Research Article

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Pore throat characteristics of tight reservoirs by a combined mercury method: A case study of the member 2 of Xujiahe Formation in Yingshan gasfield, North Sichuan Basin

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Abstract: The complex pore throat characteristics are significant factors that control the properties of tight sandstone reservoirs. Due to the strong heterogeneity of the pore structure in tight reservoirs, it is difficult to characterize the pore structure by single methods. To determine the pore throat, core, casting thin sections, micrographs from scanning electron microscopy, rate-controlled mercury injection, and high-pressure mercury injection were performed in member 2 of Xujiahe Formation of Yingshan gasfield, Sichuan, China. The pore throat characteristics were quantitatively characterized, and the distribution of pore throat at different scales and its controlling effect on reservoir physical properties were discussed. The results show that there are mainly residual intergranular pores, intergranular dissolved pores, intragranular dissolved pores, intergranular pores, and micro-fractures in the second member of the Xujiahe Formation tight sandstone reservoir. The distribution range of pore throat is 0.018–10 μm , and the radius of pore throat is less than 1 μm . The ranges of pore radius were between 100 and 200 μm , the peak value ranges from 160 to 180 μm , and the pore throat radius

ranges from 0.1 to 0.6 μm . With the increase of permeability, the distribution range of throat radius becomes wider, and the single peak throat radius becomes larger, showing the characteristic of right skew. The large throat of the sandy conglomerate reservoir has an obvious control effect on permeability, but little influence on porosity. The contribution rate of nano-sized pore throat to permeability is small, ranging from 3.29 to 34.67%. The contribution rate of porosity was 48.86–94.28%. Therefore, pore throat characteristics are used to select high-quality reservoirs, which can guide oil and gas exploration and development of tight sandstone reservoirs.

Keywords: storage space, pore throat structure, pore throat, tight sandstone, Yingshan oilfield

1 Introduction

In the twenty-first century, China has entered the peak period of continuous growth of unconventional oil and gas reserves [1–4]. The tight sandstone reservoirs become an important replacement field for future oil and gas exploration [5,6]. Tight reservoirs are generally defined as sandstone with porosity less than 10% and permeability less than $1 \times 10^{-3} \mu\text{m}^2$ [7–10]. The pore-throat structure of tight reservoirs, on the one hand, controls the porosity and permeability of reservoirs, and on the other hand, affects the difficulty of oil and gas production, which has been a hot topic of scholars in recent years [11–13].

Tight reservoirs are characterized by complex reservoir space and poor throat connectivity, resulting in strong heterogeneity of pore structure and difficulty in characterization [14–18]. In the current research process, the main techniques used include Scanning Electron Microscopy (SEM), micro CT scan, low-temperature nitrogen adsorption (LTNA), high-pressure mercury injection (HPMI),

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rate-controlled mercury injection (RCMI), nuclear magnetic resonance (NMR), etc., with distinct characteristics of different methods [19–22]. However, these methods have their limitations, and there are relatively few researches on quantitative characterization of pore throat structure of tight sandstone [23–26].

SEM can be used for the surface morphology of the pore throat, but the data of the throat cannot be obtained [27]. The LTNA method can obtain nano and micron pore data, but the scope of the characterization scale is narrow [28]. CT scan can reconstruct the three-dimensional structure of pore-throat, but it cannot effectively reflect the seepage characteristics of the fluid in the reservoir [29–31]. The NMR results are closely related to the T_2 relaxation time; to require pore radius, the T_2 spectrum should be converted by means of combination NMR with other methods [32]. HPMT can obtain throat parameters, but the pore size is limited, resulting in the loss of some pore structure information [33]. RCMI can obtain the number distribution of pores and throat and better characterize the seepage characteristics of the reservoir, but it cannot obtain the information of pore throat less than 100 nm [34]. These differences indicate that the model of HPMT is based on the assumption that the porous media is composed of capillary bundles, while the model of RCMI is based on the assumption that the porous media is composed of throat and pores of varying size and radius. Under the same mercury saturation, the pressure value of capillary pressure measured by HPMT is larger than that by RCMI, and the radius measured by HPMT is smaller than that by RCMI. The radius measured by HPMT can be close to the true value only by contact angle correction [35]. The pore structure information obtained by HPMT is completely obtained by analyzing the mercury injection curve, while the RCMI can not only obtain a mercury injection curve but more importantly, it can obtain the quantity distribution of the throat from the pressure fluctuation in the process of mercury injection. The number distribution of the throat is better than the volume distribution to characterize the seepage characteristics of the reservoir [36]. The quantity distribution of the throat cannot be obtained by HPMT, and only the volume distribution can be used to approximate the quantity distribution, which may have a small error for the pore structure dominated by primary intergranular pores, but it will have a large error for the pore structure with strong diagenesis and secondary pores [37]. Therefore, a variety of experimental methods are needed to present the pore-throat structure characteristics of tight sandstone reservoirs more efficiently and comprehensively.

