Numerical Simulation of Water Control Technology in Deep Water Gas Reservoir

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Abstract: In recent years, large deep-water gas fields such as Yacheng and Lingshen have been discovered successively in deep-water exploration in the South China Sea, with huge reserves. However, bottom water is ubiquitous in deep-water gas fields, which seriously affects gas reservoir recovery. Therefore, it is beneficial to improve the development effect of gas reservoirs to clarify the water invasion mechanism and law of bottom water gas reservoirs. Based on the study of water invasion law of deep water gas reservoir, the development effect of deep water gas reservoir under different water control technology conditions is evaluated by numerical simulation method in this paper. It provides a strong basis for rational and effective development of deep-water gas reservoirs and water control and waterproofing technology.

1. Introduction
In recent years, CNOOC has made great breakthroughs in natural gas exploration in the deep-water area of Qiongdongnan Basin, South China Sea. The first self-exploring deep-water gas field in China, Lingshui 17-2 gas field, has been discovered. The breakthroughs in deep-water exploration will bring great opportunities for natural gas development in the western South China Sea. In recent years, scholars at home and abroad have studied the seepage mechanism of water-invaded gas reservoirs through physical simulation experiments of water invasion in bottom water gas reservoirs, and studied the effect of water control technology of water-invaded gas reservoirs by numerical simulation method of gas reservoirs, which provides theoretical basis for efficient development of deep water gas reservoirs.

By comparing domestic and foreign gas reservoir development examples, it can be found that the ultimate recovery factor of water drive gas reservoir is much lower than that of pure gas reservoir development. The invasion of edge and bottom water is an important factor affecting the low recovery. The edge and bottom water is also a very important potential capacity of water drive gas reservoir. If it can be effectively utilized, the technology of water control in gas reservoir will greatly prolong the time of anhydrous gas production, prolong the life of gas wells and enhance the recovery rate, which will also have practical significance for the effective development of natural gas resources in China.

2. General situation of gas reservoirs
During the 12th Five-Year Plan period, LS17-2 gas field, LS25-1 gas field, LS18-1 gas field and other large deep-water gas fields were discovered in deep-water oil and gas exploration in the South China Sea. LS17-2 gas field structural location: in the central Canyon of Lingshui sag, Qiongdongnan basin, the main target layers are Huangliu Formation I, II, III and IV. Reservoir physical property is good, belongs to high-ultra-high porosity, high-ultra-high permeability reservoir; the content of pure hydrocarbon in gas component is high: more than 98%, formation water type is NaHCO 3.
deepwater gas fields, medium and high water-breakthrough risk wells account for a large proportion. The geological reserves driven by edge and bottom water in the block account for more than 85% of the total reserves, and the risk of edge and bottom water invasion is high. Some wells are close to the water body, and there is fast coning. Some wells are less than 50 meters away from the bottom water, while others are about 500 meters away from the edge horizontally. After water breakthrough, the water body will cone rapidly. The development characteristics of bottom water and the law of water invasion are not clearly understood, and there is no systematic research program for water invasion in deep water gas reservoirs at home and abroad. Therefore, it is of great significance to carry out the research on reasonable water control technology for the formulation of rational development technology policy[1-3].

3. Study on Numerical Simulation of deep-water gas reservoir

3.1. Establishment of Mechanism Model of Deep Water Gas Reservoir

According to the physical properties and fluid properties of deep-water gas reservoirs, a mechanism model[4-5], which conforms to the physical properties of deep-water gas reservoirs, is established. The model is shown in Figure 1 and the physical parameters are shown in Table 1 and Figure 2.

| Parameter                  | Value            | Parameter                  | Value            | Parameter                  | Value            |
|----------------------------|------------------|----------------------------|------------------|----------------------------|------------------|
| Mesh Number                | 50×20×10         | Effective Thickness        | 12m              | Porosity                   | 30%              |
| Permeability               | 500mD            | Primitive Formation Pressure | 39MPa           | Bottom Water Energy        | 10               |
| Water Case                 | Cater-Tracy      | Initial saturation         | 0.768            | Compressibility            | 5.13×10⁻⁵        |
| Edge Water Energy          | 4                | Bottom Water Gas Production| 4%              | Edge Water Gas Production  | 5%              |

Figure 1 MECHANISM MODEL OF DEEP WATER GAS RESERVOIRS
Based on the mechanism model, ECLIPSE software is used to simulate the development effect of deep-water gas reservoirs. The phase permeability curve and PVT curve are shown in Fig. 2.

![Relative permeability curve](image1)
![PVT curve](image2)

Figure 2 Fluid Physical Property Curve of Deep Water Gas Reservoir

3.2. Study on water invasion characteristics of edge and bottom water in deep water gas reservoirs

Through the mechanism model of deep-water gas reservoir, the development effect of gas reservoir with or without edge water invasion is calculated, as shown in figs. 3 and 4:

![Vertical well model of gas reservoir](image3)
![Vertical well model of edge water gas reservoir](image4)

Figure 3 Water invasion characteristics of vertical wells in deep water gas reservoirs

![Horizontal well model of gas reservoir](image5)
![Horizontal well model of edge water gas reservoir](image6)

Figure 4 Water invasion characteristics of horizontal wells in deep water gas reservoirs
Through numerical simulation, the effect of water invasion on gas reservoir development is studied quantitatively. From the results, it can be seen that the ultimate recovery and sweep volume of water invasion gas reservoir are significantly smaller than that of gas reservoir (Table 2). The horizontal well production effect for deep water gas reservoir is better than that of vertical well production. According to the water invasion characteristics of deep-water gas reservoirs, if the uniform advance of edge fixed water can be controlled, the recovery factor can be effectively improved.

