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Research Article

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Research on the Characteristics of Gas-Liquid Two-Phase Flow in Coal Pores under Different Displacement Pressures

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Abstract It is of great significance for efficient development and application of coalbed gas to accurately understand the flow characteristics of gas-liquid two phases in the pores of coal seams. In order to study the fluid migration and distribution of coal and the influence of displacement pressure on the gas-liquid migration path in the process of nitrogen water displacement, the coal samples from Tiandi Wangpo Coal Mine and Pingmi No. 4 Coal Mine were taken as the research objects, and nitrogen–water flooding experiments were carried out under constant pressure displacement and variable pressure displacement using low-field nuclear magnetic resonance technology. The results show that gas molecules are affected by Klinken-berg effect, and the influence of gas molecules on the water content in the adsorption pores is greater under low pressure displacement than under high pressure displacement. During low-pressure displacement, the connectivity between percolation pores and migration pores becomes better, and the water in migration pores mainly migrates to smaller pores. When high pressure displacement occurs, the water in migrating pores mainly migrates to larger pores. In a certain range, increasing the displacement pressure can promote the water transfer from the percolation pores to the migration pores, but with increasing the displacement pressure, the gas forms a dominant channel in the migration pores, and the influence on the water in the percolation pores is weakened. It is found that the main water reduction is distributed in the migration pores and the percolation pores, and the proportion of water reduction is the largest in the migration pores, and the percolation pores mainly bears the transport of water and the transfer of pressure during the displacement process. There is starting pressure in gas seepage process, and the starting pressure of gas seepage of high rank coal is greater than that of middle rank coal.

Keywords coal pore; nuclear magnetic resonance; nitrogen-water flooding; gas-liquid two-phase; flow characteristic

1. Introduction

Coal bed water injection technology can play a positive role and be widely used in the fields of mine dust prevention [1], impact ground pressure prevention [2] and coal and gas protrusion prevention [3], etc. However, the injected water will infiltrate into the pores of the coal bed and block the pores, which will result in the decrease of the permeability of the coal bed, affecting the extraction of coal bed methane, and at the same time, the water and the gas will have a microscopic reaction and form a gas-liquid two-phase competitive relationship [4]. Therefore, it is of great significance to correctly recognize the flow law of gas and liquid phases within the

pore space in coal beds for the efficient development and application of coalbed methane.
In recent years, scholars at home and abroad have done a lot of research on the characteristics of gas-liquid two-phase flow in coal-rock pores. Yang et al. [5] used nuclear magnetic resonance technology to conduct gas displacement water experiments under different displacement pressure differences on tight rock samples of two types of reservoirs, and concluded that displacement pressure differences have different degrees of influence on gas phase flow characteristics in rock samples of different reservoirs. Xue et al. [6] found that wall roughness has retarding effect on the distance and velocity of displacement liquid interface. Zhu et al. [7] carried out experiments on water displacement by gas and nuclear magnetic resonance, and found that the minimum pore radius of bound water driven by gas is an exponential function of the air pressure difference. Ge et al. [8] and Deng et al. [9] used nuclear magnetic resonance technology to monitor the process of nitrogen-water flooding in real time, and found that nitrogen–water flooding can drive away water in the migration pores, and has little effect on the total water content in the percolation pores and the pores below. Meng et al. [10] tested gas-water seepage parameters of coal under the condition of nitrogen-water flooding by using the unsteady state method, revealing the influence of wettability and pore structure on fluid seepage in the process of coal-bed methane drainage. Shen et al. [11] used the unsteady state method to study the relative permeability changes of gas water in different coal ranks, and found that the gas slippage effect in high-rank coal was more significant than that in low-rank coal. Wang et al. [12] conducted nitrogen and water two-phase displacement experiments under different temperatures and pressures, and found that with the increase of confining pressure and axial pressure, the two-phase seepage area decreased, and heating the coal seam could improve the production efficiency of coalbed methane. Liu et al. [13] conducted Carbon dioxide-water flooding experiments using nuclear magnetic resonance technology and found that increasing gas injection pressure did not significantly improve the displacement efficiency of the seepage hole. Xue et al. [14] used NMRI to carry out nitrogen-water flooding experiments, and found that N_2 water flooding in adsorption pores, percolation pores and migration pores requires high to low pressure gradient.
In summary, at present, many scholars have mainly studied the influencing factors of coal-rock gas-liquid two-phase flow and the distribution of residual water after displacement, but there is a lack of research on the migration and distribution of fluid in the process of coal-rock gas-liquid two-phase flow and the influence of displacement pressure on the gas-liquid migration path. Therefore, this paper takes the coal samples from Tiandi Wangpo Coal Mine and Pingmei No. 4 coal mine as the research object, and uses the low-field nuclear magnetic resonance system to explore the fluid migration and distribution of coal bodies of different coal ranks in the process of gas water displacement and the influence of displacement pressure on the gas-liquid migration path, and reveals the gas-liquid two-phase flow characteristics of coal bodies of different coal ranks, which is of great significance for the efficient development and application of coalbed methane.

