Study on the influence of parameters on chemical agent assisted cyclic steam injection

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Abstract. Cyclic steam injection is widely applied in the development of heavy oil reservoirs. However, as reservoir development continues, steam channeling phenomena become increasingly severe, Serious impact on development effectiveness. Slug combinations of gel and foam is more effective than using gel and foam alone for steam channeling control. In this study, taking a steam channeling well in the A oilfield as an example, a numerical simulation model is established using CMG software. Based on this model, the effects of foaming agent concentration, foaming agent injection rate, gel injection timing, and nitrogen injection quantity on the development performance in the gel foam slug steam channeling plugging system are investigated. The research results indicate that higher foaming agent concentration, faster injection rate, and earlier gel injection timing lead to increased oil production. The nitrogen injection quantity exhibits an optimal value. Comparing the performance of gel foam slug system assisted cyclic steam injection with steam huff and puff alone, the results show that the gel foam slug system assisted cyclic steam injection achieves an incremental oil production of 9104 m3 over four cycles, as compared to steam huff and puff alone.

Keywords: Steam channeling; Gel foam slug; Numerical simulation.

1. Introduction

In late stages of cyclic steam injection in heavy oil reservoirs, severe steam channeling phenomena occur due to factors such as mobility ratio and reservoir heterogeneity. This results in the rapid movement of high-temperature steam along high-permeability zones, followed by rapid production, forming an inefficient cycle. This leads to ineffective utilization of injected steam, greatly impacting the development efficiency [1].

Traditional methods for mitigating steam channeling include nitrogen foam and gel plugging. However, nitrogen foam has a short action time and low plugging intensity, while conventional gels have poor temperature resistance, leading to the loss of plugging performance in high-temperature environments [2,3]. By adopting a staged plugging approach where gel is injected first followed by nitrogen foam, the combination of foam and gel effectively addresses these concerns. Injecting gel first can reduce the adsorption of foaming agents by the formation, ensuring foam stability. Subsequently, injecting nitrogen foam prevents the destruction of the gel structure by the hot steam, avoiding the loss of plugging effectiveness due to high temperatures. This approach improves the plugging efficiency of steam channeling [4].

Currently, there is limited research on gel foam slug steam channeling plugging system, and the influence patterns of relevant parameters are not well-established. Additionally, there is a lack of effective methods for optimizing injection and production parameters. Therefore, conducting research in this area is of great significance.

2. Establishment of Numerical Simulation Model

2.1 Establishment of Geological Model

The geological model consists of two components: the structural model and the attribute model. Based on the analysis of the geological structure of the oilfield, the structural model utilizes well data and employs interpolation contouring technique to depict the top or bottom structure of the reservoir, revealing the local variations in the geological structure. On the other hand, the attribute model subdivides the reservoir into a three-dimensional grid and utilizes well data as a basis to interpolate the entire reservoir grid, thereby obtaining the attribute model [5]. The three-dimensional geological model constructed is depicted in Figure 1.

