International Journal of Energy
ISSN: 2957-9473 | Vol. 2, No. 2, 2023

Physical Property Analysis and Sensitivity Damage Evaluation of Tight Sandstone Gas Reservoirs

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Abstract: Tight sandstone reservoirs are widely distributed in China, because tight reservoirs have the characteristics of low porosity and low permeability, high clay mineral content, etc., it is easy to cause reservoir damage during hydraulic fracturing and is not easy to recover. X-ray whole-rock diffraction analysis was carried out through tight sandstone reservoir core, and the proportion of sensitive minerals in tight sandstone gas reservoir was clarified, and water sensitivity and flow velocity sensitivity damage experiments were carried out based on the test results. The experimental results show that the flow velocity sensitivity damage rate of tight sandstone reservoir is 28.02%, and the critical flow rate is 0.75ml/min, which is a weak flow rate sensitivity injury. The water-sensitive injury rate was 63.98%, which was moderately strong water-sensitive injury.

Keywords: Tight sandstone; XRD; Flow rate sensitive; Water sensitive.

1. Introduction

Dense sandstone is a general concept, and the definition standards vary among countries. Currently, there is no unified definition and standard. Holditch proposed that tight sandstone reservoirs refer to low permeability or extremely low permeability reservoirs, where gas production is too low to require production intervention [1]. The commonly accepted definition of commercial tight gas is the production of gas from reservoirs with low porosity and permeability, and commercial production is carried out after large-scale stimulation measures [2]. In 1970, the US government proposed using 0.1mD permeability as the critical value to define a tight reservoir; Surdam et al. defined a tight reservoir as a reservoir with a porosity of<12% and a permeability of ≤ 1mD [3]. Scholars such as Zou Caicai proposed a reservoir with a porosity of less than 10% and an original permeability of less than 1mD, a pore throat diameter of less than 1 μm, and a gas saturation of less than 60%, emphasizing that the natural production of tight reservoirs cannot meet commercial purposes [4].

Compared with conventional oil and gas fields, their development and extraction are more difficult and require higher technical requirements. Moreover, due to the low permeability of unconventional reservoir matrix, reservoir damage is prone to occur during hydraulic fracturing. Due to the small pore throat and high sensitivity of minerals in unconventional oil and gas fields, external fluid invasion can easily cause damage to the reservoir, leading to a decrease in reservoir permeability and a significant impact on production and development. Due to the presence of sensitive minerals such as water sensitivity and velocity sensitivity [5], it is easy to cause water sensitivity, velocity sensitivity, and water lock damage in large-scale fracturing stimulation measures. Reservoir protection is imperative, and its protective performance is closely related to the development efficiency of tight reservoirs. Conducting damage evaluation of tight reservoirs plays an important role.

Water sensitive damage is evaluated in the laboratory by controlling different degrees of mineralization, which leads to changes in permeability after injection into the rock core. Essentially, the incompatibility between mineralization and the formation leads to changes in pore throats, leading to changes in permeability. In 1958, scholars such as Monaghan caused changes in reservoir permeability by changing the mineralization degree of experimental fluids, and pointed out that the mineralization degree significantly decreased the permeability at the end of the month [6]; In 1963, Hewitt discovered the mechanism of water sensitivity phenomenon [7]. Because the low salinity fluid enters the formation and contacts with some clay minerals in the reservoir to produce the phenomenon of water absorption expansion, and along with the migration of clay minerals particles in the pore throat, the pore throat changes, the particle migration causes plugging, and causes irreversible damage to the reservoir [8]

Gariel and Lnamdar observed through flow experiments that the permeability of fluids compatible with reservoir rocks continues to decrease when their flow velocity exceeds the critical flow velocity, which is known as reservoir velocity sensitivity. In actual production and development, accompanied by the invasion of foreign fluids into the formation, when the fluid flows in the reservoir, the flow rate is higher than the critical flow rate, causing particle migration and pore throat blockage, resulting in a decrease in permeability and causing damage to the formation [9]. In 1966, Olsen and Poppy first proposed measuring the permeability of the core mechanism through a fixed flow rate, and calculating the changes in permeability through different flow rates [10]; Domestic research on velocity sensitivity has also achieved some results. In 1994, Zhu Bin proposed that velocity sensitivity is not only related to fluid flow velocity, but also to the state of fluid flow, mineral types, and fluid mineralization degree by studying the velocity sensitivity mechanism and main factors affecting velocity sensitivity in tight sandstone reservoirs [11]; In 2003, Pengbai Group selected tight sandstone as the research object, and found that the absolute content, composition characteristics and occurrence of clay minerals are the internal causes of velocity sensitivity damage [12]. Based on previous research experience, the physical property analysis of tight sandstone reservoir was carried out, the content of clay minerals in the reservoir was determined, and potential sensitive damage

claims were analyzed. The reservoir damage evaluation experiment was carried out to evaluate the sensitive damage existing in tight sandstone gas reservoir and provide guidance for actual development.

