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Abstract. In order to develop the Shenmu gas field efficiently, the development technology policy of Shenmu gas field was studied, including rational partition of layer series, the abandonment condition, and the reasonable production proration. The results show that the Shanxi Fm and Taiyuan Fm of Shenmu gas field gas reservoir can adopt a series of strata to product. The abandonment production rate of single well is 0.2×10⁴ m³/d. The abandonment formation pressure in Shenmu gas field is 5.29-5.44 Mpa. For the present well spacing of 151 wells and the wellhead pressure of 5 Mpa, the corresponding production scale can’t be greater than 12×10⁸ m³/a. For the lowest wellhead pressure of 2 Mpa, the corresponding production scale should not be greater than 14×10⁸ m³/year.

Introduction

Shenmu Gas Field, which borders Yulin, Daniudi, Zizhou and Mizhi Gas Fields, is located in Yuyang District and Shenmu Country, Yunlin City, Shaanxi Province, with an exploration area of 3×10⁴ km². The gas field is structurally located in the secondary structural unit, northeastern Yishan Slope, in the Ordos Basin, and its structural form is a gentle west-dipping slope, with a gradient of 6-10 m/km and dip angel of less than 1º[1-2].

The major gas reservoirs in the Shenmu Gas Field are low-permeability sandstone gas reservoirs with low abundance. Up to now, this gas field has proved gas geological reserves of 3334×10⁸ m³ and gas-bearing area of 4069 km². The major pay zone is the Taiyuan Fm and Shanxi Fm.

As a low permeability and low abundance gas reservoir, its development technology policy is different from conventional gas reservoir. Therefore, it is necessary to study the development technology policy of Shenmu gas field, including rational partition of layer series, the abandonment condition, and the reasonable production proration.

Development Technical Policy

The Partition of Layer Series

At present, there are two sets of gas-bearing strata including Shanxi Fm and Taiyuan Fm in Shenmu gas field, and the two sets of layers are mutually overlapping. In combination with the actual situation of Shenmu gas field, the six factors of pressure, temperature, gas bearing segment length, reserve distribution, reservoir physical properties and characteristics of gas components are considered in the partition of layer series (Table 1). As a result, the Shanxi Fm and Taiyuan Fm of Shenmu gas field gas reservoir can adopt a series of strata to product.
Table 1. The physical property of sands group.

<table>
<thead>
<tr>
<th>Sand group</th>
<th>Porosity (%)</th>
<th>permeability ($10^{-3} \mu m^2$)</th>
<th>Gas saturability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shan1</td>
<td>6.85</td>
<td>0.4</td>
<td>54.8</td>
</tr>
<tr>
<td>Shan2</td>
<td>6.59</td>
<td>0.46</td>
<td>56.9</td>
</tr>
<tr>
<td>Tai1</td>
<td>6.47</td>
<td>0.27</td>
<td>55.9</td>
</tr>
<tr>
<td>Tai2</td>
<td>6.57</td>
<td>0.34</td>
<td>51.35</td>
</tr>
</tbody>
</table>

**Abandonment Condition**

**Abandonment Production Rate of Gas Well.** When the gas field production enters into the natural decline period, the production will decrease continuously, and finally the production will be carried out in a constant pressure mode until the production reaches to an abandonment production rate. When the production cost is equal to the sales net income, the production at this time is the abandonment production rate of gas well, also named for economic limit production. The economic limit production refers to the lowest production of gas well with economic production value, and also refers to the production with the balance of the current production costs, taxes, other expenses and sales revenue, which can be calculated by the following equation:[3-5]

$$Q_{el} = \frac{C_i}{aP(1-T_a)} \tag{1}$$

Where $Q_{el}$ is the economic limit production of single well($10^4 m^3/d$), $C_i$ is the total production costs per day of single well($10^4 m^3/d$), $a$ is the commodity ratio(%), $P$ is the gas price(yuan/m$^3$) and $T_a$ is the composite tax rate(%). According to the change of net cash flow during the production period calculated by the economic evaluation parameters of Shenmu gas field, the economic limit production of single well is $0.2 \times 10^4 m^3/d$.

