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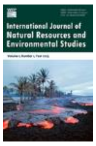

Application and Research of Multi-Scale Dynamic Diffusion Permeability Model in Different Coal Ranks

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ABSTRACT

The spatial scale of coal mining and rock layer control is distributed between 10-10 and 107, spanning 17 orders of magnitude. There are multi-scale pore cracks from millimeter to micro and nanometers in the coal, and the pore size can reach one million times, which makes the coal permeability also show a multi-scale characteristics of millions and time. For the permeability of the coal seam, it is necessary to test and analyze the distribution of micro and nano pores and cracks in the coal [1]. CBM mining is accompanied by the dynamic change of adsorption pressure in coal and the complex deformation of multi-scale heterogeneous structure of coal, and the multi-scale deformation feature of pore fissure structure plays an important role in the transport of methane [2]. However, existing studies focus on treating coal as a homogeneous isotropic medium, without considering the influence of coal multiscale pore structure on permeability. The variation of heterogeneous degree of coal structure with structural scale and its influence on dynamic diffusion and permeability are rarely reported. Li Zhiqiang et al. [3] conducted an experimental-model-mechanism study of CBM gas micro-nano series multi-scale dynamic diffusion permeability. On this basis, the dynamic diffusion and permeability of different coal scales.

KEYWORDS

Multi-Scale; Dynamic; Permeability; Diffusion.

1. INTRODUCTION

In 2023, Li Zhiqiang et al. [3] clarified the scientific and engineering application value of multi-scale seepage. The gas (CH4) / helium diffusion (He) is found, the two permeability dynamic decay phenomenon, the multi-scale dynamic seepage-diffusion mechanism is analyzed, the multi-tube series aperture structure correlation mathematical model is established, the apparent permeability model is derived, the model is tested and mathematical proof, the model is considered and stressed, and the scientific and engineering value of multi-scale permeability are discussed. On this basis, the author studies the dynamic diffusion and permeability of gas in different coal grades.

2. COAL PILLAR COAL CORE ADSORPTION-DESORPTION EXPERIMENT

2.1. Experimental device (Figure 1 below)

(1) The balance (2) Desorption of coal sample tank (3) Dry box (4) Constant-temperature water bath box (5) (desorbing) instrument (6) Helium (7) Methane (99.99% purity)

Figure 1 The adsorption-desorption experimental setup

2.2. Experimental sample preparation

Experimental samples were taken from Yuxi, Jining and Pingdingshan areas, and Φ 50mm 100mm were drilled and placed at 80℃ with drying numbers YX-1-1, YX-1-2, YX-1-3, J-1-1, J-1-2, J-3, PDS-1-1, PDS-1-3 and PDS-1-4. The side of the coal center for diffusion-seepage experiment under no stress is wrapped with heat-shrink adhesive sleeve, and the lower end of the coal center is sealed with silica gel on the lower end. Only the upper surface is kept in natural state, so that gas is only released from the upper surface during the experiment (as shown in Figure 2 below). In order to eliminate the interference of different coal cores, the same coal core was used in the experiment.

First according to GB / T the high pressure isothermal adsorption test method of coal will crush massive coal samples, with 60 and 80 sample screen coal sieve, 60-80 mesh granular coal for isothermal adsorption test, 80 granular coal for coal industrial analysis experiment, coal industrial analysis experiment gas geological laboratory in Henan university of technology, analysis data such as table 1, element analysis, analysis data as shown in Table 2.

Table 1 Original industrial analysis

Yuxi original sample industrial analysis							
Sample number	Sample mass (g)	Moisture (Mad)	volatile matter (Vad)	ash content (Aad)	Fixation Carbon (Fcad)	hydrogen content （Had)	Burn weight loss
YX-1	0.9373	1.57	7.72	6.59	84.12	3.60	91.8368
YX-2	0.9756	1.70	7.59	10.83	79.87	3.44	87.4638
YX-3	0.9823	1.59	7.77	7.90	82.74	3.56	90.5108
average value	0.9651	1.62	7.6933	8.44	82.2433	3.5333	89.9371

Jining original sample industrial analysis						
Sample mass (g)	Moisture （Mad)	volatile matter (Vad)	ash content (Aad)	Fixation Carbon (Fcad)	hydrogen content （Had)	Burn weight loss
0.9408g	0.62	16.2	15.39	67.79	3.97	83.9858
0.961g	0.77	18.65	19.59	60.98	4.01	79.6325
average value	0.695	17.425	17.49	64.385	3.99	81.80915