This study focuses on core slice, SEM, HPMT, and CRMI experiments to analyze reservoir space types, reservoir

pore throat distribution characteristics, quantitative characterization of different scale development of pore throat characteristics. Based on the above understanding, this paper's main content is (1) the pore types and physical property characteristics of the member 2 of Xujiache Formation in Yingshan Gasfield; (2) analysis of the curve characteristics of mercury injection test method and parameters of pore throat, comparison of the advantages and disadvantages of pore throat characterization, and discussion of the significance of combined characterization of pore throat structure and establish proper representation method; (3) discussion of the geological significance and influencing factors of pore structure parameters obtained by the two experimental methods. This study provides insights into the pore throat structure of tight sandstone for in-depth microscopic studies and establishes a reliable analytical method for tight sandstone reservoir characteristics.

It discusses pore parameters to control the density of reservoir physical properties of member 2 of Xujiache Formation in the Yingshan gasfield.

2 Geological setting

In terms of regional tectonic division, Yingshan gasfield belongs to the Yilong tectonic group, which is a low-even belt in the Paleo-Middle Depression of North Sichuan and is adjacent to the Paleo-High Middle Oblique Gentle Structural Zone in Central Sichuan. It is close to Huaying Mountain tectonic belt in the east, Gongshanmiao structure in the west, and Longgang structure in the north, facing Guang, a structure in the south (Figure 1a) [38]. The structure of the top boundary of the second member of Xujiache Formation in Yingshan gasfield is characterized by a long axial anticline near NW, and three rows of structures with different sizes of traps are developed from south to north, which are connected with each other by syncline and fault.

The clastic strata of the Yingshan gas field are Suining Formation, Shaximiao Formation, Lianggaoshan Formation, Ziliujing Formation of jurassic series, and Xujiache Formation of Upper Triassic series in order from the top down [39]. The Xujiache Formation developed a set of lacustrine delta sedimentary systems with interbedded sand and mudstone, with a buried depth of 2,100–3,600 m and thickness of 515–664 m (Figure 1b). Macroscopically, it thinned slightly from northwest to southeast. The top of Xujiache Formation and the Zhenzhuchong Member of Jurassic Ziliujing Formation are in pseudoconformity contact, and the bottom and the Lower Leikoupo Formation are in pseudoconformity contact. The

Figure 1: Structure sketch map and Xujiache stratigraphic column of Yingshan gasfield.

Xujiache Formation can be segmented into six members from bottom to top according to lithologic assemblage and electrical characteristics. The members 1, 3, and 5 of the Xujiache Formation are mainly composed of lacustrine sedimentary facies, which are the main source and cap beds of the Xujiache Formation. The members 2, 4, and 6 of the Xujiache Formation are mainly delta deposits, which are the main reservoirs of the Xujiache Formation. The proposed controlled reserves of the Yingshan gas field in the second member of Xujiache Formation are $1164.53 \times 10^8 \text{ m}^3$, showing good exploration and development potential.

3 Characteristics of reservoir space

3.1 Rock types

The rock types of member 2 of the Xujiache Formation are mainly feldspathic quartz sandstone and lithic feldspar sandstone. The grain size is mainly medium grain, secondary

is fine-medium grain, fine grain, medium–good sorting, good grinding round, and mostly present pore–contact type cement. SEM and XRD analysis showed that the quartz content in the detritive components generally ranged from 65.5 to 75.9%, with an average of 71.2%. The content of feldspar generally ranged from 14.4 to 17.4%, with an average of 15.9%, mainly orthoclase, followed by plagioclase. The content of rock detritus generally ranges from 8.2 to 17.6%, with an average of 12.9%, including magmatite, metamorphite, sedimentary rocks, etc. The content of the matrix was generally 2.38–6.43%, with an average of 4.25%. Hydromica was the main group, followed by organic matter. The cement content is generally 4.24%, and the main components are gray matter and siliceous (Table 1).

