Exploration and Development Technology of Fuling Shale Gas Field

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July, 2018
Outline

1. Introduction

2. Exploration and development technology
1.1 Geographical and structural location of Fuling shale gas field

Geographical location: in Fuling, Nanchuan and Wulong area

Structural location: Wanxian complex syncline of southeastern margin of Sichuan Basin
1.2 Exploration and development system

Target formations: Wufeng formation of upper Ordovician and Longmaxi formation of lower Silurian

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<thead>
<tr>
<th>界</th>
<th>系统</th>
<th>组</th>
<th>层</th>
<th>岩性</th>
<th>厚度 (m)</th>
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<td>第四系</td>
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<td>Q</td>
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<td>0-300</td>
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<td>新近系</td>
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<td>更新系</td>
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<td>0-2000</td>
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<td>侏罗系</td>
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<td>上统</td>
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<td>中统</td>
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<td>340-500</td>
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<td>600-2800</td>
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<td>三叠系</td>
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<td>二叠系</td>
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<td>三叠系</td>
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<td>上统</td>
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<td>0-1500</td>
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<td>0-600</td>
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<td></td>
<td>下统</td>
<td></td>
<td>0-1500</td>
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<td>震旦系</td>
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<td>上统</td>
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<td>200-1100</td>
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<td>下统</td>
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<td>0-400</td>
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<td>元古界</td>
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- 涪陵五峰-龙马溪组下部地层柱状图
1.3 Current exploration and development situation

Total wells: 282

Total produced shale gas: 17.9 billion cubic meters
1.4 Main development mode

At present, the shale gas development is mainly carried out by segmental fracturing of long flat section.
Outline

1. Introduction

2. Exploration and development technology
## Build 6 technologies

1. Southern Marine shale gas selection evaluation technology

2. Technical system of fine characterization and development evaluation of shale gas reservoir

3. Key technology of shale gas reservoir engineering

4. Optimal drilling technology of horizontal well under mountain conditions

5. Horizontal well network fracturing technology

6. Shale gas green development technology system in mountain environment
2.1 Southern Marine shale gas selection evaluation technology

(1) The deep-water sedimentary facies belt is a favorable facies zone for shale gas development.

High TOC and High silica content
(2) The structural stability zone is a favorable “storage box” for shale gas

The diagram of porosity, gas content and pressure coefficient in high quality shale section of main exploratory wells within southeast Sichuan basin

The pressure coefficient is a powerful characteristic parameter of the preservation condition, and the gas yield is positively correlated with the pressure coefficient. The structural stability zone is usually characterized by high pressure and high gas yield.
(3) Rich organic carbon content is the basic condition for shale gas accumulation.

In the vertical direction, the total thickness of shale is about 90 meters, the organic carbon content and the porosity of shale gas reservoir increased gradually from top to bottom.
2.2 A technical system of fine characterization and development evaluation of shale gas reservoir was established

(1) The fine characterization technique of Marine shale gas was developed

1. A new method to name shale rock facies is proposed

A new method of ‘3+1’ classification was adopted to establish the Marine shale facies division scheme.

<table>
<thead>
<tr>
<th>组分种类</th>
<th>组分含量</th>
<th>命名</th>
<th>备注</th>
</tr>
</thead>
<tbody>
<tr>
<td>单组分</td>
<td>10% ≤ X &lt; 25%</td>
<td>含X页岩</td>
<td>区分陆源与自生硅质</td>
</tr>
<tr>
<td>单组分</td>
<td>25% ≤ X &lt; 50%</td>
<td>X质页岩</td>
<td></td>
</tr>
<tr>
<td>双组分</td>
<td>25% ≤ X, Y &lt; 50%</td>
<td>X质Y质混合页岩</td>
<td>利用常规粒级划分砂质</td>
</tr>
<tr>
<td>三组分</td>
<td>25% ≤ X, Y, Z &lt; 50%</td>
<td>混合页岩</td>
<td></td>
</tr>
<tr>
<td>粘土</td>
<td>粘土 &gt; 50%</td>
<td>......粘土页岩</td>
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2. A fine division scheme for developing small layers is established.
The quantitative description of the main mineral components of shale is realized by integrating the technology of laminar X-diffraction - scanning electron microscope (SEM);

