

Rules of pulverized coal output under different components of coal petrography and different coal structure in Hancheng Block, China

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Abstract. In order to study the output mechanism and influencing factors of pulverized coal under different components of coal petrography and different coal structures during the process of drainage, the physical simulation experiments were conducted under the state of single-phase water flow displacement. The results of this experiment for different coal petrography show the weight of pulverized coal output is normally 11# coal > 5# coal > 3# coal with different displacement velocities, and the increasing ratio of pulverized coal output is 5# coal > 11# coal with the different confining stress in the constant displacement velocity. For different coal structures the pulverized coal output weight of fragmented coal is much larger than the primary structure of coal. The particle size distribution curve shows 3#, 5# and 11# primary structure of coal have a double-peak, and the grain size of primary pulverized coal is relatively small and the secondary pulverized coal is relatively large. However, the grain size distribution of fragmented coal is a double-peak distribution, and the distribution scope is relatively concentrated and the average grain size is small. Therefore, the characteristics of pulverized coal were found to be related to its coal different coal petrography components and coal structure.

1. Introduction

China has abundant coalbed methane resources [4]. The exploration and exploitation of coalbed methane in China have made great achievement in recent years; meanwhile coalbed methane commercial development also has gained success and several breakthroughs during past 20 years [2, 17]. The problem of pulverized coal output is a common phenomenon in

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China during the process of coalbed methane drainage due to the complex tectonic-thermal evolution of coal basins and the particularity of coal reservoir [6, 8].

The elastic modulus of Coal petrography is little and the tensile strength is weak, and it is also fragile. Compared to the common sandstone coal is more prone to damage and produce pulverized coal under the same conditions, which can cause the blocking of coal petrography fracture and decreasing of the coal petrography permeability [5, 12, 16]. The large amount of pulverized coal output which aggregate in the bottoms of CBM wells and drainage system can lead to the pumps sticking and becoming buried. The pumps would then need to be checked frequently which would have a negative impact on the coalbed methane yields [9-10, 15]. For all of the above reasons, researching the characteristics and origin of the pulverized coal output is the point to keep the CBM wells which have high and stable coalbed methane yields. However, the most challenge is the pulverized coal in the seepage channel that is invisible. It is hard to identify the source of pulverized coal. Various factors can affect the output of pulverized coal during the drainage in the CBM wells. The properties of coal petrography are the basis of the pulverized coal output and the engineering disturbed can induce pulverized coal output. The geological factors include the components and relative content of the coal petrography, coal seam structure, and deformation and metamorphism and other factors. Mechanical damage of coal reservoir in the process of drilling and fracturing, abrasion damage caused by the gas-liquid-solid flowing during the drainage, and complex changes in the coal reservoir stress state are classified as engineering disturbed.

Increasing attention has been focused on the harm which is caused by output of the pulverized coal. Previous research has paid much attention to the control measures, the damage to the reservoir and management in the process of drainage [3, 6-7, 9, 12-14]. However, there are few papers on the rules of pulverized coal output for different components of coal petrography and different coal structure. Some scholars have discussed the mechanism and characteristics of the pulverized coal output [1, 2, 9].

2. Experimental method

2.1. Experimental principle

The coal reservoir fracture diversion system in this experiment is the main part. In this study the author used the quartz sand to support the existing cracks and simulated the process of CBM well drainage by single-phase water flow displacement, and simulated the change of the strata stress through changing confining pressure in different conditions. In order to identify the law of pulverized coal output, the dynamic output rules of pulverized coal was tried to be concluded by means of changing the size of displacement velocity of single-phase water flow and confining pressure between coal briquettes.

2.2 Sample preparation

The experiment was performed using the HXDL-II type acid fracture flow diversion meter. Sample preparation include coal briquette, proppant pack and displacement fluid.