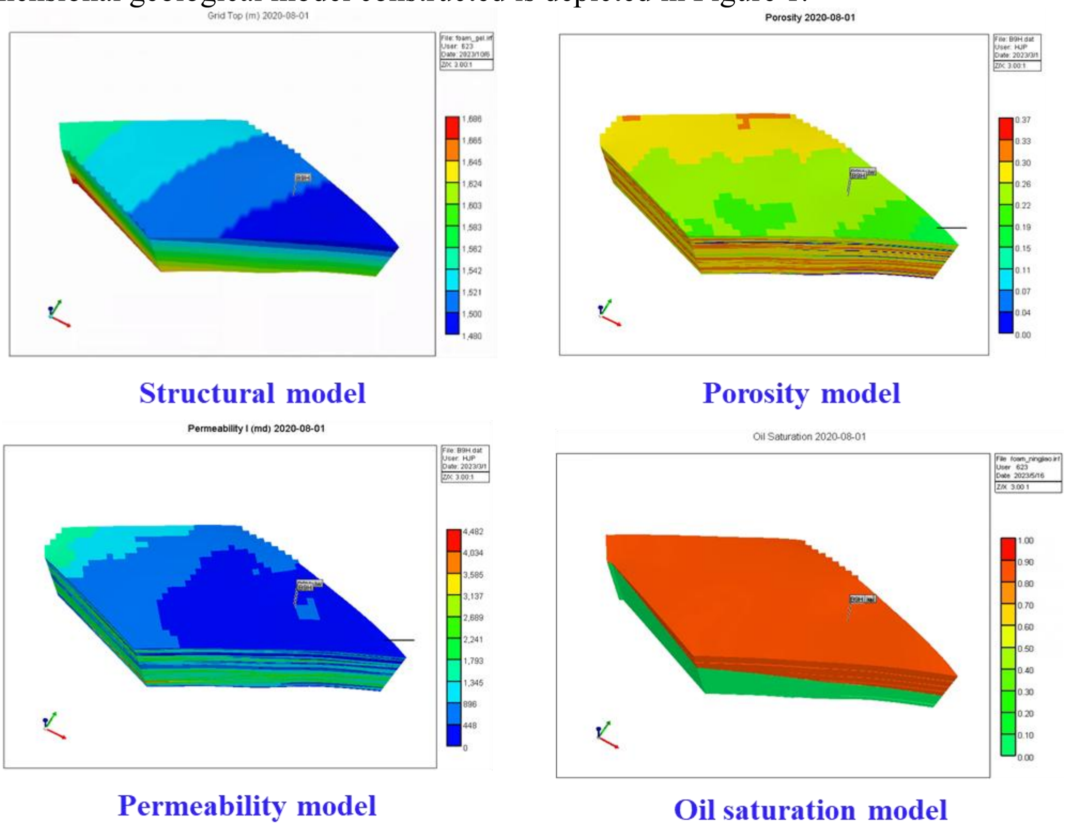

Fig. 1 Geological model

2.2 Establishment of Fluid Model

The mechanism of nitrogen foam was characterized using the empirical method in the STARS module of the CMG software. The gel is formed by the reaction of the polymer and the crosslinking agent, and two chemical reactions are set up to simulate the formation and degradation of the gel. The viscosity of the gel was characterized using a nonlinear mixing rule to represent its relationship with concentration [6]. The adsorption mechanism of the gel was characterized using the Langmuir adsorption isotherm [7]. The mechanism of rock permeability reduction caused by the gel was characterized by calculating the residual resistance factor [8]. The oil-water relative permeability curve and gas-liquid relative permeability curve used in the model are shown in Fig 2 and Fig 3.

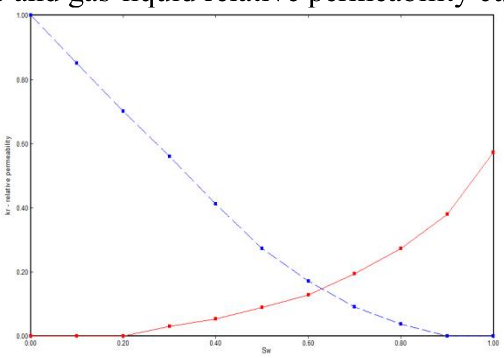

Fig. 2 oil-water relative permeability curve

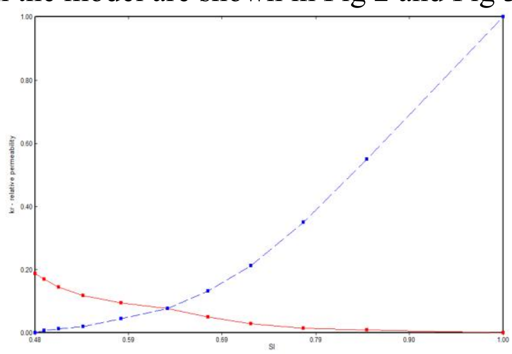

Fig. 3 gas-liquid relative permeability curve

2.3 Establishment of Production Dynamic Model

During the development period, there was only one well operating as a huff and puff well. Production started in March 2021 and ended by the end of 2021. Two cycles of huff and puff production have been completed. In the subsequent four cycles of simulation, the injection and production conditions for the well are shown in Table 1 and Table 2. The well coordinates and production dynamic data of the well were inputted into the CMG reservoir simulation software to establish a production dynamic model.

