

Article

Study on the Effect of Particle Size on NMR Pore Characterization of Cuttings

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Abstract

To study the effect of particle size on nuclear magnetic resonance (NMR) pore characterization of sandstone, core samples were gradually crushed into five particle sizes and the transverse relaxation time (T_2) spectrum and NMR response characteristics of the crushed samples were measured. The experimental results show that within the particle size range of 2.4 mm, the T_2 spectrum position, T_2 mean value, and NMR porosity of sandstone cuttings are basically consistent with the core samples. When the particle size is 1.2 mm, the right peak amplitude of the T_2 spectrum increases significantly, and the T_2 mean value representing the T_2 spectrum characteristics becomes larger, which is presumed to be related to the increase in particle surface water. A comparative analysis suggests that cuttings with particle sizes larger than 2.4 mm can accurately characterize the NMR response characteristics of core samples.

Keywords: NMR; sandstone cuttings; particle size; pore characterization

1. Introduction

Deep and ultra-deep sandstone reservoirs have become an important target for oil and gas exploration and development due to their substantial resource potential [1,2]. As a geological material, core samples can directly reflect the characteristics of a reservoir [3]. Furthermore, the pore structures of a reservoir can be analyzed through experimental methods such as rock physics and organic geochemistry [4,5]. Among these methods, nuclear magnetic resonance (NMR) can be used to detect the hydrogen-containing fluid signals in the samples to obtain physical parameters such as rock porosity, permeability, and even saturation [4–6]. However, obtaining complete core samples in the field is difficult and costly [3,7]. With the development of logging technology, field personnel in oilfields have made full use of cuttings to obtain reservoir parameters [8–10]. Ortega et al. concluded that the optimal particle size for tight sandstone cuttings is greater than 2 mm [11]. Yang et al. and Tariq et al. both conducted comparative analyses of core samples based on four groups of cuttings with particle sizes ranging from 0.42 to 4 mm; they found that larger particle cuttings had the smallest porosity deviation [12,13]. Li et al. discovered that there are significant differences in the pore structure and characteristics of sandstones with different particle sizes [14]. Wang et al. conducted experiments using samples of different sizes and shapes, and he suggested that the particle size of cuttings should be



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larger than 6.75 mm when characterizing extremely low-porosity and low-permeability formations [15].

A preliminary investigation reveals that two issues arise when measuring cuttings. Firstly, NMR porosity calibration requires knowledge of the sample volume. The volume of core samples can be measured by a vernier caliper, but the volume of cuttings has not been addressed in the previous research. Furthermore, numerous experimental studies have demonstrated that the particle size of cuttings exerts a certain influence on porosity measurements, but the optimal particle size varies between different reservoir types and is therefore not universally applicable. For the deep and ultra-deep sandstone reservoirs, two key problems are addressed to determine whether cuttings can effectively represent core samples. The first is determining the volume of irregular samples, while the second is the impact of particle size on the NMR relaxation characteristics of cuttings.

In this study, four ultra-deep sandstone samples with different physical properties were selected. The sandstone was gradually crushed into five particle sizes, and the NMR T_2 spectrum was measured. Combining immersion method and computed tomography (CT) scanning, the volume of the crushed samples was determined, and the effect of sample crushing degree on the NMR measurement results was studied. The results show that cuttings with a particle size of no less than 2.4 mm can reflect the NMR response characteristics of core samples, providing support for the selection of optimal particle sizes for cuttings in both laboratory contexts and oilfields.

2. Principle and Method

2.1. Relaxation Mechanism

Figure 1 illustrates the fluid occurrence state and transverse relaxation mechanism in water-saturated sandstone. The transverse relaxation time (T_2) is affected by three relaxation mechanisms: bulk relaxation, surface relaxation, and diffusion relaxation. The formula is expressed as follows [16]:

$$\frac{1}{T_2} = \frac{1}{T_{2B}} + \frac{1}{T_{2S}} + \frac{1}{T_{2D}} = \frac{1}{T_{2B}} + \rho_2 \frac{S}{V} + \frac{D(\gamma GT_E)^2}{12} \quad (1)$$

where T_{2B} is the bulk relaxation time, in ms; T_{2S} is the surface relaxation time, in ms; T_{2D} is the diffusion relaxation time, in ms; ρ_2 is the surface relaxivity of rock, in $\mu\text{m/s}$; S is the pore surface area, in cm^2 ; V is the pore volume, in cm^3 ; D is the fluid diffusion coefficient, in cm^2/s ; γ is the gyromagnetic ratio, in MHz/T ; T_E is the echo spacing, in ms; and G is the magnetic field gradient, in Gs/cm .

