Sand Production Mechanism Analysis of Deep Tight Sandstone Gas Reservoir in Keshen Block

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Abstract. In order to provide reference and help for sand production control in deep tight sandstone gas reservoirs. Taking Keshen block as the research object, the sand production mechanism is analyzed and verified by experiments. The additional pressure difference, fracture development and reservoir reconstruction are considered. Through the establishment of rock mechanics model, hole additional pressure difference physical model experiment, acid rock test. It is concluded that the main sand production mechanism of this formation is shear failure, additional pressure difference of rock, sand production easily caused by natural fracture development, and rock strength decreases after acid fracturing. The rock strength decreases by 20%.

Keywords: sand production mechanism; tight sandstone; high pressure gas reservoir.

1. Introduction
The Keshen block is located in the Tarim Basin. Two first-level faults and five second-level faults are developed. The structure is complex. The blocks are Quaternary System, Neogene System, Paleogene System and Cretaceous system from top to bottom. Structural fractures are relatively developed, and semi-filling-unfilling high-angle fractures predominate. The second is oblique fractures and network fractures. Natural gas is mainly distributed in the sandstones of the Lower Cretaceous Bashiqike. The depth of the Keshen block is about 6635~7004m. The formation pressure is 115.3~116.5MPa, and the pressure coefficient is 1.70~1.80. The Natural gas has high methane content and does not contain hydrogen sulfide. It belongs to ultra-deep and high-pressure gas reservoirs, and most of the wells have undergone the transformation of acidification and volume fracturing.

We can know that sand production appeared in nearly half of the wells in the Keshen block via sampling, output and oil pressure analysis. And part went out of production due to wellbore sand blockage and fluid accumulation in the wellbore. It has become a major problem that affects output and restricts economic benefits. According to site conditions and related production materials. The analysis and verification of rock force and strength are carried out via experiments, and the sand production mechanism is made clear in order to control the sand production problem.

2. Analysis of Sand Production Mechanism
The Keshen block belongs to the high-pressure gas reservoir. When high-velocity gas passes through the perforating blast-hole, there may be additional force. In addition, the development of rock fractures will cause the strength of the reservoir rock to be decreased.
There are high formation pressure, large gas output, serious heterogeneity in this block, and after large-scale fracturing and acidification transformation, therefore, the key point is on the additional force generated by the gas flow velocity and the decrease degree of rock strength after transformation. The influence of the acidizing transformation on the rock strength is evaluated via the acidizing strength test of the core in order to calculate the critical production pressure difference of sand production after acidification.

2.1. Analysis of additional force of perforating blast-hole

The non-Darcy turbulence effect is produced when the high-speed gas passes through the hole, and there may be additional force, if there is, it will be a major factor to cause sand production. In order to more clearly understand this force, object model experiment can be carried out via a cylindrical device.

2.1.1. Experiment preparation. The experimental device is composed of two outer and inner cylinders, its length is 6m and thickness is 10mm, the outer cylinder is the rubber cylinder, the inner cylinder is the carbon steel cylinder, and the carbon steel cylinder has a small hole with 3mm diameter, there is a gap between the outer cylinder and inner cylinder, the gap is injection gas channel.

The basic principle of the experiment is: inject high-pressure gas into the gap between the inner cylinder and the outer cylinder, and discharge it via the small hole, and observe the size of force generated when the high-speed gas passes through the hole.

![Fig. 1 schematic diagram of the simulation experiment device](image)

(1) Gas medium experiment

The cylinder device used in the experiment is connected with the air compressor, pressure gauge and flow meter with the high-pressure pipeline. Then using the air compressor to inject air between the inner and outer cylinders, the gas displacement is 5m$^3$/h, and the air injection pressure is 5MPa, the air compressor is turned off and the pressure is relieved after 30 minutes. Finally, the cylinder is disassembled to observe the changes of the rubber in the holes.

(2) Water medium experiment

The experiment uses water as the medium. Similarly, first the cylinder device is connected with the air compressor, flow meter, and pressure gauge. Then turn on the water pump again, and pour water between the inner cylinder and outer cylinder, the water injection pressure is 5MPa. After 30 minutes, turn off the pump and release the pressure. Then the cylinder is disassembled to observe the change of the rubber in the small hole.

2.1.2. Experimental result. In the gas medium experiment, after 30 minutes, the inner surface of the rubber tube at the hole deforms, and a piece bulges (Fig.2), in the static state, when the pressure difference is 5MPa, there will be no deformation.

After changing the air to water, there is no deformation at the holes.
2.1.3. Analysis of experimental results. The experimental results show that when high-speed gas passes through the hole, additional force will be generated in addition to the pressure difference, but fluid will not be generated. Thus it can determine that there is an additional pressure difference in the perforating hole in this block, which increases the rock force and aggravates the rock damage, and it is a major factor to cause sand production.

