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Gas Seepage Behaviors Revealed By Two Kinds of Typical Soft and Hard Raw Coals under High Pressure Water

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Abstract: To study the hydraulic fracturing effect of different types coal body, two typical raw samples namely primary structure and tectonic soft coals from the same coal mine were successfully prepared with the "twice moulding" method and their permeability's were studied with self-designed "gas seepage experiment device loaded by high pressure water" before and after the high pressure water loaded. A big difference on the gas seepage change rule of these two kinds of coal samples was revealed. The study results showed that in the case of the primary structure coal, brittle deformation was found that the internal cracks extend and derive forming extended fracture network, by which the effective porosity was increased and the permeability was significantly improved, whereas, internally plastic deformation appeared in the tectonic soft coal that the coal was compacted itself by which the cracks cannot be fully penetrating and extending and the water blocks the initial fissure of intestine coal body, as a consequence, the flow of gas was weakened and the permeability descends before the high pressure water loaded. The experimental results gave a good explanation why the hydraulic fracturing measure is not suitable to all the coal seam, meanwhile, the research conclusion can provide reference for the optimization of the "gas pressure relief and permeability increase" to the coal body, and further improve the theory and method system of gas drainage in low permeability coal seam.

Keywords: *"twice moulding" method, primary structure coal, tectonic soft coal, gas permeability*

1. Introduction

The hydraulic fracturing for coal body is a gas control technical measure that is feasible in both of theory and practice which is influenced by the gas pressure relief and the coal seam permeability, as well as physical and mechanical characteristics of coal body under high pressure water [1-7]. Vast theoretical research and field practice had proved that the effect of hydraulic fracturing for coal body is not only affected by the process and way of fracturing but also strongly influenced by the fracturing features of coal seam such as whether the deformation and fracture increasing the gas permeability, under high pressure water, can happen or not [8-10]. At present, the reason for that hydraulic fracturing technology did not work well in many mines is attributed to the unclear fracturing features of processing objects [11]. If just follow the measures and experience of successful case without considering the actual condition about coal seam, the effect of hydraulic fracturing will severely work, even the final failure will appear in some cases.

Therefore, using the two kinds of typical raw coal samples namely tectonic soft and primary structure under high pressure water, the gas seepage experiment was very meaningful to avoid the unnecessary engineering investment and the blindness in the process of technology implementation, improve the success probability of hydraulic fracturing measure.

2. State of the art:

At present, the research on hydraulic fracturing is mainly limited to the exploitation of resources such as oil, oil and gas reservoirs, in addition, mostly are confined to the surface borehole [12]. The study on improving the gas drainage effect about coal seam started late. In the 1960 s, the former Soviet Union tried the hydraulic fracturing field test in 15 coal mines. Field test showed that the gas control effect was better, the gas content reduced by 74 to 97 percent [13]. In 1964, the field test about the technology of pulse high pressure water injection to coal wall was carried out in the 6th coal mine of Prussia in Germany [14]. About 1970, the former Soviet Union coal mine safety research institute studied the coal crack technology such as hydraulic loosening and so on, and good "gas pressure relief and coal seam permeability increase" effect was achieved [15].

The research on hydraulic fracturing which in order to increase the coal seam permeability began late in china [16]. From the 1950s, many field test researches were carried out in the coal mines. Good results had been achieved in some mining areas, on the contrary, the effects were unsatisfactory in some other regions. Aim at this problem, vast scientific research had been carried out. LIN Baiquan [17] studied the dynamic variation characteristic during the hydraulic fracturing process and established the coupling model about gas pressure, coal seam buried depth and water injection pressure. ZHAI Cheng [18] studied the pulsating hydraulic fracturing deeply; the research achievement was applied to the Daxing coal mine and achieved good effect.

By a large number of outstanding theoretical and field research work, scholars at home and abroad had realized that fracturing coal body with high pressure water can reduce the gas pressure of coal seam, meanwhile, increase the coal seam permeability and improve the gas drainage effect. However, the research on hydraulic fracturing which get better gas control effect was mostly based on the primary structure coal, to tectonic coal, the relevant reports was still rare. The reason is that the formation mechanism and process of tectonic coal is complicated relatively, and the mechanical property and pore characteristics are different from the primary structure coal. Therefore, whether the hydraulic fracturing technology is universal for all the coal body waits on further discussion.