2. Experimental Principle

The experiments were carried out using a MesoMR23-060H-I low-field nuclear magnetic resonance instrument with a resonance frequency of 21.67568 MHz, a magnet temperature control of 32°C (±0.01°C), and a magnetic field strength of 0.5 T. The magnetic field of the instrument has a good stability. The essence of using the NMR system to study the characteristics of gas-liquid two-phase seepage in the pores of the coal body is to use the relaxation characteristics of the hydrogen-containing fluid molecules in the magnetic field to distinguish the distribution of the fluid in the pores of the coal body [15].
According to NMR theory [16], the transverse relaxation time T_2 is expressed as follows:

$$\frac{1}{T_2} = \frac{1}{T_{2S}} + \frac{1}{T_{2B}} + \frac{1}{T_{2D}} \quad (1)$$

where T_2 is the NMR transverse relaxation time; T_{2B} is the free relaxation time; T_{2S} is the surface relaxation time; and T_{2D} is the diffusion relaxation time.
The static magnetic field gradient of the low-field NMR system is so small that the diffusive relaxation time (T_2D) can be neglected; the free relaxation time (T_2B) is determined by the physical properties of the fluid, but the contribution of both the free relaxation term and diffusive relaxation term is much smaller than that of the surface relaxation term [17][18]. Therefore the relaxation time of pore hydrogen-containing fluids can be approximated as:

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

where ρ_2 is the transverse surface relaxation rate; S is the surface area of the pores; and V is the fluid volume. Therefore, the distribution of T_2 spectra obtained from the relaxation of hydrogen-containing fluids in a magnetic field can be used to distinguish the distribution of fluids in the pores of the coal body, and to reflect the characteristics of the pore size distribution of coal rocks.

3. Experimental Scheme Design

A. Coal sample preparation and analysis

In this experiment, coal samples were taken from Tiandi Wangpo Coal Mine (JM) and Pingmi No. 4 Coal Mine (PM), and the basic physical parameters of the coal samples were measured with reference to the national standards GB/T 212-2008 Methods of Industrial Analysis of Coal and GB/T 6948-2008 Methods of Microscopic Determination of Specular Reflectance of Coal, and the results are shown in Table 1. According to MT/T 1158-2011 "Classification of Coal Chemistry Degree of Specular Body Reflectivity", JM and PM coal samples are high-order coal and middle-order coal respectively, and the fissures of coal seams in the two mines are more developed, which are primary structural coals, and the raw coals of the two mines were processed into ⌀ 25 mm×50 mm cylindrical specimens, respectively. Figure 1 shows the finished coal samples from the two mines.

Table 1: Measurement results of basic physical property parameters of JM and PM coal samples

Coal sample	Moisture	Ash content	Volatile fraction	Fixed carbon	Maximum mirror group reflectance
JM	1.46	13.65	7.53	80.82	3.09
PM	1.20	13.47	34.70	55.52	1.08

Figure 1: JM and PM coal samples

B. Experimental program

In order to investigate the gas-liquid two-phase flow characteristics of the coal body under different replacement pressures, the experiment was divided into two parts: constant air pressure replacement and variable air pressure replacement. In the constant air pressure replacement experiment, the replacement air pressure was set to be 1MPa, 3MPa, 4MPa, 5MPa and 7MPa respectively, and the enclosing pressure was set to be 10MPa, and the replacement time was 540 min, and the samples were taken at the time of replacement of 0min, 60min, 180min, 300min, 420min, and 540min respectively; and the variable air pressure replacement experiment was divided into five stages, with the replacement air pressure increasing step by step, and the replacement air pressures were as follows. The variable air pressure replacement experiment was divided into five stages, with the replacement air pressure increasing step by step, and the replacement air pressure was as follows: 1→3→4→5→7MPa (with an interval time of 120 min), and the peripheral pressure was set to be a constant 10MPa, and the samples were taken at the end of each stage, respectively. The experimental flow is as follows:

(1) Referring to the standard specifications of GB/T 50123-1999 "Geotechnical Test Methods" and SY/T 6490-2007 "Specification for Laboratory Measurement of Nuclear Magnetic Resonance Parameters of Rock Samples", the specimens were put into the high-temperature oven set to dry at a constant temperature of 80°C for 24 h, and then taken out of the coal samples and put them into the evacuation saturated device to first take the vacuum at 0.1 MPa negative pressure pumping for 6 h, in the negative pressure environment to make it soaked for 20 h, so that the internal pores of the sample fully saturated with water. In order to avoid the use of hot air gun heating water saturated coal samples in part of the water will be evaporated by heat, and gas drive process through the gap between the heat shrink tubes and coal column gas streaming, resulting in experimental

errors, so this experiment uses the coal samples saturated with water, the surface of the coal column wrapped around a circle of raw material tape, so that the surface of the smooth and flat, to avoid the gas streaming, will be wrapped around the heat shrink tubes after the coal samples continue to saturate the treatment, so that the coal samples to reach the saturated state again. Figure 2 shows the state of the coal column after wrapping the raw material tape and heat-shrinkable tube.

Figure 2: Coal Sample Holder

(2) The heat-shrink tube-wrapped coal column is loaded into the NMR gripper and installed in the magnet coil, connected to the temperature control system, high temperature and high pressure circulation system, and liquid phase gas phase injection system.
(3) Set the experimental perimeter pressure, apply the perimeter pressure to the sample by fluorine oil, when the perimeter pressure is stabilized, the error between the perimeter pressure sensor's displayed pressure and the set pressure should be less than 5%.
(4) Open the gas-phase injection system to remove the air and water from the pipeline, then set the required experimental replacement pressure and carry out the replacement experiment according to the experimental parameters.
The T_2 spectra under constant air pressure replacement and variable air pressure replacement can be obtained through the above experiments, which can be used to analyze the characteristics of gas-liquid two-phase flow in the pores of the coal body during the replacement process.