3.2 Types of reservoir space

There are complex reservoir spaces in member 2 of the Xujiache Formation in the Yingshan gas field. According to the statistics of the cast thin-section data, the types of

Table 1: The sandstone components of member 2 of Xujiache Formation in Yingshan gasfield

Well	Samples	Average content (%)			Matrix (%)	Average cement (%)	
		Quartz	Feldspar	Detritus		Dolomitic	Silicic
Y21	609	75.9	15.5	8.6	5.34	2.52	0.87
Y22	583	72.7	17.4	9.9	3.81	2.19	0.88
Y23	25	74.7	17.1	8.2	2.38	1.70	1.76
Y24	15	70.1	14.4	15.5	6.43	4.73	0.41
YS104	25	65.5	16.9	17.6	3.29	2.93	2.35
YS 106	16	68.8	14.4	16.8	4.25	1.31	3.81
Average value	1,273	71.2	15.9	12.9	4.25	2.56	1.68

reservoir space include primary pores, secondary pores, and microfractures. The residual intergranular pores are common primary pore, which is generally seen in fine sandstone supported by grains. The cemented minerals grow along the edge of the grain, and the boundary can be seen clearly between them (Figure 2a and b). Secondary pores are widely developed such as intergranular pores and dissolved pores. The intergranular dissolution pores are often be found in the matrix and cement. The pore shape is more irregular, which varies according to the degree of dissolution (Figure 2c). There are some dissolution pores in unstable components, for instance, along the joint direction of feldspar, the dissolution pores have the characteristics of directional arrangement and retained the original lattice shape. The feldspar particles will be dissolved into a honeycomb due to stronger dissolution (Figure 2d). When the soluble minerals were completely dissolved, the molded pores were formed. The intercrystalline pores are principally developed in the mineral aggregates with good crystalline forms, and the common intercrystalline pores are the minerals of kaolinite, illite, and quartz (Figure 2e). Microfractures are mainly of tectonic origin and often cut through clastic

grains and cement such as feldspar and quartz (Figure 2f). Under the influence of geological tectonic stress, there will be some fractures, which are characterized by unrestricted composition and varying in size (Figure 2f). Microfractures provide paths for the dissolution fluid, which can not only expand the scope of dissolution influence but also concatenate independent pores, thus improving the properties of tight sandstone reservoir.

The porosity of member 2 of the Xujiahe Formation in the Yingshan gas field is between 0.18 and 16.29%, with an average of 5.99%. The sandstone porosity mainly concentrates between 3 and 9%, accounting for 71.2% (Figure 3a). The permeability ranges from 0.0001 to $16.3 \times 10^{-3} \mu\text{m}^2$, with an average of $0.103 \times 10^{-3} \mu\text{m}^2$, indicating that the permeability of member 2 of Xujiahe gas reservoir in Yingshan gasfield is low. As can be seen from the histogram of sandstone permeability distribution (Figure 3b), sandstone permeability mainly concentrates between 0.001 and 1 mD, accounting for 98.5%, and >0.1 mD samples only account for 18.9% of the total. The porosity is positively correlated with the permeability of tight sandstone (Figure 3c), indicating poor connectivity between pores and mainly isolated pore distribution.

Figure 2: Storage space characteristics of member 2 in Xujiahe of Yingshan gasfield. 2.3 Porosity and permeability. (a) Primary pore development between fine sandstone grains, YS107, 2934.28 m, single polarized light; (b) intergranular pores and laminated fractures in fine sandstone, Y23, 2510.45 m, single polarized light; (c) intergranular dissolution pore in fine sandstone, YS106, 2949.5 m, single polarized light; (d) intragranular dissolution pore development in fine sandstone, YS102, 2739.61 m, single polarized light; (e) intercrystalline pores formed by filamentous illite filling between grains of fine sandstone, YS102, 2724.54 m, SEM; (f) microfracture development in fine sandstone, YS104, 3252.70 m, single polarized light.

Figure 3: Reservoir property characteristics of member 2 of Xujiahe Formation in Yingshan gasfield.