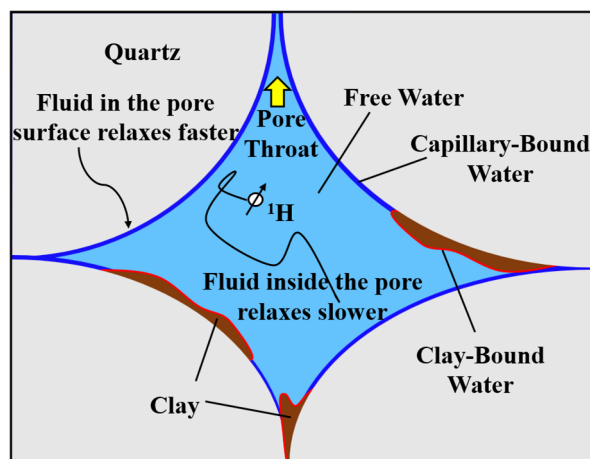


Figure 1. Fluid occurrence state and transverse relaxation mechanism in water-saturated sandstone.

In porous media, the motion speed of fluid molecules is faster than in the free state, so $1/T_{2S} \gg 1/T_{2B}$, and bulk relaxation can be neglected [17]. In a uniform magnetic field with a small T_E , the effect of diffusion relaxation can also be ignored [16]. Therefore, the transverse relaxation in water-saturated sandstone can be approximated as follows [18]:

$$\frac{1}{T_2} \approx \frac{1}{T_{2S}} = \rho_2 \frac{S}{V} = \rho_2 \frac{F_S}{r} \quad (2)$$

where F_S is the formation shape factor ($F_S = 2$ for cylindrical pores, and $F_S = 3$ for spherical pores), and r is the pore radius, in μm .

2.2. Experimental Samples

Sandstone, as a representative sedimentary rock, is consolidated and compacted from sand particles with diameters ranging from 0.05 to 2 mm [14]. As shown in Figure 2, four core samples were prepared with a diameter of 2.5 cm and a length of 3 to 5 cm, and their basic information was recorded using a vernier caliper. By manual crushing, five groups of cuttings were obtained with particle sizes of approximately 4.5 mm, 2.4 mm, 1.2 mm, 0.6 mm, and 0.3 mm.



Figure 2. Sandstone samples.

2.3. Experimental Instruments

The NMR analyzer used in this study is MacroMR12-60-M from Suzhou Niumag Analytical Instrument Corporation (Suzhou, China), with a magnetic field strength of approximately 0.3 T (^1H resonance frequency of 12 MHz). T_2 measurements were conducted using the Carr–Purcell–Meiboom–Gill (CPMG) pulse sequence. The measurement parameters were set as a waiting time (T_W) of 6000 ms, an echo time (T_E) of 0.2 ms, a number of echoes of 12,000. The T_2 spectrum of 100% water-saturated core samples was measured, and the signal intensity was calibrated with standard samples to convert it into porosity. The specific conversion formula is as follows [16]:

$$\varphi_{NMR} = \sum_i \frac{m_i}{M} \cdot \frac{S}{s} \cdot \frac{G}{g} \cdot \frac{V}{v} \times 100\% \quad (3)$$

where φ_{NMR} is the NMR porosity, M is the total amplitude of the T_2 spectrum of the standard sample, m_i is the amplitude of the i -th T_2 component of the rock sample, V and v are the volumes of the standard sample and rock sample, S and s are the repetitions of the standard sample and rock sample during NMR data acquisition, and G and g are the receiver gains of the standard sample and rock sample during NMR data acquisition.

According to Formula (3), the measurement of sample volume is crucial for porosity calibration. The immersion method is highly applicable for large particle cuttings, while CT scanning is suitable for cuttings of any size but at a higher cost. Therefore, this study uses both volume measurement methods. The principle of the immersion method is shown in Figure 3. A beaker containing liquid is shown on the left. The sample is fully immersed

in water, and the volume of water changes. According to Archimedes' principle, when the sample is immersed in liquid, it will displace an equal volume of liquid [3,19].

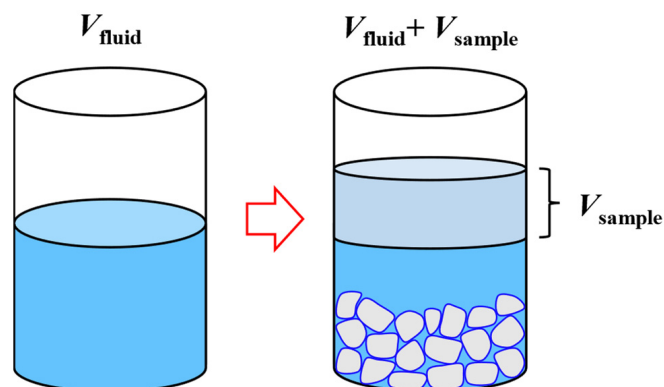


Figure 3. Schematic diagram of immersion method principle.