4. Experimental Results and Analysis

A. Pore Distribution Characteristics

The T_2 spectrum can accurately observe the distribution of moisture in coal samples and the internal pore structure of coal samples, in which the X-axis is the relaxation time, which is directly proportional to the size of the pore, the smaller the pore is to the left, the larger the pore is to the right; the size of the Y-axis signal intensity is directly proportional to the number of pore, i.e. the larger the amplitude is, the larger the number of pore is of this aperture size; the connection between the peaks represents the connectivity of the apertures between the different sizes, and the higher the peak value of the connection is, then the better the two pore connectivity is[19][20]. Literature [21][22][23] categorized the pore size of coal body pore fractures into adsorption pores (0.001~0.1 μm), percolation pores (0.1~100 μm), and migration pores (100~1000 μm) based on the pore size of coal body pore cleavage, which corresponds to lateral relaxation times of about 0.01~2.5 ms, 2.5~100 ms, and 100~10,000 ms, respectively.
The T_2 spectra peak areas were first calibrated using different porosity specimens, and a linear expression for the NMR signal volume-porosity can be obtained as expression:

$$P = 125.32 + 738.25\emptyset \quad (3)$$

where $\emptyset$ is the total porosity of the coal rock in % and P is the cumulative NMR signal per unit volume of the coal sample.
Then JM coal samples and PM coal samples were selected for post-saturation testing, respectively, and the T_2 spectra of the two samples were obtained, as shown in Fig. 3.

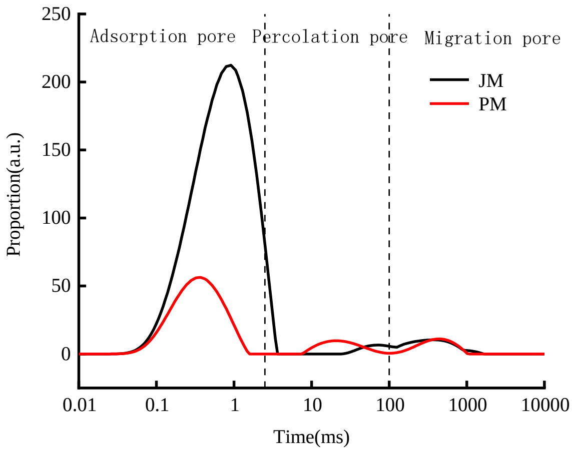
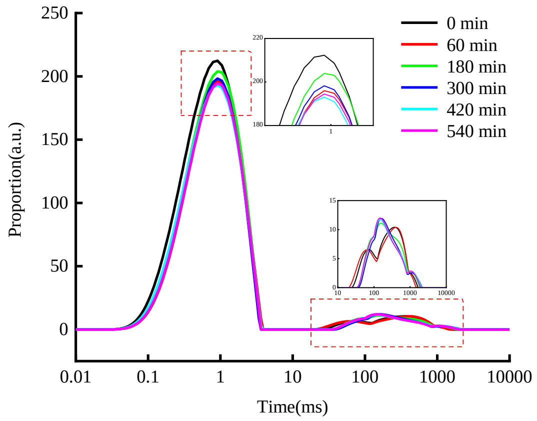


Figure 3: T_2 spectra of JM and PM saturated coal samples

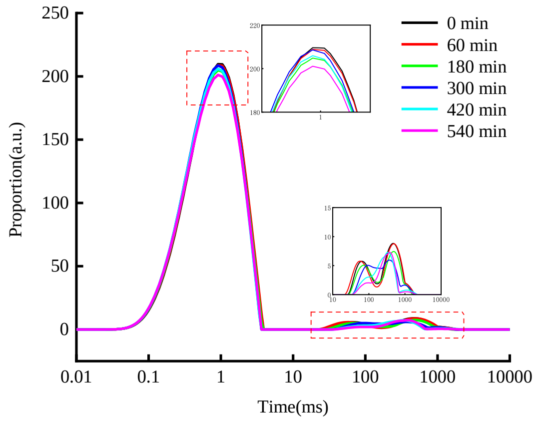
As can be seen from Fig. 3, the T_2 spectral distribution of JM and PM coal samples showed a three-peak structure as a whole, and there were percolation pores connected with migration pores, and the connectivity between adsorption pores and percolation pores and migration pores was poor; among them, the percentage of adsorption pores in the JM and PM samples was 91.88% and 78.33%, the percolation pores accounted for 4.26% and 10.95%, and the migration pores accounted for 3.86% and 10.72%, and the porosity was 9.36% and 2.45% when bringing peak areas into the fitting results. 10.72%, the peak area is brought into the fitting results can be seen that the porosity is 9.36% and 2.45%. The overall porosity of JM coal samples is much larger than the porosity of PM coal samples, most of the pores in JM coal samples are adsorption pores, which accounted for 91.88%, and the percolation pores and migration pores of PM coal samples are much larger than those of JM samples, which accounted for 21.67%. The reason is that the JM coal sample is a high-order coal and the PM coal sample is a middle-order coal, and the coalification of the high-order coal is higher than that of the middle-order coal, and the molecular structure of the coal body is changed and adjusted, which produces a lot of adsorption pore structure, and thus many percolation pores and migration pores are reduced continuously accordingly.