2.2.1. Preparation of the coal briquette.

Coal samples were collected from 3#, 5#, and 11# coal seams in the Xiangshan coal mine, Hancheng area. The coal samples were crushed using the crushing machine and selected by

100 mesh standard sieve. The pulverized coal which is less than 100 mesh standard sieve was made of coal briquette. Using electronic scaled 35g pulverized coal which was used to make the coal briquette under the confining stress of 20MPa. The shape of the coal briquette by acid etching fracture diverting instrument diversion chamber specification shall prevail. It covers an area of 64.5 cm², straight line length is 139.7 mm, and the diameters of the semicircle on both ends are 38.1 mm.

2.2.2. The production of proppant pack

The proppant was the quartz sand with the standard of 20~40 mesh which were tiled in the middle of two pieces of coal briquette to simulate the coal reservoir with the pressed proppant.

2.2.3. Configuration of the displacement fluid

The formation water in the coal reservoir was simulated using the displacement fluid with salinity of 8% standard saline. The formula (mass ratio) of NaCl: CaCl₂: MgCl₂ H₂O=7: 0.6: 0.4.

2.3 Experimental approach

The experiment was designed two groups of variables: the velocity of displacement fluid and confining stress. The method was to keep one variable stable and change another variable to study the rule of the pulverized coal output. The experimental device process and conditions are shown in Figure 1 and table 1, respectively. The experiment used the coal briquette with the same specification, and each displacement fluid flow velocity and confining stress condition lasted 2 hours in the experiment.

Table 1. The experimental method of different components of coal petrography

Coal samples	Experimental conditions	
3# coal	Confining stress for 5MPa, Flow velocity for 5ml/min	Flow velocity for 10ml/min, Confining stress for 3MPa
	Confining stress for 5MPa, Flow velocity for 15ml/min	Flow velocity for 10ml/min, Confining stress for 5MPa
	Confining stress for 5MPa, Flow velocity for 25ml/min	Flow velocity for 10ml/min, Confining stress for 7MPa
5# coal	Confining stress for 5MPa, Flow velocity for 5ml/min	Flow velocity for 10ml/min, Confining stress for 3MPa
	Confining stress for 5MPa, Flow velocity for 15ml/min	Flow velocity for 10ml/min, Confining stress for 5MPa
	Confining stress for 5MPa, Flow velocity for 25ml/min	Flow velocity for 10ml/min, Confining stress for 7MPa
11# coal	Confining stress for 5MPa, Flow velocity for 5ml/min	Flow velocity for 10ml/min, Confining stress for 3MPa
	Confining stress for 5MPa, Flow velocity for 15ml/min	Flow velocity for 10ml/min, Confining stress for 5MPa
	Confining stress for 5MPa, Flow velocity for 25ml/min	Flow velocity for 10ml/min, Confining stress for 7MPa

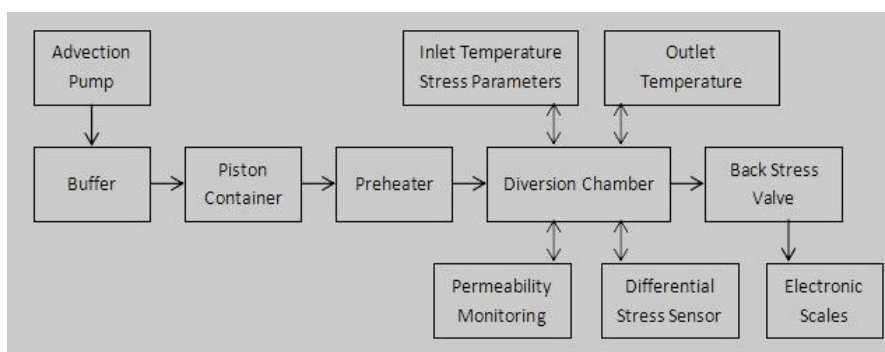


Figure 1. The physical simulation experimental device process of single-phase water of flow displacement

3. The effects of different coal petrography on the pulverized coal output

In this experiment for coal samples of 3#, 5#, and 11#, we kept the confining stress constant which was 5MPa and changed the displacement fluid flow velocity from 5ml/min to 15ml/min, 25ml/min gradually.

