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# Research on microscopic features of salt rock being damaged via loading osmosis on the basis of CT scanning

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**Abstract:** In order to study the microscopic characteristics of the salt rock being damaged through diverse level of osmosis, CT scans are made to the salt rock before the osmosis loading and after it is damaged, in which the stress-strain is applied to the whole process. The differences of the micro-features of damaged salt rock are discussed. The experimental results show that: (1) the microscopic characteristics observed from CT scan indicate that the critical confining pressure of salt rock is 10MPa. When the confining pressure is lower than 10 MPa, shear crack can be seen obviously in the cross and longitudinal section of the salt rock, with the form of shear damage; While confining pressure is more than 10MPa, the fissure is short and the rock is damaged in a drum-shaped deformation; An impervious point occurs when it exceeds 10MPa. (2) The number of cracks demonstrates the intrinsic crack development of salt rock. The salt rock has a critical point ( $d=0.6\text{mm}$ ) in the number of small cracks ( $d\leq 1\text{mm}$ ). 0.6mm is the boundary point. When it is 0.6mm or less, the number of fissures in the salt rock with confining pressure of 5MPa is more than those with 10MPa. The larger the diameter of the fissure is, the closer the number of fissures with the above two confining pressures is. While boundary point is more than 0.6mm, it will have the opposite effect. (3) The internal mechanism of that the end effect has an impact on the osmosis evolution of salt rock is uncovered. Due to the stress-intensive effect at the ends, the development path of the small cracks gradually spreads from the both ends to the inside, therefore, the osmosis of the gas osmosis channels at the ends is hindered, resulting in a low salt rock permeability during the loading process.

## 1. Introduction

As energy is the bedrock for human subsistence, its reserves play a key role in building and improving energy supply system, and in the path to sustainable development as well. Salt caves are considered to be the best natural underground reservoirs. Salt rocks boast many advantages such as high strength, low porosity, low permeability, strong self-recovery ability [1-2]. Actually, its porosity and permeability are very low, approaching to zero, so that the salt rock also has good liquid tightness and airtightness. However, in China, most of the salt rock is distributed in stratification, with unfavorable factors such as many interlayers and high impurity content [3]. Sealing is an important factor for consideration for the safety of underground energy storage. The impurities and interlayers change the dense internal crystal structure of original salt rock, affecting mechanics, deformation and



permeability of the salt rock. Therefore, from a microscopic point of view, it is necessary to study the damage characteristics of salt rock with stable crystal structure.

With the development and application of salt rock gas storage, many scholars have carried out basic research on the permeability and damage characteristics of salt rock. Gorham et al [4] conducted long-term permeability in-situ test on reservoir salt rock based on Darcy's law; Popp And Kern [5] analyzed the correlation between the permeability, porosity, ultrasonic wave velocity and microcracks in salt rock amid gas seepage conditions; Based on the field permeability test results of pure salt rock, professor Stormont [6] found that the permeability in the damaged and disturbed area of surrounding rock reached 0-16mD~10-20mD, while in the non-disturbed deformation area, the permeability was relatively low, only 10-21mD. Brouard et al. [7] obtained that the permeability of salt rocks under axial loading reached 10-21~10-20mD according to the laboratory permeability test of salt rocks. Berest et al. [8] also found that the salt rock permeability reached 10-19mD through the long-term field permeability test in Etrez natural gas reservoir in France. Colin j. Peach et al. [9] obtained the characteristics of the influence of brittle plastic deformation of salt rocks on the permeability of salt rocks on the basis of the osmosis experiment during the loading process of synthetic salt rocks.

The above scholars used acoustic emission, ultrasound, electron microscope scanning and other methods and technologies to study the mechanical damage or permeability features of salt rocks in mechanical experiments. Compared with the above experimental research methods, CT scanning provides a more intuitive test method to display the internal damage characteristics of the specimens. Ge Xiurun et al. [10-11] scanned the deformation and damage process of rock using the loading equipment with medical spiral CT, and obtained CT images of the internal fissures of rock samples in different stress conditions from compaction to initiation, bifurcation, development and finally fracture and damage. Ren Jianxi, Ge Xiurun et al. [12] explained the estimation method of fissure width and found the preliminary law of rock damage propagation. Mao Lingtao [13] studied the deformation field and strain field inside the sample in the process of rock uniaxial compression damage based on the three-dimensional digital image obtained by CT scan, and found that the strain localization area in deformation damage was consistent with the position of the specimen's final damage surface. This provides a new method for the visualization of rock internal deformation. Compared with other rocks, the internal particle structure of salt rocks is compact. The internal micro-structure damage characteristics will be demonstrated through CT scanning. Based on CT scanning, this paper shows the difference in micro-structure characteristics of salt rocks amid loading osmosis.