2.2. Analysis of the influence of fracture development on rock strength
The development of fractures will inevitably cause the strength of the reservoir rock to be decreased, namely decrease of Young's modulus.

Data is obtained via rock mechanics experiment (Table 1)

| Table 1. Experimental data of uniaxial rock mechanics of block |
|---------------------------------------------------------------|
| core type          | well number | depth m | modulus of elasticity GPa | compression strength MPa |
|---------------------|-------------|---------|--------------------------|-------------------------|
| substrate sandstone core | 6741.77     | 43.28   | 217.72                   |
|                     | 6744.80     | 34.75   | 205.52                   |
|                     | 6721.73     | 27.72   | 199.98                   |
|                     | 6695.00     | 34.72   | 185.60                   |
| full-filling sandstone core | ———         | 26.89   | 98.33                    |
|                    | ———         | 21.87   | 94.89                    |
|                    | ———         | 19.16   | 79.76                    |
|                    | ———         | 23.09   | 102.18                   |
|                    | ———         | 31.84   | 108.91                   |
| semi-filling sandstone core | ———         | 23.97   | 114.76                   |
|                    | ———         | 26.06   | 66.56                    |

2.2.1. Analysis of experimental results. The rock mechanics experiment results of this block show that the substrate sandstone core strength without fractures is higher than the rock strength with fractures. However, micro-fractures are sometimes not reflected in the logging curve, so the rock strength calculated by the logging data may be greater than the actual strength of the formation rock. Therefore, the influence of fractures is also an important factor to cause sand production.

2.3. Analysis of the influence of acidizing transformation on rock strength
The acid liquid changed the parameters of rock mechanics after the acidizing transformation. The core acidification experiments are carried out to evaluate the acidizing transformation on rock strength, and provide reference and help for the prevention and control of sand production in the future. The elastic modulus and Poisson's ratio of the rock before and after acidification can be obtained via the core uniaxial compression test; the cohesion and internal friction angle of the rock before and after the acidification can be obtained via the core shear test. Finally, the decline range of rock mechanical
parameters after the core is acidified is calculated to evaluate the influence of acidification on rock strength.

2.3.1. Experiment preparation. The acidic liquid is prepared in accordance with the block acidizing liquid formula before the start of the experiment:

\[ 9\% \text{HCl} + 3\% \text{HAc} + 2\% \text{HF} + 0.3\% \text{BD1-6B} + 2\% \text{TRF-2} + 4.5\% \text{TG201} + 1\% \text{DJ-02} + 2\% \text{DJ-07} + 5\% \text{CH3OH} \]

Twelve cores of two wells are obtained and processed to form the cylindrical rock samples required for the experiment.

2.3.2. Shear experiment. 12 rock samples are selected and number them in the form of 2-x. After the surface is cleaned, they are put in the vacuum equipment to vacuum and dry with moisture. The rock samples numbered 2-1, 2-2, 2-3, 2-7, 2-8, and 2-9 are put in the configured acid solution soaked for 48 hours. They are cleaned with clean water and soak in clean water for 3 hours, continue to ish with clean water to thoroughly ish off the acid. Then carry out vacuuming and drying treatment. The adjusted lower seat of the variable-angle shearing fixture are put on the material testing machine, so that its center line coincides with the centerline of the bearing plate, install the rock sample and install the upper seat of the fixture, adjust the spherical seat of the bearing plate, and make the force of the variable-angle shearing fixture uniform. After the fixture and the rock samples are adjusted, load at 0.5 to 1.0 MPa/s speed until they are destroyed.

2.3.3. Compressive deformation experiment. The difference is that the number is in the form of 1-x, which is consistent with the shear test. After the rock sample is acidified and cleaned, vacuumed and dried. The processing accuracy of the rock samples is checked, record the size of the measured rock sample, and then start the material testing machine, put the rock samples in the center of the bearing plate of the material testing machine, adjust the spherical seat, make the upper and lower force of the rock sample even, for example, brittle rocks need the protective cover. Finally, load at 0.5~1.0 Mpa/s speed of until they are destroyed.

2.3.4. Experimental results. In the shear test, by measuring the laboratory shear strength of 12 rock specimens, the data obtained are shown in the Table 2.