Table 2. The analysis of coal samples

Coal petrography samples	Microscope composition/%			Relative contents of vitrinite and inertinite/%		Moisture/%	Volatile/%	Ash/%
	Vitrinite	Inertinite	Clay minerals	Vitrinite	Inertinite			
3# coal	83.69	10.09	7.86	89.24	10.76	1.15	12.25	8.92
5# coal	75.38	13.16	11.45	85.14	14.86	1.21	13.12	11.31
11# coal	69.07	13.62	16.54	83.53	6.47	0.80	13.36	12.76

The analysis of pulverized coal output

We used the electronic scale to weigh the pulverized coal output which was collected in the experiment. The data on pulverized coal output are shown in Figure 2. We can see from the Figure 2, the weight of pulverized coal output in the experiment was 11# coal > 5# coal > 3# coal with the increasing of the displacement fluid flow velocity.

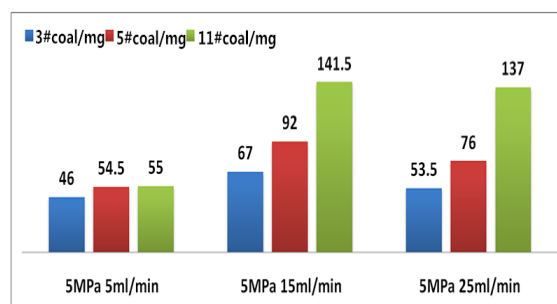


Figure 2. The pulverized coal output of different coal petrography under constant confining stress and variable displacement fluid velocity

This was due to the content of clay mineral was 11# coal > 5# coal > 3# coal (as shown in table 2) and the clay mineral more easily shed from coal skeleton particles under the shearing stress of the high-speed displacement fluid, which break into particles moved out with the displacement fluid.

When we kept the displacement fluid velocity constant and changed the confining stress (as shown in table 2), The rate of increase on pulverized coal output was 5# coal > 11# coal with the rising of the confining stress. The results are shown in Figure 3.

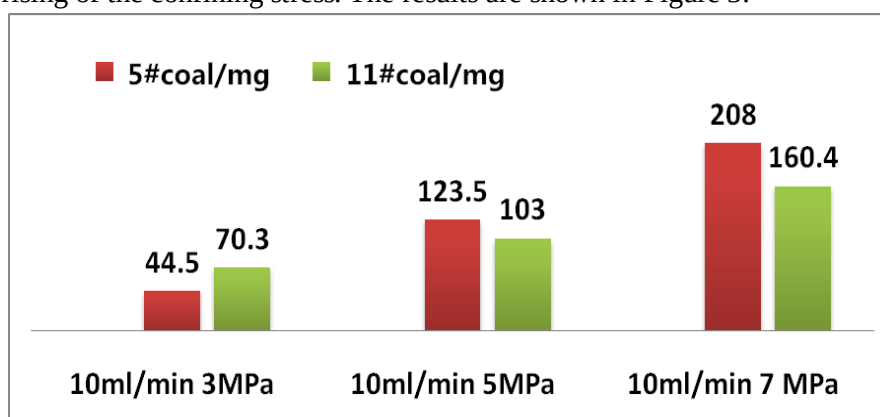


Figure 3. The pulverized coal output of different coal petrography under constant displacement fluid velocity and variable confining stress

The reason is that the content of vitrinite of 5# coal is more than 11# coal (as shown in table 1), microhardness of vitrinite is less than inetrinite and mineral, and microscopic brittleness is more than inetrinite and mineral. The vitrinite is more easily to break into coal particles.