B. Characterization of gas-liquid two-phase flow at constant air pressure

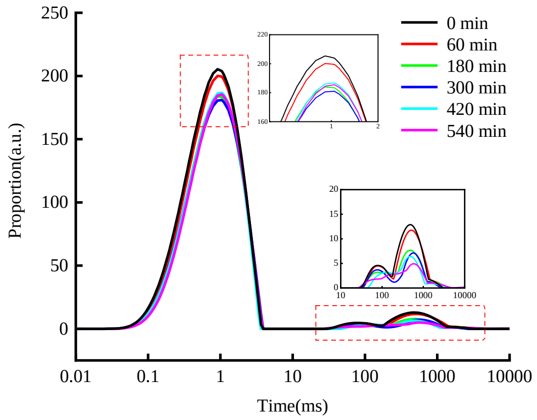
The experiment of nitrogen-water flooding under constant pressure was carried out in the laboratory, and it was found that the T_2 spectrum basically no longer changed after 540min, so 540min was selected as the end point of the experiment. FIG. 4 shows the T_2 spectra obtained by sampling of JM and PM water-saturated coal samples at 1MPa, 3MPa, 5MPa, and 7MPa after nitrogen flooding for 0min, 60min, 180min, 300min, 420min, and 540min respectively



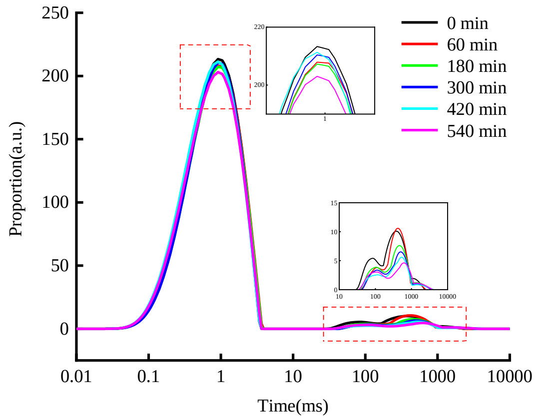
(a) JM Coal Sample 1MPa Replacement



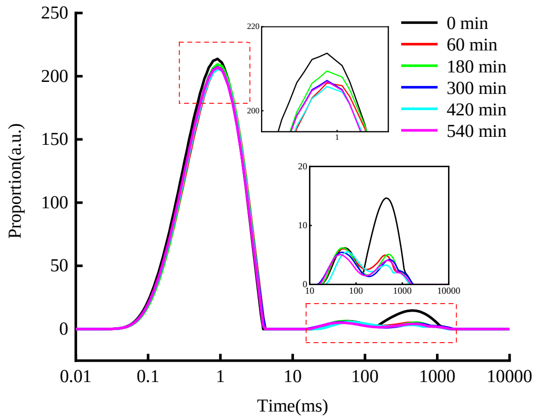
(b) JM Coal Sample 3MPa Replacement



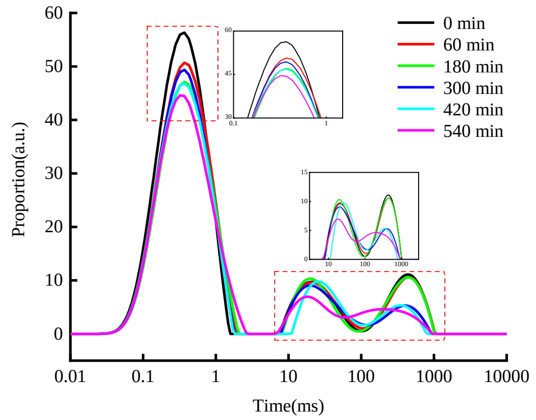
(c) JM Coal Sample 4MPa Replacement



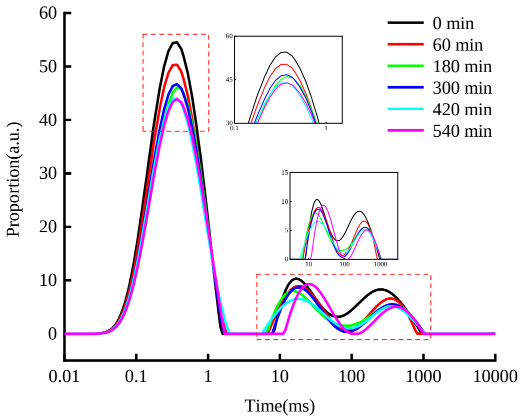
(d) JM Coal Sample 5MPa Replacement



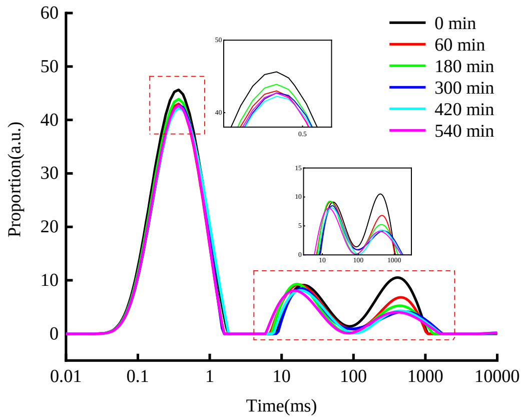
(e) JM Coal Sample 7MPa Replacement



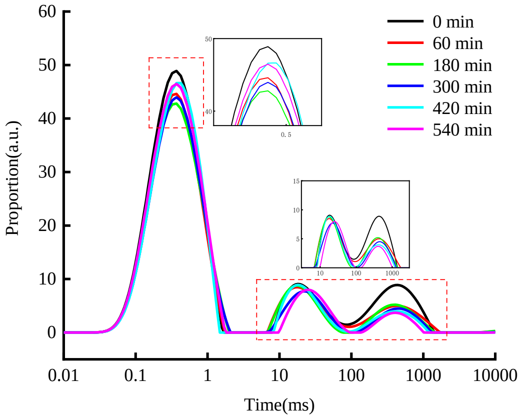
(f) PM Coal Sample 1MPa Replacement



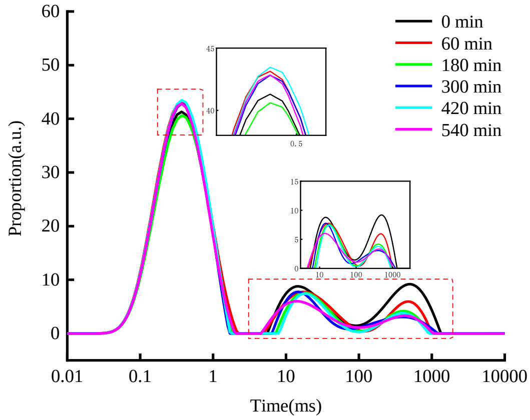
(g) PM Coal Sample 3MPa Replacement



(h) PM Coal Sample 4MPa Replacement



(i) PM Coal Sample 5MPa Replacement



(j) PM Coal Sample 7MPa Replacement

Figure 4: T_2 spectrum of constant pressure displacement of JM and PM coal samples

From Fig. 4, it can be seen that the T_2 spectra of the two coal samples have different distribution patterns under different air pressures. From Fig. 4(a-e), it can be seen that the peak value of adsorption pores of JM coal sample decreased at 1MPa and 4MPa, and basically remained stable at other air pressures; the percolation pores merged with the tr migration pores to form a single-peak structure at 1MPa, and then the peak value gradually decreased and shifted to the right at 3MPa, 4MPa, and 5MPa, and basically remained unchanged at 7MPa; the peak value of migration pores slightly decreased and the connectivity with the percolation pores became better at 3MPa, and then the peak value shifted to the left at 4MPa, and then it shifted to the left at 4MPa, and then it shifted to the left at 4MPa. The peak value of the migration pores is slightly reduced at 3MPa gas drive, and the connectivity between the migration pores and the percolation pores becomes better, at which time the peak value is shifted to the left, and the peak value is gradually reduced at 4MPa, 5MPa and 7MPa gas drive, at which time the peak value is shifted to the right. The experiments showed that the effect of JM coal samples on the moisture in adsorption pores was greater than that of higher gas pressure alternation at no more than 4 MPa, i.e., under the condition of low gas pressure, gas molecules were more likely to diffuse and infiltrate under the influence