Pingdingshan original sample industrial analysis							
Sample number	Sample mass (g)	Moisture（Mad)	volatile matter (Vad)	ash content (Aad)	Fixation Carbon (Fcad)	hydrogen content （Had)	Burn weight loss
PDS-1	0.9466	0.95	21	15.49	62.56	4.12	83.5629
PDS-2	0.9013	0.96	21.26	15.18	62.61	4.15	83.8681
PDS-3	0.9334	1.04	21.18	15.24	62.53	4.14	83.7168
average value	0.9271	0.9833	21.1467	15.3033	62.5667	4.1367	83.7159

Table 2 Analysis of Original Elements

Yuxi element analysis							
order number	N %	C%	H%	S%	O%	H / C atomic ratio	O / C atomic ratio
1	1.15	82.9	2.9	0.46	2.46	0.42	0.02
2	1.15	77.05	4.34	0.37	5.4	0.68	0.05
average value	1.15	79.98	3.62	0.415	3.93	0.55	0.035

Jining element analysis					
	N%	C%	H%	S%	O%
1.00	0.92	70.93	3.57	0.29	5.42
2.00	0.50	73.56	3.51	0.30	56.66
3.00	0.80	73.46	3.40	0.30	56.66
average value	0.65	73.51	3.46	0.30	56.66

coal sample number	Pingdingshan element analysis				
	N%	C%	H%	S%	O%
PDSBK	1.15	77.05	4.34	0.37	5.40

Figure 2 Schematic diagram of the coal pillar package

2.3. Experimental conditions and operation procedures

(1) Put the original coal sample into the coal sample tank for sealing;

(2) The helium gas is connected to the experimental system, the inflation pressure is the set pressure, close the valve connected between the coal sample tank and the atmosphere. After the pressure gauge shows that the pressure of the coal sample tank reaches the requirements and gradually stabilizes, close the cylinder, the pressure balance within 12h, which can be regarded as good air tightness, and then the specific experimental steps are as follows;

(3) Close the intake valve of the cylinder, open all valves except the pressure regulating valve, connect the vacuum pump between the empty valve and the pressure regulating valve, and vacuum the system until the pressure of the coal sample tank drops to-0.1MPa. After stabilizing for a period of time, close the coal sample tank valve and the exhaust valve, and remove the vacuum pump;

(4) In the coal sample tank to the 25℃ constant temperature water bath, open the methane intake valve, pressure regulating valve and the coal sample tank, maintain the inlet valve of the sample cylinder, that is, into the adsorption balance process, the whole adsorption process is 7d, until the methane gas pressure reaches the predetermined value, close the methane gas cylinder pressure reducing valve and intake valve;

(5) with the aid of drainage gas collection method under the same adsorption time, the same balance pressure point (2.5MPa) under different coal steps, gas desorption experiment, the last gas tank, start natural desorption, with the volume of water timing release gas volume, record desorption related data, the whole experiment time 180 min. Record the desorption-related data.

2.4. Gas desorption amount, desorption rate, and diffusion coefficient were recorded

(1) Adopt the drainage and gas collection method.

(2) Desorption quantity recording frequency: First 30min: once/30s; 30-60min: once/1min; The 1-2 hours: once/2min; The 2-3 hours: once/5min.

(3) Ambient temperature and real-time air pressure were recorded during the desorption process.

(4) Data processing, considering the influence of indoor atmospheric pressure and temperature during the experiment, the following formula is used to convert the standard state of the data.

In the formula, Q—Desorption volume under standard conditions,cm3/g;

Qt—The amount of desorption recorded experimentally,cm3/g;

tw—Room temperature at the time of the experiment,℃;

patm—Atmospheric pressure, at the time of the experiment, kPa;

ht—The corresponding time is the height of the liquid column in the measuring cylinder at t, mm;

p0—Saturated water vapor pressure at room temperature, kPa.

Using the laboratory diffusion-seepage experiment system, dry different coal steps coal samples at 80℃ and do the unstressed diffusion-seepage experiment. The method is the same as above.