**Abandonment Formation Pressure.** Many scholars have concluded that the abandonment formation pressure is the pressure when the gas reservoir production decline to abandonment production rate, mainly determined by gas reservoir depth, heterogeneity and permeability(see Table.1). Because Shenmu gas field is a closed constant-volume gas reservoir with low permeability, the relationship between the extrapolated abandonment formation pressure and extrapolated initial formation pressure can be described by the following equation:[6-8]

$$P_a/Z_a = 0.5 P_i/Z_i \tag{2}$$

The gas reservoir buried depth in Shenmu gas field is 2635-2928m, and by using the relational expression between the buried depth and the formation pressure, the initial formation pressure of the gas reservoir is calculated for $26.906 \sim 27.563$Mpa. Using temperature-depth formula, the gas reservoir temperature is calculated for $82.25^\circ C \sim 91.56^\circ C$. The Z-factor at the initial formation condition is $0.941 \sim 0.950$, and the Z-factor at the abandonment condition is 0.936. Through the equation (2), the abandonment formation pressure in the area is calculated as $5.29-5.44$Mpa.
Table 2. The abandonment formation pressure of different types of gas reservoirs.

<table>
<thead>
<tr>
<th>Gas reservoir type</th>
<th>Application condition</th>
<th>Empirical equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak water drive and fractured gas reservoir</td>
<td></td>
<td>$P_a/Z_a = (0.2 \sim 0.05)P_i/Z_i$</td>
</tr>
<tr>
<td>Strong water drive and fractured gas reservoir</td>
<td></td>
<td>$P_a/Z_a = (0.6 \sim 0.3)P_i/Z_i$</td>
</tr>
<tr>
<td>Constant-volume porosity gas reservoir with high permeability</td>
<td>$k \geq 50 \times 10^{-3} \mu m^2$</td>
<td>$P_a/Z_a = (0.2 \sim 0.10)P_i/Z_i$</td>
</tr>
<tr>
<td>Constant-volume porosity gas reservoir with middle permeability</td>
<td>$k = 10 \sim 50 \times 10^{-3} \mu m^2$</td>
<td>$P_a/Z_a = (0.4 \sim 0.2)P_i/Z_i$</td>
</tr>
<tr>
<td>Constant-volume porosity gas reservoir with low permeability</td>
<td>$k = 1 \sim 10 \times 10^{-3} \mu m^2$</td>
<td>$P_a/Z_a = (0.5 \sim 0.4)P_i/Z_i$</td>
</tr>
<tr>
<td>Constant-volume porosity tight gas reservoir</td>
<td>$k &lt; 1 \times 10^{-3} \mu m^2$</td>
<td>$P_a/Z_a = (0.7 \sim 0.5)P_i/Z_i$</td>
</tr>
</tbody>
</table>

Annnotation: $P_i, Z_i$ is the initial formation pressure and its Z-factor respectively. $P_a, Z_a$ is the abandonment formation pressure and its Z-factor respectively.

Reasonable Production Proration

The determination of reasonable production of gas well has always been a great concern to gas reservoir developers, and it is an important issue for rational development of gas reservoirs. Because the research area has not yet officially production, not the use of dynamic data for production proration research. Therefore, the production proration rely mainly on the AOF obtained by "one point method" test. Then combined with the experience of similar gas reservoir, using the numerical simulation to predict stable time, and lastly the reasonable production proration is determined.

Based on the calculating results of AOF, the production can be set as a quarter-a third of AOF and the basic proration plan is formed. Using the method to make production proration for 151 gas wells in the study area, the annual gas production is about $10 \times 10^8$ m$^3$, which is a basic production proration plan. On this basis, through the increase and decrease the single well production, the seven kinds of proration schemes are formed, including $20 \times 10^8$ m$^3$/a, $18 \times 10^8$ m$^3$/a, $16 \times 10^8$ m$^3$/a, $14 \times 10^8$ m$^3$/a, $12 \times 10^8$ m$^3$/a, $10 \times 10^8$ m$^3$/a, $8 \times 10^8$ m$^3$/a and $6 \times 10^8$ m$^3$/a. Table 3 show the detailed data of seven production schemes.

