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Journal of Scientific and Engineering Research, 2023, 10(6):212-218

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Study on dispersion characteristics of loaded coal complex electricity and permeability evaluation

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Abstract In order to accurately predict and evaluate the permeability of coal bodies, we measured the parameters of complex electricity and permeability of coal samples in different directions under different water-bearing conditions at room temperature and pressure, and analyzed the experimental phenomena by using the physical and chemical structural characteristics of coal bodies and their conductive and dielectric mechanisms, and initially established a method for evaluating the permeability of coal bodies with complex electricity. The results show that (1) The dispersion characteristics of coal body re-electricity change regularly with the change of pressure on the coal body. As the pressure increases, the absolute values of the real part *R* and the imaginary part *X of the complex resistance of coal* samples gradually decrease, especially in the frequency band near the slowly decreasing *R* and the very small value of *X. The dispersion* curve is shifted to the right, where *X is* shifted to a large extent and the capacitance *C* gradually decreases. (2) There are anisotropic characteristics in the dispersion of the complex electrical properties of the coal body. The absolute values of the real part *R* and the imaginary part *X of the complex resistance of the* water-saturated coal sample and the naturally dried coal sample decrease in the order of *z-direction*, y-direction and x-direction. (3) There is a good correlation between the coal complex electrical properties and the permeability under the corresponding conditions. The value of permeability *k of coal* samples in all three directions decreases with the decrease of relaxation time *τ of the* inversion parameter of the complex electrical properties model, and the directional change of *k of coal body under the* same pressure condition is opposite to the value of *τ*. The preliminary method for evaluating the permeability of the coal body by complex electrical properties is established, which provides a theoretical basis for the subsequent accurate prediction and evaluation of the coal body permeability by using the complex electrical properties exploration method.

Keywords coal; complex electrical properties; dispersion characteristics; permeability

1. Introduction

With the rapid development of the economy, the future mining of coal resources is still the core of China's energy, accounting for 95% of the fossil energy resources in China. Underground mining is the mining method adopted by 95% of coal mines in China, and the phenomenon of coal-rock dynamic disaster is serious due to the influence of objective elements such as geological endowment conditions of coal seams [1]. In the process of coal seam mining, when its internal pore and fissure structure changes with the change of stress state and the degree of deformation produced, its permeability performance will also change accordingly. The study of coal permeability is of great significance for the prevention and management of gas disaster accidents and the rational development of coalbed methane. In recent years, the complex electrical properties exploration method has become a hot issue for discussion in the logging community in recent years. Wang Yungang [2-3] concluded that with the increase of gas adsorption time and stress, the coal resistivity value appears to decrease significantly and then increase slightly, and its resistivity decreases slowly in the process of uniaxial compression of anthracite. By monitoring the resistivity change pattern of coal samples during uniaxial compression, Lu Hailong [4] obtained that the apparent degree of resistivity change of compressed coal samples increased with their hardness, and there was a good correspondence between loading stress and resistivity of coal samples in cyclic loading. Jianjie Chen [5] measured the apparent resistivity of primary structural coal and tectonic coal with different degrees of metamorphism at three frequency points, and obtained that the former apparent resistivity was greater than that of the latter. Li Zhonghui [6] concluded that the surface potential variation of the loaded coal body was affected by factors such as moisture conditions and loading rate. Enyuan Wang [7] pointed out that the variation pattern of resistivity of coal body before expansion is related to the stresses applied and the gradual closure of pore fissures. Xiaokai Xu [8] tested the complex resistivity of coal bodies with different degrees of metamorphism at three frequency points in three directions, namely, vertical lamina face, parallel face cut and parallel end cut, and pointed out that at the same frequency, the electrical characteristics of coal bodies showed isotropy between two directions of parallel laminae and anisotropy between parallel and vertical laminae. Xiaojie Guo [9-10] pointed out that the complex resistivity modulus of coal body has strong anisotropic characteristics in the low frequency band under the conditions of room temperature and one atmosphere pressure, and the dominant frequency band corresponding to the basic properties of coal rock and coal quality was identified by correlating the measured impedance amplitude values of coal body with each physical property parameter respectively.

2. Experimental protocol

The water content saturation of coal samples was determined using the weight method by measuring the complex electrical properties of coal blocks with different water contents in different directions at room temperature and pressure. Firstly, the briquettes were put into a drying oven and dried continuously at 105°C for 12 hours; secondly, the briquettes were immersed in water and removed and weighed every 6 hours due to their rapid water absorption at the beginning, and after 12 hours, they were removed and weighed every 12 hours and could be considered saturated after 72 hours of immersion. The mass of the briquettes was measured with an electronic balance. The work of measuring the recharge parameters (R, X and C) was carried out separately for naturally dried and saturated coal briquettes in different directions.