According to Equation (1), figure out Q∞, Draw the cumulative diffusion amount of coal columns under different coal steps the curve of Qt and time (Figure 4-12 below).

$$Q_\infty = \left(\frac{abp}{1+bp} - \frac{abp_a}{1+bp_a} \right)(1-A_{ad}) + \frac{10\times 273\times (p-p_a)\phi}{\rho(273+\theta_w)} \tag{1}$$

Among them, Qt is the cumulative diffusion amount, Q_∞ is the gas content at adsorption equilibrium, in units of cm3/g; p , p_a is the corresponding initial equilibrium pressure and atmospheric pressure, in Mpa; a is the adsorption constant, in cm3/g; b is the adsorption constant, in units of MPa-1; A_{ad} is ash content, in %; ϕ is the porosity; ρ is the apparent density, in g/cm3; θ_w is the experimental temperature, in ℃.

According to the Qt/Q∞~t image of equation (2), calculate the attenuation coefficient of the dynamic apparent diffusion coefficient of the coal sample based on the multi-scale dynamic diffusion permeability experimental model β And the initial diffusion coefficient D0.

$$\frac{Q_t}{Q_\infty} = 1 - \frac{8}{\pi^2}\sum_{m=0}^{\infty}\frac{1}{(2m+1)^2}\times\exp\left[-\frac{(2m+1)^2\pi^2 D_0\left(1-e^{-\beta t}\right)}{4L^2\beta}\right] \tag{2}$$

$$K(t) = \frac{D(t)\mu}{p_a} \tag{3}$$

According to (3), calculate the dynamic apparent permeability of the coal sample, where p_a is the reference pressure and μ is the gas dynamic viscosity coefficient. Analyze the data (as shown in Table 4-12).

Compare and analyze the permeability measured by the steady-state method of the original coal sample with the permeability measured by the multi-scale dynamic diffusion permeability experimental model.

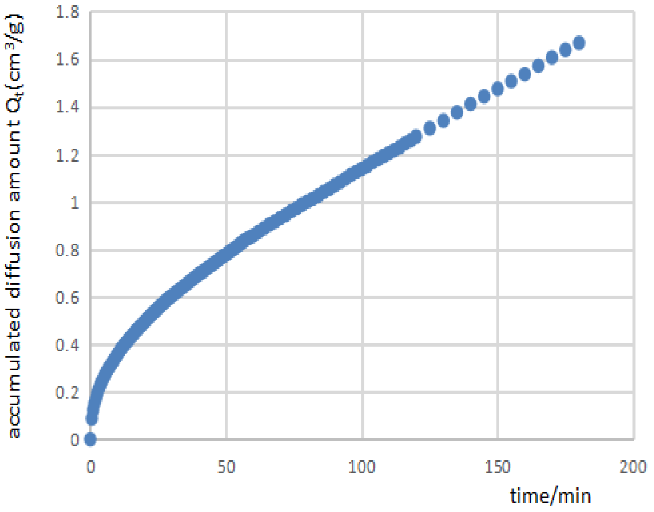

Figure 4 Raw coal pillar YX-1-1(2.5MPa) desorption-diffusion curve

Table 4 Permeability calculated by the original coal pillar YX-1-1(2.5MPa) model

P balance	2.50E+05	
P average	175500	
μ	1.08E-05	
Pa	101000	
β	0.002867153	
Π²D0/400β	0.603282298	
D0	0.070173328	Unit cm²/min
	0.001169555	cm²/s
K0	1.25061E-13	cm²
	0.012268521	mD

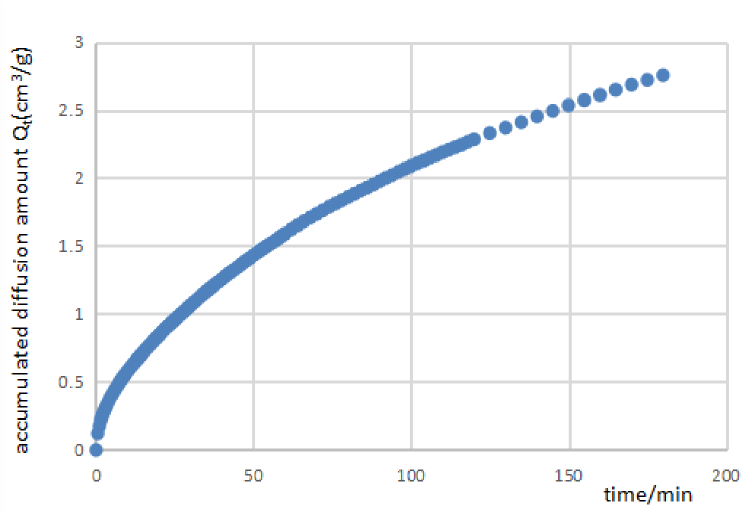

Figure 5 Desorption-diffusion curve of the original coal pillar YX-1-2(2.3MPa)