The CT equipment is nanoVoxel-3000 from Sanying Precision Instruments Co., Ltd (Tianjin, China). The principle is based on X-ray penetration of an object from various angles, and reconstruction software is used to generate images from the projection data received by the flat-plate detector [9], as shown in Figure 4. The scanning voltage is 140 kV, the current is 200 uA, the single frame exposure time is 1.5 s, the image merging number is 2, the scanning frame rate is 360, and the spatial resolution (voxel) is 21.6 μm .

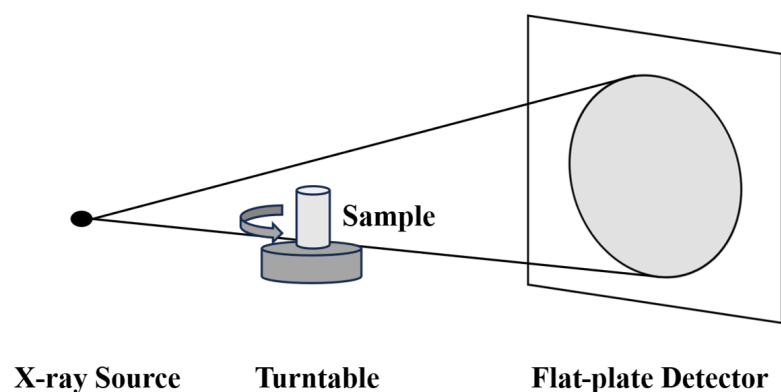


Figure 4. Schematic diagram of CT scanning.

The volume of a sample can be extracted using the “Interactive Thresholding” command in Avizo (version 2020.1) software. A grayscale value is selected to divide the image into foreground and background. If f is defined as the input image and g as the output image, then the mathematical expression for thresholding is as follows [20]:

$$g(i,j) = \begin{cases} 1, & f(i,j) \geq T \\ 0, & f(i,j) < T \end{cases} \quad (4)$$

where T is the threshold, $g(i,j) = 1$ represents the image foreground, and $g(i,j) = 0$ represents the image background.

As shown in Figure 5, after threshold segmentation, the values in the gray area are marked as 1, and the values outside the gray area are marked as 0. The number of pixels in the gray area of each slice is counted, and then multiplied by the cube of voxels, which is the volume of cuttings particles.

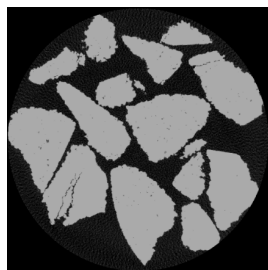


Figure 5. Particle volume extraction.

2.4. Experimental Procedure

Studies have shown that there is a strong correlation between pore volume and particle size [21]. Figure 6 shows a schematic diagram of the crushing process. When the core sample is crushed, the large particles in the sample are broken into small particles. The clay minerals blocked between the pores then disappear. Until the crushing reaches a certain extent, the large particles in the sample are completely destroyed, and the pore volume is decreased.

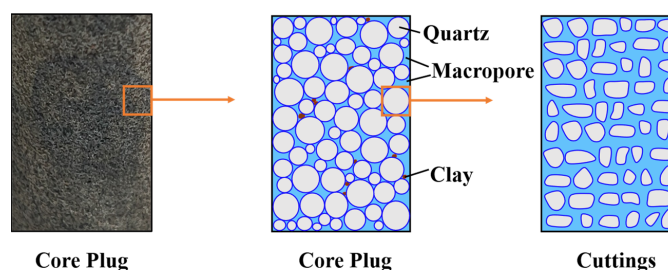


Figure 6. Schematic diagram of crushing process (modified according to Reference [7]).

The experimental flow diagram is shown in Figure 7, and the experimental steps are as follows:

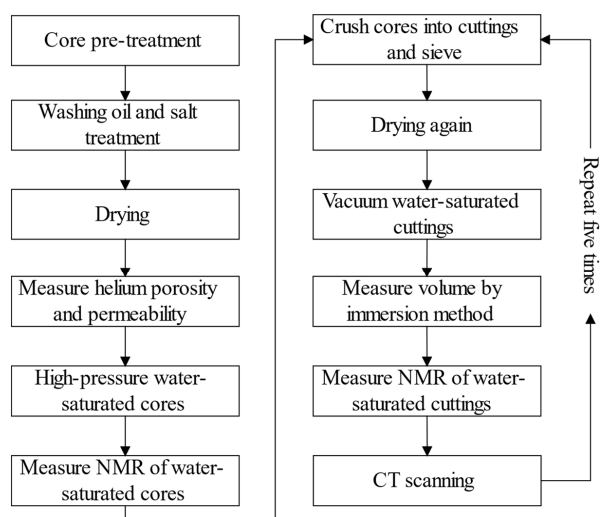


Figure 7. Experimental flow diagram.