of the Klinken-berg effect [24][24], and therefore gas molecules were more likely to enter into the adsorption pores of the coal samples at low pressures, which led to the expulsion of water from the adsorption pores, while under the condition of high gas pressure, gas molecules entered into adsorption pores, which led to the expulsion of water from the adsorption pores. conditions, the ability of gas molecules to enter the adsorption pores is relatively weak, so the effect on the moisture in the adsorption pores is relatively small. For the percolation pores and migration pores, when the low-pressure replacement (≤3MPa), part of the pore throat between the percolation pores and migration pores opened, the connectivity between the two pore became better, the moisture in the percolation pores was transported to the larger pore, and the moisture in the migration pores was partly driven out and partly transported to the smaller pore, and at this time, the peak of the transport was shifted to the left, that is, the moisture was mainly transported to the smaller pore; when the high-pressure replacement (＞3MPa), the percolation pores water was transported to the larger pore, and the migration pores water was driven out and the migration pores water was transported to the smaller pore. During high-pressure drive (>3MPa), the water in the percolation pores is transported to the larger pore, and the water transport in the percolation pores is also divided into two parts, but at this time, the transport peak is shifted to the right, the water is mainly transported to the larger pore, and the bound water in the pore throat between the two pores starts to be driven out.

As can be seen in Fig. 4(f-j), the peak values of adsorption pores of PM coal samples decreased at 1MPa and 3MPa, and basically remained stable at other air pressures; the peak values of percolation pores slightly decreased at 1MPa and 3MPa, and basically remained stable at other air pressures, and the connectivity between percolation pores and migration pores deteriorated with the increase of air pressures; the peak value of the peak value of the migration pores gradually decreased and the peak value gradually shifted to the right at different air pressure drives. The experiments showed that the seepage characteristics of PM coal samples in the process of nitrogen water repulsion were similar to those of JM coal samples, and the influence of gas molecules on the water in the adsorption pores due to the Klinken-berg effect was greater than that in the high-pressure repulsion in the case of low-pressure repulsion (≤3MPa); meanwhile, the influence on the water in the percolation pores was found to be smaller than that in the case of PM coal samples in the case of JM coal samples.