Table 5 original pillar YX-1-2(2.3MPa) model

P balance	2.30E+05	
P average	165500	
μ	1.08E-05	
Pa	101000	
β	0.002859567	
Π²D0/400β	1.961219761	
D0	0.227523988	Unit cm²/min
	0.003792066	cm²/s
K0	4.05488E-13	cm²
	0.039778402	mD

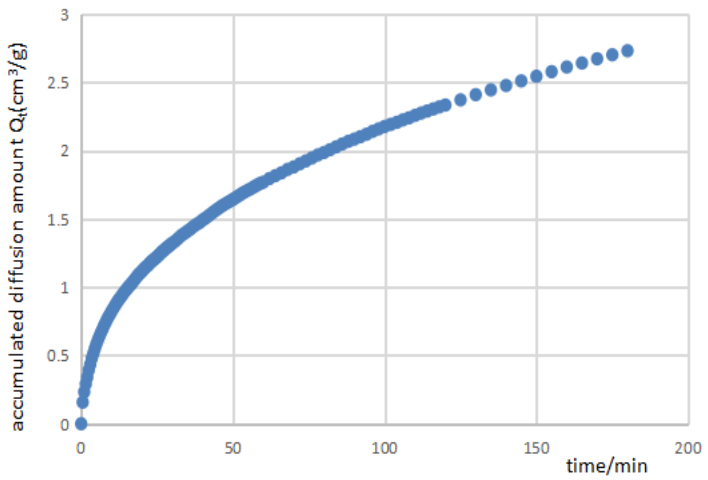

Figure 6 YX-1-3(2.45MPa) Desorption-diffusion curve

Table 6 YX-1-3(2.45MPa) The permeability calculated by the model

P balance	2.45E+05	
P average	173000	
μ	1.08E-05	
Pa	101000	
β	0.004906898	
Π²D0/400β	1.91964106	
D0	0.382144618	Unit cm²/min
	0.006369077	cm²/s
K0	6.8105E-13	cm²
	0.066810987	mD

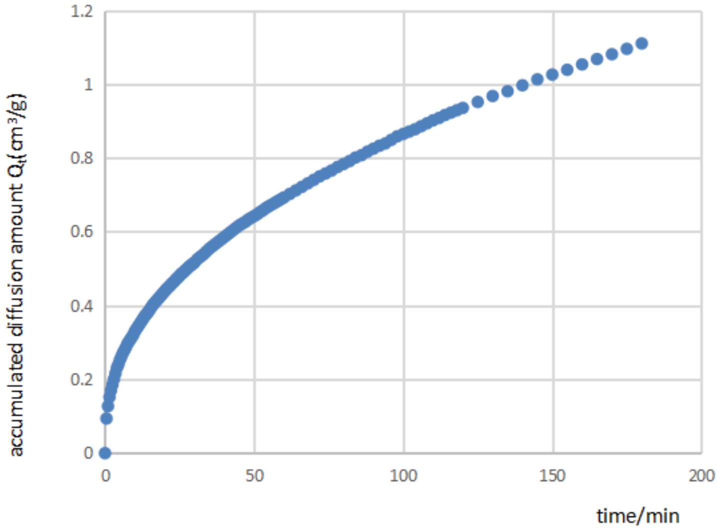

Figure 7 J-1-1(2.18MPa) Desorption-diffusion curve

Table 7 J-1-1(2.18MPa) The permeability was calculated by the model

P balance	2.18E+05	
P average	159500	
μ	1.08E-05	
Pa	101000	
β	0.004905602	
Π²D0/400β	0.099321948	
D0	0.019766883	Unit cm²/min
	0.000329448	cm²/s
K0	3.52281E-14	cm²
	0.003455877	mD