(1) After pre-treatment such as oil washing and salt washing, the core must be dried using an electric drying oven. The drying temperature is set to 120 °C.

(2) Measure the helium porosity and permeability of the core, and use a vacuum pressurization saturation device to saturate the dried sample with deionized water. Vacuum for 2 h (−0.1 MPa) and pressurize to 24 MPa.

(3) Take out the saturated core, wipe the excess liquid on the surface with filter paper, weigh and record the weight of saturated core, and then proceed with the NMR T_2 measurement.

(4) Crush the core plug, minimizing mass loss during the crushing process. Sort the cuttings using a standard mesh sieve, place the cuttings in the drying oven to dry, and record the dry weight.

(5) To prevent high-pressure saturation damaging the crushed samples, the vacuum saturation method is used. Add deionized water to a beaker, place it in a vacuum device, vacuum for 0.5 h and let it stand for two days.

(6) Use the immersion method to measure the volume of cuttings. Wipe the samples with filter paper until they are not sticky, record the wet weight, and then measure the T_2 spectrum, followed by CT scanning.

Repeat steps (4) to (6) using the standard sieves and halving the particle size at each time to ensure a representative and well-distributed range of particle sizes. Finally, five sandstone samples with different particle sizes (approximately 4.5 mm, 2.4 mm, 1.2 mm, 0.6 mm, and 0.3 mm) can be obtained for NMR experiments.

3. Experimental Results

Four cores are taken from different depths, with the helium porosities ranging from 9.22% to 19.19%, and the NMR porosities of water-saturated cores ranging from 9.40% to 18.93%. There were differences in the helium permeabilities (see Table 1).

Table 1. Basic parameters of the cores.

Core No.	Sampling Depth (m)	Length (cm)	Diameter (cm)	NMR Porosity of Water-Saturated Cores (%)	Helium Porosity (%)	Helium Permeability ($10^{-3} \mu\text{m}^2$)
1	4396.75	2.880	2.587	13.31	13.68	1.04
2	4123.68	4.325	2.584	18.93	19.19	49.30
3	4122.90	4.311	2.579	12.94	12.87	4.04
4	4220.33	4.151	2.588	9.40	9.22	2.25

Figure 8 shows the NMR T_2 spectrum of four water-saturated cores. Core No. 1 has moderate porosity and low permeability; the T_2 spectrum shows an approximately trimodal distribution and ranges from 0.05 to 2682.7 ms. Core No. 2 has high porosity and permeability; the T_2 spectrum shows a single peak and ranges from 0.05 to 2154.4 ms. The peak center of Core No. 2 shifts to the right compared with Core No. 3; this means that Core No. 2 has a longer relaxation time. Core No. 3 has moderate porosity and relatively high permeability; the T_2 spectrum shows a single peak and ranges from 0.05 to 1389.5 ms, with the peak center located at $T_2 = 64.5$ ms. Core No. 4 has relatively low porosity and permeability; the T_2 spectrum shows a bimodal distribution and ranges from 0.05 to 1389.5 ms.

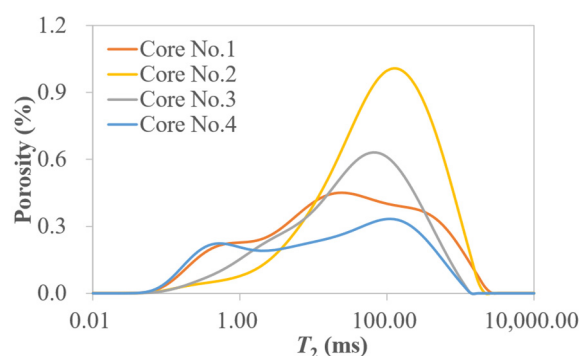


Figure 8. NMR T_2 spectra of water-saturated cores.

As shown in Figure 9, when the four samples were crushed from core plugs to the particle size of 2.4 mm, there was no significant change in the shape of the T_2 spectrum overall. As the particle size decreased, the amplitude of the T_2 spectrum increased sharply. The right peak of the T_2 spectrum for Sample No. 1 shifted towards shorter relaxation times. For Samples No. 2 and No. 4, the right peaks shifted significantly when the particle size was 0.3 mm.