Table 3. The production proration of eight kinds of proration schemes.

<table>
<thead>
<tr>
<th>Scheme 1#</th>
<th>Scheme 2#</th>
<th>Scheme 3#</th>
<th>Scheme 4#</th>
<th>Scheme 5#</th>
<th>Scheme 6#</th>
<th>Scheme 7#</th>
<th>Scheme 8#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production scale (10$^8$m$^3$/a)</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Daily gas production of study area (10$^4$m$^3$/d)</td>
<td>177.5</td>
<td>236.7</td>
<td>295.8</td>
<td>355.0</td>
<td>414.16</td>
<td>473.32</td>
<td>532.49</td>
</tr>
<tr>
<td>Average production of single well (10$^3$m$^3$/d)</td>
<td>1.175</td>
<td>1.567</td>
<td>1.959</td>
<td>2.351</td>
<td>2.743</td>
<td>3.135</td>
<td>3.526</td>
</tr>
</tbody>
</table>

The Wellhead Pressure of 5 Mpa. The eight proration schemes are predicted for production by numerical simulation. The production time is from June 1, 2014 to June 1, 2043, and the abandonment production rate of gas well is $0.2 \times 10^4$ m$^3$/d. Considering the high pressure gas collection that the inlet pressure of gas gathering stations not less than 5 Mpa, the wellhead pressure during numerical simulation is set of 5 Mpa. Consider workover and other factors that affect production, the annual production time is set of 340 days. The simulation results are shown in Figs.1-2.
From Figs.1-2, we can see there is different stable production period for different production scale. The bigger the production scale, the shorter the stable production period. In the eight production scale, the stable production period changes from 0 to 15 years. In field application, the appropriate proration scheme can be selected according the requirement of stable production period. Since the current well pattern in Shenmu gas field is not perfect, the stable production period will be less than 4 years when the production scale is greater than $12 \times 10^8 \text{ m}^3/\text{a}$. Therefore, for the present well spacing of 151 wells, in order to a stable production period of more than four years, the corresponding production scale can’t be greater than $12 \times 10^8 \text{ m}^3/\text{a}$.

The wellhead pressure of 2 Mpa. The eight proration schemes are predicted for production by numerical simulation. The production time is from June 1, 2014 to June 1, 2043, and the abandonment production rate of gas well is $0.2 \times 10^4 \text{ m}^3/\text{d}$. Considering the low pressure gas collection that the inlet pressure of gas gathering stations not less than 2 Mpa, the wellhead pressure during numerical simulation is set of 2 Mpa. Consider workover and other factors that affect production, the annual production time is set of 340 days. The simulation results are shown in Figs.3-4.
From Figs. 3-4, it can be seen that when the wellhead pressure is 2 Mpa, the corresponding stable production period in eight production scales is 0.5-21 years. Compared with the wellhead pressure of 5 Mpa, the stable production period of different production scales all have certain to improve. For the production scales of 6-14×10^8 m³/a, the stable production period can increase 2 to 6 years. For the lowest wellhead pressure of 2MPa, in order to a stable production period of over 4 years, the corresponding production scale should not be greater than 14×10^8 m³/year.

**Conclusion**

(1) The Shanxi Fm and Taiyuan Fm of Shenmu gas field gas reservoir can adopt a series of strata to product.

(2) The abandonment production rate of single well is 0.2×10^4 m³/d. The abandonment formation pressure in Shenmu gas field is 5.29-5.44Mpa.

(3) For the present well spacing of 151 wells and the wellhead pressure of 5Mpa, the corresponding production scale can’t be greater than 12×10^8 m³/a. For the lowest wellhead pressure of 2MPa, the corresponding production scale should not be greater than 14×10^8 m³/year.

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References