Table 1. Injection conditions of the well

pressure (kPa)	velocity (m^3/d)	temperature (°C)	time (day)	dryness
30000	300	340	20	0.5

Table 2. Production conditions of the well

Liquid production (m^3/d)	Maximum pressure drop (kPa)	time (day)	Minimum bottom-hole pressure (kPa)
100	3000	300	2000

2.4 Production History Matching

By utilizing oil rate and water cut fitting using curve fitting methods, the production rate and water cut of the well have been fitted. The fitting results are illustrated in Figure 4 and Figure 5. The fitting errors are relatively small, indicating that these results can be utilized for subsequent numerical simulation studies.

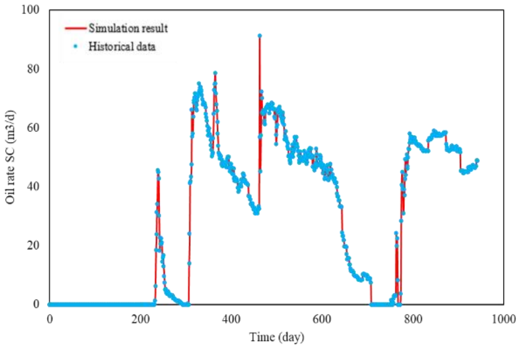

Fig. 4 Oil rate fitting results

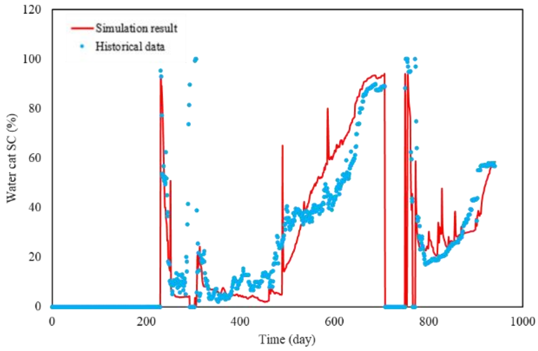

Fig. 5 water cut fitting results

3. Research on the Influence Law of Parameters

After completing the model fitting, a study was conducted on the impact of various parameters on gel foam slug system in the subsequent four cycles. The research included four factors: foaming agent concentration, foaming agent injection rate, gel injection timing, and nitrogen injection quantity. The gel injection volume was set at 300 m^3, polymer concentration at 4000 mg/L, crosslinking agent concentration at 1000 mg/L, injection rate at 300 m^3/d, foaming agent solution injection at 400 t, and the soaking time is 3 days.

3.1 Foaming agent concentration

The influence of foaming agent concentration on incremental oil production and chemical oil increment per ton is shown in Figure 6. As the foaming agent concentration increases, the incremental oil production continues to increase while the chemical oil increment per ton decrease. When the foaming agent concentration exceeds 5%, the foam already exhibits certain plugging strength. Further increasing the foaming agent concentration does not significantly improve the incremental oil production, but instead reduces the chemical oil increment per ton [9].