C. Characterization of gas-liquid two-phase flow under variable air pressure

The experiment of nitrogen-water flooding under variable pressure was carried out in the laboratory, and it was found that the change of T_2 spectrum was the most intense within 120min, and the subsequent change slowed down. Therefore, 120min was selected as the change time of displacement pressure. FIG. 5 and FIG. 6 show the T_2 spectra obtained by sampling of JM and PM water-saturated coal samples after each stage of displacement pressure: 1→3→4→5→7MPa (interval 120 min).

As can be seen from Fig. 5, the peak value of adsorption pores of JM coal sample basically remained stable; the peak value of percolation pores increased slightly at 1MPa and 3MPa, and then decreased gradually at 4MPa, 5MPa and 7MPa, and the peak value of percolation pores shifted to the right; the peak value of migration pores showed the phenomenon of stabilization followed by gradual decrease, and the peak value of migration pores shifted to the right gradually. This phenomenon once again verifies the conclusion that water in the migration pores is mainly transported to smaller pores during low-pressure replacement (≤3MPa), and to larger pores during high-pressure replacement (>3MPa).

As can be seen from Fig. 6, the peak value of adsorption pores of PM coal samples basically remains stable; the peak value of percolation pores shows the phenomenon of gradual decrease; the peak value of migration pores fluctuates slightly at 1MPa gas drive, and the peak value is shifted to the left, and it starts to decrease at 3MPa gas drive, and it remains stable at 4MPa, 5MPa, and 7MPa alternation and the peak value is gradually shifted to the right. The experiments show that the peak value of the migration pores is greatly reduced at 3MPa, and then the effect of increasing the replacement pressure on the water in the migration pores is weakened.

Comparison of the T_2 spectra obtained from the two coal samples with variable air pressure drive shows that in low-pressure drive, the moisture in the migration pores is driven preferentially into smaller pores, and in high-pressure drive, the moisture in the migration pores is driven out in large quantities, and the moisture in the percolation pores is transported to the migration pores and driven out, which indicates that the percolation pores are mainly responsible for the transportation of the moisture and the transfer of the pressure in the process of the drive.

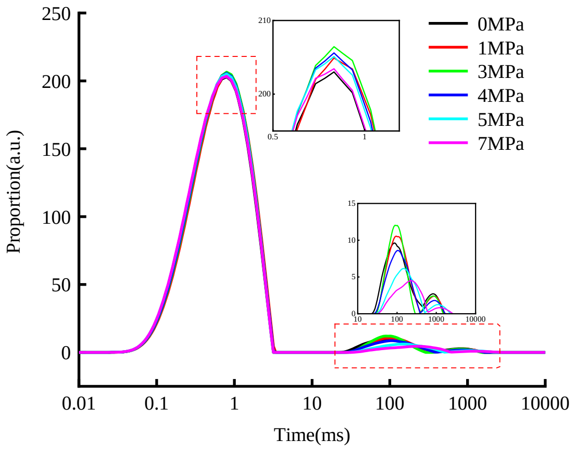


Figure 5: T_2 spectrum of JM coal sample under variable pressure displacement

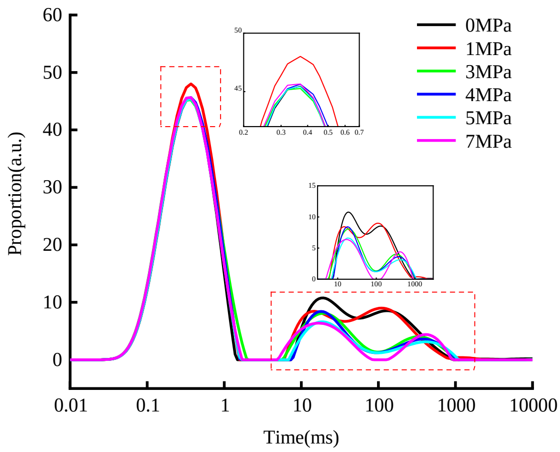


Figure 6: T_2 spectrum of PM coal sample with variable pressure displacement

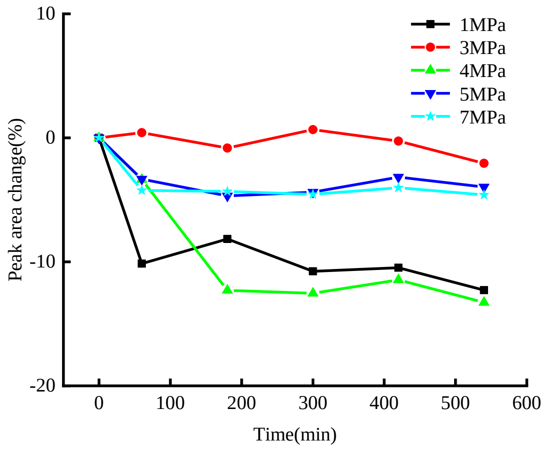
D. Replacement efficiency under different replacement pressures