4 Structure characteristics of pore throat

4.1 HPMI test

The HPMI curves can reflect the throat with different scales, which also control the development and connectivity of pore volume. The samples can be divided into two categories according to the mercury injection curves characteristics (Figure 4). When the mercury saturation of the I type curve is between 5 and 40%, a flat segment appears, indicating that the throat and corresponding pores are relatively developed at this time. When the saturation is more than 40%, the mercury inflow curve begins to rise slowly, which is the second stage of concentrated development of pore throat. At this stage, the sorting characteristics of pore throat are slightly poor,

and the radius of pore throat is small. The displacement pressure of the II type curve is higher than I type, and the mercury inflow curve does not have a flat segment. The median saturation pressure of the samples is close, with an average of 7.68 MPa. The total mercury saturation of the samples is 84.47% on average, and the mercury removal efficiency is low, only 27.44% on average. The mercury ejection curve decreased slowly, indicating that the throat developed continuously in the reservoir, while the mercury ejection efficiency was low, indicating that the “ink bottle” pore structure with fine pore and large throat developed in the reservoir.

According to the capillary pressure curve characteristics of the tight sandstone in member 2 of the Xujiahe Formation, the distribution characteristics of the pore throat are closely related to porosity and permeability. Since porosity and permeability decrease, the distribution range of pore-throat radius is narrow, the peak of the pore-throat radius is small, the general permeability is less than $0.1 \times 10^{-3} \mu\text{m}$, multiple peaks coexist, and the distribution curve fluctuates strongly. When the porosity and permeability increase, the distribution range of pore throat radius becomes wider, the peak pore throat radius becomes larger, the general permeability is greater than $0.1 \times 10^{-3} \mu\text{m}$, and there is only one main peak. Therefore, when the permeability increases, the main peak of pore-throat radius distribution of tight sandstone reservoir shifts to the right (Figure 5a), and the fluctuation of tail peak becomes weaker, indicating that the tight sandstone reservoir has good properties and large pore-throat radius. However, the pore-throat radius is small in a reservoir with low properties, and the characteristics of the pore throat are more developed in intercrystalline pores of clay minerals. With the increase of pore-throat radius, the heterogeneity of the reservoir becomes weaker and the type of pore throat tends to be homogenized, which is common in the primary pore (Figure 2a). The distribution of pore throat in the high-pressure mercury injection test is mainly in the range of

Figure 4: Capillary pressure curves of pressure-controlled mercury intrusion.

Figure 5: Distribution characteristic of member 2 of Xujiahe reservoir pore throat of different physical properties by high-pressure mercury.

0.026–10.000 μm . The pore throat radius of a tight sandstone reservoir is generally less than 1 μm , and the permeability is mainly contributed by the pore throat (Figure 5b).

4.2 Rate-controlled mercury penetration test

According to the curves characteristic of RCMI, the samples can also be divided into two categories, and the classification result is consistent with that of HPMI. The overall capillary pressure curve of the type I curve is consistent with the pore capillary pressure curve at the initial stage of mercury entry, indicating that mercury enters the macropores first (Figure 6a). Then, the pore capillary pressure curve rises rapidly, and the overall capillary pressure curve tends to be consistent with the throat capillary pressure curve. At this time, the mercury entry into the pores is basically completed, and mercury

mainly enters the smaller throat. The saturation of mercury into the pore is greater than that of the throat. The overall capillary pressure curve of the type II curve is consistent with the capillary pressure curve of the throat, and the mercury saturation of the throat is greater than that of the pore (Figure 6b). The total mercury injection saturation of constant rate mercury injection is low, averaging about 46.57%, mainly because the final mercury injection pressure of constant rate mercury injection method is low, and the pore throat less than 0.12 μm cannot be measured.

The rate-controlled mercury penetration test distinguishes the pore and throat according to the change of mercury inlet pressure [40,41]. The 12 samples were tested by RCMP. The data of some samples indicated that the pore-radius of the tight sandstone in the second member of Xujiaoguan Formation was relatively small, with a relatively concentrated distribution between 100 and 200 μm and a peak distribution between 160 and 180 μm (Figure 7a). The distribution of laryngeal radius

Figure 6: Capillary pressure curves of rate-controlled mercury intrusion.

