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Abandonment Formation Pressure & Ultimate Reserve Recovery Boundary of Water-Bearing Sandstone Gas Reservoir

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Abstract
In order to figure out the abandonment formation pressure distribution and ultimate reserve recovery boundary of water-bearing sandstone gas reservoir, the gas reservoir pressure depletion was simulated on the long core which is consist of a few same permeability cores and is 50cm in length. The pore pressure of different positions along the long core was recorded during the experiment. At the end of the depletion, when gas rate is 0 ml/min and every position pressure remains constant, the relation plate of the pore pressure (P) and depletion path length (L) is plotted. The relation of pore pressure (P) and depletion path length (L) was established at near well-bore region (the distance from gas outlet is 5～20cm) and far from well-bore region (the distance from gas outlet is 20～50cm) and the abandonment pressure gradient of different location was derived. Based on pressure gradient derived from the experiment, combined with the percolation theory of gas reservoir, the ultimate reserve recovery boundary of different pressure gradient was calculated. The research result shows that: (1) Abandonment pressure of water-bearing sandstone gas reservoir increases with the distance from the location to the gas outlet. The abandonment pressure gradient at a distance of 5～20cm is 3~20 times more than that of the distance of 20～50cm. Physical simulation experiment carried on long core is more representative and more accurate on abandonment formation pressure distribution description than that on conventional short core, whose result is practical in deriving the reserve recovery boundary of the gas reservoir. (2) The relationship of ultimate reserve recovery boundary, formation permeability and water saturation in water-bearing sandstone gas reservoir is very close, which provide the theoretical foundation for well control reserve evaluation of complex gas reservoir.

Key Word and Phrases
Water-Bearing Sandstone Gas Reservoir, Gas Reservoir Exploitation, Physical Simulation, Abandonment Pressure Gradient, Reserve Recovery Boundary.

1. Introduction

The abandonment formation pressure distribution characteristic is the important foundation of reserve recovery evaluation which is based on the analysis of production performance and experiment method of “rate-differential pressure”. Learned from the pressure drawdown distribution of gas well, the pressure changing law of different distance from the gas well during gas reservoir pressure depletion was simulated on the long core, which is consist of a few same permeability cores and is 50cm in length, by the experimental method of testing pressure of multipoint along the long rock core. Based on the above experiment data, the abandonment formation pressure distribution curve is drawn. Besides, based on the characteristic of pressure distribution, the pressure gradient of different region can be calculated. The gas reservoir development is simulated practically by above experimental method. The derived result is functional in engineering application and development evaluation of gas reservoir.

2. Testing Pressure of Multipoint along the Long Rock Core

In the progress of gas reservoir exploitation, the pressure cone of depression often forms around the gas well. The pressure spread until to the physical boundary of seepage with the gas well yielding. Combined with the above characteristics, the experimental method of testing multipoint pressure along the long rock core is established, by which the law of pressure dropping and spreading is simulated, and then the abandonment formation pressure gradient is derived.

2.1 The Experiment Workflow

The pressure of different pressure tap which is showed as P_1～P_6 in figure 1 is tested on the series of high pressure core holder. The pore pressure of different location along the core can be tested by the experiment workflow.

2.2 Experimental Procedure

(1) The same permeability rock cores were selected and used for experiment. The cores were dried at 120℃ for 48 hours. Then, the cores were saturated with water under vacuum for 24 hours.

(2) The core was placed in the core holder. An overburden pressure of 25MPa was applied. Then the core was saturated with the moisture to a pressure of 20MPa by high pressure gas source. Close the gas source after cores were saturated with the moisture at a pressure of 20MPa and make sure cores are in an independent pressure system. The pressure tap location is shown as P_1～P_6 in figure 1. The pressure of every pressure tap is same after cores are saturated with moisture.

(3) The fixed volume gas reservoir pressure depletion is simulated by a certain gas rate is yielded at gas outlet. The pressure, time, gas flow rate, and total gas volume is recorded in the experiment. The experiment would be stopped until the gas rate is zero and the pressure of every pressure tap is constant.

2.3 Parameters of the Experimental Core

The cores are from Sichuan Xujiahe gas reservoir. The experimental scheme and parameters of core are shown in Table 1.