2. Experimental part

The content of clay minerals in tight sandstone gas reservoir is analyzed and evaluated by XRD to determine the content of clay minerals in the reservoir and analyze the potential sensitivity damage of the reservoir. Based on this, the evaluation experiment of reservoir sensitivity damage is carried out to determine the different sensitivity damage degrees of the reservoir.

2.1. Materials

The drying temperature of the dense sandstone reservoir is 70 ℃. After 48 hours of drying, it is weighed every 8 hours to compare the quality difference before and after. When the difference between the two masses is less than 10mg, the quality of the core is recorded; Measure the air permeability and porosity of core samples and conduct research experiments. The physical parameters of the experimental core are shown in the table below:

Table 1. Basic Physical Parameters of Experimental Core

Number	Length/cm	Dry weight/g	Initial gas permeability /mD	Porosity /%	Test items
1-1	5.521	71.71	0.3284	6.41	water sensitivity
1-2	6.313	82.46	0.0182	2.58	Velocity sensitivity

2.2. Procedure

(1) The operation of the velocity sensitivity experiment is as follows:

a. The experimental fluid is configured with simulated formation water samples based on the water sample data of the Shihezi Formation in the Linxing Shenfu block, and the experimental core is saturated; b. Load the fully saturated rock sample into the core holder, and ensure that the flow direction of the experimental fluid in the rock sample is consistent with the gas flow direction in the gas permeability measurement, while ensuring good airtightness of the experimental instrument. During the entire experimental process, there should be no air left in the experimental system, and the fluid should fill the entire experimental system. Then, adjust the confining pressure to 2.0MPa. c. During the experiment, the confining pressure should always be greater than the inlet pressure by 2MPa; The experimental flow rate is set at 0.1cm3/min, 0.25cm3/min, 0.75cm3/min, 1.0cm3/min, 1.5cm3/min, 2.0cm3/min, 3.0cm3/min, 4.0cm3/min, 5.0cm3/min, 6.0cm3/min. Measure in sequence, and measure the permeability obtained at this flow rate when the pressure stabilizes. For low-permeability dense sandstone core samples, the experimental flow rate does not reach 6.0cm3/min, and the pressure gradient is greater than 2MPa, the experiment can be ended. The damage rate of flow velocity sensitivity is calculated as follows:

$$D_{\mathrm{vn}} = \frac{\left|\mathrm{K}_n - \mathrm{K}_i\right|}{K_i} \times 100\% \quad (1)$$

In the equation:

Dvn—The change rate of core permeability corresponding to different flow rates, %;

Kn—Permeability measured at different experimental flow rates, mD;

Ki—The permeability measured at the lowest flow rate, mD.

The evaluation indicators for the degree of damage to flow velocity sensitivity are shown in Table 2 below:

Table 2. Flow Rate Sensitivity Evaluation Indicators

Speed sensitivity damage rate/%	Extent of damage
$D_w \leq 5$	Not have
$5 < D_w \leq 30_w$	Weak
$30 < D_w \leq 50$	Moderately weak
$50 < D_w \leq 70$	Moderately strong
$70 < D_w$	Strong

(2) The water sensitivity experiment operation is as follows:

a. In the experiment, the initial salinity fluid was used to measure the initial liquid permeability of the rock sample; b. After measuring the initial liquid permeability, use 1/2 salinity experimental fluid to displace, the displacement speed is consistent with the initial flow rate, displace 10PV~15PV, stop the displacement, keep the confining pressure and temperature unchanged, and make the experimental fluid react with clay minerals for more than 12h;c. Adjust the experimental flow rate to the initial flow rate, use a 1/2 salinity experimental fluid for displacement, measure the core permeability, and record the relevant experimental data; d. Repeat steps b to c for indoor logistics flow simulation experiments using 1/4 mineralization degree and 1/8 mineralization degree experimental fluids, as well as distilled water. Measure the permeability of different experimental fluids, draw relationship curves, and analyze the experimental results.