3. Methodology:

3.1. The preparation of raw coal samples:

Experimental coal samples can be classified into two types, example, type coal sample and raw coal sample. Type coal sample can be made by grinding raw coal into small particles followed by adding a certain amount of bonding material. Raw coal sample is prepared by drilling with core drill or mechanical processing. Generally, type coal sample is made with core drill directly, but the preparation of tectonic soft raw coal sample is more difficult in this way because of the strong geological activity during its long formation period. Therefore, type coal sample is popular in the study of the tectonic soft coal. However, the type coal sample is difficult to reflect the actual characteristics of tectonic soft coal differences between type coal samples and raw coal samples in structure characteristics. It is necessary to take raw coal sample in the research which is much closer to the coal body itself. Primary structure coal and tectonic soft raw coal samples were collected from Daning coal mine.

3.1.1 Specimens preparation and raw coal samples collection of tectonic soft and easy broken coal

The floppy and fragile tectonic soft coal will rupture even crush due to the vibration of the core drill during sampling, by which the integrated raw coal samples cannot be obtained. Thus "twice moulding" method was developed which was performed as following: collect large raw coal with regular shape underground and carry it to the ground followed by processing the coal into the designed size.

1. Collection of big size coal

Firstly, cut out a regular coal cube approximately followed by covering the cube with the processed tin box (200 × 200 × 200 mm, figure 1). The gap between coal body and tin box is filled with polyurethane. The bottom of the resulting coal cube is cut off with a hand saw. The coal cube is taken out followed by being sealed with wax for protection from the air (figure 2).

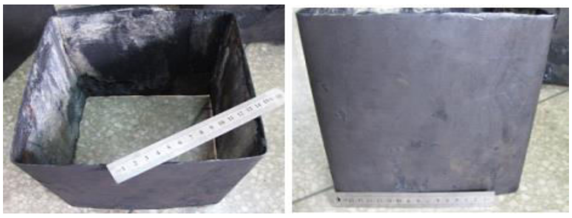


Figure 1: *The processed tin box*

Figure 2: *Tectonic and primary structure coal body*

2. Mechanical processing of coal body

(1) A hole in the polyurethane layer was drilled, put drilling tool close to the tin box, made saw blade through the hole and fixed it on the saw bow. The polyurethane layer was cut along slowly and the polyurethane between coal body and tin box was taken out.

(2) Remove the tin box, cut the coal body into cuboid (120×120×150 mm) followed by smoothing the two ends.

(3) Cut off the four sides of the cuboid coal body for a cylindrical shape followed by polishing highlight edges on the analogous cylindrical to make it as smooth as possible. After these two steps, the coal sample was basically close to the cylinder. The size of polished raw coal samples was smaller due to grinding friction. A cylinder grinding apparatus with an inside diameter of 50 mm and a height of 100 mm was prepared with open up and down sides, as shown in figure 3. The coal samples were put into the cylinder, followed by replenishing into standard sizes (Φ50mm×100mm) with silicate glass glue.

(4) Transfer grinding apparatus in a cool and dry room after the silicate glass glue becoming solidification, removed the top and bottom cover, pushed out the coal samples from the grinding apparatus, polished away the residue colloid in the samples with rough type gauze, the standard samples were successful to be made, as shown in figure 4.

3.1.2. Specimens manufacture and raw coal samples collection of primary structure coal

Although the primary structure coal raw coal sample is easy to prepare by core drilling method, for comparison with the tectonic soft raw coal samples, both of the two type samples are prepared by "twice moulding" method, the standard primary structure coal samples are successful to be made, as shown in figure 4.

Figure 3: *The stainless steel cylinder*

Figure 4: *Tectonic and primary structure coal samples*

3.2 The design and modification on gas seepage experiment device loading high pressure water

The self-designed gas seepage experiment device has two main functions: simulate the hydraulic fracturing process and study the gas seepage rule of coal samples.

The gas seepage experiment device consists of eight parts, example, the high pressure water connection and control system, the gas connection system, the stress loading system, the coal sample sealing system, the gas flow acquisition system, the water storage system, the gas negative pressure loading system, the experimental data collection and analysis system, as shown in figure 5.