## 2. Test equipment and plan

### 2.1 equipment

The triaxial osmosis test of pure salt rock is carried out on the comprehensive test system of rock mechanics under CO<sub>2</sub> percolation introduced by Sichuan university, as shown in figure 1. The details of the equipment are as follows: maximum axial load is 2000kN; three axis horizontal range extensometer is - 50 ~ + 50mm; confining pressure is 100 MPa; hydraulic seepage pressure is 100 MPa; the difference of gas osmotic pressure is determined by the external cylinder; the range of temperature is from room temperature to 200 ° C; the test accuracy of each sensor is 3% of the current calibration range point.



Fig.1 THMC rock triaxial test system

The industrial CT scanning equipment used in the salt rock sample being penetrated and damaged in this test is GE Phoenix v|tome|x m300, which is different from the line array scanning. This CT machine is a scanning form of surface array, with the maximum detection object range of 400mm\*400mm, the ray source of 300kv/500w, the scanning speed of 7.5 frames/second, and the spatial resolution determined by the scanning sample. When CT scan is done, VG Studio MAX is employed to reconstruct, analyze and process the scanned image data. In this way, the basic information of specimen microscopic features can be acquired.

## 2.2 plan

This is a three-axis compression test with osmosis involved in the whole process which includes 5 different confining pressures: 3 MPa, 5 MPa, 10 MPa, 15 MPa and 20 MPa. Given that the osmotic pressure should not be higher than the hydrostatic confining pressure in the experiment, when the confining pressure is 3MPa, the osmotic pressure and the osmotic pressure difference in the test should be 2 MPa. Otherwise, they should be 3MPa amid other confining pressures. The samples of pure salt rock in the triaxial osmosis test are preserved in dry condition. In process of loading, the permeability is tested at 7 stress points whose stress is roughly in proportion to the loading stress. The operation is explained as follows: 4 tests are conducted before the peak, 1 test near the peak, and 2 tests after the peak. To study the influence of osmotic pressure on the mechanical behavior of pure salt rock test, as well as to form a seepage field with constant osmotic pressure inside the sample during loading, the gas pressure  $P_w$  is applied to the lower end of the sample during loading. Besides, the pressure is the set value of the test, and the upper end is connected to the atmosphere. The pressure difference attenuation method is adopted for the permeability test. The initial pressure difference between the upper part and lower part of the sample in the test is the initial set value, in which the osmotic pressure of the lower part of the sample is higher than that of the upper part, and the first point of the permeability test is the hydrostatic pressure test after the confining pressure is loaded into the target value. The salt rock samples used in the test are processed into a standard specimen with a diameter and height of 50/100mm by using the dry lathe method in accordance with the Rock Test Code for Water Conservancy and Hydropower Engineering [14] and the Engineering Rock Test Method Standard [15]. All samples are used water-soluble method to determine the insoluble content which is regarded as the salt rock impurity content.



Fig.2 Experimental salt rock samples

After the experiment, industrial CT scanning equipment is used to conduct microscopic scanning of salt rock samples after damage. By doing this, the data of reconstructed by CT scanning is obtained.

## 3. Results and analysis

### 3.1 microscopic characteristics of section

Based on the features of the salt rock being damaged through loading osmosis and the data of reconstructed by CT scanning, longitudinal and cross section are sliced for analysis. When the confining pressure is 3MPa, the lateral restraint is small, with many tiny fissures on the surface of the cross section. Furthermore, there are obvious shear damage on the longitudinal section and it can be seen that the direction of main fissure is from upper right to lower left through the center of the sample. With the increase of confining pressure, all fissures can be seen that their directions are the same as the

main fissure. Compared with the samples with confining pressure of 3MPa, those with 5MPa and 10MPa have a few larger fissures with tiny fissures around them, forming a group of fissures of a certain scale, rather than being disorderly distributed throughout the longitudinal section. In addition, the trapezoid region at both ends affected by the end effect is relatively obvious. However, no large and obvious fissures can be observed on the cross section when the confining pressure is 15MPa and 20MPa. Besides, when confining pressure of the sample increases to 10MPa, the permeability cannot be measured. The author suggests that when the confining pressure is greater than the critical confining pressure, salt rock is transformed from strain softening into strain hardening, making a drum-shaped sample. Both ends generate stress shielding area because of friction and circumferential restraint, resulting that extreme difficulty for test gas to go through the sample ends, relatively low permeability, and even low instrument resolution range. Therefore, from microscopic analysis obtained via CT scan, it can be seen that the 10MPa confining pressure is the critical confining pressure for observation of salt rock osmosis characteristics.