The formula (2) for calculating the change rate of water sensitive permeability is:

$$D_w = \frac{\left|K_i - K_w\right|}{K_i} \times 100\% \quad (2)$$

In the equation:

Dw—The change rate of permeability of rock samples corresponding to experimental fluids with different mineralization degrees, %;

Kw—Permeability of rock samples corresponding to experimental fluids with different mineralization degrees, mD;

Ki—The permeability of the rock sample corresponding to the initial fluid, mD.

The evaluation indicators for the degree of water sensitivity damage are shown in Table 3:

Table 3. Evaluation indicators for water sensitivity damage degree

Water sensitivity damage rate /%	Extent of damage
$D_w \leq 5$	Not have
$5 < D_w \leq 30_w$	Weak
$30 < D_w \leq 50$	Moderately weak
$50 < D_w \leq 70$	Moderately strong
$70 < D_w \leq 90$	Strong
$D_w > 90$	Extremely strong

3. Experimental Results and Discussion

The rock mineral content is determined by X-ray whole rock diffraction analysis to determine the relative content proportion of clay minerals existing in the reservoir and analyze the potential factors causing damage. The results are shown in Table 4:

Based on the analysis of XRD clay minerals content test results, the relative mineral content of 1-1 Smectite mixed lay in core accounts for 78%, which may cause potential water sensitivity damage; The test results of core 1-2 show that the relative mineral content of kaolinite is relatively large, and the analysis shows that the core may be damaged by velocity sensitivity. Sensitivity damage analysis was conducted on 2 rock cores, and the experimental results are as follows:

Table 4. Test Results of XRD clay minerals

Number	Core number	Mineral Content (%)				Mixed layer ratio (%)	
		Smectite mixed lay	Illite	kaolinite	chlorite	I/S	C/S
1	1-1	78	12	2	8	30	/
2	1-2	31	8	34	27	25	/

(1) Water sensitive damage

Based on the analysis of rock and mineral resources, it can be concluded that the relative content of the 1-1 Smectite mixed lay in core is relatively large. Therefore, in actual production and development, foreign fluids entering the reservoir can easily cause water sensitivity damage. In order to clarify the degree of water sensitivity damage in the reservoir, evaluate the changes in permeability under different mineralization conditions, and provide theoretical support for subsequent reservoir protection. The experimental results are as follows:

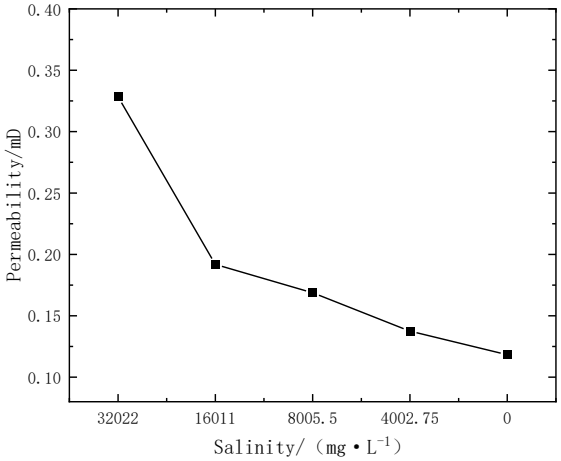


Figure 1. Evaluation curve of water sensitive injury experiment

According to the results of core 1-1 water sensitivity damage experiment, as the mineralization degree of the simulated formation water sample decreases, the permeability change curve shows a downward trend. When the mineralization degree is 16011mg/L, the water sensitivity damage degree reaches 41.60%. When the mineralization degree is 0 (i.e. distilled water) is used for water sensitivity damage degree evaluation, the permeability decreases to 0.1183mD, and the permeability damage rate caused by water sensitivity damage reaches 63.98%, as shown in Table 3, Core 1-1 exhibits moderate to strong water sensitivity damage.