4. The effect of different coal structure on pulverized coal output

Table 3. The experimental scheme of different coal structure

Coal samples	Coal structure	Experimental conditions
3# coal	Primary structure of coal	Constant confining stress and variable displacement fluid flow velocity
	Fragmented coal	Confining stress for 5MPa, flow velocity for 5ml/min Confining stress for 5MPa, flow velocity for 15ml/min
5# coal	Primary structure of coal	Confining stress for 5MPa, flow velocity for 25ml/min
	Fragmented coal	Flow velocity for 10ml/min, confining stress for 3MPa
11# coal	Primary structure of coal	Flow velocity for 5ml/min, confining stress for 5MPa
	Fragmented coal	Flow velocity for 5ml/min, confining stress for 7MPa

All equipment and coal samples and displacement fluid and other conditions used in this experiment were the same to the experiment which studied the effect of different coal petrography on pulverized coal output. Using displacement fluid and confining stress simulated the intensity of water production and the coal reservoir stress to study the effect of primary structure of coal and the fragmented coal on pulverized coal output. The experimental scheme was shown in table 3.

4.1. Analysis of pulverized coal output

As shown in table 4, the output of pulverized coal of the fragmented coal was much larger than the primary structure of coal under the same experimental conditions.

Table 4. The weight of pulverized coal output for different coal structure

Coal samples conditions	5MPa-5ml/min	5MPa-15ml/min	5MPa-25ml/min	10ml/min-3MPa	10ml/min-5MPa	10ml/min-7MPa	Percent age of pulverized coal output /%
3# primary structure of coal	46	67	53.5	80.5	66.5	103	0.06-0.14
3# fragmented coal	142.2	755	1227	1500	740	700	0.19-2.0
5# primary structure of coal	54.5	92	72	44.5	123.5	208	0.06-0.28
5# fragmented coal	460	567	930	720	390	410	0.52-1.24
11# primary structure of coal	55	141.5	137	70.3	103	160.4	0.07-0.21
11# fragmented coal	150	500	550	510	260	350	0.2-0.73

We can see in table 4 that the output of pulverized coal of 3#, 5#, 11# primary structure of coal was 46~208mg, making up 0.06~0.28% of the total weight of coal samples before conducting experiment. Compared to the fragmented coal, the output of pulverized coal was 142.2~1500mg and accounted for 0.19~2.0%, respectively. Due to the effect of tectonic stress, the coal structure of the fragmented coal was more broken and coal developed many tiny cracks within coal matrix. As a result of the fluid erosion and confining stress failure, the fragmented coal is more susceptible to form fine coal particles under the same experimental conditions causing the output increasing of pulverized output immediately.

4.2 Granularity characteristics of pulverized coal output

4.2.1. Research method

The size of the pulverized coal particles is an important factor to determine the stuck pumps. By studying the characteristics of different particles size of pulverized coal output, we can

recognize and resolve the problem of stuck pumps. We used the China University of Mining and Technology (Beijing) State Key Laboratory of Coal Resources and Safe Mining's XY-P polarizing microscope and the CBM national Engineering Center' Mastersizer 2000 to analyze the sizes of coal particles.

4.2.2. Analysis of pulverized coal output of primary structure of coal

In this experiment the grain size distribution curves are shown in Figure 4. The pulverized coal output particle size distribution curve of 3#, 5#, 11# primary structure of coal showed a double-peak, and the grain size of primary pulverized coal was relatively small and the grain size of secondary pulverized coal was relatively large except for Figure 4(c). The grain size distribution had a wide scope with range from 0.02~2000 μm .