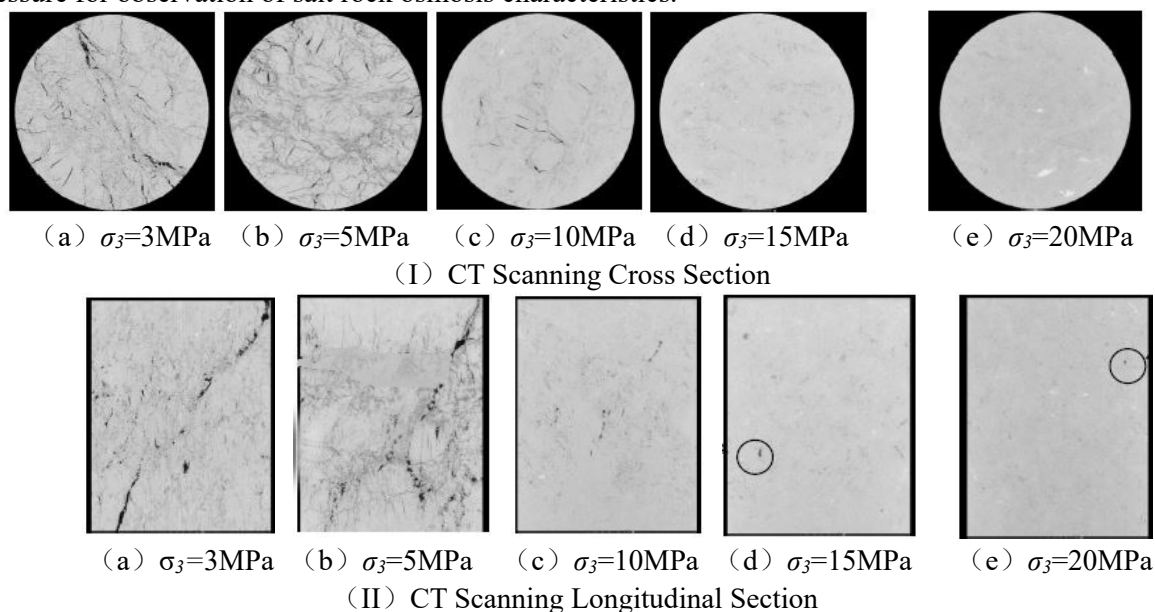


Fig. 3 Scanning slice of salt rock after loading failure

### 3.2 features of fissures

From a macroscopic perspective, the evolution features of the permeability are closely related to the extension and expansion of the internal fissure of the sample. Moreover, and the development of the fissure is also related to the instability and damage of the sample. To some extent, the extension of the fissure is the formation of the gas osmosis channel. The formation and expansion of fissures are the result of crack penetration. It is of great significance to study the formation of small cracks. Therefore, fissures within 1mm with the same impurity content are selected for comparative analysis (figure 4).

It can be known from the above analysis that 10MPa confining pressure is the critical confining pressure for observation of salt rock osmosis features. Because of the large amount of data,  $\sigma_3=5\text{MPa}$  and  $\sigma_3=10\text{MPa}$  are selected to be compared with. In terms of the contents of diverse impurities, the higher the content of impurities is, the smaller the difference in the number of small fissure is. At this point, the difference in confining pressure is not obvious. When it comes to the number of small fissure with different impurity contents within the confining pressure, it can be seen that when the impurity content is similar. Approximate 0.6mm is the cut-off point of the salt rock sample. That is to say, when the cut-off points is within 0.6mm, the number of fissures in the sample with the confining pressure of 5MPa is more than those with 10MPa. With the increase of the fissure diameter, the number of fissure of the two confining pressures is closer. While the cut-off point exceeds 0.6mm, it will have the opposite effect. The loading process is influenced by stress shielding effect of both ends,



resulting that when the axial loads stress to a certain stage, end constraint effect reaches to maximum. At this point, the permeability reaches to its “frozen point”(lowest point). Due to the formation of macroscopic damage surface or instability in drum-shaped, permeability of the salt rock is gentle. The tiny fissures in the internal part of salt rock sample are developed in a reversal way. Confining pressure growth will make the internal tiny fissures gradually interconnected, however, they do not extend to become larger fissures ( $d \geq 10\text{mm}$ ) due to outer restraint. This is an observation of the evolution features of permeability of salt rock from microscopic perspective.