The high pressure water connection and control system is responsible for the control of high pressure water switch by which the the water pressure and flow can be controlled. The gas connection system mainly supplies high purity CH_4 (≥ 99.99%), and adjusts the gas pressure according to the actual need. The stress loading system is responsible for loading axial pressure and confining pressure to coal samples. The coal sample sealing system is a closed space ensuring the loaded pressure to the coal samples during experiment process. The gas flow acquisition system can read the gas flow by flowmeter with a fault alarm system inside. The water storage system mainly stores the water percolating from coal samples in the process of fracturing. The negative gas pressure loading system is responsible for pumping the water from the crack of coal samples after hydraulic fracturing. The experimental data collection and analysis system collects experimental data including axial compression, confining pressure and water pump injection pressure, the information acquisition frequency can be set by a computer program.

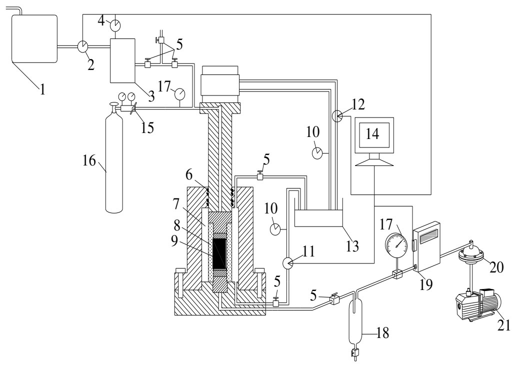
The main parameters from each attachment of the experimental system are as follows:

(1) Mini-type experiment metering pump, the largest rated flow: 6L/h, the largest outlet pressure: 20Mpa.

(2) Gas pressure range: 0-10MPa, precision: 0.1MPa,

(3) Axial compression: 0-30MPa, precision: 0.1Mpa,

(4) Confining pressure: 0-20MPa, precision: 0.1MPa.



1-Water tank 2-Water flow meter 3-Metering pump 4-Water pressure gauge 5-The valve 6-O-ring seal 7-Pressure chamber 8-Confining pressure booster aprons 9-Coal test specimen 10-Oil pressure gauge 11-Confining pressure control valve 12-Axial pressure control valve 13-Fuel tank 14-Computer 15-Pressure release valve 16-High pressure gas 17-Gas Pressure gauge 18-Gas-water separator 19-The gas flow meter 20-Damper 21-Vacuum pump

Figure 5: *The sketch map of gas seepage experiment device loaded by high pressure water*

4. Result Analysis and Discussion:

4.1 The experiment preparation and scheme:

4.1.1. The experiment preparation:

1. Put the coal samples in the special cylindrical rubber sleeve after daub 704 silicone rubbers to them. Put the rubber sleeve in dryer for swelling by which the sides of the coal samples contacts close with the rubber sleeve. Put the rubber sleeve into the seal container and pass into the high pressure gas to inspect the air tightness. The system tightness was checked by stability gas pressure without gas flow.
2. Close the air outlet after air tightness test, vacuum for the coal samples 12 hours to degas the system.
3. Open the high-pressure gas valve followed by passing high pressure gas to coal sample for 24 hours to make the coal sample adsorption as far as possible.
4. According to the scheduled plan, load axial compression, confining pressure to the coal samples and adjust the gas pressure, carry out infiltration experiments.

4.1.2. The preparation scheme:

Under the premise of experiment preparation, gas permeability of tectonic soft coal and primary structure coal samples were tested before hydraulic fracturing under the same gas pressure and different confining pressure (axial pressure). After hydraulic fracturing, the water was extracted from the crack of coal samples. The gas permeability of fractured coal samples was tested.

In this experiment, the loaded axial compression was always equal to confining pressure, that was 2,3 and 4 MPa, and the gas pressure was 0.4 and 0.6 MPa, respectively. Tectonic soft coal and primary structure coal samples were 6 groups, respectively. The serial numbers of tectonic soft coal samples was from DNR1 to DNR6, meanwhile, the serial numbers of tectonic soft coal samples was from DNH1 to DNH6. The experimental scheme has been shown in table 1.

Table 1: *The experimental scheme*

Serial number of coal samples	Coal samples type	Gas pressure p/MPa	Axial compression=confining pressurecon/Mpa	Serial number of coal samples	Coal samples type	Gas pressure p/MPa	Axial compression=confining pressurecon/Mpa
DNR1	Tectonic soft coal	0.4	2	DNH1	Primary structure coal	0.4	2
DNR2			3	DNH2			3
DNR3			4	DNH3			4
DNR4		0.6	2	DNH4		0.6	2
DNR5			3	DNH5			3
DNR6			4	DNH6			4

4.2. Permeability test of raw coal samples:

The flow meter which installed in the simulation experiment device collected the gas flow through coal samples automatically, the permeability was calculated by computer programme, the computation basis about permeability was shown as the following formula.

$$K = \frac{2\mu p_0 Q_0 L}{\left(p_1^2 - p_2^2\right)A}$$

In the formula: K is the permeability, mD; Q_0 is the gas flow quantity, cm^3/s; P_0 is the atmospheric pressure, MPa;μ is the gas dynamic viscosity coefficient, the value is 10.8×10^{-6} Pa. s; P_1 is the gas pressure through coal samples; P_2 is the gas pressure through the samples exit, is equal to the P_0; A is the sectional area of coal samples, cm^2; L is the length of coal samples.

