Challenges & Effective Solutions on gas development of Sebei Gas Field, Chaidam Basin

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Abstract
Sebei Gas Field is a unique biogenic gas reservoir with the buried depth ranging from 429m to 1740m and 54 to 84 separate layers in over 1000m productive interval. The reservoir formations are unconsolidated fine sandstone. Edge water invasion, sand production and the interference among layers are three major challenges in the development of Sebei gas field. An integrated technology has been built and it is proved to be benefit to the gas development in Sebei Gas Field. The accumulative gas production has been reached 20BCM at the end of 2008.

Key words: unconsolidated fine sandstone, multi-layer gas reservoir, edge water invasion, sand production, interference

Introduction
Sebei gas Field, locates in Three Lakes depression of Chaidam basin, which includes Sebei Sebei 2 and Tainan gas filed. It is the largest biogenic gas field in China [1].

Sebei Gas Field is a multi-layer unconsolidated sand gas reservoir. The main geologic characteristics can be summarized as following.

(1) As a syndepositional anticline in quaternary, the structure is simple and integral with the strata dip in range of 1.5° to 3°.
(2) The buried depth is shallow (429.0-1740.7m) and the sandstone is unconsolidated. For well S3-2-4, the Young's modulus is in range of 120 to 440MPa, average of 296.7MPa, the uniaxial compressive resistance is in range of 2.78 to 5.4MPa, average of 3.71MPa; the modulus ratio is in range of 43.17 to 111.86, average of 78.84. Due to the weak strength between particles, the reservoir is easy to sand production, especially when the well producing water \(^2\).

(3) The reservoir includes 54 to 84 separate layers in over 1000m productive interval. The average thickness of single net pay is in range of 2.9m to 4.2m and extend stable in lateral.

(4) The gas reservoir is typical edge water-stratified reservoir (Figure 1), with the GWC of partial reservoirs higher in south and lower in north.

(5) The shale content of the reservoir formation is in range of 10%-39%, and the mean value is 25%. The average-log interpretation-porosity is in range of 24.5~32.6%, the permeability is in range of 4.4~43.2mD. The in-layer heterogeneity, the interbed heterogeneity and the areal heterogeneity are all strong. For example, the permeability difference is in range of 44~16379 of Well TS5, the coefficient of anisotropy is in range of 1.10~9.62.

**Challenges in development of Sebei gas field**

Edge water invasion, sand production and interference are the critical Challenges in development of Sebei gas field.

1. The water invasion decreased the gas well production

   (1) All the gas well producing water, but only part of the discharging well affect the gas production

   The average water production of Sebei 1 gas field is 1.36m\(^3\)/d per well. There are about 30 wells with water production larger than 1m\(^3\)/d, which reduces the gas production rate significantly. For example, the production deliverability reduced 60% to 90%, and the gas production rate reduced more than 40% (table 1) of 5 wells with larger water production of Unit \(\square\)-1 in Sebei 1 gas field.

   **Table 1 The effects of water production on deliverability**

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Present Reservoir pressure (MPa)</th>
<th>Deliverability (10(^4) m(^3)/d)</th>
<th>Rate of reduce(%)</th>
<th>Gas production(10(^8) m(^3))</th>
<th>Rate of reduce(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before producing water</td>
<td>After producing water</td>
<td>Before producing water</td>
<td>After producing water</td>
<td>Before producing water</td>
</tr>
<tr>
<td>S 4-20</td>
<td>11.856</td>
<td>55</td>
<td>7.59</td>
<td>86.2</td>
<td>8.5</td>
</tr>
<tr>
<td>S4-9</td>
<td>11.74</td>
<td>35.7</td>
<td>3.84</td>
<td>89.3</td>
<td>4</td>
</tr>
<tr>
<td>S4-5</td>
<td>11.65</td>
<td>30.7</td>
<td>20.17</td>
<td>34.3</td>
<td>6</td>
</tr>
<tr>
<td>S 4-14</td>
<td>12.01</td>
<td>85.6</td>
<td>26.24</td>
<td>69.4</td>
<td>7</td>
</tr>
<tr>
<td>S4-2</td>
<td>11.57</td>
<td>35.7</td>
<td>13.74</td>
<td>61.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Average</td>
<td>11.58</td>
<td>35.7</td>
<td>13.74</td>
<td>61.5</td>
<td>11.5</td>
</tr>
</tbody>
</table>

   (2) The water produced is dominated by edge water invasion

   There are 21 producing wells of unit \(\square\)-1 in Sebei 1 gas field since 1996. Commonly, the gas production rate is 4.47×10\(^4\) m\(^3\)/d and 16.43×10\(^8\) m\(^3\) gas produced totally, and the water production rate is 1.39m\(^3\)/d and 3.3×10\(^4\) m\(^3\) water produced totally. Figure 2 shows that the wells with larger water/gas ratio are located in the northern and southern flanks.
For example, well S4-14 was perforated 4-1-7, 4-2-1, and 4-2-2 since August 1999. In May 2002, perforated all the other six layers (4-1-1 to 4-1-6) in Unit -1, and continued to produce from all the nine layers. In January 2004, after amplifying gas nipples from 6mm to 7mm, the gas production rate increased a little, but the water production increased sharply. But the daily water production rate couldn't be restores to the original level when the nipple were reduced to 6.5mm, the water production rate raised up to about $3m^3/d$.