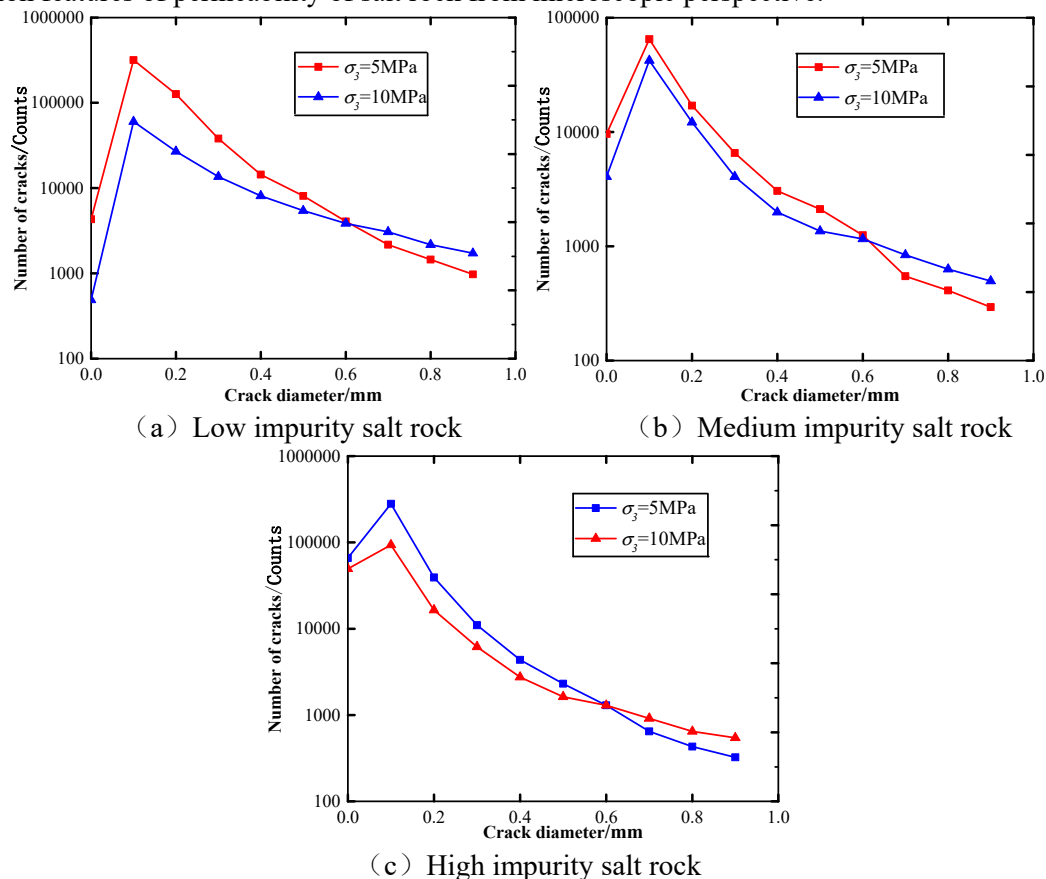


Figure 4: The number of cracks in 1mm in small cracks - impurity relationship

### 3.3 features of salt rocks

Based on the diameter of the outer ball of the internal crack, the crack distribution diagram of the impurity salt rock, which has no osmosis hole, with the confining pressure of 5MPa is extracted (5). It can be seen that with the rise of impurity content, the number of cracks in each diameter section reduces, while the fissure volume increases. Seen from extension path of diameters of small fissures, it is different from salt rock with osmosis hole. The latter is extended to the border of both ends from unconnected places. Because there is intensive effect at the ends of the rock, its tiny cracks develop and interlink from the end to the internal part, shaping macroscopic fissures. It is also an evidence for that intensive effect at the ends is the reason for why gas osmosis channel is not smooth, resulting in low permeability in the rock.

