Study on the seepage characteristics and influencing factors of low permeability reservoir based on microscopic seepage experiments in real sandstones-taking Dongsheng gas field in Hangjinqi area as an example

Zhanyang Zhang1, Tao Lei1, Ting Hao1, Jianbiao Wu1, Hui Guo1, Di Chen1, Yushuang Zhu2

1Sinopec North China Oil & Gas Branch, Zhengzhou, Henan 450006, China
2State Key Laboratory of Continental Dynamics/Department of Geology, Northwest University, Xi’an, 710069, China

Abstract: Taking the dense sandstone gas reservoirs of Shibang Group and Shanxi Group in Dongsheng area of Ordos Basin as an example, based on the characterization of the dense sandstone reservoirs in the study area in terms of petrological features, pore structure and diagenesis, we carried out real sandstone microscopic seepage experiments to analyze the gas-water seepage law and fluid storage state of different types of reservoirs, and systematically evaluated the efficiency of gas-water repulsion from the dense sandstone reservoirs and the microscopic influencing factors. The results show that the study area has strong non-homogeneity and different degrees of pore density, so a variety of fluid transportation channels are formed, and different transportation channels represent different types of evacuation. When the residual pore space and dense sandstone microporous space exist at the same time, gas and water are mainly transported along the residual pore space, and the microporous space of the dense particles almost does not enter; gas and water transport is very much affected by permeability, and the transport resistance will increase with the decrease of permeability; the pressure has a certain effect on the efficiency of the replacement, but it can only improve the efficiency of the replacement to a certain extent; the fluids in the process of rock transport, there will be varying degrees of bubbles stuck off In the process of fluid transport in the rock, there will be different degrees of bubble jamming phenomenon, resulting in the transport needs to overcome a large capillary resistance, which greatly increases the replacement pressure; for the low-permeability sandstones in Hangjinqi area, the good homogeneity of the pore structure of the conductor does not mean that the transport effect is good, in the area of the conductor pore space is strongly developed, the gas-water transport will form an advantageous channel, and its transport effect is better.

1 Introduction

Tight sandstone reservoir is a reservoir type with significant mine resource prospects. However, its heterogeneity is strong, which brings certain challenges to natural gas exploitation and reservoir evaluation [1,2]. The results of the study show that the efficiency of gas reservoir development is mainly affected by internal factors of the reservoir and external factors of the development system and thus is low due to the lack of energy supplementation; Visual seepage experiment of real sandstone is one of the main means to characterize the microscopic seepage characteristics of unconventional reservoirs, which has advantages in the study of microscopic seepage mechanism and fluid storage state because of its obvious intuition and authenticity [3]. Therefore, it is very important to study the influence of geological characteristics and development regime of tight sandstone gas reservoirs on production efficiency in order to use this technology.

At present, there are fewer researches to explore the microscopic seepage law and influencing factors for the low development efficiency of Dongsheng gas field in Hangjinqi area of Ordos Basin. In this study, Dongsheng gas field was taken as the research object, and representative samples were selected to carry out microscopic gas-driven water seepage experiments. The seepage law and fluid storage characteristics of gas drive water were explored by means of scanning electron microscopy, casting thin sections and high-pressure mercury injection, and the influencing factors were analyzed by combining the microscopic image of gas drive water seepage, in order to provide guidance for the development of similar reservoirs.

2 Geology

The Ordos Basin is the second largest sedimentary basin in China, with an area of 37×10^4 km^2, from Yinshan in
the north to Qinling in the south, Lvliang Mountain in the east and Tengger Desert in the west (fig 1) [4]. The study area was in a long-term uplift state before the late Paleozoic, and began to be reaccepted for deposition in the Late Carboniferous. The Upper Paleozoic strata overlap on the mixed metamorphic rock basement from south to north. From bottom to top, the Carboniferous Taiyuan Formation, Permian Shanxi Formation, Lower Permian Lower Shihezi Formation, Upper Permian Upper Shihezi Formation and Shiqianfeng Formation were successively deposited. The Triassic, Jurassic and Cretaceous strata were successively deposited in the Mesozoic, and the Cenozoic strata were lost due to tectonic uplift. The layers of this study are the Shanxi Formation and the Lower Shihezi Formation.

3 Basic reservoir characteristics

Dongsheng gas field is mainly located in the north of Ordos basin and the south of Yimeng uplift. The main producing formations in the study area are divided into Shanxi Formation and Shihezi Formation [5,6].