According to the production logging data (See Fig.3), water produced from layers of 4-1-7 and 4-2-1 first, and then followed by layer 4-1-6. Water producing advanced from bottom to the upper, the lower sections were flooded and no gas producing at the later time. The individual gas rate declined obviously along with the intensified water producing, until the well was shut down.

(3) The water-yield layers

The sandstone is unconsolidated, and the gas wells are prone to sand production

(1) Sand production is universal in Sebei Gas field
According to the production data of Sebei gas field in 2007, the height of sand column in the wellbore mostly in range of 50m to 150m (Table 2), the sand face rise up was about 18.9~66.4m/a.

Table 2 The statistic of sand face increasing rate of SB gas field in 2007

<table>
<thead>
<tr>
<th>Gas field</th>
<th>Number of wells</th>
<th>Height of sand in the wellbore</th>
<th>&lt;50(m)</th>
<th>50~100(m)</th>
<th>100~150(m)</th>
<th>&gt;150(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB 1</td>
<td>12</td>
<td></td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SB 2</td>
<td>3</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Tainan</td>
<td>5</td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td></td>
<td>7</td>
<td>9</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Percent(%)</td>
<td></td>
<td></td>
<td>35</td>
<td>45</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Avg. rate(m/a)</td>
<td></td>
<td></td>
<td>18.9</td>
<td>66.4</td>
<td>124</td>
<td>368</td>
</tr>
</tbody>
</table>

(2) The water production stimulates the sand production

According to the statistical results of sand production and water production, we find that the sand production in nine wells of the whole ten wells were closely related to larger water production rate. Core testing results showed that the water production is the key reason causing sand producing, water production is prone to induce sand production.

3. Strong heterogeneity leading to interferences

(1) The deliverability varies greatly

The absolute open flow potential of Tainan gas field varied greatly from 0.35 to 122.87×10^4 m^3/d, in average of 36×10^4 m^3/d, so that of Sebei 1 and Sebei 2 gas field.

![Figure 4 The permeability difference in each well of Unit -1, Sebei 1 gas field](image)

(2) Reservoir heterogeneity and water production affect the production profile

The maximum permeability of each well in Unit -1 of SB 1 gas field varies from 5.4mD to 49.1 mD, the permeability difference is in range of 1.8~54.7, which could be classified as strong to medium heterogeneity(See Fig.4). The permeability difference of well S 4-2 and S 4-12 is 13.1 and 11.2 respectively, and there is no gas produced from the layer of 4-1-3(See Fig.5). According to the statistic of the production logging data of 2007, it shows that there are about 11% layers have no any gas produced at that moment.
Water production from pay formations also affects the production profile, e.g. S4-14 (See Fig. 3).

**Solutions for gas field development**

The reservoirs of Sebei gas fields are weak cemented, multi-layered with quite complicated gas-water relationship. The solutions to water invasion, sand production and interferences are as following.

1. Water Control technology
   (1) Estimate the GWC accurately

   The reservoirs of SB gas fields are composed of siltstone, argillaceous siltstone, and silty-mudstone, they are fine grain-sized, and micro-pores are developed, the water saturation is high. Therefore, some low-resistivity gas bearing layers are formed and which is difficult to identify. The reason for that is as following: the compatibility between natural potential and natural gamma ray logging is low, it's hard to subdivide the reservoirs; Logging data affected by adjacent formations seriously due to the thin beds; The computational accuracy of the reservoirs parameters is low; The “image” characteristics of the porosity are indistinct.

   In order to resolve the logging interpretation difficulties mentioned above, we confirmed the origin of the low-resistivity layers and the characteristics of the reservoirs firstly, and developed integrated well log interpretations as defining well log curve qualitatively, structure dominated rules, porosity difference ratio method, and NMR logging. The accuracy exceeded 92%.

   (2) Integrated water control technology

   Due to thin bedded, small dipping, wider transitional zones of water-gas, it's crucial to determine the GWC based on logging and integrated geologic interpretation.

   (2) Integrated water control technology

   For the sake of lowering the effects of water production, enhancing the development efficiency, based on the structural location, the amount of water produced, and the type of the water, we established an integrated technology to control the water production.
In general, for the wells on the structural boundary which affected by edge water, the gas production rate should be controlled properly, in order to avoid or slow down the edge water invasion along the high permeability zone; or shut off the intervals with severe water invasion.

For The wells on the down-structure location, it is mostly affected by the mobile water and interlayer water under the pressure difference. The strategy is to decrease gas production rate, control the pressure drop to achieve stable gas production rate, prolong the developing period with low gas-water ratio as possible.

