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Research on Non-Linearity Percolation Characteristics in Tight Sandstone Gas Reservoir

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Abstract

The microcosmic pore throat structure is complex in tight sandstone reservoir so that the fluid lodging situation and flow condition in the pore space is difficult to determine, which has an influence on the effective displacement and efficient development directly. Research on gas/water percolation feature in the formation is the foundation of recognizing the tight gas reservoir. Taking a tight gas reservoir block in Ordos Basin for example, constant speed mercury-injection method is carried on leading to a research and analysis about microcosmic pore throat structure features and fluid physical property relative parameters in the formation. Using the steady-state method, an experiment has been done that takes 15 pieces of cores as examples which gets gas/water relative permeability curves. We conduct normalization processing and analyze relative permeability characteristics. Flow-pressure testing method is applied for studying gas/water relative permeability features. In view of the tight gas, the permeability is lower and the velocity of flow is more slowly under a certain pressure difference. By controlling differential pressure, flow velocity's subtle changes are tested and the commensurable curve can be got. Research shows that the water liquidity in the small pore throat is poorer and the residual water saturation is higher; the two-phase seepage area spans a narrow range while the whole liquidity is poorer; there is threshold pressure gradient in the tight sandstone formation so that it presents non-linear seepage characteristics; the threshold pressure gradient in the target block is higher at about 0.151 MPa/m. Based on the above reasons, effective displacement in the tight gas reservoir gets more difficult.

Key words: Tight gas; Gas/water relative permeability features; Non-linearity seepage; Threshold pressure gradient

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INTRODUCTION

The natural gas is referred to as the "21st century's energy". At the same time, natural gas in the tight sandstone gas reservoir is regarded as the most important exploration and development field in the aspect of unconventional gas development. There are many different characteristics between conventional gas reservoir and unconventional one[1-3]. Firstly, the permeability is very low under 0.1 mD in normal circumstances so that the pore throat is very small. It exists the pressure sensitivity in the formation to a certain extent as well. Secondly, flowing of fluid in the formation does not follow Darcy's Law because its percolation has to overcome a certain threshold pressure gradient. Thirdly, natural energy shortage and formation pressure drop quickly lead to precipitous production decline. In the process of the tight gas reservoir development, the permeability and porosity get decreased with the decline of the formation pressure which makes it more and more complicated. Research on non-linearity percolation characteristics is the foundation of high efficient development in tight sandstone gas reservoir.

1. STUDY ON MICROSCOPIC PORE STRUCTURE CHARACTERISTICS IN THE TIGHT GAS FORMATION

At present, there are many microstructure research methods of formation, such as centrifuged laboratory experiment, nuclear magnetic resonance, CT imaging technology and so on[4,5]. Among them, constant speed mercury-injection method is the most commonly used one in the research of microscopic pore throat structure in the tight gas formation.

Constant speed mercury injection technology is mercury at a constant and very low speed (close to quasi static) injection liquid metal mercury[6] that oil and water are not wetting to the pore space, test the relationship between pressure change and the mercury content in the process of forward and backward, record the changing process of pressure curve. Due to varying degrees of pore throat contraction, when mercury break throat and into the channel instantaneous, mercury distribution in the channel space quickly, and generate a pressure decline, the pore surface contact with the mercury meniscus fluctuation occurs, macro performance is capillary pressure fluctuation, the subtle in mercury pressure fluctuation can be quantitative determination of size and number of pore and throat, and can get the pore and throat of capillary pressure curve.

Constant speed mercury injection experiment steps:

(a) Drilling the 2.5 cm in diameter standard core from the whole diameter core, drying after wash oil;

(b) Using the gas measuring method measure standard core porosity;

(c) Using the gas measuring method measure standard core permeability;

(d) Selecting a good property (porosity, permeability) standard core from each well do constant speed mercury injection experiment;

(e) Soaking in the fluid of the mercury after sample vacuum;

(f) Injectting mercury to the core at a constant low speed (0.00005 ml/min), in the process of injecting mercury the pressure cycle down a rebound, when the pressure up to 6MPa the experiment ended, the corresponding throat radius is about 0.13μm.

Experiment was carried out 15 pieces samples of constant speed mercury injection test, the core sample was taken from the Ordos basin, porosity and permeability are very low, the porosity distribution is 8%-12.5%,the average is 10.42%, permeability distribution range is 0.005-0.109 mD, the average is 0.644 mD.