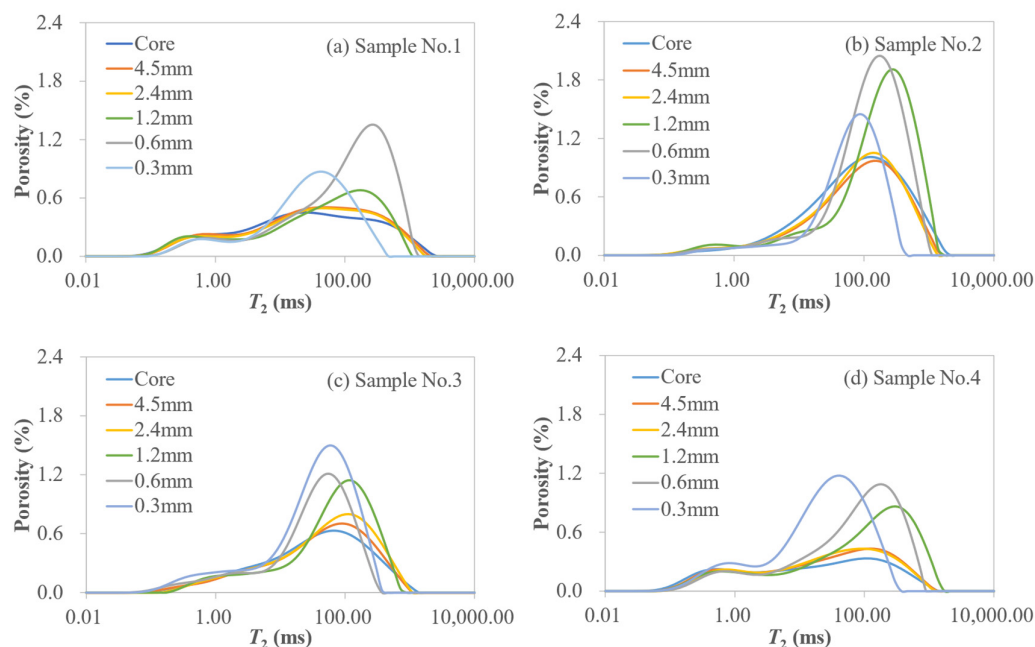


Figure 9. NMR T_2 spectra of crushing samples (a–d).

4. Experimental Result Analysis

The strength of the NMR signal is related to the content of hydrogen-containing fluid in the pore space [16]. In the gas measurement method, helium gas is used to measure the interconnected pores. As shown in Figure 10, the NMR porosity of water-saturated cores is close to the helium porosity, and both have a linear relationship. At the same time, according to the NMR relaxation mechanism, the T_2 spectrum of fully water-saturated pure sandstone can reflect the pore distribution of rock. Figure 8 shows that both small and large pores are distributed in Cores No. 1 and No. 4, while medium and large pores are distributed in Cores No. 2 and No. 3.

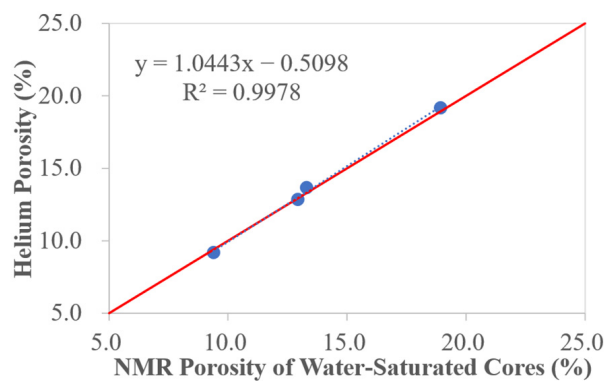


Figure 10. Core porosity comparison. The blue solid dot represents the cores. The red solid line represents the equal value line. The blue dashed line represents the fitting line.

4.1. Differences in T_2 Spectrum Positions

The position of the T_2 spectrum can be characterized by $T_{2-\text{Min}}$, $T_{2-\text{Max}}$, and $T_{2-\text{Mid}}$. The first two parameters are the transverse relaxation times for the first and final non-zero values of interval porosity, which correspond to the minimum and maximum pore size distributions, respectively. Meanwhile, $T_{2-\text{Mid}}$ is defined as the value of T_2 when the cumulation of the interval porosity accounts for 50% of the total interval porosity [22]. Table 2 shows the T_2 spectrum position of different crushed samples. For Sample No. 1, when gradually crushed to 2.4 mm, $T_{2-\text{Min}}$ remained unchanged, and the amplitude at $T_2 > 10$ ms increased, indicating that more water had saturated the pores. Furthermore, $T_{2-\text{Mid}}$ increased, corresponding to a larger cumulative pore area and storage space. $T_{2-\text{Max}}$ shortened when the particle size was smaller than 1.2 mm, indicating that macropores were destroyed. For Sample No. 4, $T_{2-\text{Max}}$ remained unchanged when gradually crushed to 2.4 mm, meaning macropores in the sample had not yet been destroyed, and crushing did not change the pore size distribution or pore structure of sandstone. However, $T_{2-\text{Mid}}$ and long relaxation components increased, indicating that it was easier for the fluid to enter the pores after crushing. $T_{2-\text{Max}}$ shortened after further crushing, indicating that larger particles in the sample were destroyed.