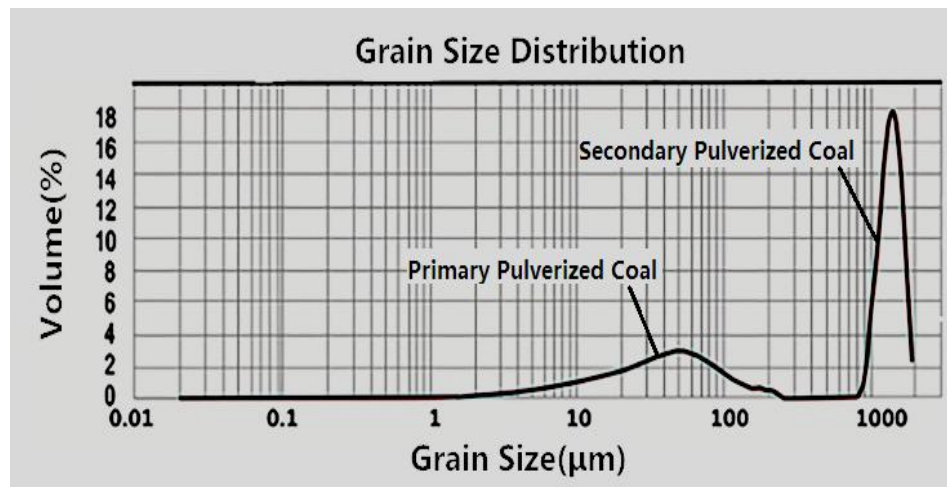


Figure 4. (a) 3# primary structure of coal

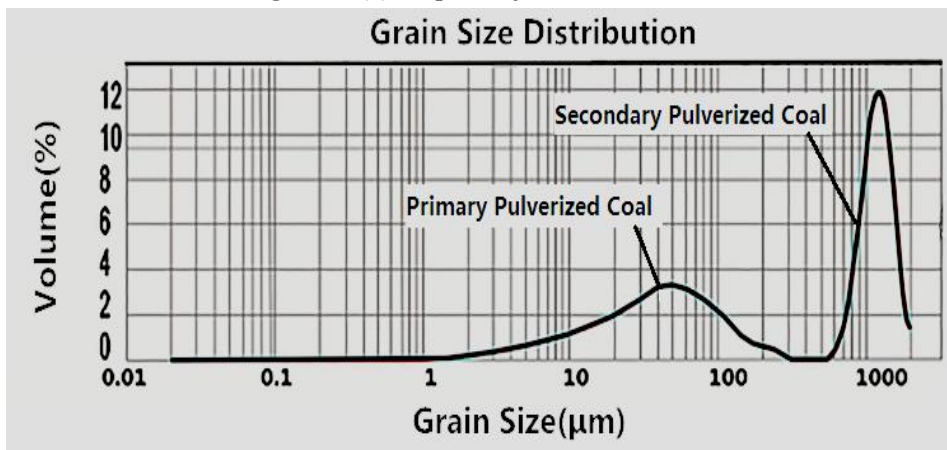


Figure 4. (b) 5# primary structure of coal

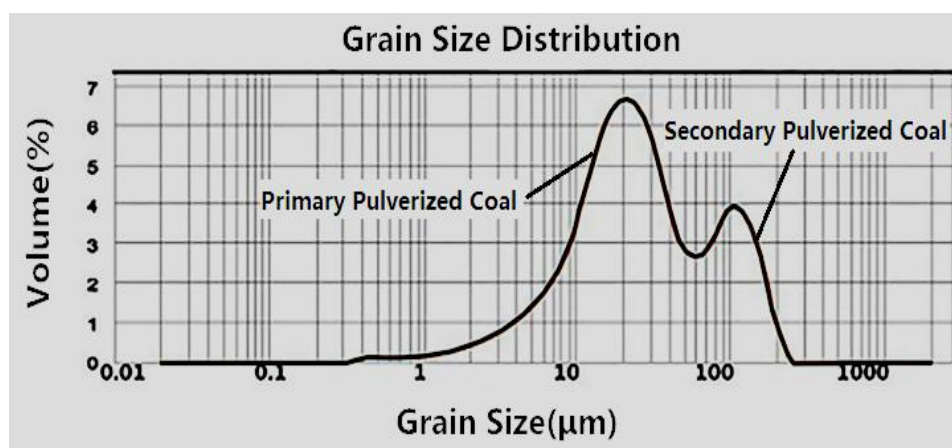


Figure 4. (c) 11# primary structure of coal

Figure 4. The grain size distribution of different primary structure of coal

The range of the grain size was $0.02\sim 2000\mu\text{m}$ in Figure 4. We can see the grain size distribution of 3# primary structure of coal in Figure 4. (a), which showed a double-peak distribution curve. The primary pulverized coal appeared from $20\mu\text{m}$ to $90\mu\text{m}$, and the second pulverized coal was from $900\mu\text{m}$ to $1600\mu\text{m}$. In Figure 4. (b), the 5# primary structure of coal for the grain size distribution had a double-peak distribution curve. The size of the primary pulverized coal ranged between $20\mu\text{m}$ and $100\mu\text{m}$, and the second pulverized coal was from $700\mu\text{m}$ to $1700\mu\text{m}$. As shown in Figure 4. (c), the grain size distribution of 11# primary structure of coal presented a double-peak distribution. The primary pulverized coal was between $8\mu\text{m}$ and $40\mu\text{m}$, and the second pulverized coal varied from $50\mu\text{m}$ to $180\mu\text{m}$. Due to the effect of tectonic stress, the coal structure of the fragmented coal was more broken and coal developed many tiny cracks within coal matrix. As a result of the fluid erosion and confining stress failure, the fragmented coal is more susceptible to form fine coal particles under the same experimental conditions causing the pulverized coal output to increase immediately.

4.2.3. Analysis of pulverized coal output of fragmented coal

As shown in Figure 5, the grain size distribution of fragmented coal was a unimodal distribution, and the distribution scope was relatively concentrated and the average grain size was small. The particle size of fragmented coal ranged from $0.02\sim 2000\mu\text{m}$ in Figure 5.