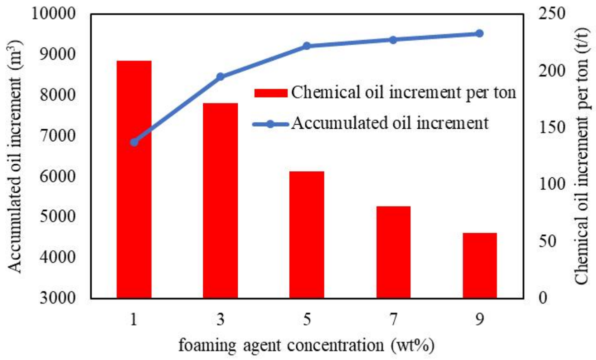

Fig. 6 Effect of foaming agent concentration

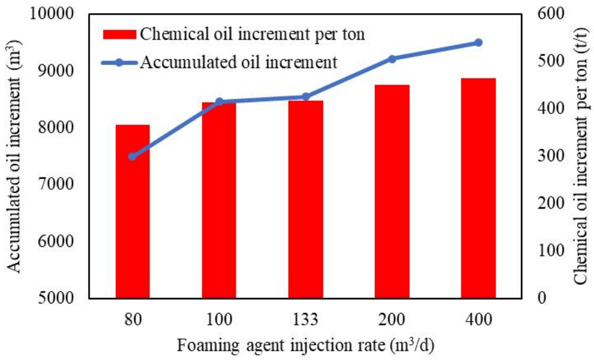

Fig. 7 Effect of foaming agent injection rate

3.2 Foaming agent injection rate

The influence of foaming agent injection rate on incremental oil production and chemical oil increment per ton is depicted in Figure 7. As the foaming agent injection rate increases, both the incremental oil production and chemical oil increment per ton show an upward trend. Compared to low-rate foaming agent injection, increasing the injection rate helps in promoting the movement of the foaming agent solution and gel deep into the reservoir, prevent the subsequent injection of steam to form a bypass flow, and achieving better deep plugging effects.

3.3 Gel injection timing

The influence of gel injection timing on incremental oil production and chemical oil increment per ton is illustrated in Figure 8. The later the gel injection timing, the poorer the incremental oil production. In the late stage of development, when high-permeability channels have already formed, plugging at this point would negatively impact the incremental oil production effect. Injecting gel earlier, on the other hand, allows subsequent injection of foam and steam to divert into low-permeability and unaffected areas, effectively targeting the remaining oil-rich zones and improving the incremental oil production effect.

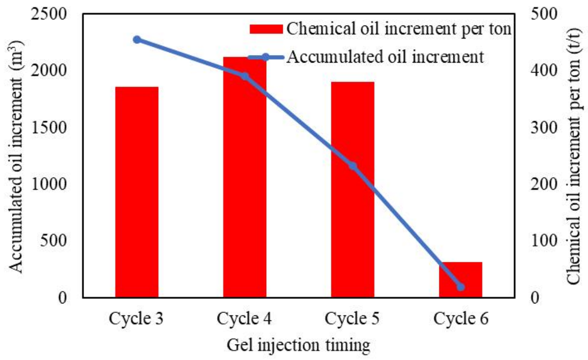

Fig. 8 Effect of gel injection timing

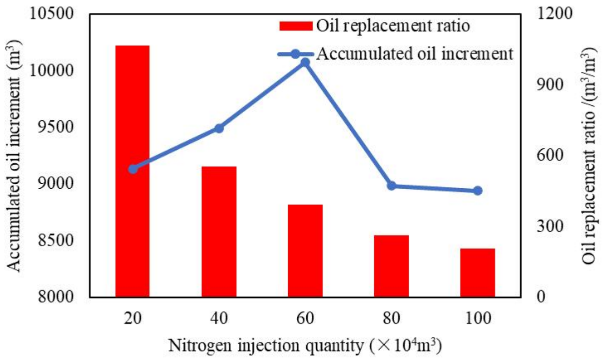

Fig. 9 Effect of nitrogen injection quantity

3.4 Nitrogen injection quantity

The influence of nitrogen injection quantity on incremental oil production and chemical oil increment per ton is depicted in Figure 9. As the nitrogen injection quantity increases, the incremental oil production initially rises and then declines. Among them, the maximum incremental oil production is observed when the nitrogen injection quantity is 600,000 cubic meters. With the increase of nitrogen injection, the foaming ability of the foam is enhanced, the mobility ratio is reduced, and the displacement effect is improved. However, when the injection rate becomes excessively high, an excessive amount of nitrogen is injected into the reservoir, resulting in significant gas production during the production stage and adversely affecting the overall oil production. There exists an optimal nitrogen injection quantity that needs to be considered [10].

4. Development Effect Comparison

Comparing the performance of gel foam slug system assisted cyclic steam injection with steam huff and puff alone, where the foaming agent concentration is 5%, foaming agent injection rate is 400 m^3/d, gel injection starts in the third cycle, and nitrogen injection rate is 60×10^4 m^3. The results show that, compared to steam huff and puff alone, the gel foam slug system assisted cyclic steam injection achieves an incremental oil production of 9104 m^3 over four cycles. The cumulative oil production comparison curve is shown in Figure 10.