Table 2. T_2 spectrum position of different crushing samples.

Core No.		1	2	3	4
Core Plug	$T_{2-\text{Mid}}$ (ms)	21.5	80.3	33.4	17.3
	$T_{2-\text{Min}}$ (ms)	0.05	0.05	0.05	0.05
	$T_{2-\text{Max}}$ (ms)	2682.7	2154.4	1389.5	1389.5
4.5 mm	$T_{2-\text{Mid}}$ (ms)	33.4	80.3	41.6	26.8
	$T_{2-\text{Min}}$ (ms)	0.05	0.05	0.05	0.05
	$T_{2-\text{Max}}$ (ms)	2154.4	1730.2	1115.9	1389.5
2.4 mm	$T_{2-\text{Mid}}$ (ms)	33.4	80.3	51.8	26.8
	$T_{2-\text{Min}}$ (ms)	0.05	0.05	0.14	0.07
	$T_{2-\text{Max}}$ (ms)	2154.4	1389.5	1115.9	1389.5
LRMSE	$T_{2-\text{Mid}}$ (ms)	0.14	0	0.14	0.13
	$T_{2-\text{Min}}$ (ms)	0	0	0.22	0.07
	$T_{2-\text{Max}}$ (ms)	0.07	0.11	0.07	0

The T_2 spectra of Samples No. 2 and No. 3 both showed a single peak. When Sample No. 2 was gradually crushed to 2.4 mm, $T_{2-\text{Min}}$ and $T_{2-\text{Mid}}$ remained unchanged, and the amplitude of the T_2 spectrum with longer relaxation time changed slightly compared to Sample No. 3. Sample No. 2 is high-porosity and high-permeability reservoir. Under the premise that the original pore structure was not destroyed, even after crushing the sample, the pores were already saturated with fluid, and the T_2 spectrum amplitude was not changed. $T_{2-\text{Max}}$ only significantly shortened when the particle size was reduced to 0.3 mm. For Sample No. 3, $T_{2-\text{Mid}}$ increased when gradually crushed to 1.2 mm, and the amplitude at $T_2 > 33$ ms increased. With further crushing, $T_{2-\text{Max}}$ first decreased and then remained unchanged, indicating that the larger particles had been almost completely destroyed.

To quantitatively compare the difference in the T_2 spectrum position between the crushed sample and the core, the logarithmic root mean square error (LRMSE) is calculated. The formula is as follows:

$$\text{LRMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n [\log(T_{2,i}) - \log(T_{2,\text{core}})]^2} \quad (5)$$

where $\log(T_{2,i})$ is the logarithmic T_2 value of the i -th particle size cuttings, and $\log(T_{2,core})$ is the logarithmic T_2 value of the core. The LRMSE is the smallest for Core No. 2 with high porosity and permeability. Although the LRMSE of the other three cores is greater than that of Core No. 2, the value is still small. The T_2 spectrum position of cuttings with particle size greater than 2.4 mm is not much different from that of the core.

This study found that the amplitude at $T_2 > 100$ ms increased significantly when samples with different porosities and permeabilities were crushed to form smaller particle sizes. To investigate the reason for this, the particles of cuttings were separated and each individual particle was further wiped with filter paper. Repetitive experiments were conducted with the same measurement parameters, and the NMR results before and after removing the surface water were compared (Figure 11). The smaller the particle size, the larger the specific surface area of particles; as a result, more surface water adheres between the particles, resulting in the NMR porosity being severely overestimated. After removing the surface water, the NMR porosity decreased. Theoretically, the surface water is fluid in a free state and should have a longer transverse relaxation time than the fluid within the pores. However, the experimental results show that its signal partially overlaps with that of the pore fluid. This phenomenon arises from the adsorption of water onto the rock surface, where the interaction between fluid molecules and rock matrix gives rise to surface relaxation. As a result, the transverse relaxation time of surface water partially overlaps with that of the intra-pore fluid, which is consistent with findings reported in previous studies [19].

