efficiency because the accumulation of carbon dioxide prevents the heat loss to the overburden. This is beneficial for oil production. Finally, since the density of carbon dioxide is higher than that of steam, co-injection increases the amount of steam entering into the downdip zone, resulting in more oil being produced.

lasts for a long time and is an important stage in the SAGD and SAGP production process. At this stage, oil production rate and cumulative oil production in SAGP process increases rapidly. The heat loss is reduced by the adiabatic action of carbon dioxide. In addition, the high density of carbon dioxide makes more steam enter the downdip zone, which in turn mobilizes more heated crude oil into the producer. Finally, the steam chamber reaches the formation boundary, the oil production rate begins to decrease at this stage because of the confinement of boundary.

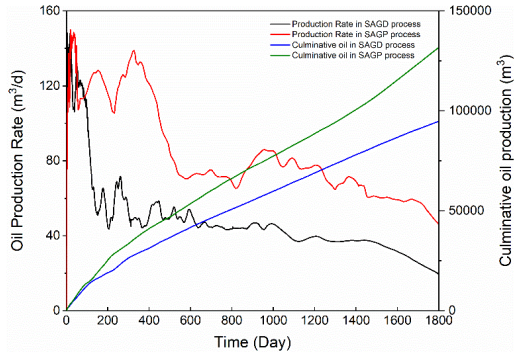

Fig. 5 oil production rate and cumulative oil production

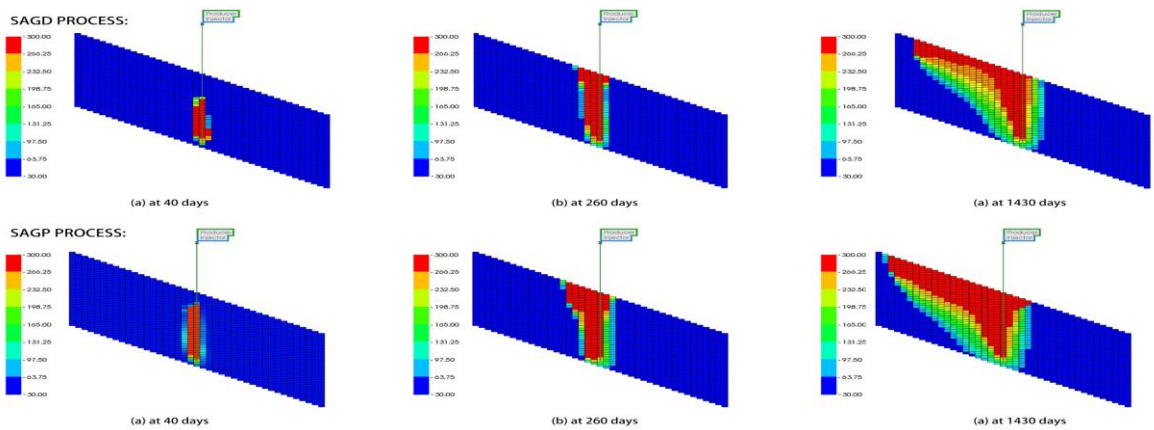

Fig. 4 steam chamber evolution for dip heavy reservoir in SAGD and SAGP processes at different times

3.2 Production index

In this section, the comparison results in two different processes are further analyzed in terms of the oil production rate and cumulative steam oil ratio by numerical simulation results.

3.2.1 oil production rate comparison

The oil production rate for these two processes are shown in Fig. 5. In the early stage of production, the oil production rate of the two processes is basically the same. The early production time corresponds to the rising period of the steam chamber, and the co-injected carbon dioxide has not played its effect yet. Later the steam chamber begins to expand laterally, this stage

3.2.2 steam oil ratio

Steam oil ratio is another important parameter to evaluate the economy of heavy oil thermal recovery project.

The comparison results by numerical simulation show that the SAGP process has a lower cumulative steam oil ratio, which indicates the SAGP process have a higher production efficiency than the SAGD process. At the end of the simulation, the cumulative steam oil ratio of SAGP process is 3.6, which is lower than 4.4 of SAGD process. A small change of the cumulative steam oil ratio can bring a great economic benefit for the practical engineering.

4. IMPROVEMENT METHOD FOR DIP ANGLE

According to the above, the important reason for the low oil production rate is that little amount of steam moves to downdip zone because of its low density. As a result, decreasing the area of the downdip zone and increasing the area of the updip zone to allow more steam to enter and mobilize the flow of crude oil is an effective way to improve the cumulative oil production. The well location is a critical factor to divide the dip reservoir into the undip and downdip zone as Fig. 6 shows.

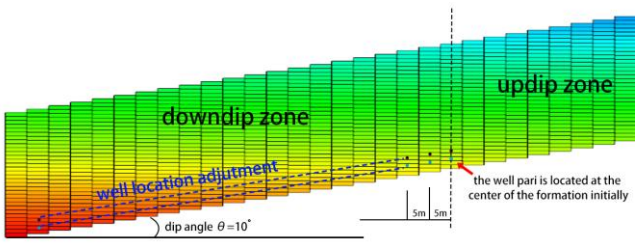

Fig. 6 Schematic diagram of relation between well location and different areas divided by wells

In order to determine the reasonable well location, the well location was arranged, changing 5 m at each time as shown in Fig. 6. Correspondingly, the total of 21 new numerical models are established to determine the reasonable well location based on cumulative oil production.

It can be seen from the simulation results of the 21 cases mentioned above that when the distance between the well pair and the side boundary of the downdip zone gradually decreases, the cumulative oil production gradually increases due to the decrease of the downdip zone area. However, if the distance between the well pair and the side boundary is too small, the steam entering in the downdip zone will soon contact the side boundary, resulting in more heat loss. This further leads to a reduction in cumulative production. Therefore, 25 m away from the side boundary is the best position for the well pair.

5. CONCLUSIONS

Due to the geological tectonic movement, heavy oil reservoirs with dip angles are widely distributed all over the world. The presence of reservoir dip angle has a strong influence on both SAGP and SAGD processes. By numerical simulation comparison, we find that SAGP has a better production performance based on higher cumulative oil production and lower SOR compared with SAGD by CMG-STARS. We improve the low production caused by reservoir dip angle by optimizing well pair location. In addition, carbon dioxide injection in SAGP process is also conducive to reducing greenhouse effect and contributing to environmental protection. This paper has a certain guiding significance for the development of widely distributed dip angle heavy oil reservoir.

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