Table 2 Water invasion development effect of deep water gas reservoir

|               | Vertical well | Horizontal well |
|---------------|---------------|-----------------|
|               | gas reservoir | Bottom water gas reservoir | Edge water gas reservoir | gas reservoir | Bottom water gas reservoir | Edge water gas reservoir |
| recovery ratio (%) | 72.4          | 57.8            | 61.3          | 75.6          | 59.5          | 64.8          |
| Sweep volume (%)  | 78.2          | 63.6            | 66.8          | 81.6          | 65.5          | 70.6          |

4. Study on the Effect of Water Control Technology in Deep Water Gas Reservoir

4.1. Construction of numerical simulation of water control process

Petrel RE software is used to set up wellbore and stratum of water control technology and simulate operation to study gas production effect of different water control technology. Firstly, the horizontal section is infilled, and the wellbore model, the parameters of the horizontal section, the water body model and the parameters of the horizontal section are built to simulate the development effect of different water control technologies. As shown in Figure 5:

4.2. Study on the effect of water control technology

Water control technology mainly uses different water control mechanisms and different production modes to control the water invasion speed of gas reservoir, to maximize the uniform advance of edge
and bottom water, to minimize the loss of water invasion reserves, thereby improving gas reservoir recovery and improving gas reservoir development effect. The water control technology in this paper includes central pipe, bypass pipe, variable density screen pipe and superhydrophobic material.

(1) Study on the effect of central water control
The central water control technology can effectively control root effluent by placing a central pipe in the middle of the horizontal screen tube to change the root fluidity of the horizontal section. Its water control effect is shown in Fig. 6:

Under the condition of central pipe, the wellbore pressure profile is divided into two sections. The inflow profile is more uniform than the single section, which can effectively prevent the early water breakthrough at the heel of the wellbore and improve the recovery factor.

(2) Study on bottom hole water control effect of bypass pipe
By-pass pipe bottom hole water control technology can achieve balanced fluid production by realizing oil and gas cross-grade flow at toe end and balancing production pressure profile in horizontal section. Its water control effect is shown in Figure 7:

Under the condition of by-pass pipe bottom hole, the wellbore pressure profile is divided into several sections and distributes in the shape of wavelet. The inflow profile is flat again, which can
balance the radial inflow along the wellbore, effectively prevent bottom water ridge inflow and improve recovery.

(3) Study on Water Control Effect of Variable Density Screen Tube

By changing the number of holes per unit length of sieve tube, variable density sieve tube can achieve balanced water control. Its water control effect is shown in Fig. 8:

![Figure 8 Water Control Effect Chart of Variable Density Screen Tube](image)

The variable density sieve pipe can eventually achieve the goal of balancing the radial inflow along the wellbore and reducing the ridge inflow of bottom water by adjusting the water influx of edge and bottom water.

(4) Study on Water Control Effect of Super-hydrophobic Materials

Superhydrophobic material water control technology is through superhydrophobic molecular coating on the material, using the principle of surface tension to achieve hydrophobic effect, good permeability and water resistance, and can withstand higher pressure and temperature conditions. Its water control effect is shown in Fig. 9:

![Figure 9 Water Control Effect Chart of Super-hydrophobic Material](image)

Super hydrophobic materials can prevent water and gas production and slow down water coning.
Study on the Effect of Different Water Control Technologies

Comparing different water control processes, the effect is shown in Fig. 10:

Figure 10 Effect Chart of Water Control Technology for Water Infiltration Gas Reservoir

Super-hydrophobic materials are mainly water-blocking and gas-producing, with a slight delay in water-breakthrough time. The technology of central pipe, annulus multistage bottom hole and variable density screen pipe mainly controls the ridge advance of bottom water in advance, adjusts the water invasion profile, and makes the edge and bottom water advance more evenly. The technology of variable density sieve has the best effect. The water breakthrough time is delayed by 3.8 years, and the recovery and sweep volume are increased by 12.8% and 13.3% respectively.

5. Conclusion

(1) Based on the analysis and summary of the physical properties of deep water gas reservoirs, a mechanism model is established which conforms to the actual situation of deep water gas reservoirs.

(2) The numerical simulation of deep-water gas reservoir is carried out, and the development effect of horizontal wells in deep-water gas reservoir is better than that of vertical wells. According to the water invasion characteristics of deep-water gas reservoirs, if the uniform advance of edge fixed water can be controlled, the recovery factor can be effectively improved.

(3) Petrel RE software was used to construct numerical models of different water control processes and analyze the effect of water control. Super-hydrophobic materials are mainly water-blocking and gas-producing, with a slight delay in water-breakthrough time. The technology of central pipe, annulus multistage bottom hole and variable density screen pipe mainly controls the ridge advance of bottom water in advance, adjusts the water invasion profile, and makes the edge and bottom water advance more evenly. The technology of variable density sieve has the best effect. The water breakthrough time is delayed by 3.8 years, and the recovery and sweep volume are increased by 12.8% and 13.3% respectively.

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