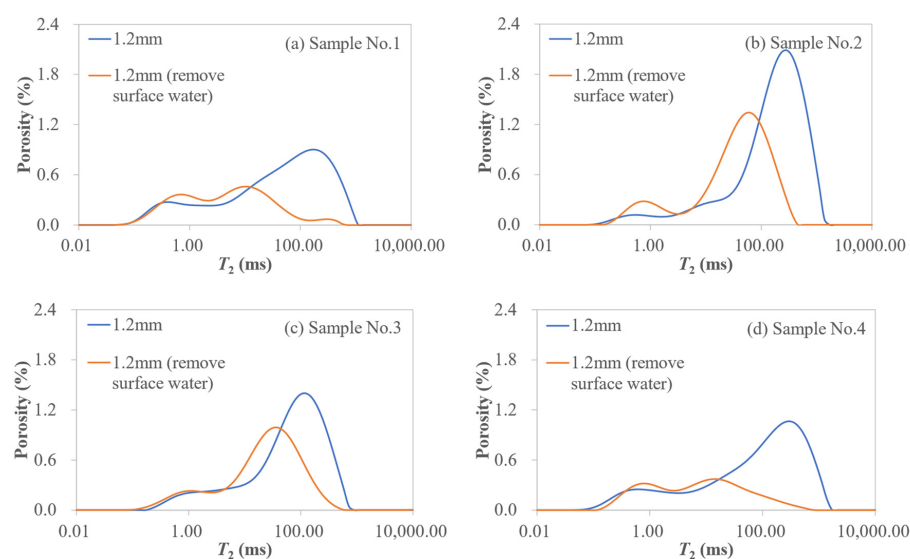


Figure 11. NMR T_2 spectra found when removing surface water (a–d).

Table 3 records the changes in NMR parameters before and after removing surface water. After removing the surface water, the right peak center of the T_2 spectrum shifts toward to the left, and the relaxation time is shortened. According to the LRMSE, NMR parameters of Sample No. 1 and Sample No. 4 change the most, and the changes in Sample No. 2 and Sample No. 3 are relatively small.

Table 3. Comparison of NMR parameters before and after removing surface water.

Sample No.		1	2	3	4
Peak center (ms)	Before	193.1	299.4	124.5	299.4
	After	8.9	64.5	33.4	13.9
	LRMSE	1.34	0.67	0.57	1.33

4.2. Differences in T_2 Spectrum Mean Values

As parameters quantitatively describing the mathematical characteristics of the T_2 spectrum, the arithmetic mean of T_2 (T_{2am}) and the geometric mean of T_2 (T_{2gm}) are often used to describe the overall characteristics of T_2 distribution [22]. T_{2am} represents the average position of pore size distribution, while T_{2gm} is related to the movable fluid percentage and permeability calculations [16]. Figure 12 shows the changes in mean values of different crushed samples. When the core plugs were crushed to 2.4 mm, T_{2am} values changed smoothly. The T_{2am} values of Samples No. 1 and No. 2 decreased, while those of Samples No. 3 and No. 4 increased. However, the T_{2am} values of the former samples were higher than 120 ms, indicating that the pore space of Samples No. 1 and No. 2 is larger. After further crushing to smaller particle sizes, the T_{2am} value of Sample No. 3 first decreased and then leveled off, indicating that the particle size of this sample is concentrated around 1.2 mm, and its pore structure has been mostly destroyed when reduced to 0.6 mm. The T_{2am} values of other samples first increased sharply and then decreased, as surface water at the particle caused the average pore value to increase. Once the particle size reached a certain threshold, macropores in the sample were crushed into medium and small pores, and the pore value decreased sharply. The T_{2gm} value remained stable before the particle size was reduced below 2.4 mm, indicating that the pore connectivity within this size range was less affected by crushing. Sample No. 2 had the highest T_{2gm} value, indicating better pore connectivity, which is further supported by its highest helium permeability (Table 1).

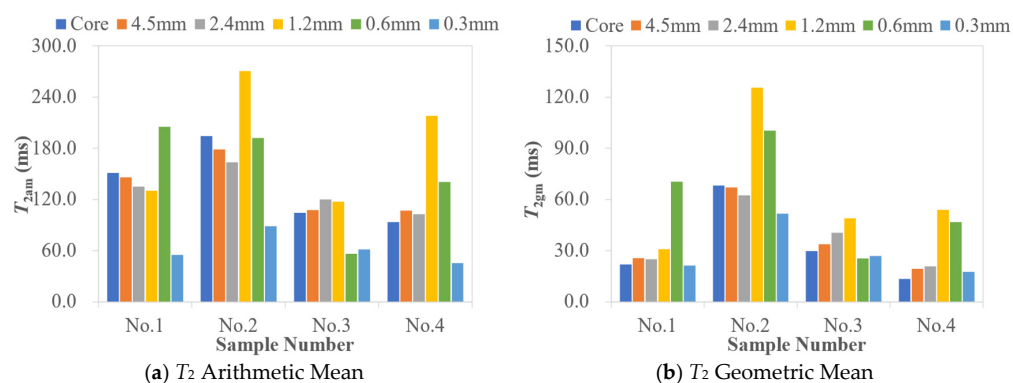


Figure 12. T_2 mean values of different crushing samples.