Mercury injection experiments show that the sample has the high displacement pressure, between 0.972 and 13.656 MPa, the average is 6.934 MPa, the corresponding largest throat is between 0.056 and 0.922 μm, the average is 0.519 μm; the mean pore throat coefficient is larger, between 9.326 and 15.392, the total average pore throat radius is lesser, narrow throat is the dominant in the pore throat. sorting coefficient is bigger, is between 0.699 and 2.761, pore size is uneven and distribution is not concentration, pore sorting is poor.

Research shows that: with the increase of porosity and permeability, effective weighted average throat radius has the tendency of increase, different level of permeability of rock sample, its permeability is controlled by different levels of the throat radius. For the low permeability and porosity, the throat radius with the change of porosity and permeability curve slope is bigger, the change is more apparent, with the increase of porosity and permeability, throat radius and the correlation between porosity and permeability curve slope is reduced, it shows that small throat of low permeability reservoir quantity is relatively large, with the increase of permeability, the small throat number is relative small. It also shows that high permeability reservoir, the larger throat is mainly contribution to the permeability, the fluid seepage channel is big, seepage resistance is small, the seepage ability is strong, the reservoir has large development potential.

On the other hand, the low permeability reservoir, the tiny throat is mainly contribution to the permeability, the fluid seepage resistance is large and seepage ability is weak, the development of the reservoir is difficult. 15 pieces of core capillary force curve is to the top right, away from the horizontal axis, and angle is bigger, no basic platform, sorting is poorer, expulsion pressure value is bigger, it shows that the biggest connected throat radius is small, expulsion pressure increase with the decrease of the permeability, especially when the permeability is less than 0.015 mD, expulsion pressure increase rapidly, increased difficulties of reservoir development, and belongs to the poor reservoir.

2. TEST OF RELATIVE PERMEABILITY CURVE

According to Darcy's Law percolation theory, ignoring capillary pressure and gravity, use the steady-state method to measure the phase permeability curve of tight gas cores. In experiment, the flow rate is unchanged, at the same time the gas and water according to certain proportion constant speed injection into the core, when the import and export pressure and oil and gas flow are stable, water saturation is constant, achieve stable seepage state, so using the import and export flow and pressure in the sample, according to the darcy's law to calculate gas effective permeability and relative permeability of water, change the gas and water injection rate, they can get a series of different water saturation of gas-water relative permeability value, and draw gas water phase permeability curve.

15 pieces of tight gas reservoir cores experiment data analysis results show that the experimental zone core irreducible water saturation is higher, between 49.32% - 60.03%, and the lower the permeability, the higher the irreducible water, and this is closely related to small throat and the complex pore throat connection; two phase region span range is relatively narrow, lies between 10.01%-14.91%; the higher the permeability of the core, the larger two-phase area span; isotonic point of irreducible water saturation is larger, general at around 60%; residual gas saturation is about 30%. With the increase of pressure gradient, the characteristics of the gas phase relative permeability curve are left, and under the same water saturation, the greater the pressure gradient, the lower the gas phase relative permeability.

If the same reservoir has many core test results, calculate the average relative permeability.

$$K_{rw}= a_1\times(S_w\text{-}S_{wi})^3+b_1\times(S_w\text{-}S_{wi})^2+c_1\times(S_w\text{-}S_{wi})\ , \tag{1}$$

$$K_{rg}= a_2\times(S_w\text{-}S_{gr})^3+b_2\times(S_w\text{-}S_{gr})^2+c_1\times(S_w\text{-}S_{gr})\ . \tag{2}$$

Where K_{rw} denotes water phase relative permeability; S_w denotes water saturation, %; S_{wi} denotes irreducible water saturation, %; K_{rg} denotes oil phase relative permeability; S_{gr} denotes residual oil saturation, %; a_1, a_2, b_1, b_2, c_1, c_2 denote respectively wettability and pore throat structure constant.

Tight gas reservoir's relative permeability curve is obtained by type (1), (2) after the normalization, it is shown in Figure 1.