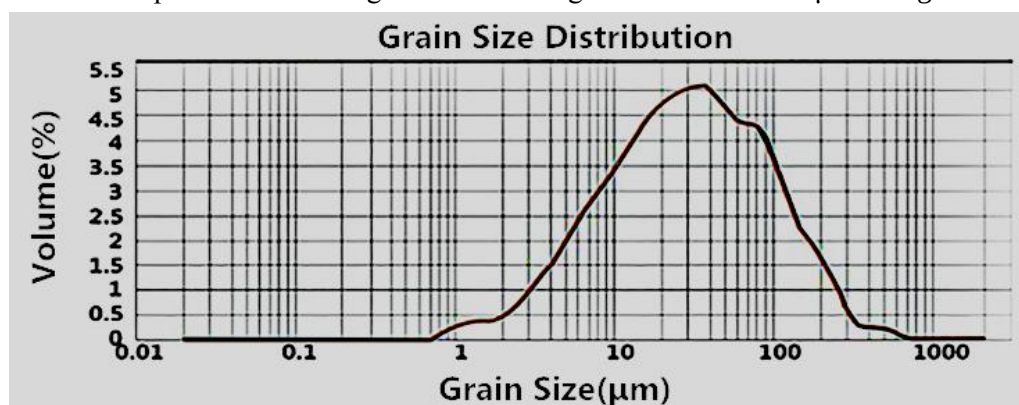


Figure 5. (a) 3# fragmented coal

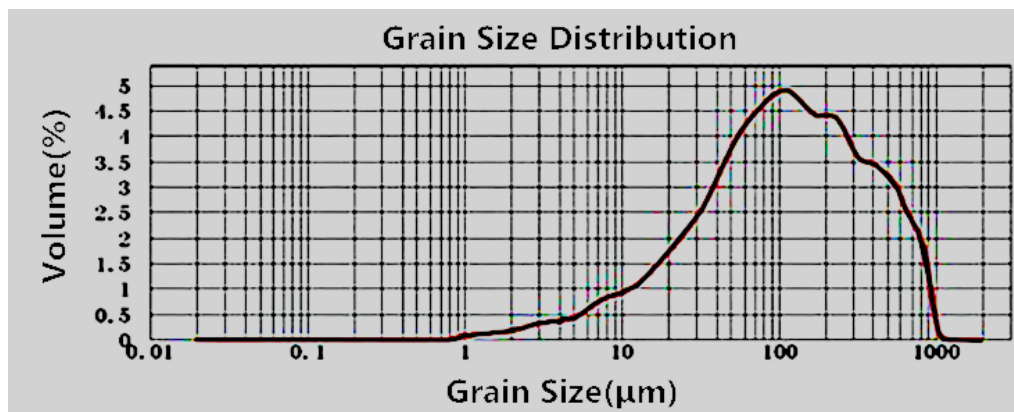


Figure 5. (b) 5# fragmented coal

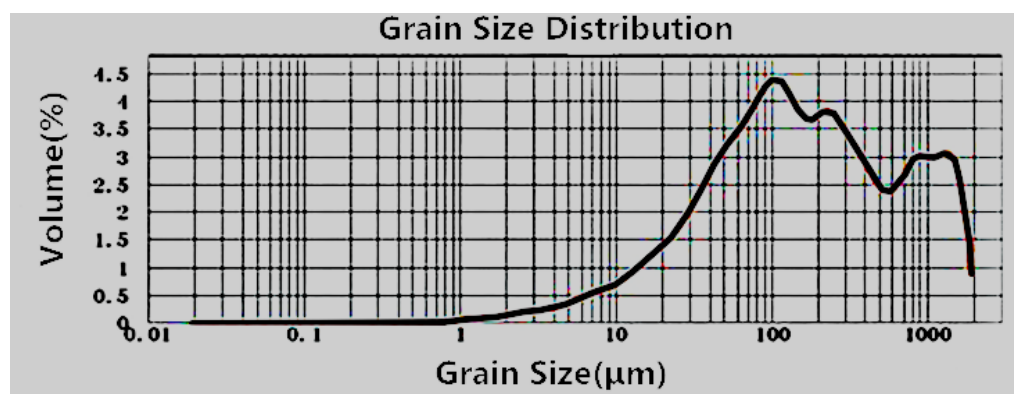


Figure 5. (c) 11# fragmented coal

Figure 5. The grain size distribution of different fragmented coal

The 3# fragmented coal showed a pulverized coal particle size distribution curve with a single peak. The grain size ranged from 0.02~2000 μm , and the main peak appeared between 10 μm and 100 μm . As shown in Figure 5, the pulverized coal particle size distribution curve of 5# fragmented coal was a single peak with the range from 0.02~2000 μm and the main peak was between 50 μm and 300 μm . The pulverized coal grain size distribution curve of 11# fragmented coal was shown in Figure (c). The particle size ranged from 0.02~2000 μm and the main peak appeared between 60 μm and 1300 μm . The reason for the single peak was that the original fine pulverized coal accounted for large proportion of pulverized coal output of fragmented coal and the size range of pulverized coal output was concentrated.

4.3 Morphological characteristics of pulverized coal output in the experiment

The morphological characteristics of the pulverized coal were found to be related to the source of different coal body structure. Examinations of the morphological characteristics of pulverized coal output may lay a foundation for the development of the control measures. Special analysis was performed at the China University of Mining and Technology (Oxford) IE 250 S-3400 SEM.