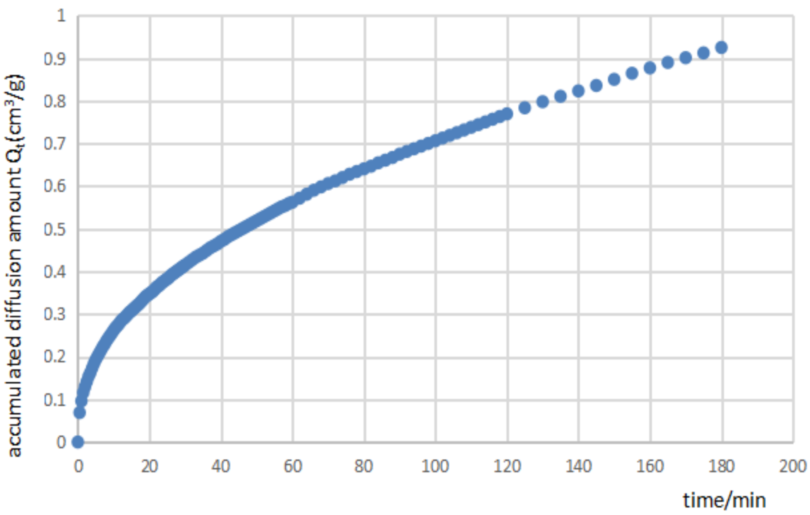

Figure 8 J-1-2(2.22MPa) Desorption-diffusion curve

Table 8 J-1-2(2.22MPa) The permeability that is calculated by the model

P balance	2.22E+05	
P average	161500	
μ	1.08E-05	
Pa	101000	
β	0.003412015	
$Π^2D0/400β$	0.089246797	
D0	0.012353906	Unit cm^2/min
	0.000205898	cm^2/s
K0	2.20169E-14	cm^2
	0.002159854	mD

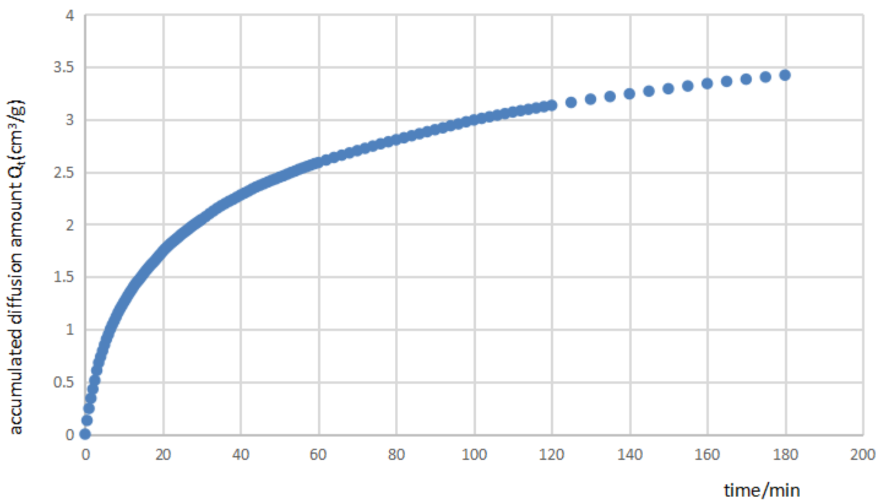

Figure 9 J-3(2.2MPa) Desorption-diffusion curve

Table 9 J-3(2.2MPa) The permeability as calculated by the model

P balance	2.20E+05	
P average	160500	
μ	1.08E-05	
Pa	101000	
β	0.013501981	
$Π^2D0/400β$	0.621349209	
D0	0.340356417	Unit cm^2/min
	0.005672607	cm^2/s
K0	6.06576E-13	cm^2
	0.059505085	mD