4.3. Differences in NMR Porosities

The higher the crushing degree, the larger the specific surface area of the samples, and the more susceptible they are to the influence of surface water between particles during volume measurement [23,24]. Therefore, the immersion method was no longer used to determine the volume of crushed samples with particle sizes smaller than 1.2 mm. The volume of cuttings with different particle sizes obtained by CT scanning is shown in Table 4. Due to the difference in density between the rock and the gap of particles, the gray distribution curve is a bimodal distribution, and the trough point between the two peaks is selected as the threshold. The threshold-based segmentation introduces operator-dependent uncertainty, which may have an impact on the measurement accuracy of volume, but for the gray curve of bimodal distribution, this effect is relatively small.

Figure 13a shows the NMR porosity calibrated using volume measured by the immersion method. During the process of crushing to 2.4 mm, the porosity measurement values of core plugs and crushed samples showed small changes, indicating that the integrity of sandstone pores had not been destroyed. When the crushing reached a certain level (<1.2 mm), there was a clear inflection point where the porosity increased significantly, making it no longer representative of the porosity of the sandstone reservoir itself. Figure 13b

shows the NMR porosity calibrated using the volume measured through CT scanning. The trend in the porosity measurement values for four core plugs crushed to 2.4 mm is similar to that in Figure 13a, indicating that the volumes of irregular samples measured by the two methods were comparable. For Samples No. 1 and No. 2, the porosity values first increased and then decreased after further crushing, while Sample No. 3 only showed a significant inflection point at 0.3 mm, with other segments of the curve remaining relatively stable. Sample No. 4 exhibited an inflection point after the particle size was reduced to less than 1.2 mm. Repeated measurement and experimental uncertainty assessment were not carried out in this study due to weight loss during the crushing process. Nevertheless, the experimental observations appear internally consistent.

Table 4. Thresholds and volumes obtained by CT scanning.

Sample No.		1	2	3	4
4.5 mm	Threshold	29,183	18,943	19,455	22,527
	Volume (cm ³)	7.05	11.5	11.04	10.58
2.4 mm	Threshold	38,399	25,343	26,879	33,023
	Volume (cm ³)	5.57	6.6	10.04	7.37
1.2 mm	Threshold	38,143	26,034	28,279	27,903
	Volume (cm ³)	3.06	3.4	5.1	4.05
0.6 mm	Threshold	24,319	21,503	31,231	26,879
	Volume (cm ³)	7.04	7.27	5.18	7.28
0.3 mm	Threshold	28,927	23,341	25,343	17,663
	Volume (cm ³)	5.9	5.97	2.8	3.05

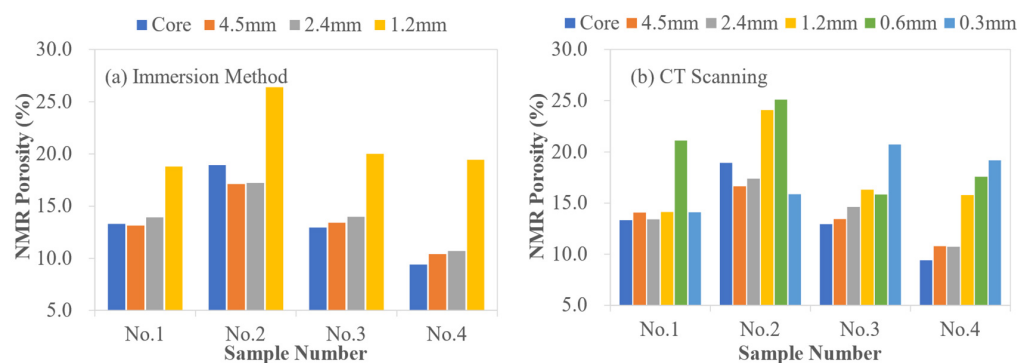


Figure 13. NMR porosities of different crushing samples.

5. Conclusions

Based on the analysis of the experiment results obtained by crushing core plugs into five particle sizes and measuring their NMR T_2 spectra, and then determining the sample volume through a combination of the immersion method and CT scanning, the following conclusions were drawn:

(1) When the particle size of sandstone cuttings is larger than 2.4 mm, the T_2 spectrum position, mean values, and NMR porosity measurement values are generally consistent with the core plugs, and are reflective of the porosity of the reservoir itself. However, the number of sandstone samples is small, and it remains to be verified whether the particle size threshold (2.4 mm) is applicable to other reservoirs.

(2) For smaller particle sizes, it is speculated that the surface water between particles affects the characteristic parameters representing the pores. Whether this applies to other lithologies requires further research.

(3) This study uses cuttings to determine the NMR porosities of core plugs, providing experimental support for selecting the optimal particle size of cuttings for characterizing core samples in both laboratory and oil field conditions.

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