The quantitative characterization of shale pore structure is realized by integrating the experimental analysis technology of shale reservoir with full scale and multidimensional degree.
(2) A geological evaluation system for shale gas development was established

1. The evaluation system and standard of shale gas content have been established

In view of the fact that the measured gas content cannot effectively represent the gas content of shale, two kinds of 6 parameters evaluation index system of shale gas content are innovated
2. The evaluation system and standard of shale compressibility are established.

Early use of brittle shale mineral poisson's ratio evaluation shale parameters such as young's modulus can be compressional fuling based development practice, deepen the embedded depth of the fracture structure form and completion quality of the impact of shale can be pressed.
3. A technical evaluation system for Marine shale gas development was established

Considering shale native quality hydrocarbon showings fracturing test many factors such as air condition, established the Marine shale gas development geological evaluation technology system, effectively guide the shale gas development district evaluation in southern China.

Table of evaluation system of shale gas development in complex structural area of fuling shale gas field

<table>
<thead>
<tr>
<th>Evaluation grades</th>
<th>Shale original quality</th>
<th>gas content ability</th>
<th>Fracturing gas test</th>
</tr>
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<tr>
<td></td>
<td>TOC ( % )</td>
<td>Silica content ( % )</td>
<td>Total hydrocarbon values ( % )</td>
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<tr>
<td>I</td>
<td>&gt; 3</td>
<td>&gt; 65</td>
<td>&gt; 10</td>
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<tr>
<td>II</td>
<td>2-3</td>
<td>50-65</td>
<td>5-10</td>
</tr>
<tr>
<td>III</td>
<td>&lt; 2</td>
<td>&lt; 50</td>
<td>&lt; 5</td>
</tr>
</tbody>
</table>
2.3 Established the key technologies of shale gas reservoir engineering

(1) Developed the shale gas experimental evaluation technology and revealed the whole flow mechanism of shale gas.

1. Shale gas flow experimental equipment under gas reservoir conditions has been developed for the first time.

Developed a cutting and anhydrous sampling device and high temperature and high pressure experimental device for a full diameter shale (150 ℃, 70MPa), which are central experimental equipment for seepage of shale gas.
2. The flow mechanism of shale gas under reservoir conditions is preliminarily revealed.

(1) The results of physical simulation and molecular simulation show that:

◆ When the shale formation pressure of Fuling gas field is less than 12MPa, shale gas begins to be desorbed in a large amount, and the gas in the process of shale gas extraction is dominated by free gas, and the content of adsorbed gas is not more than 15% of the accumulated gas.

◆ The contribution of the diffusion slippage effect to the accumulated gas in Fuling gas field accounts for about 5%.

(2) Under the temperature and pressure condition of Fuling reservoir, Darcy flow is the main flow in more than 100 nanoscale joints, and 20-100 nanometers pore is dominated by slipstream, and 1-20 nanoscale holes are slippage flow and transition flow. Under low pressure, less than 1 nanoscale holes are dominated by diffusion.
(2) Established a new method for productivity evaluation and dynamic analysis of shale gas horizontal wells

1. An analytical method for unsteady state productivity evaluation of shale gas nonhomogeneous fractured horizontal wells is established.

By the method, the single section fracture half length is quantitatively described, and the coincidence rate of single well production prediction is more than 85%.
2. The production rules of gas wells in different stages are preliminarily grasped

Two stages in the production of shale gas wells in Fuling: stable production—pressure reduction and constant pressure reduction.

◆ Stable production—pressure reduction: Output is constant production or variable production, and production pressure is reduced to external pressure.