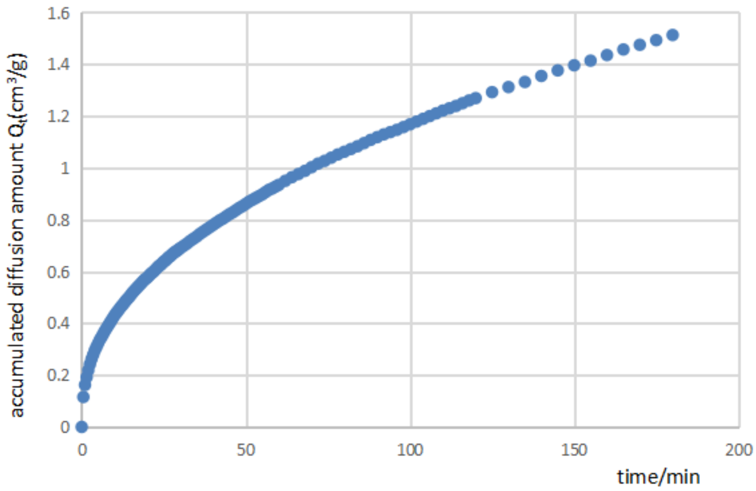

Figure 10 pds-1-1(2.66MPa) Desorption-diffusion curve

Table 10 pds-1-1(2.66MPa) The permeability that is calculated by the model

P balance	2.66E+05	
P average	183500	
μ	1.08E-05	
Pa	101000	
β	0.003847487	
Π^2D0/400β	0.109228921	
D0	0.017049652	Unit cm^2/min
	0.000284161	cm^2/s
K0	3.03855E-14	cm^2
	0.002980819	mD

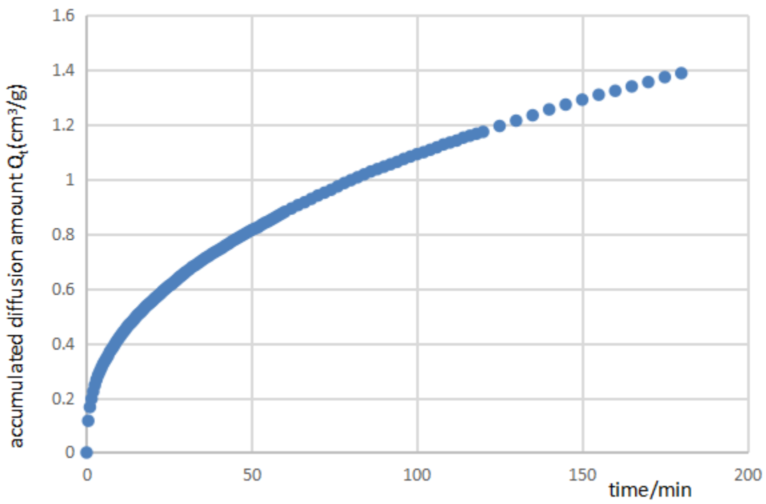

Figure 11 pds-1-3(2.6MPa) Desorption-diffusion curve

Table 11 pds-1-3(2.6MPa) The permeability that is calculated by the model

P balance	2.60E+05	
P average	180500	
μ	1.08E-05	
Pa	101000	
β	0.005427947	
Π²D0/400β	0.072683267	
D0	0.016005555	Unit cm²/min
	0.000266759	cm²/s
K0	2.85248E-14	cm²
	0.002798278	mD

Figure 12 pds-1-4(2.58MPa) Desorption-diffusion curve

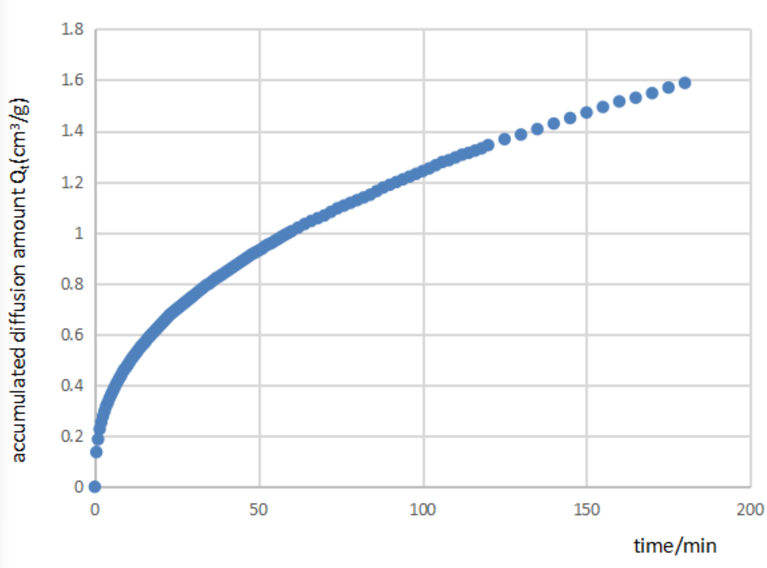

Table 12 pds-1-4(2.58MPa) The permeability that is calculated by the model

P balance	2.58E+05	
P average	179500	
μ	1.08E-05	
Pa	101000	
β	0.005378482	
Π²D0/400β	0.095167673	
D0	0.020765859	Unit cm²/min
	0.000346098	cm²/s
K0	3.70085E-14	cm²
	0.00363053	mD