Table 1 The Experimental Scheme and Parameters of Core

Experimental Scheme	Category	Air Permeability $\times 10^{-3}\ \mu m^2$	Diameter×Length cm×cm	Initial Water Saturation Sw,%
TEST 1	I	1.63	2.51×52.04	30.3
TEST 2	I	1.63	2.51×52.04	50.1
TEST 3	II	0.58	2.51×51.56	35.9
TEST 4	II	0.58	2.51×51.56	46.2
TEST 5	III	0.175	2.51×52.00	30.3
TEST 6	III	0.175	2.51×52.00	45.5
TEST 7	IV	0.063	2.51×52.26	29.8
TEST 8	IV	0.063	2.51×52.26	49.8

3. Experimental Result and Analysis

3.1 The Abandonment Formation Pressure Distribution Characteristics

That the gas rate is zero and the pressure of every pressure tap is constant signed the end of the experiment. The pressure distribution of every pressure tap is shown in Figure 2. The pressure distribution characteristic of near well-bore region is different from that of far from well-bore region. The pressure drawdown rate of near well-bore region is great and that of far from well-bore region is small. The abandonment formation pressure gradient derived from the flow rate – differential pressure curve which is obtained from displacement method on the short rock core usually represents the pressure drawdown distribution of the near well-bore region. So the abandonment formation pressure gradient derived from short core experiment is often too large to be applied in the gas reservoir engineering computation.

3.2 The Abandonment Formation Pressure Gradient Computation

The relation of pressure value and the distance from the gas well of the near well-bore region and far from well-bore region is established. The relation of pressure and distance can be written as

$$P = aL + b \tag{3.1}$$

The abandonment formation pressure gradient of two areas derived from testing data is shown in Table 2. The three characteristics can be known from Table 2.

(1) In the condition of the same permeability model and same water saturation, the abandonment pressure gradient of near well-bore region is 3~20 times more than that of far from well-bore region. (2) The abandonment pressure increases with the water saturation in the same permeability model. (3) The abandonment pressure increases with the decrease of permeability in the condition of similar water saturation.

Table 2 The Abandonment Formation Pressure Gradient Computation Result

Experimental Scheme	The abandonment pressure gradient of near well-bore region	The abandonment pressure gradient of far from well-bore region	The ratio of abandonment pressure gradient of near well-bore region to that of far from well-bore region
TEST 1	\	\	\
TEST 2	1.024	0.104	10
TEST 3	0.090	0.024	4
TEST 4	2.641	0.133	20
TEST 5	0.593	0.032	19
TEST 6	4.222	0.201	21
TEST 7	5.749	1.047	5
TEST 8	8.533	3.265	3