(2) Velocity sensitivity damage

Based on the rock and ore analysis, it can be seen that the relative content of kaolinite in core 1-2 is relatively large, so that in the actual production and development, the inflow of foreign fluid into the reservoir is easy to cause velocity sensitivity damage. In order to clarify the damage degree of velocity sensitivity of the reservoir, and evaluate the changes in permeability under different flow conditions, the test results are as follows:

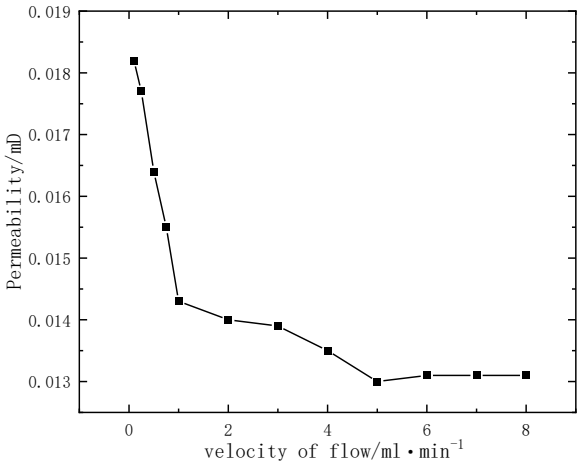


Figure 2. Flow velocity sensitivity injury evaluation curve

According to the flow rate sensitivity damage evaluation experiment conducted on core 1-2, the permeability decreases to a certain extent with the increase of flow rate. When the flow rate reaches 6ml/min, the permeability remains stable and does not change; When the flow rate is 1ml/min, the degree of permeability decrease reaches 21.43%, and the degree of damage exceeds 20%. Therefore, a flow rate of 0.75ml/min belongs to the critical flow rate; At a flow rate of 6ml/min, the degree of permeability damage is the highest, with a damage degree of 28.02%, which belongs to weak flow rate sensitivity damage.

4. Conclusion

(1) The test results of clay minerals in experiment 1-1 core

show that the relative mineral content of Smectite mixed lay is 78%, and the relative content of kaolinite in core 1-2 is 34%. Core 1-1 may have water sensitivity damage, and core 1-2 may have velocity sensitivity damage.

(2) Based on the evaluation experiment of water sensitivity damage and flow velocity sensitivity damage, the water sensitivity damage rate of core 1-1 is 63.98%, belonging to moderate to strong water sensitivity damage; The critical flow rate of core 1-2 is 0.75ml/min, and the damage rate of flow rate sensitivity is 28.02%, which belongs to weak flow rate sensitivity damage.

References

[1] Holditch S A. Tight Gas Sands. JPT 58 (6): 86–93[R]. SPE-103356-PA. DOI: 10.2118/103356-MS, 2006.

[2] Rogner H H. An assessment of world hydrocarbon resources[J]. Annual review of energy and the environment, 1997, 22(1): 217-262.

[3] Surdam R C, Jiao Z S, Heasler H P. Anomalously pressured gas compartments in Cretaceous rocks of the Laramide basins of Wyoming: A new class of hydrocarbon accumulation[J].MEMOIRS-AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, 1997: 199-222.

[4] Caineng Z, Guangya Z, Shizhen T, et al. Geological features, major discoveries and unconventional petroleum geology in the global petroleum exploration[J]. Petroleum Exploration and Development, 2010, 37(2): 129-145.

[5] Lei Ke. Study on Formation Protection Technology of Tight Gas Reservoir in Linxing-Shenfu Block[D]. China University of Petroleum (East China), 2018. DOI: 10.27644 / d.cnki.gsydu.2018.001958.

[6] Zhang Shao Huai. Protection reservoir technology[M]. Petroleum industry press,1993.

[7] Luo Ping Ya. Reservoir protection technology[M] Petroleum industry press,1999.

[8] Gao Bin, Xu Shijing, Hu Xinling et al. Experimental Study on Effect of Water Sensitivity on Oil-Water Two-Phase Seepage in Low Permeability Reservoir[J]. Journal of Xi'an Shiyou University(Natural Science Edition), 2022,37(06):75-81.

[9] Shi Jingping, Gong Wenchao, Cao Weizheng et al. A Research Into The Damage Mechanism Of Velocity-Sensitivitu In Sandstone Of A Reservoir[J]. Journal of Chengdu University of Technology (Science & Technology Edition), 2022, 37(06): 75-81.

[10] Olsen H W, Poppy T. Darcy's law in saturated kaolinite[J]. Water Resources Research, 1966, 2(6): 287-295.

[11] Zhu Bin. The Rate Sensibility In Reservoir Rock In Relation To The Formation Layer Minerals[J] Oilfield Chemistry, 1994(01): 1-4+44.

[12] Peng Baiqun. Reservoir Sensitivity Research Of Some Basins[D]. Harbin Engineering University,2003.