Research on Water Control and Production Enhancement Process in TY Gas Field

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Abstract—In order to solve the problem of water intrusion seriously affecting the development of each production well in TY gas field, a numerical model was established with reference to well X in TY gas field to study the characteristics of water intrusion in TY gas field, and four sets of water control and production increase experiments were completed, including elastic extraction experiment, water plugging experiment, side drilling experiment and combined water plugging and side drilling process experiment, which were verified by physical experiments on this basis. The results show that different water control and production enhancement measures have different effects, among which the combination of water plugging and lateral drilling process has the best effect, which can increase the gas production by 84.1%, and the error between the physical experiment results and the numerical simulation results is 7.7%.

1. INTRODUCTION

Water intrusion during gas reservoir development can lead to rapid pressure drop in gas wells, resulting in a decrease in reservoir recovery, gas field development benefits, increased production management workload and safety and environmental risks, and in severe cases, even cause flooding of the reservoir, causing irreversible damage to the reservoir [1]. TY gas field sandstone development, fracture system complex reservoir thickness is generally around 200-600m, porosity average 19.8%, permeability 136mD on average, which is a medium pore medium permeability reservoir. At present, there are few development wells in this block, and there are problems of insufficient understanding of water intrusion characteristics and the distribution pattern of remaining natural gas reserves. As the gas reservoir enters the late stage of development, the rate of advancing water at the bottom of the margin accelerates, and the water volume starts to rise sharply in a short period after 2011, and then the gas production drops sharply, which makes it difficult to stabilize the gas production.

In recent years, a large number of domestic and foreign experts have carried out numerical simulations [2-4] and physical experiments [5-9] on water intrusion in gas reservoirs in order to solve the problem of water control and production increase in gas reservoirs, but there are no actual cases of successful water control and production increases in gas wells that have seen water at low exploitation levels. Therefore, in this paper, based on the existing research content, we study the water intrusion characteristics of gas field by establishing a numerical model for well X in TY gas field as an example, and conduct numerical simulation and physical simulation experiments of water control process based on it, focusing on the evaluation of the effect of water control and production increase measures, and provide a basis for the implementation of water control and production increase process in TY gas field.

2. NUMERICAL SIMULATION PROCESS

2.1 Numerical modeling

In this study, on the basis of reservoir geological modeling, combined with production dynamic information, and according to the actual situation of the study area, the geological structure model, attribute model, numerical model, reserves and history fitting process of TY gas field is completed sequentially by modeling software. Fault polygons are used to complete the fault modeling, and then accurate fault waveforms are established by combining seismic interpretation data and single well data. Considering the geological conditions of the study area, the accuracy of the model and the amount of numerical model operations, a 50×50m grid of corner points parallel to the
main axis direction of permeability was finally selected. In order to avoid the non-homogeneous differences caused by the different time of reservoir deposition formation, the model is divided in the vertical direction based on the stratification data. The study area is modeled with phase-controlled properties using the sedimentary phase data as a constraint, and the porosity model is established by using the sequential Gaussian stochastic method to simulate the relationship between permeability and porosity, and the porosity is used as the second variable in the co-simulation to ensure a good positive correlation between porosity and permeability in the study area and improve the accuracy of the model. Finally, the reservoir and history of the whole area and single wells were fitted to the model to verify the accuracy of the model. The fitting results show a good degree of fit and the errors are within reasonable requirements. The numerical model is shown in Figure 1.

2.2 Water intrusion characterization

The water intrusion pattern of well X is shown in Figure 2. At the beginning of production, bottom water showed an overall, slow uplift, and after 6 years, the bottom water rise rate increased significantly, and bottom water began to intrude laterally into the bottom of the well from the northwest in 8 years of production, with obvious local protrusion phenomenon. From production to 2019, the X-well reservoir was completely flooded, and bottom water intruded to about 60m of the gas-water interface in the northwestern part of the well location,

![Figure 2. X-well water intrusion characteristics](image)

while water intrusion basically did not occur in the part of the well location and only caused the gas-water interface to move up about 10m in the vertical direction, and the overall reservoir was still mainly gas-bearing. From the lateral analysis of the gas-bearing situation at different depths, the reservoir at the bottom of well X is completely flooded and the water saturation of the reservoir plane decreases with increasing distance from the gas-water interface, while the top reservoir is less affected by water intrusion. Above 20m at the gas-water interface, well X is completely flooded; above 40m at the gas-water interface, the degree of water intrusion decreases, and the degree of water intrusion at the well point location is greater; above 60m at the gas-water interface, the reservoir is mostly gas.

The main factor causing water intrusion in well X is the non-homogeneity of the reservoir, the high degree of sandstone development in the northwest, which provides a dominant water intrusion channel, and the bottom water bursts into the bottom of the well along the strip with a larger effective sandstone thickness.

2.2.1 Water control and yield increase program design

According to the water intrusion characteristics and production situation of well X, four sets of water control and production increase experiments were designed, namely, elastic extraction experiment, water plugging experiment, side drilling experiment and combined water plugging and side drilling process experiment, to simulate the production dynamics of well X in the next 20 years. The water plugging process is to close the hole from -909.5m to -926.1m and shut down all the injection holes below -941.4m, with a production rate of 10,000 m³/d; the lateral drilling process is to drill laterally at the top of the reservoir towards the remaining gas area in the northwest direction on the basis of the water plugging experiment, with all the injection holes in the horizontal section of 200m, with a production rate of 40,000 m³/d.