The T_2 spectra were divided into adsorption peaks, percolation peaks and migration peaks according to the size of adsorption, percolation and migration pore sizes, and the corresponding spectral areas were calculated. Comparing with the initial spectral areas of the corresponding pore sizes, we can analyze the relative rates of change of the different pore spaces under different exclusion pressures. The three-peak change rate ΔA was calculated as:

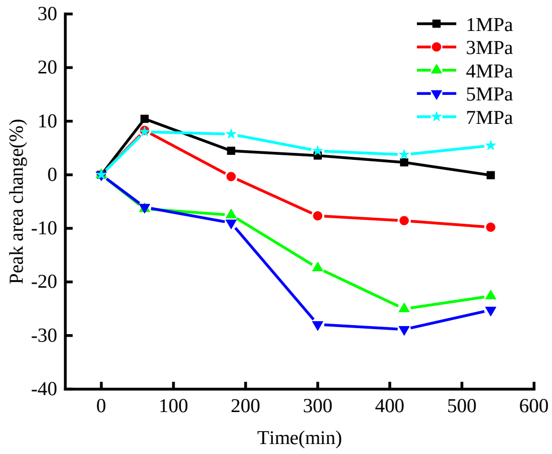
$$\Delta A = \frac{A_i - A_0}{A_0} \times 100\% \qquad (4)$$

where A_i is the spectral area corresponding to the three peaks when the driving pressure is i; A_0 is the spectral area corresponding to the initial three peaks.

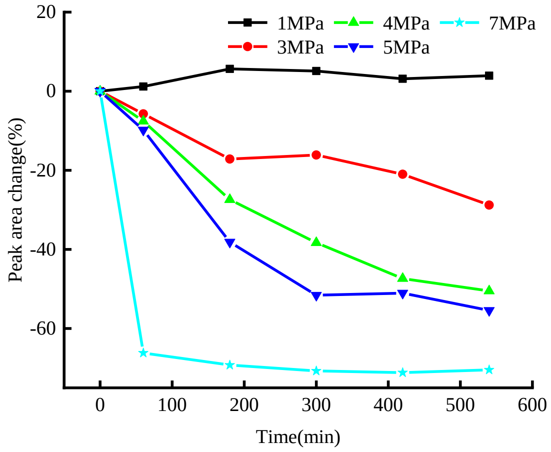
Figures 7 and 8 below show the dynamic change curves of the three peak areas during constant air pressure driving and variable air pressure driving for JM and PM coal samples, respectively.



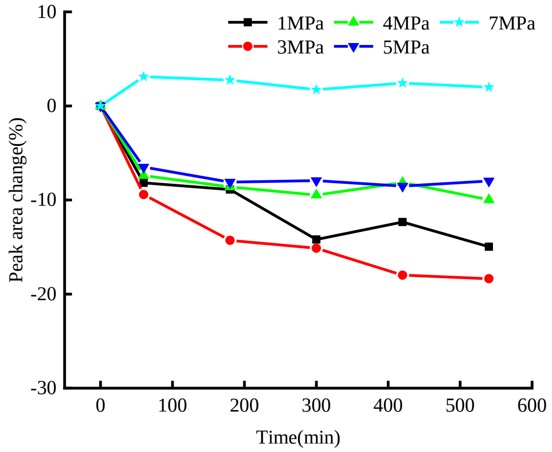
(a) Rate of change of peak area of constant air pressure driven adsorption peak of JM coal samples



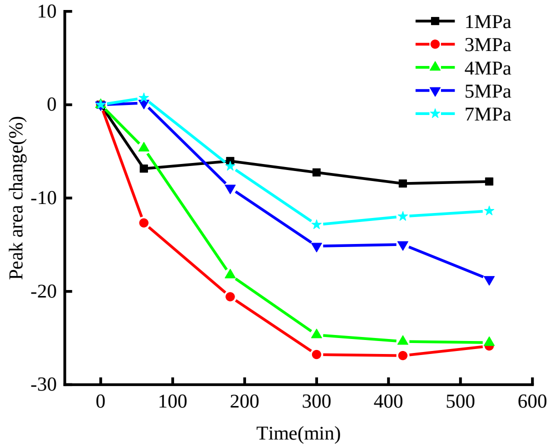
(b) Rate of change of peak area of constant air pressure driven percolation peak of JM coal samples



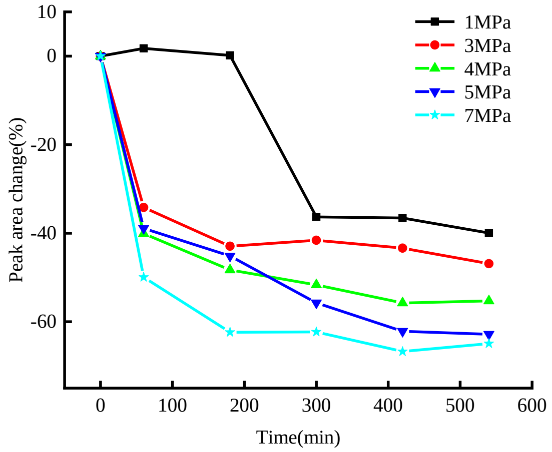
(c) Rate of change of peak area of JM coal samples at constant air pressure driven migration peaks



(d) PM coal samples constant air pressure driven adsorption peak area change rate



(e) PM coal samples constant air pressure driven percolation peak area change rate