Table 2. Data of shear test

| well number | number | acid soaking time (h) | normal stress (MPa) | shear stress (MPa) |
|-------------|--------|-----------------------|---------------------|-------------------|
| core        | 2-1    | 48                    | 15                  | 19.45             |
|             | 2-2    | 48                    | 25                  | 24.45             |
|             | 2-3    | 48                    | 35                  | 28.7              |
|             | 2-4    | 0                     | 15                  | 22                |
|             | 2-5    | 0                     | 25                  | 28                |
|             | 2-6    | 0                     | 35                  | 37                |
| 4core       | 2-7    | 48                    | 15                  | 16.2              |
|             | 2-8    | 48                    | 25                  | 21.5              |
|             | 2-9    | 48                    | 35                  | 27                |
|             | 2-10   | 0                     | 15                  | 18                |
|             | 2-11   | 0                     | 25                  | 24                |
|             | 2-12   | 0                     | 35                  | 37                |
Data calculation

\[
\begin{align*}
\tau &= c + G \sin \phi \\
c &= \tau_2 \cdot \sigma_2^{-\sin \phi} \\
\phi &= \arctan \frac{\tau_2 - \tau_1}{\sigma_2 - \sigma_1}
\end{align*}
\]

In the formula: \(c\) is the intercept of the rock strength curve on the \(\tau\) axis, namely the cohesion of the rock; \(\phi\) is the inclination angle of the rock strength curve, namely the internal friction angle of the rock.

Draw the shear strength curve after acidification (Fig.5) and obtain that the cohesion of the well after acidification is 11.2MPa, the internal friction angle is 28°; according to the same method, the cohesion of the well core before acidification is 15.5, and the internal friction angle is 34°.

![Fig. 3 shear strength curve of rock after acidification](image)

In the compressive deformation test, the data table is obtained by measuring the laboratory compressive strength of 12 test pieces.

| well number | number | acid soaking time (h) | load limit(KN) |
|------------|--------|-----------------------|----------------|
| 1-1        |        | 48                    | 52             |
| 1-2        |        | 48                    | 58             |
| 1-3        |        | 48                    | 57             |
| 1-4        |        | 0                     | 74             |
| 1-5        |        | 0                     | 80             |
| 1-6        |        | 0                     | 73             |
| 1-7        |        | 48                    | 50             |
| 1-8        |        | 48                    | 55             |
| 1-9        |        | 48                    | 49             |
| 1-10       |        | 0                     | 78             |
| 1-11       |        | 0                     | 75             |

Data calculation

During the process of rock deformation experiment, the uniaxial compressive strength, elastic modulus, Poisson's ratio and other parameters of the rock depend on the structural composition \(k\), the properties of mineral particles, and microscopic fractures of the rock. These parameters need to be calculated

(1) Calculation of uniaxial compressive strength of rock samples

\[
R = \frac{P}{F} \times 10^4
\]

(2) Calculation of stress
(3) Calculation of elastic modulus

\[ E = \frac{\sigma - \sigma_u}{e_b - e_a} \]  

(6)

(4) Calculation of Poisson's ratio

\[ \mu = \frac{e_a}{e_b} \]  

(7)

After calculation, the elastic modulus of the well core before acidification is 45 GPa, the Poisson's ratio is 0.25, the elastic modulus after acidification is 40 GPa, the Poisson's ratio is 0.283; the elastic modulus of the well before acidification is 49 GPa, the Poisson's ratio is 0.268, the elastic modulus after acidification is 43 GPa, and the Poisson's ratio is 0.3.

According to the test data, calculate the elastic modulus, Poisson's ratio, cohesion and internal friction angle of the well core before and after acidification (Table 4).

| well number | state                | elastic modulus (GPa) | Poisson's ratio | Cohesion (Mpa) | internal friction angle (°) |
|-------------|----------------------|-----------------------|-----------------|----------------|-----------------------------|
|             | after acid soaking   | 40                    | 0.283           | 11.2           | 28                          |
|             | no acid soaking      | 45                    | 0.25            | 15.5           | 34                          |
|             | after acid soaking   | 43                    | 0.3             | 11.7           | 28.5                        |
|             | no acid soaking      | 49                    | 0.268           | 16.2           | 35                          |

Table 4. Changes of core mechanical parameters before and after acidification.

2.3.5. Analysis of experimental results. The experimental results show that the rock strength decreases to a certain extent after acidification, the cohesion decreases by about 30%, the elastic modulus decreases by about 10%, the Poisson's ratio decreases by about 15%, the internal friction angle decreases by about 18%, and the overall rock strength decreases by about 20%.

3. Conclusion

(1) The main mechanism of sand production in this formation is shear failure.

(2) The simulation experiment and numerical analysis of the high-speed gas passing through the hole show that when the high-speed gas passes through the perforating hole, since the turbulence effect will produce a large additional pressure difference, this increase the rock force and cause damage;

(3) The development of natural fractures reduces the rock strength of the rock and is more likely to cause sand production;

(4) The acidification experiment shows that the rock strength decreases after the acidification fracturing transformation. The rock strength decreases by about 20% after acidification.

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