The wells on the updip are generally free of water invasion, it’s necessary to increase the gas production rate properly, and to improve cementing quality to prevent from the interbed aquifer.

It is considered to take different measures according to unique features of water: “prevent” for the low water rate wells and new wells, “dewater” for the water invasion wells for the wells with lower water production, “aquifer shut-off” for inter-aquifer & severe water invasion wells.

2. Sand prevention technique to reduce the possibility of sand production

(1) Producing by controlling pressure difference

The production pressure difference has been controlled within 10% of the initial pressure. According to the statistics of production data in 2007(Fig 7), when the ratio of production pressure difference to the formation pressure is less than 10%, the average sand rising velocity was 16.3m/a. On the contrary, the average rising velocity was as high as 75.4m/a.

(2) Sand prevention technology

On the basis of activity sand prevention, the main technology of sand prevention during the gas field development includes high pressure packing and compositional fiber fracturing, which can reduce the danger of sand entry in the gas wells. High pressure packing was used in 21 wells in 2007, the average daily gas production increased 0.7×10⁴m³, the effective period was 536days, effective ratio was 80.9%. The compositional fiber fracturing was used in 32 wells, the average daily gas production increased 0.38×10⁴m³, the effective period was 396days, effective ratio was 84.4%.

3. Technique to reduce the interferences

(1) Built accurate 3D geological modes

Through strata comparison, accurate interpretation of well logging and combined geology researches, the GWC can be clarified. Based on the integrated geology study, the distribution of reservoir formation, the gas-water distribution and the reservoir physical properties were described accurately. The 3D geology model has been built to characterize the heterogeneity.

(2) Minimize production layers to reduce the interferences

Multi-layer perforation is the major technology in the development of Sebei gas field, the interference between layers result in the low perm layer has less contribution in the development of multi-gas layers. According to the thickness of intervals, reservoir pressure, gas-bearing area, range of gas-bearing in wells, reserves scale and distribution of major gas-layers etc. In 1998, Sun Hedong investigated the heterogeneity affect on the gas recovery for commingled production, the less the permeability difference, the higher the gas recovery will be. The statistic data show that the production rate is lower when the production layer is more
than 5. Therefore, Sebei gas field was optimized to perforate 3~4 layers in each new well.

(3) Horizontal well applying technology

For multi-layered gas fields like Sebei gas field, when dispose the layers for horizontal wells. The shale content should lower than 30%, the gas saturation should be larger than 60%, net pay should larger than 2m, gas-bearing area should be bigger than 10km², reserves should larger than $15 \times 10^8 m^3$. The barrier condition should be good with thickness larger than 5m. There are no obvious aquifer layers around the wellbore.

The horizontal well TH5-1 and TH5-2 in Tainan gas field which have been put into development with daily gas production as high as $20 \times 10^4 m^3/d$, which is about 2 to 4 times of the vertical well. There are more than 30 wells has been drilled in Tainan gas field right now.

4. Development optimization

Based on the above technologies and strategies, the general developing strategies were used to reduce the developing risk and increase the developing effect.

(1) Optimizing the production well locations

The gas reserves is mainly distribute on the high structures, with 78% of the reserves distribute in 15km².

(2) Perforation optimization

For the weak edge water driving gas reservoir, the proper well area/gas-bearing area is 0.3~0.4. According to the gas-bearing area, the distance between perforation and edge water is around 400~1000m, averaging in 800m.

(3) Well allocation optimization

According to allocation experiences of conventional sandstone gas reservoirs, the maximum allocation can be as high as $20~30 \times 10^4 m^3/d$. But the gas reservoirs are easy for the sand production, which affected the production ability of wells.

The production pressure difference should be as low as no sand is produced. On the other hand, reducing the gas rate by 10%~30% for the well near GWC to prevent from the edge water invasion.

Applying the integrated optimization and the advanced engineering technologies, the developing effect of Sebei gas field turned out to be good. The sand entry and water production was controlled effectively. By the end of 2008, the total gas production had been up to $200 \times 10^8 m^3$.

Conclusion and results

1. Sebei gas field characterized as shallow buried depth, high shale content, loose lithology, long gas-bearing interval, thin layers, multi gas layers and complex gas-water relation, et al.
2. Edge water invasion, sand production and interferences are three key challenges in Sebei gas field development.
3. For the water control, one is to estimate the GWC accurately by the integrated well log interpretation. The wells should be drilled in the structure high and the perforation should be more than 500-800m apart from GWC. Different strategies should be used for the wells in different water producing situation.
4. Confining the production pressure difference less than 10% of the initial pressure is practical to decrease the sand production. The sand control technique, such as high pressure packing and composition fiber fracturing, enhance the gas production and prevent from sand production effectively.

5. In order to minimize the interference among the layers, the productive group is optimized to 3-4 layers with similar permeability, and horizontal wells are drilled in those layers with net pay is great than 2m and the shale content less than 30%.

References