Figure 7: Distribution characteristic of member 2 of Xujiahe reservoir pore and throat radius of different physical properties by rate-controlled mercury penetration.

was significantly different, ranging from 0.1 to 0.6 μm (Figure 7b). When the permeability increases, the distribution range of throat radius is relatively wide, and the unimodal throat radius becomes larger and has the characteristic of right deviation. On the contrary, the distribution range of the laryngeal radius becomes narrower, and the unimodal laryngeal radius becomes smaller, showing the characteristic of left-skew. The difference in throat radius also affects the change of pore-throat radius ratio. When the permeability is low, the distribution range of the pore-throat ratio is large and the peak of the pore-throat ratio is relatively small. With the increase of permeability, the distribution range of the pore-throat ratio gradually narrows, and the peak of the pore-throat ratio tends to increase (Figure 7c).

The HPMT test is sensitive to relatively small pores but cannot measure pores larger than 40 μm . The RCMP test has a good characterization effect on macropores and cannot identify the pore throat smaller than 0.12 μm [42–44]. Its main function is to distinguish the pore and throat in the reservoir. The HPMT and RCMP test data (Figure 8) of the samples from YS102 at a depth of 2739.6 m were analyzed. The distribution range of pore-

throat ranged from 0.026 to 300.00 μm , with some intervals overlapping. The results of the HPMT test were 7.81% and $0.0495 \times 10^{-3} \mu\text{m}^2$, and those of rate-controlled mercury penetration test were 7.53% and $0.021 \times 10^{-3} \mu\text{m}^2$. There is little difference in permeability and porosity between the two tests. This is because the permeability is mainly controlled by the large throat, and the contribution of the small throat is not obvious. The small throat with a radius of less than 0.12 μm contributes significantly to porosity and provides reservoir space for tight sandstone reservoir [45–47]. The combination of the two can more effectively evaluate the contribution of throat radius and pore radius at different scales to permeability and porosity.

4.3 Physical contribution rate of pore-throat

The size and distribution characteristics of pore-throat are closely related to the permeability of a tight sandstone reservoir, and the general permeability is mainly affected by the large radius of pore-throat. When the mercury inflow reaches the peak value of pore-throat

Figure 8: The pore sizes distribution characterized of 2739.61 m sample by integrating the rate-controlled porosimetry and pressure-controlled porosimetry in the YS102 well.

Figure 9: Distribution characteristic of tight sandstone reservoir cumulative intake mercury and permeability contribution and cumulative permeability contribution.

radius, the cumulative permeability contribution curve is relatively steep, and the cumulative mercury saturation curve is also relatively steep, and the cumulative mercury saturation is 40–50%. With the continuous injection of mercury, the cumulative mercury saturation curve is still steep, and the cumulative permeability contribution curve increases slowly, indicating that although the small pore throat can allow mercury to enter the pore, it has little influence on the permeability and makes a great contribution to the porosity. For the sample of YS 102 with a depth of 2721.41 m, the contribution rate of permeability of the large pore throat is 96.0%, the cumulative mercury saturation is 49.8%, and the maximum mercury saturation is 98.4%, indicating that the pore throat controls 54.6% mercury saturation (Figure 9).

As can be seen from Figures 7–8, the permeability of tight sandstone in member 2 of the Xujiahe Formation is mainly controlled by a large pore throat and pores with a radius less than $0.10\text{ }\mu\text{m}$ have little influence on permeability, but significant influence on porosity. The contribution rate of nano-sized pores to permeability is 3.29–34.67%, and the contribution rate of porosity is 48.86–94.28%. Therefore, the large pore throat in the tight sandstone reservoir is the main factor controlling oil and gas production, and a large number of nanoscale pores provide reservoir space for oil and gas storage.

5 Result

5.1 Parameters of HPMI

Mean and maximum pore throat radius have a positive relation with porosity and permeability (Figure 10a–d), in

which the correlation between permeability and average and maximum pore throat radii is slightly stronger than that of porosity (Figure 10b and d). The average pore throat radius can better reflect the development interval of pore throat size of tight sandstone reservoir, reflecting its control effect on reservoir physical property, while the maximum pore throat radius is not representative.

The sorting coefficient of pore-throat can better represent the distribution law of pore-throat size. The larger the sorting coefficient is, the worse the sorting is, and *vice versa*, the relatively homogeneous development of pore-throat is, and the sorting performance is good. There is a positive correlation between sorting coefficient and porosity and permeability (Figure 10e and f). This is due to the large number of pore throats developed in tight sandstone reservoirs, and the distribution of pore throat radius is relatively uniform. With the increase of separation coefficient, the number of large pore throats increases, and the increased space has more significance on permeability than the porosity.