◆ Constant pressure reduction: Divided into two stages: continuous production and intermittent production. In continuous production stage, production is reduced to continuous liquid production. After that, it entered the intermittent production stage.
3. Established a new method for production dynamic analysis of shale gas wells

(1) A method for predicting production performance of horizontal wells with shale gas fracturing is established

The unsteady linear flow equation is established to predict the pressure change, stable production time, stable production period and decreasing period of gas well bottom flow pressure, and the forecast coincidence rate is above 90%.
(2) Established a method for predicting the recoverable reserves of shale gas wells

Based on the unsteady linear flow equation, the concept of "productivity coefficient of shale gas well" is put forward, and a new method for predicting the recoverable reserves of shale gas wells with productivity coefficient is established.

Productivity coefficient evaluation char
(3) Formed a shale gas complex structure development policy optimization technology

The development technology policy has been further optimized, and a technical policy for shale gas development adapted to complex structural areas has been established.
2.4 Optimal drilling technology of horizontal well under mountain conditions

1. The drilling optimization design technology of the horizontal well of Fuling shale gas

(1) Shale formation well wall stability evaluation analysis method

By considering the formation and fluid intrusion, a collapse pressure calculation model was established, which guided drilling fluid density and intermediate casing optimization.
(2) The well structure design technology of Fuling shale gas horizontal well

Shalegas formation pressure system in Fuling area was described accurately. Clarified the distribution law of shallow gas. Optimized and perfected the wellbore structure scheme: Guide+ Three spud section structure.

- “Slimming” upper large size wellbore
- Lifting depth under each well section
- “Double guide” structure on deep and complex areas

(3) Three-dimensional wellbore orbit design technology for cluster horizontal wells

A wellbore orbit design model based on stratigraphic drift was established. Developed a wellbore orbit design technique under a three-dimensional geoscience model.
2. Excellent drilling technology series for Shale gas horizontal well

(1) Drilling speed-up tools such as high-efficiency PDC bits and screw drills

Based on the basis of 5 drilling speed-up tools, the drilling speed of open section increased by nearly 4 times, The drilling speed of directional section PDC bit increased 87.1%, The drilling speed of Wufeng horizontal section increased 130%.

- Large size smooth cutting PDC bit
- Directional dedicated PDC bit
- Supporting both Longmaxi and Wufeng
- Long-life screw drilling tool for oil-based drilling fluids
- Drag reduction tool for horizontal section
(2) Well trajectory control technology based on high efficiency curved screw + MWD

Proposed low-cost "MWD + natural gamma" well trajectory measurement technology. Optimized the lower assembly and drilling. The proportion of composite drilling footage is up to 97.2%.

- The average stable slope length is 1000m, and the longest stable slope length is 1680m.
- The horizontal section has an extension capacity of 2200m and the longest horizontal section has a length of 2193m.

(3) Drilling speed-up series of Fuling shale gas drilling

The drilling acceleration technology series is formed by the integrated application of various speed-raising tools and processes.
3. High-efficiency “well factory” drilling mode of shale gas in complex mountain environment

Five core technologies

- Fast moving drilling rig and equipment matching technology: Drill rig movement time is less than 3 hours
- Platform ground layout optimization technology
- Drilling factory operation design technology: Relocation and completion time reduced by more than 50%
- Drilling fluid recycling technology:
  Reduce drilling fluid usage by 41.46%
- Technology integration technology based on learning curve: Drilling cycle reduced by 30% year-on-year
4. Low-cost domestic oil-based drilling fluid system

The indicators of dynamic shear, electrical stability and water loss are better than foreign oil-based drilling fluid systems.

It has significant advantages in drilling efficiency, leakage prevention and recycling, and recycling. The cost is reduced by more than 40%. The amount of emulsifier was only 11%, which was 28.1% lower than that of foreign systems.