The Lower Shihezi Formation is developed in the study area. The lithology is mainly sandstone, with a small amount of argillaceous rock. The sandstone color is mainly light gray-green, gray-white and gray-yellow, and the grain size is mainly gravel-bearing coarse-medium sandstone and fine sandstone. The mudstone is mainly purple brown, brown and gray green. According to the sedimentary cycle, the Lower Shihezi Formation is divided into three sections, namely, He 1, He 2 and He 3 section. The content of lithic sandstone and quartz in the sandstone of the Lower Shihezi Formation is high, mainly developed lithic sandstone and feldspathic lithic sandstone, which are well sorted and rounded.

3.1 Physical characteristics

Based on the physical property test statistics of Dongsheng gas field reservoir samples and the relevant data collected on the physical properties of the target layer in the study area (fig 2), the porosity is distributed between 5 and 9%, with an average of 8.76%; the permeability is distributed between 0.19 and 1.4 mD, with an average of 0.92 mD. The distribution of the porosity-permeability relationship shows that there is a good positive correlation between permeability and porosity. With the increase of porosity, permeability increases gradually.

3.2 Detrital composition and interstitial material development characteristics

Through the analysis of the lithology data of the Lower Shihezi Formation in the collected samples, it is found that the lithology of different target intervals in the study area is quite different. The lithology of the Shan 2 Member and the Lower Shihezi Formation in the study area is similar, with higher lithic content, while the Shan 1 Member is significantly different, with lower lithic content, mainly quartz sandstone and sub-lithic sandstone [7]. Therefore, in this study of the target layer, the Shan 1 and Shan 2 members and the Lower Shihezi Formation were studied separately, and the differences in rock characteristics within the same target layer were analyzed.
3.3 Distribution characteristics of pore structure

The high-pressure mercury injection testing was mainly used to study the reservoir pore structure (Table 1). Although the high-pressure mercury injection cannot separate the pores and throats, it can reflect the development of smaller pore and throats due to its large experimental pressure and is very suitable for low-permeability reservoirs. High-pressure mercury injection can characterize the pore throat size, heterogeneity and connectivity of the reservoir.

<table>
<thead>
<tr>
<th>type</th>
<th>sample</th>
<th>por/%</th>
<th>sem/mD</th>
<th>median pressure /Mpa</th>
<th>median radius/μm</th>
<th>displacement pressure/Mpa</th>
<th>SHg/%</th>
<th>mercury withdrawal efficiency/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>D-35</td>
<td>13.623</td>
<td>2.198</td>
<td>2.446</td>
<td>0.300</td>
<td>0.280</td>
<td>83.563</td>
<td>29.778</td>
</tr>
<tr>
<td>II</td>
<td>D-9</td>
<td>11.218</td>
<td>1.003</td>
<td>15.835</td>
<td>0.046</td>
<td>1.164</td>
<td>76.253</td>
<td>32.920</td>
</tr>
<tr>
<td></td>
<td>D-15</td>
<td>5.940</td>
<td>1.099</td>
<td>36.706</td>
<td>0.020</td>
<td>0.740</td>
<td>66.633</td>
<td>40.223</td>
</tr>
<tr>
<td></td>
<td>D-18</td>
<td>9.241</td>
<td>2.538</td>
<td>0.290</td>
<td>0.271</td>
<td>71.759</td>
<td>29.974</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>D-5</td>
<td>5.253</td>
<td>0.418</td>
<td>116.268</td>
<td>0.006</td>
<td>1.804</td>
<td>57.498</td>
<td>35.255</td>
</tr>
<tr>
<td></td>
<td>D-25</td>
<td>4.430</td>
<td>0.307</td>
<td>114.781</td>
<td>0.006</td>
<td>1.169</td>
<td>57.330</td>
<td>36.718</td>
</tr>
</tbody>
</table>

Fig.3 High pressure mercury intrusion curve

Based on the mercury injection data and capillary pressure curve (fig 3), combined with the relevant characteristics of the reservoir physical properties in the study area, the results show that the mercury injection curves can be divided into three categories (fig 1).

4 Reservoir seepage characteristics

4.1 Instruments and equipment and experimental steps

The microscopic simulation experiment system includes three parts: real sandstone microscopic model, microscopic observation system (mainly solid microscope, equipped with a camera and video system to monitor and observe the experimental process, and can take photos and videos at the same time) and pressurization system [3,8].

In the gas-water displacement experiment, the simulated gas used in the experiment is nitrogen, and the simulated water is distilled water.

