Developing Situation and Trend Analysis of Combined Well Pattern of Horizontal Well in Low Permeability Reservoir: Case in Yushulin Horizontal Wells in the Development Block

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1 Introduction

Now, the key of oil-field’s increase production is the development technology for extra-low permeability reservoirs whose porosity is less than 5% and permeability less than 5 mD. The technologies of horizontal well, fracturing and gas driving are the advanced means of improving recovery. The complexity of forming conditions, microscopic holes roar conditions, percolation mechanism of extra-low permeability sandstone reservoirs cause serious difficulties in the use of these technologies for development. YⅠ7 reservoir of Yushulin oil-field is a kind of typical extra-low permeability reservoir, whose average porosity is 11.5%, air permeability is $2.21 \times 10^{-3}$ $\mu m^2$ (Shi Jingping, 2003). Since 1993, the reservoir has been in the development of vertical wells for 14 years, combined well pattern of horizontal-vertical well of water driving experiment for 4 years and another 4 years of combined well pattern of horizontal-vertical well of carbon dioxide driving experiment (Li Chuanjiang, 2009). It is basically in the forefront of extra-low permeability reservoir development in China. Based on YⅠ7 reservoir of Dong14 area, summary and analysis of relevant literature, this paper has analysed all stages of development issues and correlative controlling factors to explore the appropriate solutions of the combined well pattern of horizontal-vertical well.

2 Complex Pore Structure Anisotropism of the Study Area

The core experiment data of adjacent wells show that the deposition to the reservoir pore structure characteristics is mainly influenced by argillaceous fillings and skeleton particles characteristics of reservoir. The rock particles with more thoroughly weathering before sedimentation and weaker hydrodynamic environment will have higher shale content and finer skeleton particles in the reservoir. So low porosity and permeability reservoir characteristics are more obvious (Fig.1a). When the agglutinate between particles in the process of digenesis is higher and the agglutination and compaction are stronger, the characteristics of low pore and permeability reservoir is more obvious (Fig.1b).

The major reservoir of Dong14 block is YⅠ7. The oil area is 0.9km$^2$, and the average effective thickness is 6.4m. The top structure of YⅠ7 is a grabbed block, whose shape is “Y”. YⅠ7 has a stable development and bigger effective thickness. Its middle part is thick and the around is thin. The sedimentation type of sand body is distributaries channel marginal bank sedimentary. It is ribbon in plane, and it appears lateral accretion in profile. The width of sand body is 800~1500m, length is more than 2000m, and the burial depth is 2026~2125m. The level shift of permeability is up to 20.1, the anisotropy ratio is 0.38. The anistrope of sand bodies and planes is worse (Table 1). Previous studies show that the property of reservoir and the ability of percolating of oil and gas are greatly restricted by extra-low porosity and permeability (Zhang Meiling, 2011).

3 Development Effect of Horizontal Well Water Driving in Study Area

The Dong14 block of Yushulin oil-field was put into production at the end of 1993. The form of well pattern is 300 m× 300 m, and direction of wells row is north east 77.5°. It’s direction is basically identical to the direction of maximum horizontal main stress of the block (Li Chuanjiang, 2009). And it uses anti-nine point area water
flooding. There are 15 development wells in test area, and all the developed reservoir are perforated and put into production. The average daily water injection at preliminary stage of four water injection wells is 61m³/d, and the pressure of water injection is 18.8MPa. The average daily liquid production of single well of 11 production wells is 6.0t/d at preliminary stage, the daily oil production is 5.2t/d, the moisture content is 13.9%, and production speed is 2.1%. To 1999, production declined quickly. The production speed declined to 0.13%, the average oil production of single well is 0.9t/d.

For the situation of poor using and low speed of oil production, we took infilling adjustment measures in September 1999. The ratio of oil and water wells is up to 1.78. Well spacing density increased from 11.1 wells/km² to 44.4 wells/km². At preliminary stage, the average daily water injection of single well is 6.0t/d at preliminary stage, the daily oil production is 5.2t/d, the moisture content is 13.9%, and production speed is 2.1%. To 1999, production declined quickly. The production speed declined to 0.13%, the average oil production of single well is 0.9t/d.

Fig.1 Influence of shale content (Vsh) and calcium content (Vca) on the porosity and permeability of Y17 layer

Then we tried to use the mode, which combine the water injection of horizontal well and production oil of vertical well with well pattern against Y17 in February, 2007. We shrink the row space to 75 m, and the oil well row space to 150 m.

The productivity increased effectively in the oil wells after putting in horizontal wells. The daily oil production of single well reached 2.0t/d at the preliminary stage. The oil pressure of water injection in horizontal wells is 25MPa and the injection amount is 25m³/d. 14 months later, the oil pressure increased to 29MPa and the water absorption was lower. Despite the drilling way of horizontal wells is widely used with its function of extending the area of oil drilling of low permeable reservoir and increasing the recovery efficiency (Vo D.T., et al., 1997). Summarizing the data undertaken in this respect and the corresponding research in several large oil-fields, it can be found that the horizontal joint well net of extra-low porosity and permeability reservoirs mostly experienced several production stages. The oil production raised from the rise to the final decline of stability and the ultra-low permeable reservoir YⅠ7 of the Dong14 block of Yushulin oil-field further reflected that the surrounding wells experienced three production stages of increasing production, stable production and decreasing production. Among those the period of the stable production is short mainly because that the long-term water absorption capacity of the horizontal wells was poor.
and stable.