(f) PM coal samples constant air pressure driven migration peak area change rate

Figure 7: Change rate of three peak areas during constant pressure displacement of JM and PM coal samples

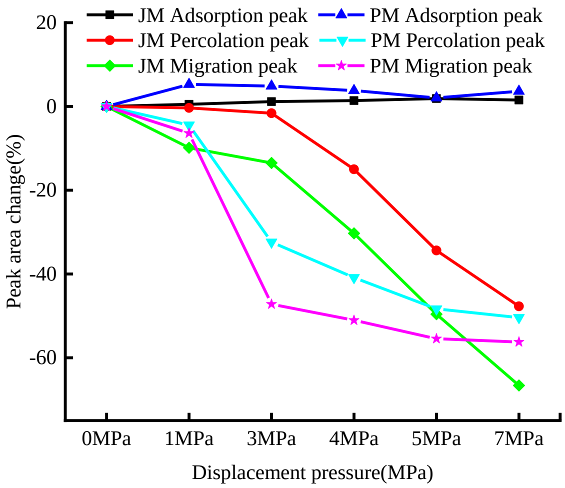


Figure 8: Change rate of the three peak area of JM coal sample and PM coal sample under variable pressure displacement

From Fig. 7 (a) (d), it can be found that the adsorption peak area of JM and PM coal samples decreased the most at 4MPa and 3MPa substitution, reaching -13.27% and -18.37%, respectively, and the decrease of adsorption peak area decreased by continuing to increase the substitution pressure. From (b) (e) in Fig. 7, it can be found that the peak areas of percolation peaks of JM coal samples and PM coal samples decreased the most at 5MPa and 3MPa substitution, reaching -28.86% and -26.88%, respectively, and the decrease in the peak areas of migration peaks continued to increase the substitution pressure. From Fig. 7 (c) (f), it can be found that the rate of change of the migration peaks area of both JM and PM coal samples increases with the increase of the replacement pressure, and the rate of change of the migration peak area tends to stabilize after a period of time of replacement, and the larger the replacement pressure, the shorter the time needed to reach stability. Studies have shown that a certain range of elevated drive pressure can promote the transfer of moisture in the percolation pores to the migration pores, but there are dominant channels in the process of gas seepage in the pores [9], when a certain air pressure is reached and then continue to increase the drive pressure, the moisture in the migration pores will be driven out quickly, thus forming the dominant channels of the gas in the migration pores, which results in the gas flowing out directly from the other end of the coal samples through these channels, which rather attenuates the effect on the moisture in the percolation pores.

From Fig. 8, it can be found that the variation rates of adsorption, percolation and migration peak areas of JM coal samples were 0 ~ 1.88%, 0 ~ -47.71% and 0 ~ -66.61%, respectively; and the variation rates of adsorption, percolation and migration peak areas of PM coal samples were 0 ~ 5.26%, 0 ~ -48.35% and 0 ~ -56.24%, respectively. Comparing the peak area changes of the two coal samples during the variable gas pressure driving process, it was found that the main reduction of water in the different gas pressure driving process was distributed in the migration pores and percolation pores, among which the migration pores had the largest reduction rate; due to the formation of dominant channels in the migration pores and percolation pores in the process of driving, the effect of different gas driving pressures on the adsorption pores was weaker; the reduction of water in the migration pores and percolation pores of the two samples suddenly increased in the gas driving of the two coal samples at 4 and 3 MPa, respectively. The decrease of water in the migration pores and percolation pores of the two coal samples suddenly increased at 4MPa and 3MPa respectively, which indicated that the two coal samples had a starting pressure during the gas seepage process, and the water in the pores would be driven out quickly and in large quantities after reaching the starting pressure, and the starting pressure of gas seepage in the JM coal sample was larger than that in the PM coal sample.

5. Conclusion

(1) In the process of nitrogen-water flooding, the gas molecules were affected by the Klinken-berg effect, and both JM and PM coal samples showed that the effect on the water in the adsorption pores was larger than that in the high-pressure drive during the low-pressure drive. During low-pressure replacement, some of the pore

throats between the percolation pores and the migration pores were opened, and the connectivity of the two pores became better, at which time the water in the migration pores was mainly transported to the smaller pores; during high-pressure replacement, the water in the migration pores was mainly transported to the larger pores, and the bound water in the pore throats between the two pores was driven out.

(2) In the process of nitrogen-water flooding, a certain range of elevated driving pressure can promote the transfer of water in the percolation pores to the migration pores, but continue to increase the driving pressure, the water in the migration pores is driven out quickly, and the gas forms a dominant channel in the migration pores, which in turn results in a weakening of the impact on the percolation pores water.

(3) During the variable air pressure replacement process, it was found that the main reduction of moisture in JM and PM coal samples was distributed in the migration pores and percolation pores, in which the ratio of moisture reduction in the migration pores was the largest, with -66.61% and -56.24%, respectively, and the percolation pores were mainly responsible for the transfer of moisture and the transfer of pressure in the replacement process.

(4) JM coal samples and PM coal samples in the gas seepage process there is a start-up pressure, after reaching the start-up gas drive pressure in the pore space will be rapidly driven out a large number of water, and the gas seepage start-up pressure of the higher-order coals is greater than that of the middle-order coals, the start-up pressures are 4MPa and 3MPa, respectively.

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