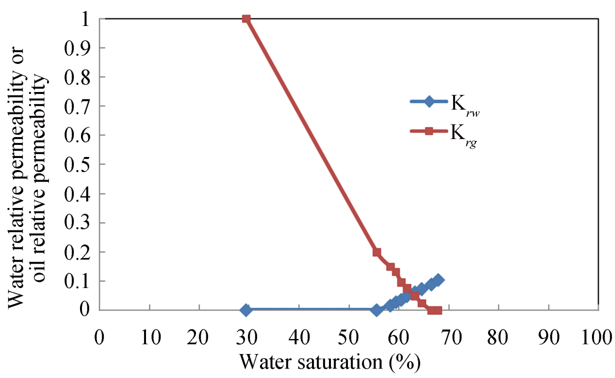

Figure 1
Tight Gas Reservoir Relative Permeability Curve

The tight gas reservoir resulting from the normalized relative permeability curve has the following characteristics: Reservoir core average irreducible water saturation is 55.54%, tight pore throat in micro scale and complex structure is the leading reason; two-phase area span range is relatively narrow, the normalized result is 12.27%, the overall liquidity is poor, lead to this kind of reservoir production decline is fast, stable time is short; isotonic point irreducible water saturation is larger, is 64.18%, mining mode of conventional gas reservoir is difficult to effectively use the tight reservoir.

3. ANALYSIS OF NONLINEAR SEEPAGE CHARACTERISTICS

There are mainly two kinds of experimental test methods of percolation flow curve: Differential pressure-flow and flow-difference pressure method[7-9]. Differential pressure-flow method is by setting the core entrance side pressure, measure the core outlet fluid flow, and then gradually change core inlet side pressure, measure different pressure stable flow, according to the stability of flow rate and pressure draw seepage curve. Flow-pressure difference is by setting the core entrance side flow, record the differential pressure, draw seepage curve. In view of the tight gas reservoir, its permeability is lower, under a certain pressure difference velocity is smaller. So take flow-difference pressure method to measure tight gas reservoir percolation curve.

Experimental methods:

(a) Wash oil and dry the experiment of core, vacuum, fully saturated with experimental fluid.

(b) Put the core into the core gripper, and confine pressure, when the displacement pressure is big, by adjusting the cylinder flow, control the pressure on both ends of the holder, seepage experiment carried out in accordance with the experiment scheme, record fluid flow under different pressure surface displacement and the time required, calculate the velocity of flow. When the displacement pressure is small, the low pressure constant pressure device provides the low pressure source.

(c) According to the test pressure and velocity, and draw the seepage curve.

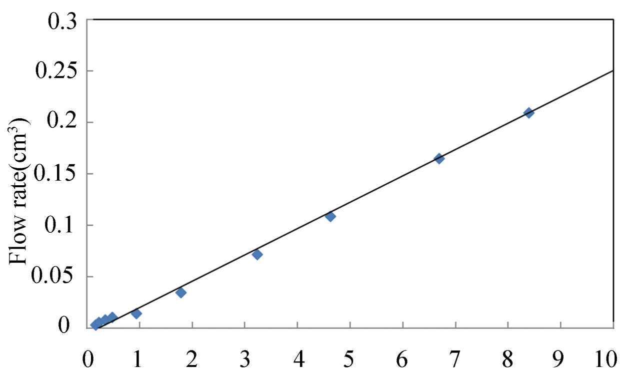

Figure 2
Tight Gas Reservoir Percolation Characteristic Curve

Experimental results show that tight gas reservoir because of the small pore throat, the surface is large, rock surface acting force by the fluid in the process of flowing is large, the power of the tight gas reservoir start-up pressure gradient exists, has the characteristics of nonlinear seepage. Study block start-up pressure gradient is higher, about 0.151 MPa/m, tight gas reservoir effectively use is more difficult.

CONCLUSION

(a) The fluid's poor liquidity leads to higher residual water saturation in tight sandstone gas reservoir. The leading role of narrow throat increases the difficulty that the fluid flows.

(b) What makes tight gas' complex seepage characteristic is that its pore throat is in micro scale. Relative permeability curve has the features as follows: The two-phase region span a narrower range; the irreducible water saturation is higher at the isopotal point, at about 64.18%.

(c) There is threshold pressure gradient in tight gas reservoir so that it presents non-linear seepage characteristics which results in that effective development in thus gas reservoir are more difficult.

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