2.5. The permeability test of the original steady-state method

Test purpose: To test the permeability of the original coal sample

Experimental setup: The permeability test was conducted using the "Low Permeability Coalbed Methane Phase Displacement and Increasing Production Experimental setup" in Laboratory 915 (as shown in Figure 3)

Sample size: Yuxi mine, coal sample is a column shaped coal sample with a diameter of 50 * 100mm, with 3 samples.

Test gas: Select nitrogen to test permeability

Test conditions: confining pressure and axial pressure are 2MPa respectively, nitrogen pressure at the inlet end is 1.0MPa, and outlet end is 0.1MPa (atmospheric pressure). The test temperature is set at the actual 25 ℃ of the test coal sample.

Test method:

The purpose of this experiment is to test the permeability and gas composition changes during the N2 injection displacement process in coal seams. The volume fraction of N2 used in the experiment is 99.99%. During the experiment, the parameter settings strive to be close to the real situation of Yuxi No.3 coal seam, with confining pressure and axial pressure of 2MPa, nitrogen pressure at the inlet end of 1.0MPa, outlet end of 0.1MPa (atmospheric pressure), and experimental temperature of 25 ℃.

The specific experimental steps are as follows:

(1) Load the processed experimental coal sample into a clamp, connect various pipelines, and inspect the sealing of the equipment;

(2) Input the parameters such as diameter and height of the experimental coal sample into the computer;

(3) Perform 24-hour vacuum treatment on the system;

(4) Apply axial pressure. Slowly and steadily apply axial pressure from low to high, until the set axial pressure is 2MPa, and the pressure loading rate is basically controlled between 0.15 and 0.20MPa/s to avoid damage to the coal sample caused by too fast stress loading;

(5) Load the ring pressure to 2MPa as required in step (4);

(6) When the permeability during the displacement process does not change, the experiment is completed, all valves are closed, the experimental instrument system is cleaned, and the data is measured (as shown in Table 3) for data analysis.

Figure 13. Low-permeability CBM phase displacement and stimulation test device

Table 13 The permeability was measured by the steady-state method

Sample number	diameter	length	The entrance pressure（MPa）	Axial pressure MPa	Ring pressure（MPa）
			1	2	2
			pressure	rate of flow（ml/min）	equilibration time
YX-1-1	5.03	10	1	133.5	15min
YX-1-2	5.03	9.97	1	61.5	15min
JN-1-1	5.02	10	0.99	5.07	15min
JN-1-2	5.01	10	1.05	12.48	15min
JN-3	5.03	10	1.05	0.51	15min
YX-1-3	5.03	10	1	21.54	15min
pds-1-1	4.83	9.99	1	18.66	15min
pds-1-3	4.82	9.98	0.99	7.89	15min
pds-1-4	4.81	9.97	1	41.34	15min

3. CONCLUSION

(1) It was found that the permeability measured by the steady-state method is about 10 times higher than that measured by the multi-scale dynamic diffusion permeability experimental model.

(2) Coal rank: Pingdingshan<Jining<Yuxi;

Under the same equilibrium pressure, permeability: Pingdingshan<Jining<Yuxi;

Gas content (maximum diffusion) at Q∞ adsorption equilibrium: Pingdingshan>Jining>Yuxi.

It can be seen that when the equilibrium pressure is the same, the higher the coal rank of the coal pillar, the higher the permeability and the lower the limit diffusion.

REFERENCES

[1] Kang Hongpu Spatial scale analysis of coal mining and rock layer control [J] Journal of Mining and Rock Formation Control Engineering, 2020, 2 (2): 1-26.

[2] Zhou Dong, Feng Zengchao, Wang Chen, etc Multiscale characteristics of structural deformation of coal adsorbed methane [J] Journal of Coal Science, 2019, 44 (7): 2159-2166.

[3] Li Zhiqiang, Chen Jinsheng, Li Lin, Peng Jiansong Experimental Study on Multi scale Dynamic Diffusion Permeability of Coalbed Methane Micro Nano Series - Model, Mechanism and Significance [J] Journal of Coal Science, 2023, 48 (04): 1551-1566.