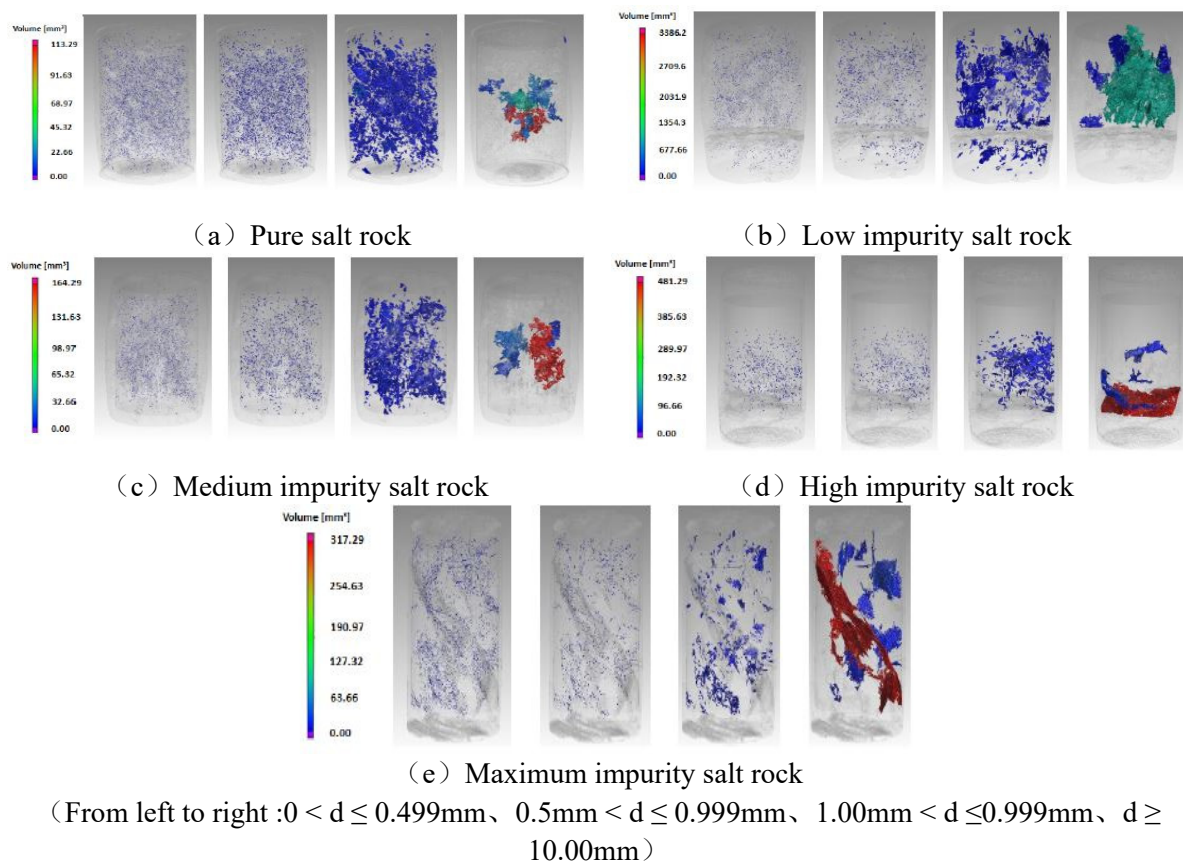


Fig.5 Fracture distribution of each diameter section

#### 4. Conclusion

(1) The microscopic features observed from CT scan show that the critical confining pressure of salt rock is 10 MPa. When the confining pressure is lower than 10 MPa, there are obvious shear fissures in both cross and longitudinal section of the salt rock; When it is more than 10MPa, the fissure is short and the rock is damaged in a drum-shaped deformation; An impervious point occurs when it exceeds 10 MPa.

(2) The number of cracks explains the intrinsic crack development of salt rock. The salt rock has a critical point ( $d=0.6\text{mm}$ ) in the number of small cracks ( $d \leq 1\text{mm}$ ). Take 0.6mm as the boundary point. When it is 0.6mm or less, the number of fissures in the salt rock with confining pressure of 5MPa is more than those with 10MPa. The larger the diameter of the fissure is, the closer the number of fissures with the above two confining pressures is. While boundary point is more than 0.6mm, the effect is just the reverse.

(3) The internal mechanism of the impact of end effect on the osmosis evolution of salt rock is disclosed. Because of the stress-intensive effect at the ends, small cracks expand and interconnect from the both ends to the inside. Therefore, the osmosis of the gas osmosis channels at the ends is impeded, causing a low salt rock permeability during the loading process.

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