4.2 Experimental result

4.2.1 Type-Ⅰ

In the process of water flooding, when the inlet pressure is 79.4KPa, water fills the channel and enters from the middle first, and the speed is slow. After pressurizing, the water is rapidly fingered forward and reaches the outlet; if the displacement pressure is reduced to below the outlet pressure, the water stops flowing, but the water still retains the original channel. At this time, if the pressure is increased again, the water still advances along the original channel, and the outlet pressure does not change (fig 4).
4.2.2 Type-Ⅱ

In the process of water flooding (Fig.4), when the inlet pressure is 35.5KPa, the water filling groove enters from the bottom first, and the speed is slow. After pressurization, the water moves forward along the bottom and the range gradually expands. If the displacement pressure is reduced to below the outlet pressure, the water stops flowing, but the water still retains the original channel. With continuous pressurization, the water still advances along the original channel, and the water flooding range does not change.

4.2.3 Type-Ⅲ

In the process of gas water driving (fig 4), when the inlet pressure is 45 KPa, the gas enters the matrix from the lower part after filling the groove at a slow speed. After continuous pressurization, the range of gas flooding has not been significantly expanded; If the displacement pressure is reduced to below the outlet pressure, the gas stops flowing, and the original channel is separated by the liquid to form a new resistance. At this time, the pressure is increased, and a new channel appears in the middle, and the outlet pressure increases.

In the process of saturated water entering the matrix, the saturated water enters very slowly. Finally, the saturated water enters the matrix more completely, but it takes a longer time.

4.3 Occurrence state of residual water

The original water saturation of Dongsheng ranges from 47.37% to 66.0%, with an average of 56.06%. The shapes of residual water observed after gas-driven water mainly include: Residual water at the corner, Membrane residual water, and Cluster residual water (fig 5).

Based on the above analysis, the occurrence state of formation water in the microscopic pore throat is divided into three types: free water, capillary water and bound water.

Bound water refers to groundwater that is bound to the surface of mineral particles or exists in the corner of pores and cannot flow.

Capillary water develops in the micro-pore throat of reservoirs with low porosity, low permeability and strong heterogeneity. It cannot move freely under the action of gravity, and the water output after fracturing is generally small.
5 Influencing factor

5.1 Permeability and gas migration resistance

As the permeability of the model decreases, the displacement pressure applied to the model increases significantly. Physical properties and irreducible water content control different types of formation water content and residual water saturation. (fig 6).

5.2 Pressure and displacement efficiency

The pressure can improve the displacement efficiency within a certain range, but after reaching a certain degree, that is, the injected water has formed a relatively stable seepage channel. Increasing the pressure can only increase the flow rate of water, but has little effect on the displacement efficiency [2,9].

With the increase of displacement pressure gradient, the residual water saturation decreases continuously (fig 7). The results show that the correlation coefficient on the intersection diagram of displacement pressure gradient and residual water saturation reaches 0.94, and the correlation coefficient between porosity and permeability and residual water saturation is low, only 0.23. Therefore, when the displacement pressure gradient is quite constant, the physical properties control the residual water saturation.

5.3 Bubble breaking phenomenon in the migration process

During the displacement experiment, different degrees of bubble breakage were observed, that is, the advancing continuous gas phase was broken when passing through the pore throat. After the broken bubble moved forward, it was necessary to overcome the large capillary resistance, resulting in the abnormal outburst of the Jamin effect, thus increasing the displacement pressure.

When the pressure decreases, the continuous gas column will be disconnected from certain parts during the gas migration process, which destroys the continuity of the gas and also increases the capillary resistance of the gas migration.

6 Conclusion

1. Due to the differences in the size of the model particles and the developed cements, the pore density is different, thus forming a variety of fluid migration channels. When the residual pores and the micropores of tight sandstone exist at the same time, gas and water mainly migrate along the residual pores, and the micropores of tight particles almost do not intake air and water.

2. The migration of gas and water is greatly affected by permeability, and migration resistance will increase with the decrease of permeability; pressure has a certain impact on displacement efficiency.

3. During the migration of fluid in rocks, bubble droplets will get stuck, which makes the migration need to overcome a large capillary resistance, thus greatly increasing the displacement pressure.

Acknowledgement

This work is financially supported by the scientific research project of Shaanxi Provincial Department of Science and Technology (No.2024JC-YBQN-0563); the Postdoctoral Research Project in Shaanxi Province, China (No.2023BSHYDZZ131).

Reference