The consequence of the starting pressure gradient test about the cores with different permeability in the Fuyang oil reservoirs indicated that a better power function relation exists between the starting pressure gradient and the permeability. And the starting pressure gradient increased with the reduction of permeability. The starting pressure gradient increased sharply when the reservoir permeability is lower than 1×10⁻³ μm². The lower the permeability, the higher the starting pressure gradient. Even adopting the mode of water injection of horizontal well under the higher injection pressure, it is also difficult to establish an effective driving system (Figure 2).

Table 1 Plane anisotrop of Dong14 area in Yushulin oil-field

<table>
<thead>
<tr>
<th>Layer</th>
<th>Even permeability</th>
<th>Level shift of permeability</th>
<th>Coefficient of Variation</th>
<th>Anisotrope ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y17</td>
<td>1.58</td>
<td>20.10</td>
<td>0.69</td>
<td>0.38</td>
</tr>
</tbody>
</table>

4 Development Effect of Horizontal Well Gas Driving in the Study Area

Carbon dioxide gas drive can make crude oil inflate, reduce viscosity of crude oil, change the density of crude oil, acidize the rock, make the light fraction of crude oil vaporization and extraction, decline the pressure leading to dissolving the gas flooding, and reduce the interfacial tension. Several factors play a relevant role in oil displacement under the condition of different temperature and pressure and the crude oil composition, which reduce the impact of pore throat radius, solid liquid interaction and starting pressure gradient under the condition of water flooding, and improve the oil displacement efficiency (Zhang Yanyu, 2007).

So we carried out the gas injection in the horizontal joint well in May, 2010. The distance between wells narrows, forming the well pattern of which row spacing is 75 m and well spacing is 150m (Because of the exist of well deviation, the row spacing and the well spacing underground is complex. Therefore, combined with the actual condition when evaluating the development effect). Finally form the development mode of joint well net that inject gas in 3 horizontal wells and extract oil in 20 vertical wells (Fig. 3). Horizontal wells adopt the work system which is intermittent gas injection. The effect of the oil-field was obvious when injection pressure is stable at 25MPa and the injection rate is 10m³/d. The average daily oil production of single well of 11 infill vertical wells is stable from 0.5t/d at the preliminary stage to 1.12t/d that form the effective displacement. But the oil production is not good. According to the analysis, it can be concluded that because of complex inner structure of the reservoir, uneven distribution of remaining oil and the great changes of vertical property that lead to the low degree of reserves controls. At the same time, It is because of the effect of horizontal well trajectory and the role of gas drive overlap that caused low degree of producing reserves.

5 The Future Research Trend Based on the Current Situation

In the last few years, the effective flooding development mode of horizontal well and vertical well combined well pattern in low permeability reservoir has some exploration results in theory and practice. The first, in the research of water flooding and gas drive mode theory, we should find out the influence of bottom water drive and edge water drive way of horizontal well production; In theory, study the effect of gas injection by different injection methods, such as advanced gas injection, periodic injection and intermittent gas injection (Jiang Youwei, 2010). Secondly, in the concrete production practice, the law of groundwater seepage field is detected by using micro seismic method. Meanwhile, the practice of carbon dioxide gas intermittent injection, carbon dioxide gas continuous injection, carbon dioxide gas and water alternating injection, etc., is also used to explore the recovery rate. Thirdly, due to horizontal well goes through the rock, the vertical and horizontal stress for crack formation have very different effects on the vertical well, which further promote the development of horizontal well fracturing theory and numerical simulation technology. The first research focuses on the theoretical and experimental aspects of three direction underground stress, and the hydraulic fracture
shape and extension. The second is about fractured horizontal well productivity prediction, the focus is in the more advanced numerical reservoir under the guidance of the study on the fracture characteristics and fracture zone, unfractured zone, cracks and well bore fluid flow features, the formation of as far as possible consistent with the actual production capacity prediction model (David Pardo, 2013).

Research area of the horizontal well water flooding and gas drive development practice in recent decades shows that effective flooding of the ultra-low permeability oilfield is a work closely related to the theory and field practice. At present, the domestic and foreign research results are still limited in the theory and practice of the trial stage, the development of theoretical research to the actual production of the guiding role is still limited, the effective integration of the technology system has not yet been formed. Therefore, it is necessary to from the domestic and foreign low permeability oilfield horizontal well pattern theory and practice of research starting, combined with examples of Yushulin Oil field development is given practical application, improve the recovery rate of super low permeability reservoir development system technology.

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