By measuring the complex electric parameters (R, X and C), permeability and strain in different directions and at different pressures (axial pressure variation) of the coal body, we compare and analyze the change patterns of complex electric properties and permeability strain of coal samples in the same direction, at different pressures, and at different directions of the same pressure, respectively, and the correlation between the three.

3. Experimental study on the dispersion characteristics of the complex electrical properties of the loaded coal body

The pressure on the coal directly affects the structural changes of its pore fissure. Under the designed conditions of constant temperature (28℃), constant surrounding pressure (5MPa), constant air pressure (1MPa gas pressure), and equal gradient variation of axial pressure (1MPa, 3MPa, 5MPa, 7MPa), the complex resistance R and X dispersion curves were measured under different pressures, as shown below:

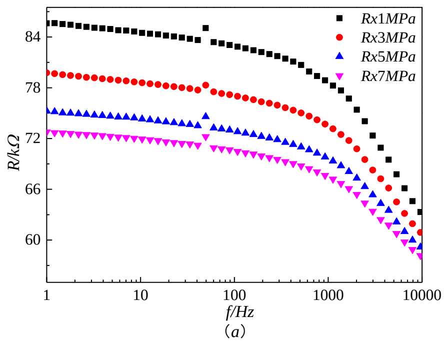

Figure 1: R Dispersion curve of complex resistance of coal samples under different pressure

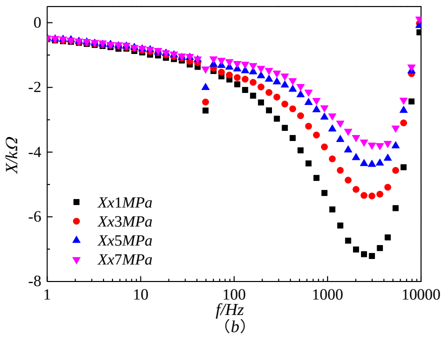

Figure 2: X Dispersion curve of complex resistance of coal samples under different pressure

As can be seen from the figure, the real part *R* and the imaginary part *X* of the coal sample each show a consistent variation pattern under the action of constant temperature, constant air pressure and constant circumferential pressure, and equal gradient variation of axial pressure: for *R*, *the value* is positive under any pressure condition, and with the increase of frequency, *R* decreases slowly and then accelerates, and a jump point is generated at 49 Hz due to industrial electricity interference; with the increase of pressure, R gradually decreases, and it is especially obvious in the frequency band of R decreases slowly, and the dispersion curve of X tends to be consistent in the frequency band of R accelerates. The dispersion curve tends to be consistent in the frequency band where R decreases slowly, and the dispersion curve tends to be consistent in the frequency band where *R* decreases faster; for *X*, the value is negative under any pressure condition, and with the increase of frequency, *X* decreases first, and then increases close to zero; similarly, at the same frequency of 49Hz, it is affected by industrial electricity and deviates from the dispersion curve, and the increasing phase of *X* is affected by electromagnetic interference and does not appear. The slowly increasing phase; with the increase of pressure, the absolute value of X all gradually decreases, especially in the frequency band near the point where the *X dispersion* curve appears to be very small value. Comparing the complex electric dispersion curves of coal sample *R* and *X*, it is easy to find that *X can highlight the* characteristics of complex electric change more, and the trend of X dispersion curve gradually shifts to the right with the increase of pressure is more significant than that of *R*.

The capacitance *C* measurements for different pressures on coal samples under the same directional conditions are shown below:

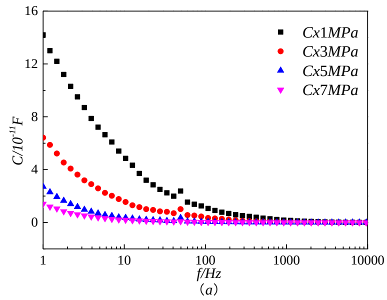

Figure 3: Dispersion curve of coal sample capacitance C under different pressure

4. Correlation study between permeability of loaded coal body and rechargeability

According to the discussion on the dispersion law and mechanism of the complex electrical properties of the loaded coal body in the previous sections, it is found that the complex electrical properties of the coal body have a strong correlation with the pressure, and through the model inversion of the complex electrical properties measurement parameters, the model inversion fitting parameter τ is preferably selected to characterize the change law of the complex electrical properties response of the loaded coal body. τ value indicates the retardation of the excitation polarization effect of the coal body, which is influenced by its pore-fissure development characteristics and directionality, and the pore-fissure structure characteristics of the coal body The variation of the permeability is also affected by its pore-fissure development characteristics and direction. Therefore, it is of great significance to correlate the coal body permeability with the complex electrical properties.