2.3 Water control and yield increase program design

The numerical simulation results are shown in Figure 3 and Table 1. The results of numerical simulation show that, compared with the elastic extraction experiment, the remaining three groups of experiments have different effects on water control and production increase, among which the water plugging process can effectively reduce the water production of

![Figure 3. Numerical modeling of TY gas fields](image)
gas wells by blocking the water-emitting layer, but as the production progresses, the gas-water interface continues to rise and the degree of water intrusion increases, and the gas recovery rate is limited due to the low reservoir permeability at the top of the gas reservoir, resulting in low production. The combination of water plugging and lateral drilling process can minimize the degree of water intrusion and increase production at the same time, which has the optimal effect of water control and production increase, and can extend gas recovery and increase gas production by 84.1% compared with the water plugging experiment.

### Table 1: Numerical Simulation Results

<table>
<thead>
<tr>
<th>Water control process</th>
<th>Flexible mining</th>
<th>Water plugging process</th>
<th>Side drilling process</th>
<th>Combined water plugging and side drilling process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas production volume (10^4 m³)</td>
<td>1638.2</td>
<td>1789.3</td>
<td>2545.7</td>
<td>3014.5</td>
</tr>
<tr>
<td>Increase the percentage of gas production (%)</td>
<td>0</td>
<td>9.2</td>
<td>55.4</td>
<td>84.1</td>
</tr>
</tbody>
</table>

### 3 Physical Simulation Process

In order to verify the numerical simulation results and guide the effective water control and production increase in TY gas field, the simulation of water control and production increase process was carried out with well X in TY gas field as the experimental reference. The physical experiments were conducted in a three-dimensional high-temperature and high-pressure resistant reactor with a maximum withstanding pressure of 75 MPa and a maximum temperature of 150°C. The inner chamber of the reactor was a square body of 0.5m×0.5m×0.5m, in which several pressure sensors and 105 water saturation sensors were set. Water distilled water was injected into the bottom of the reactor by ISCO pump to simulate the bottom water equalization injection in the formation. The overall experimental parameters were designed according to the similar theory of physical simulation of gas reservoir development [10], and the temperature and pressure were the same as those of the TY gas field while ensuring that the sand-fill model used the same pore medium, fluid density and viscosity as the gas reservoir, and the simulated wells were located in the middle of the kettle body with a length of 35 cm, the average porosity of the sand-fill after compaction was 20%, and the permeability of each section of the reservoir and the corresponding cores were 25:1 Equivalence is performed.

According to the numerical simulation scheme, a physical experiment was designed to simulate the production situation within 5 hours, as shown in Figure 4: the elastic extraction experiment is to extract without any

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**Figure 3.** Numerical simulation of production dynamic curves

c Side drilling process
d Combined water and side drilling process
measures relying only on formation energy; the water plugging experiment is to close the injection hole in the straight section below the gas-water interface; the sidetracking process is to set a sidetracking well with a length of 5 cm at 10 cm from the wellhead position in the straight section for production.

The results of the physical experiments are shown in Figure 5, Table 2. The experimental results are basically consistent with the numerical model results, in which the combination of water plugging and lateral drilling process can maximize the gas recovery, and improve the gas volume by 77.6% compared with the elastic extraction experiment, with an error of 7.7% compared with the numerical simulation results, which proves the effectiveness and feasibility of this water control and production increase scheme.

<table>
<thead>
<tr>
<th>Water control process</th>
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<th>Water plugging process</th>
<th>Side drilling process</th>
<th>Combined water plugging and side drilling process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas production volume(L)</td>
<td>9.8</td>
<td>10.8</td>
<td>14.6</td>
<td>17.4</td>
</tr>
<tr>
<td>Increase the percentage of gas production(%)</td>
<td>0</td>
<td>10.2</td>
<td>49.0</td>
<td>77.6</td>
</tr>
<tr>
<td>Tolerance(%)</td>
<td>0</td>
<td>10.9</td>
<td>11.6</td>
<td>7.7</td>
</tr>
</tbody>
</table>

4 CONCLUSIONS

(1) By establishing a numerical model to analyze the water intrusion characteristics of well X in TY gas field, the degree of water intrusion decreases with increasing distance from the gas-water interface, and most of the reservoir above 60m at the gas-water interface is gas, which still has a large development potential;

(2) Different water control and production enhancement measures have different effects, among which the combination process of water plugging and lateral drilling is more effective and can increase the recovery rate gas production by 78.7%;

(3) The physical experimental results are consistent with the numerical simulation results, in which the error of the combined process of water plugging and lateral drilling to increase gas production is 8.4% compared with the numerical simulation results, which proves the effectiveness and feasibility of the water control and production increase scheme.

ACKNOWLEDGMENT

This work was supported by the Natural Science Foundation of Hainan Province under the project of "Phase change-pore-stress-percolation" synergistic control mechanism of hydrate sand production (521MS0793) and the major science and technology program of Hainan Province under the project of "Deepwater intelligent drilling and completion key technology and drilling and logging tool development" (ZDKJ2021025).

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