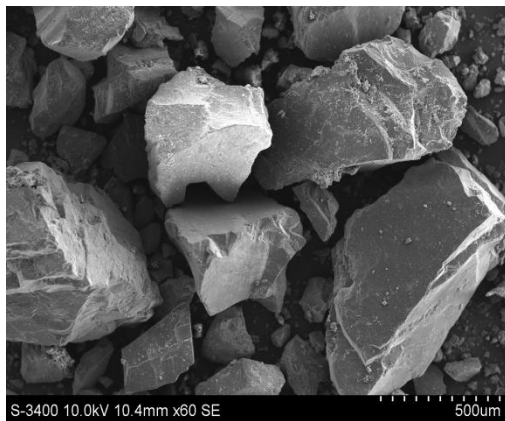


Figure 6. (a) 3# primary structure of coal

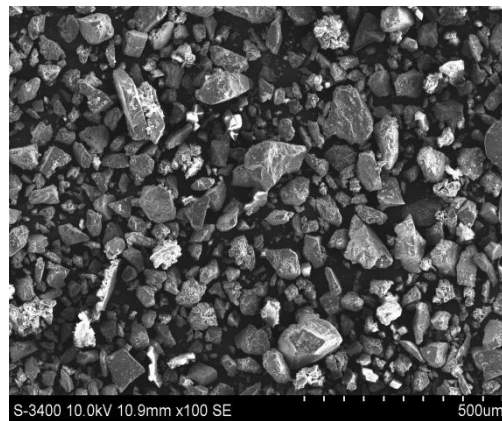


Figure 6. (b) 3# fragmented coal

Figure 6. Morphological characteristics of pulverized coal output under the condition of 10ml/min, 3MPa

As shown in Figure 6. (a) and Figure 7. (a), The microscopic morphology for the pulverized coal output of primary structure of coal was angular and roundness commonly sorted edge angle, and the shape characteristic was predominantly cylindrical shape and block shape, and the surface characteristics of pulverized coal was smooth.

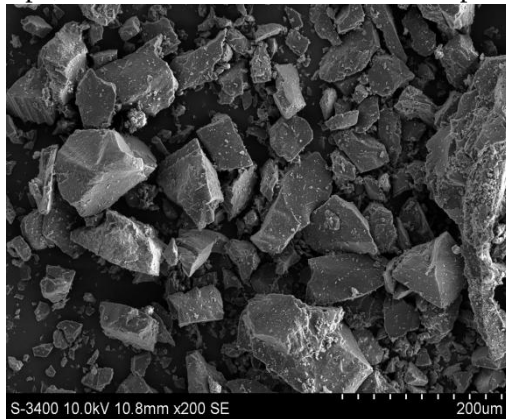


Figure 7. (a) 5# primary structure of coal

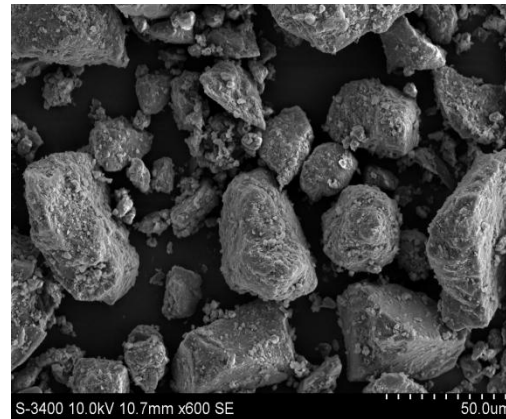


Figure 7. (b) 5# fragmented coal

Figure 7. Morphological characteristics of pulverized coal output under the condition of 15ml/min, 5MPa

We can see in Figure 6. (b) and Figure 7. (b) that the microscopic morphology for the pulverized coal output of fragmented coal was roundness, which was predominantly sub-angular shape and sub-round shape, and round shape. The surface characteristic of pulverized coal of fragmented coal was relatively rough and the shape characteristic sorted mainly granular.

5. Conclusion

The weight of pulverized coal output is related with displacement fluid velocity and confining stress. When the confining stress keeps stable, the weight of pulverized coal output increase with rising of the displacement fluid velocity. This shows that the weight of pulverized coal output is positively correlated with the displacement fluid velocity of single-phase water flow. When the velocity of displacement fluid keeps constant and changes the confining stress, the weight of pulverized decrease relatively. This shows that the weight of pulverized coal output

is negatively correlated with the confining stress.

Coal body structure was found to be one of primary factors of pulverized coal output. The clay mineral more easily shed from coal skeleton particles under the shearing stress of the high-speed displacement fluid, which caused to break into particles with the displacement fluid moving out. Due to the effect of tectonic stress, the coal structure of the fragmented coal was more broken and coal developed many tiny cracks within coal matrix. The morphology of pulverized coal output particles was found to be related to the nature of the coal, coal body structure and the late mechanical damage.

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