The permeability *k value of coal samples in* different directions gradually decreases with increasing pressure. τ value also changes according to the pore fissure development characteristics and directional pattern of the coal body, τ value of coal samples in different directions gradually decreases with increasing pressure, and the degree of pore fissure development and extension direction of coal samples in vertical laminae direction is stronger than that of coal samples in parallelogram direction in terms of gas permeability and charge migration hindrance, resulting in lower permeability *k value is* smaller, the excitation polarization completion time is longer, and the τ *value is larger; the* penetration of pore fissures in the vertical main fissure direction in the coal body is weaker than that in the parallel main fissure direction, the permeability is lower, and the τ value is larger. Therefore, the change pattern of permeability *k* value and τ *value* has a strong correlation.

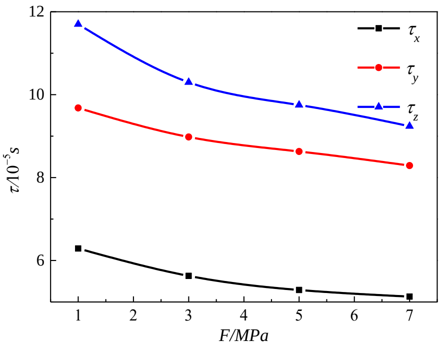

Figure 4: Variation curve of relaxation time τ of coal sample in each direction under different pressure

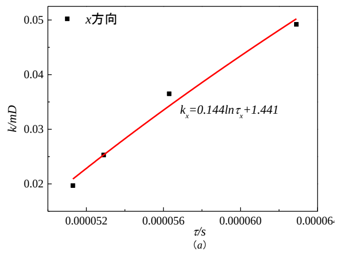

Figure 5: Relationship between k and τ for coal samples in x-direction

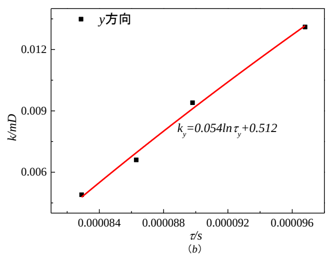

Figure 6: Relationship between k and τ for coal samples in y-direction

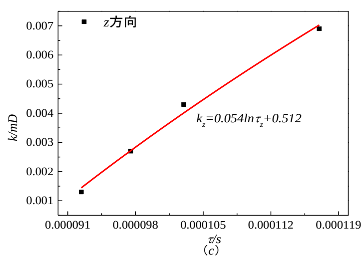

Figure 7: Relationship between k and τ for coal samples in z-direction

Correlating the values of τ with the values of permeability k *for* different directions of the coal body under the same pressure, the following relationship is obtained:

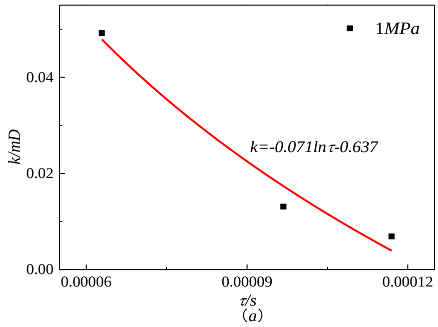

Figure 8: Fitted relationship between k value and τ value of coal samples at 1MPa

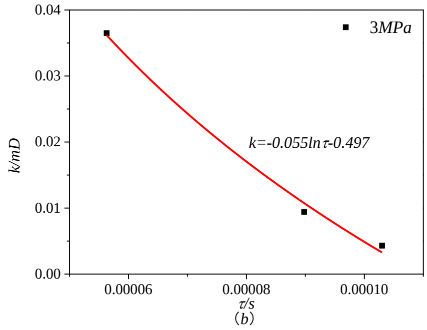

Figure 9: Fitted relationship between k value and τ value of coal samples at 3MPa