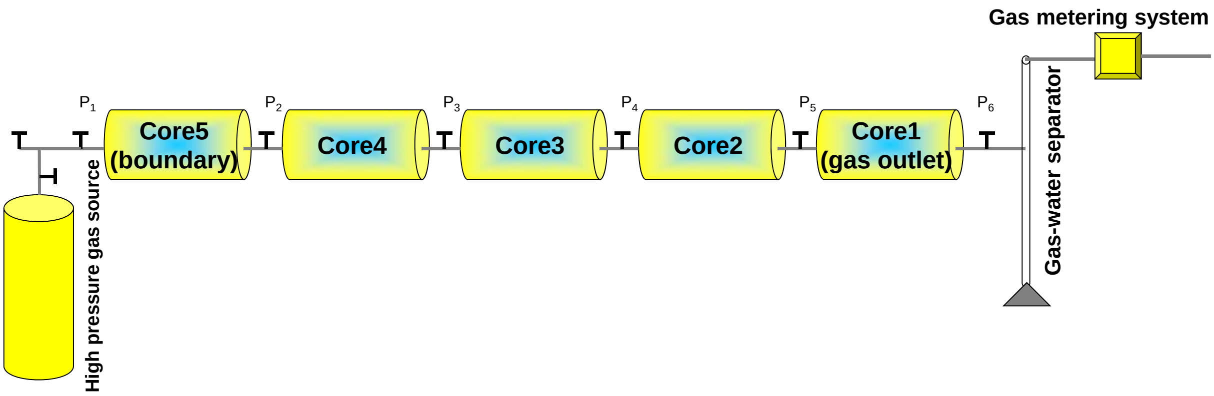

Fig. 1 The Experiment Workflow and the Location of Pressure Tap

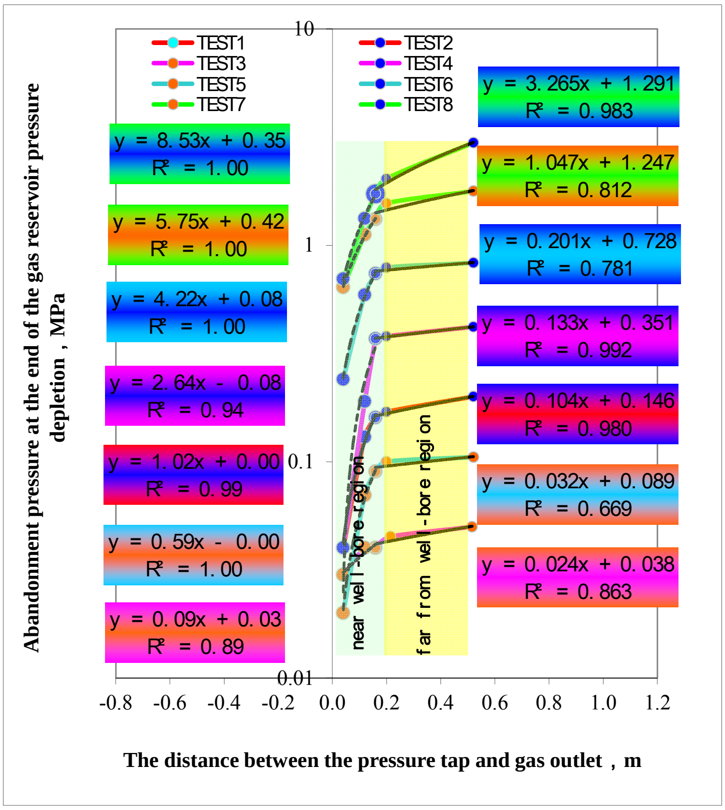

Fig. 2 The Abandonment Formation Pressure Distribution Characteristics

4. The Ultimate Reserve Recovery Boundary

The ultimate reserve recovery boundary of gas reservoir means that the biggest gas drainage region at the end of the gas reservoir depletion, which is closely related to the sand body physical property, physical boundary and seepage boundary.

According to equation (3.1), we have:

$$L = \frac{P - b}{a} \tag{3.2}$$

The ultimate reserve recovery boundary of gas reservoir of certain physical property can be calculated by equation (3.2). Based on the fitting function of far from well-bore region pressure and length in Figure 2, the ultimate reserve recovery boundary is calculated at a formation pressure of 30MPa, which is shown in Figure 3. Beyond the above, the ultimate reserve recovery boundary is closely related to permeability and water saturation. When the permeability is more than 1mD, the ultimate reserve recovery boundary is more than 1000m and increases with the decrease of water saturation. Besides, when the permeability ranges from 0.1mD to 1mD, the ultimate reserve recovery boundary is between 100m and1000m. Finally, when the permeability is less than 0.1mD, the ultimate reserve recovery boundary is less than 100m.

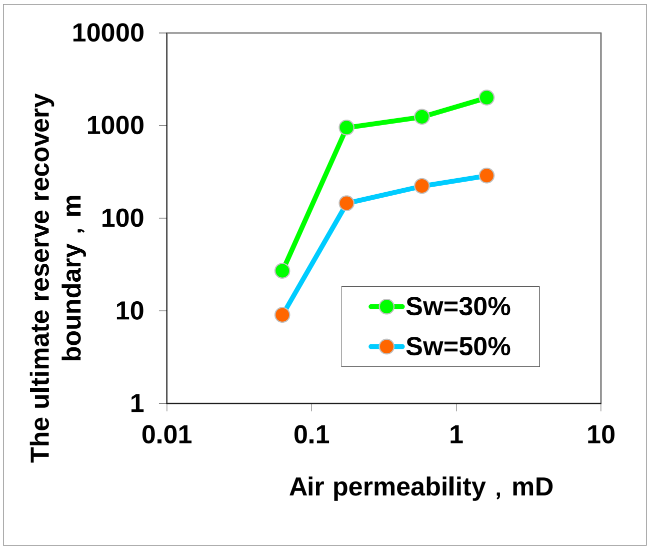

Fig. 3 **T**he Relation of Ultimate Reserve Recovery Radius and Permeability, Water Saturation at a Pressure of 30 MPa

5. Conclusions

The abandonment pressure distribution along the length is studied by the method of testing pressure of multipoint along the long rock core. In the condition of the same permeability model and same water saturation, the abandonment pressure gradient of near well-bore region is 3~20 times more than that of far from well-bore region, which appears to pressure drop funnel. The abandonment pressure gradient of different location is derived from the relation of pore pressure and distance.

Because the ultimate reserve recovery radius is the biggest gas drainage distance at the end of the gas reservoir depletion, the ultimate reserve recovery boundary of 30% and 50% water saturation is calculated at a pressure of 30MPa according to pressure gradient of far from well-bore.

The relation plate of ultimate reserve recovery boundary, water saturation and permeability is established and provides the theoretical foundation for the well control reserve evaluation of complex gas reservoir. The ultimate reserve recovery radius of certain water saturation and permeability can be got from the relation plate. And then the well control reserve in the range of ultimate reserve recovery radius can be computed by volumetric method.

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