4.2.1. Permeability test of raw coal samples before hydraulic fracturing:

Before hydraulic fracturing, the gas permeability of coal samples was tested following experimental procedure above, as shown in Table 2.

Table 2: *The penetration results of tectonic coal raw and primary structure coal raw coal sample before water loaded*

Coal samples type	Gas pressure(MPa)	The permeability when confining is 2MPa(mD)	The permeability when confining is 3 MPa(mD)	The permeability when confining is 4 MPa (mD)
Tectonic soft raw coal samples	0.4	0.11355	0.07567	0.04711
	0.6	0.14434	0.12557	0.10229
Primary structure coal raw coal samples	0.4	0.1332	0.08421	0.05944
	0.6	0.16744	0.13889	0.11377

Under constant gas pressure, the curves between confining pressure and permeability of primary structure coal and tectonic soft coal samples were shown as figure 6.

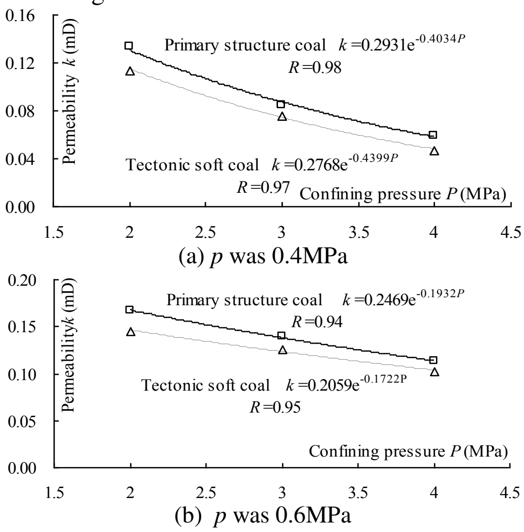


Figure 6: *The curve about penetration of tectonic and primary structure coal raw samples with confining pressure under constant gas pressure*

Seen from figure 6, under constant gas pressure, the permeability of both primary structure coal and tectonic soft raw coal samples decreased with the increasing of confining pressures, moreover, the relationship between permeability (k) and confining pressure (P) followed the exponent formula.

The decreasing of permeability while confining pressure increases can be explained in two ways: the passage between the pores and fractures was blocked due to the compaction of coal samples and the formation of new pore and fissure was more difficult because of the coal samples' capacity of bearing damage deformation increases.

4.2.2. Comparison of permeability before and after hydraulic fracturing:

1. The principle of permeability changing of tectonic soft raw coal samples before and after hydraulic fracturing carried out high hydraulic loading fracturing experiments to the six tectonic soft raw coal samples. The permeability of coal samples was shown as Table 3 and the contrast diagram about permeability before and after hydraulic fracturing was shown as figure 7.

***Table 3:** The data of tectonic soft raw coal samples under the condition of constant gas pressure before and after water loaded*

Gas pressure (MPa)	Serial number of coal sample	Loaded confining pressure (MPa)	Permeability (mD)	
			Before fracturing	After fracturing
0.4	DNR1	2	0.11356	0.01369
	DNR2	3	0.07568	0.01109
	DNR3	4	0.04712	0.00865
0.6	DNR4	2	0.14435	0.02995
	DNR5	3	0.12558	0.02114
	DNR6	4	0.1023	0.01376

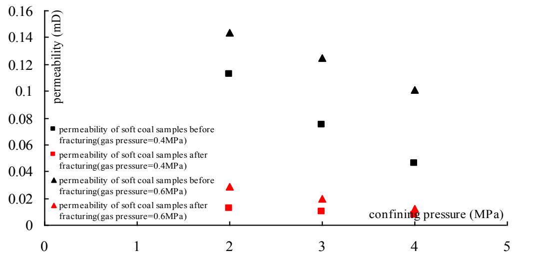


***Figure 7:** The change about confining pressure and penetration of tectonic soft coal raw samples before and after water loaded*

The Table 3 and figure 7 revealed that after high water pressure loaded to the tectonic soft coal samples, the permeability of the six samples decrease dramatically, falling by 79% in average with a maximum value of 89%. The decrease of permeability proved that the hydraulic fracturing was not feasible. The tectonic soft layers coal samples of Daning coal mine was with small primary structure coalness and the coal property was soft and easy to broken. Hydraulic fracturing as antireflection measures was not suitable for this kind of coal.