<table>
<thead>
<tr>
<th>Oil-based drilling fluid index and cost comparison</th>
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<tbody>
<tr>
<td>system</td>
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</tr>
<tr>
<td>Fuling</td>
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<td>Fuling</td>
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<tr>
<td>Foreign</td>
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<td>Foreign</td>
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</table>
5. Long horizontal section cementing technology

On the base of Elastic toughness cement slurry system, Shale gas special casing, Shale gas production casing sealing repair technology and Shale gas casing safety entry technology, The success rate of One-time down to scheduled well depth is 100% on the 1500-3000m horizontal section length.
2.5 Improve the horizontal well network fracturing and its supporting technology

(1) Revealed the morphology and mechanism of shale fractures in different buried depths

- The tests reveal that the fractures developed like radial mesh or spindle shape.
- The weak layers, especially the bedding, have an important influence on fracture morphology and its complexity.
- With the increase of buried depth, the rock failure mode tends to be single style and the bedding shear is weakened. The hydraulic fracture complexity is significantly decreased.
(2) Improved the fracturing technology for reservoirs shallower than 3500m

Based on the complex network fracking mode in the main shale gas exploitation area

- The fracture extension mechanism and the comprehensive pre-fracking evaluation have been considered;
- The three-scale reservoir reformation ideas and techniques including “planar, horizontal and interval” were applied;
- The fracturing technology for reservoirs shallower than 3500m were improved.

These technologies have been applied for over 1600 sections of more than 90 wells with remarkable results.
3. A new method for real-time diagnosis and post-fracking evaluation of horizontal shale gas well is proposed

a. The dynamic diagnosis technology and bulk-volume reformation assessment are improved

**Dynamic diagnosis**

The dynamic fracking extension model is applied in fracturing operation curve analysis, quantitative discriminant standard for real-time fracture extension has been established, fracking pressure feature identification has been carried out, and the real-time fracking adjustment has been guided.

**Bulk-volume reformation assessment**

Based on the numerical simulation and the micro seismic monitoring, bulk-volume reformation assessment model has been established, and it can rapidly assess the reforming volume of shale intervals in different area.
b. The gas production profile testing technology for horizontal Wells has independent intellectual property rights

-- independently developed temperature and pressure profile testing instruments with fully independent intellectual property rights;
-- formed the gas production profile test technology of "continuous tubing + combination tester";
-- established the interpretation model and method for shale gas production profile based on temperature and pressure tests;
-- developed a gas production profile interpretation software applied to horizontal gas wells.

The testing process is simple and reliable.
At present, 43 Wells /616 sections /1558 cluster gas production profile tests have been completed.
2.6 The green development technology system of shale gas in mountain area was preliminarily constructed

(1) A system of environmental management and risk assessment and control for shale gas development was established

Fuling shale gas field environment management has been formed depending on the State-Chongqing city-Sinopec environmental regulations and territorial ecological regionalization. The system includes organization, regulation, technology and standards as the cores.

For the whole process of shale gas development, a list of shale gas environmental risk sources has been established, and a complete implementation method for environmental emergencies has been formulated.
(2) Established an efficient treatment and disposal technology for pollutants in Fuling shale gas development

a. Established oil-based cuttings pyrolysis and harmless treatment technique

Established oil-base drilling cuttings pyrolysis processing technology, developed two sets of laboratory test device ("vacuum - horizontal furnace" and "nitrogen – vertical furnace"), pyrolysis ash petroleum content is 0.039%, far lower than the national standard of 0.3%.

b. Integrated shale gas production water treatment process

According to the characteristics of high salt content, high COD and hard degradation of the water produced during shale gas development, the high efficiency treatment technology of the produced water is integrated. The treated water quality reaches A level.
c. Suitable soil - repairing microbes were screened

- Simulation experiments were carried out on microbial remediation of soil contaminated by oil-based mud.
- Three functional strains of polycyclic aromatic hydrocarbons (pahs) were screened and isolated from high efficiency oil based mud.

It has significant advantages such as strong environmental adaptability and high efficiency of organic matter degradation.
Thanks for your attention!