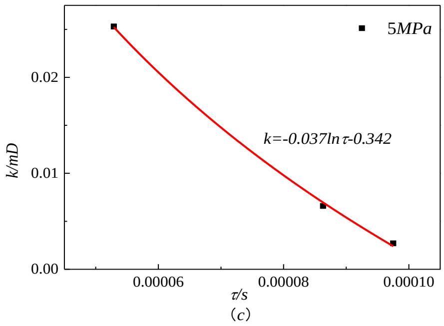

Figure 10: Fitted relationship between k value and τ value of coal samples at 5MPa

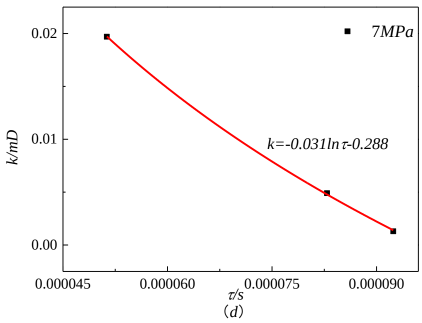

Figure 11: Fitted relationship between k value and τ value of coal samples at 7MPa

$$k=\alpha ln\tau+\beta \tag{4-1}$$

where, k is the permeability at different pressures, τ is the relaxation time at different pressures, and α , and β is the fitting parameter, which is related to the pressure and directionality to which the coal body is subjected.

Table 1: Fitting coefficients of k values and τ values of coal samples in each direction under different pressures

Coal body direction	*α*	*β*	R^2 /%
x-direction	0.144	1.441	97.818
y-direction	0.054	0.513	99.1
z Direction	0.024	0.221	98.964

Table 2: Fitting coefficients of *k* values and *τ* values of coal samples in different directions under the same pressure

Air pressure/MPa	Surrounding pressure/MPa	Axial pressure/MPa	*α*	*β*	R^2 /%
1	5	1	-0.07	-0.637	94.512
1	5	3	-0.055	-0.497	99.01
1	5	5	-0.037	-0.342	99.848
1	5	7	-0.031	-0.288	99.973

As shown above, the permeability *k* values of coal samples in the three directions show a good relationship with the relaxation time *τ* values: with the decreasing value of *τ*, the permeability *k* of coal samples in all three directions gradually decreases, that is to say, the greater the pressure on the coal body, the shorter its excitation effect completion time, the smaller the corresponding permeability, which is related to the coal body constantly being compressed and deformed, and gradually reducing the development of closed pore fissures, and the curve of the two change laws conforms to the logarithmic function relationship;

Under the same pressure condition, the permeability *k value* and *τ value* of coal samples in different directions also have a certain regular relationship: the smaller the *τ* value, the larger the *k* value, that is, the *τ* value of coal body decreases in the order of *z direction*, *y* direction and *x* direction, while the permeability *k* value of coal body increases in the order of the same direction. The reason is that the pore fissures in the vertical laminar direction (*z-direction*) are more complex, mostly in the vertical gas flow direction and electric field action direction, resulting in weaker gas percolation and longer time to complete the excitation effect. The corresponding relationship between *k* value and *τ* value also conforms to the logarithmic function relationship. The relationship is shown in 4-1. According to the fitting of the logarithmic expression, it can be seen that the parameters *α* and *β* keep decreasing regularly, regardless of the fitting of the coal body in different directions or under different pressures, which shows that the parameters *α* and *β are* related to the pressure and direction to which the coal body is subjected.

5. Conclusion

The complex electrical properties of the coal body change regularly with the change of pressure. The absolute values of *R* and *X of the coal* samples gradually decrease with the increase of pressure in the selected measurement band from 1 to 10000 Hz, especially in the band near the point where *R* decreases slowly and *X is* very small, and the dispersion curve is shifted to the right, where *X is* shifted to a large extent and the capacitance *C* gradually decreases.

The coal body shows anisotropic characteristics under different measurement conditions. Although the variation of the complex electrical parameters of the coal body under ambient temperature and pressure is disturbed by electromagnetic interference, the overall directional variation of the dispersion curve is consistent with the water content rule. The conductivity also varies according to the directional difference of pore fissure development in the three directions of the coal body.

With the increase of pressure, the strain *ε values of coal* samples in three directions decrease with the decrease of relaxation time *τ*. The directional changes of coal body *ε* values under the same pressure conditions are opposite to the *τ* values, which also conform to the logarithmic function relationship, which also verifies the correctness of the law between coal body permeability and complex electrical properties. This empirical formula is used to evaluate the coal body permeability, which provides a theoretical basis for the subsequent accurate prediction and evaluation of the coal body permeability by using the complex electrical properties exploration method.

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