The characteristic structure coefficient can reflect both the sorting degree and the connectivity degree of the pore throat. The larger the value, the better the pore structure, the better the pore connectivity, and the higher the permeability (Figure 10g and h). The characteristic structure coefficient has a poor correlation with porosity and a good positive correlation with permeability, indicating that with the increase of pore characteristic coefficient, the pore-throat structure of tight sandstone reservoir gradually develops toward homogeneity, and the connectivity between pores becomes better, but the characteristic structure coefficient has little effect on the improvement of reservoir space. Therefore, the characteristic structure coefficient can be used as an important index to evaluate the permeability of the reservoir.

Figure 10: Relationships between porosity or permeability and high-pressure mercury penetration parameters.

Figure 11: Relationships between porosity or permeability and rate-controlled mercury penetration parameters.

5.2 Parameters of rate-controlled mercury penetration

The throat radius has no correlation with porosity (Figure 11a), whereas the throat radius has a relatively good positive correlation with permeability (Figure 11b). The average pore radius has a certain positive correlation with porosity (Figure 11c), and a poor correlation with permeability (Figure 11d). It shows that the throat is a significant parameter to evaluate reservoir permeability, and its shape, size, and connectivity have an effect on permeability. The average pore radius only reflects the pore size in the reservoir but cannot represent the connectivity of the throat. Therefore, its variation is closely related to porosity, and permeability is insensitive to pore radius.

The pore-throat ratio has negative relation with permeability (Figure 11f) but has a poor correlation with porosity (Figure 11e). When the pore-throat ratio is relatively small, the difference between pore radius and throat radius is small, the pore connectivity is good, the permeability is high, and the flowability of oil and gas in the reservoir is increased. The fine sandstone reservoir of the second member of the Xujiahe Formation in the Yingshan gas field has a large pore throat and a wide distribution span, so it is difficult for oil and gas displacement to come out.

Microscopic homogeneity coefficient has negative relation with permeability (Figure 11h) but has a poor relationship with porosity (Figure 11h). This is because when large pore throats are developed in the pores, the contribution rate to the permeability of the reservoir is higher, and the microhomogeneity coefficient is relatively small. When pore throats are mainly developed, pore connectivity is poor, seepage capacity is reduced, and microscopic homogeneity coefficient is high.

6 Conclusion

- (1) The reservoir space in member 2 of the Xujiahe Formation in Yingshan oilfield includes three types: primary pores, secondary pores, and microfractures. The primary pores are mainly residual intergranular pores, the secondary pores are mainly intercrystalline pores and dissolved pores, and the tectonic fractures are widely developed.
- (2) The pore throat of member 2 of Xujiahe reservoir ranges from 0.018 to 10.000 μm , which is less than 1 μm . The distribution range of pore radius is relatively concentrated from 100 to 200 μm , and the distribution

of peak value is between 160 and 180 μm . The distribution range of laryngeal radius is 0.1–0.6 μm . The pore-throat characteristics can be objectively evaluated by combining that two methods together.

- (3) The permeability of member 2 of the Xujiahe reservoir is under the control of the large pore throat. The contribution rate of nano-scale pores for permeability is small, but the contribution rate to reservoir porosity is high. The higher the content of nano-sized pore throat, the worse the permeability of pores. The contribution rate of nano-sized pores to permeability is 3.29–35.67%; meanwhile, the contribution rate of nano-sized pores to porosity is 48.86–94.28%.
- (4) Different microscopic pore throats measured by HPMP and RCMP have a certain control effect on reservoir porosity and permeability. The average pore throat radius, maximum pore throat radius, sorting coefficient, and characteristic structural parameters acquired from HPMP have a better positive correlation with permeability, but a weak correlation with porosity. The throat radius obtained by rate-controlled mercury penetration has a positive correlation with permeability, while the pore-throat ratio and microhomogeneity coefficient are negatively correlated with permeability. The impact of nanoscale pore throats on the permeability was negligible. Nanoscale pore throats widely occurred across the tight reservoirs but had little influence on the permeability, but they could be used as oil and gas storage space and improved the reservoir porosity.
- (5) HPMP and RCMP experiments reflect the same physical process, and in the sample experiment, the mercury injection curve obtained by combining the two methods on the same chart is consistent, which indicates the rationality of the combining study.

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