2. The principle of permeability changing of primary structure coal raw coal samples before and after hydraulic fracturing

Carry out high hydraulic loading fracturing experiments to the six primary structure coal raw coal samples. The permeability of coal samples was shown as Table 4 and the contrast diagram about permeability before and after hydraulic fracturing was shown as figure 8.

***Table 4:** The experimental penetration data of primary structure coal raw coal sample under the condition of constant gas pressure before and after high pressure water loaded*

Gas pressure (MPa)	Serial number of coal sample	Loaded confining pressure (MPa)	Permeability (mD)	
			Before fracturing	After fracturing
0.4	DNH1	2	0.16634	0.35674
	DNH2	3	0.13779	0.36559
	DNH3	4	0.11267	0.36225
0.6	DNH4	2	0.20121	0.63148
	DNH5	3	0.17458	0.61998
	DNH6	4	0.15741	0.61058

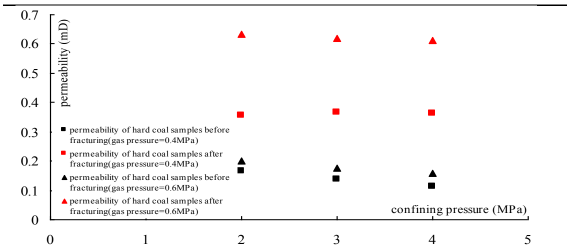


***Figure 8:** The change curve about confining pressure and penetration of primary structure coal raw samples before and after high pressure water loaded*

It was found in table 4 and figure 8 that:

(1) After high water pressure loaded to the primary structure coal samples, the permeability of the six samples increased dramatically which was increased 4 times in maximum, by which the feasibility of hydraulic fracturing to the primary structure coal seam of Daning coal mine was proved.

(2) On the condition of the same gas pressure with varying confining pressure (axial pressure), the permeability of the specimens of the primary structure coal samples decreased with the increase of confining pressure before the high pressure water was loaded. However, after the high pressure water was loaded to the primary structure coal samples, the permeability increased greatly which was almost doubled. No obvious relationship was found between the maximum gas permeability and confining pressures

The results showed that brittle deformation appeared in the primary structure coal samples under high pressure water, internal cracks were fully expanded and derivative, the transfixion crack network formed, effective porosity increased, the permeability increased than before fracturing.

5. Conclusion:

This paper firstly made the two typical raw coal samples with "twice moulding" method instead of traditional "processing coal samples", then, the gas seepage experiments were carried out. The experimental results proved that hydraulic pressure relief measures were not applicable to all coal seams, the effect about the "gas pressure relief and the coal seam permeability increase" strongly related with the intrinsic physical and mechanical characteristics of coal body under high pressure water. The main conclusions were drawn as follows:

1. With a constant gas pressure, the permeability of both primary structure coal and tectonic soft raw coal samples decreases with the increasing of confining pressure, which was consistent with the coal mine production practice experience. The mine ground pressure can be treated as confining pressure loaded to the samples. The permeability of coal seam in the stress concentration belt was low, these areas were likely to cause the gas enrichment by which the coal and gas outburst accidents occur easily. The aim of hydraulic fracturing, hydraulic punching and high pressure jet flow was transferring the stress concentration belt to increase the coal permeability so as to make gas drainage more easily.

2. Generally, the change rule about permeability between primary structure coal raw coal samples and tectonic soft raw coal samples was different before and after the high water pressure loading. In the case of the primary structure coal raw coal samples, brittle deformation appeared within the primary structure coal under the effect of high pressure water, internal cracks were fully expanded and derivative, the transfixion crack network forms, effective porosity increased, the permeability increased more than before fracturing. On the contrary, in tectonic soft raw coal samples, plastic deformation appeared internally, coal was compacted by high pressure water, cracks cannot be fully penetrating and extending, the water blocked the initial fissure by which the flow of gas was weakened and permeability descends than before fracturing.

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