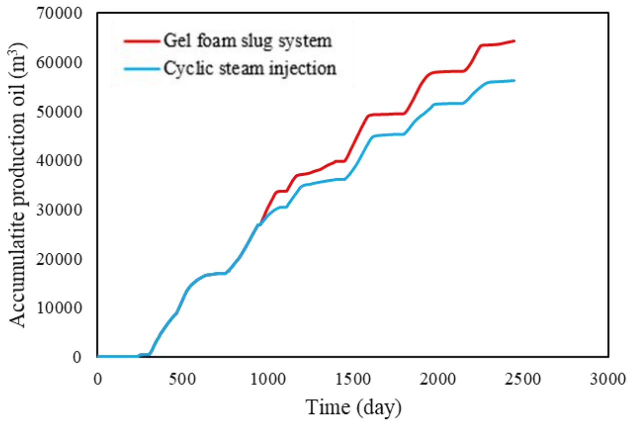

Fig. 10 Comparison results of cumulative oil production

The comparison of the oil saturation field near the wellbore between gel foam slug system assisted cyclic steam injection and steam huff and puff alone is shown in Figure 11. Compared to steam huff and puff, the oil saturation near the wellbore significantly decreases, indicating that the system can effectively prevent the injected steam from flowing along the high permeability channel, and effectively improve the development effect.

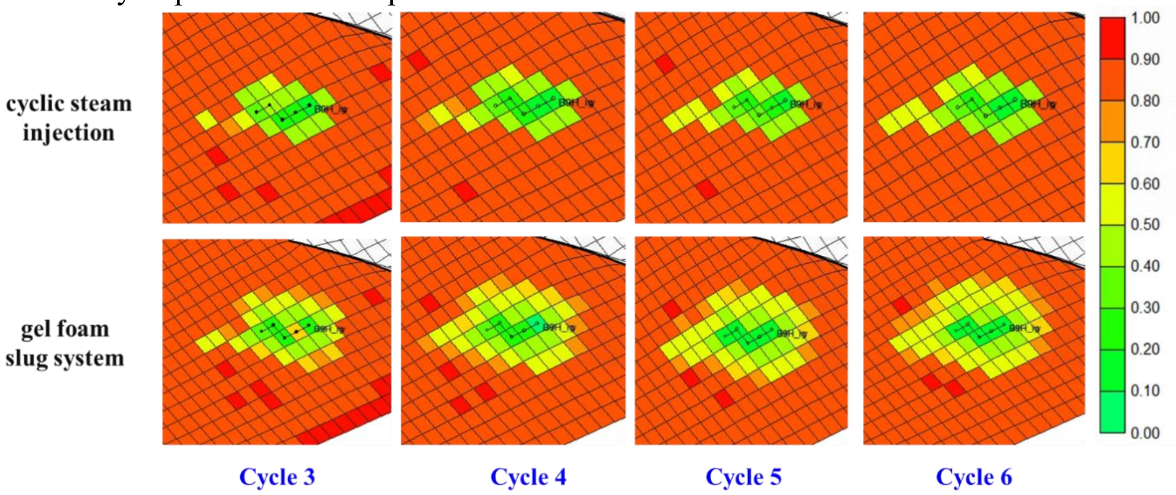

Fig. 11 Comparison of oil saturation after each production cycle

5. Summary

(1) Taking the steam huff and puff well in the A oilfield as an example, a corresponding geological model, fluid model, and production dynamic model were established using CMG software based on actual geological data and production data. The production rate and water cut were fitted to validate the accuracy of the model.

(2) Based on the established model, a study was conducted on the four influencing factors: foaming agent concentration, foaming agent injection rate, gel injection timing, and nitrogen injection quantity. The results showed that higher foaming agent concentration resulted in higher incremental oil production, but the incremental effect became less significant when the foaming

agent concentration exceeded 5%. Higher foaming agent injection rates were associated with increased incremental oil production. Earlier gel injection timing led to better incremental oil production. As the nitrogen injection quantity increased, the incremental oil production initially increased and then decreased.

(3) Comparing the development performance of gel foam slug system assisted cyclic steam injection with steam huff and puff alone, the results show that the gel foam slug system assisted cyclic steam injection achieves an accumulated incremental oil production of 9104 m^3 over four huff and puff cycles, indicating a significant improvement in development performance compared to steam huff and puff alone.

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