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DESULFURIZATION OF COAL BASED ON HIGH PRESSURE WATER JET COMMINUTION

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ABSTRACT

High pressure water jet grinding and mineral processing technology has been combined with a view to reduce the sulphur and ash content of finely ground coal, for the purpose of preparation of super-clean coal water slurry. The target type water jet mill based on the principle of abrasive entrained water jet with self resonator was used for the finely grinding raw coal. The subsequent mechanical classification was carried out using hydrocyclone for obtaining the expected -10μm coal fines. At the same time, finely grinding of coal with ball mill was also done for the -10μm coal fines. Froth flotation tests using ground coal fines both by water jet mill and ball mill, under the identical chemical conditions, were conducted. The liberation of the different component grains from one another well preserved its crystal form and origin surface, and the kinetics of particle flotation and surface hydrophobicity were greatly improved. The experimental results demonstrate that the waterjet-ground coal fines have a very good performance of flotation, and achieve much higher combustible recovery (up to 80%) and much lower ash content (down to 13.67%), with less grinding power consumption. The article introduced the whole experiments and discussed the results.

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1. INTRODUCTION

Coal burning is the cause of 70% of sulfur dioxide emissions into the atmosphere. This gas is the main cause of acid rain. As the largest coal producer and consumer in the world and, China's coal output accounts for 25% of that of the world and the 75 percent of the country's primary energy consumption comes from coal. Since coal is the single energy resource found abundant in China and the increasingly worldwide demand for oil, the country's energy consumption will continue to be coal-based. The statistics show that 90 percent of the sulfur dioxide and 75 percent of the smoke dust were generated by direct coal combustion, which causes serious air pollution problem [1]. The clean coal technology, therefore, is essential for China's sustainable development. Thus the cleaning utilization of coal is one of the long-term strategic tasks in China.

The super-clean coal water slurry (super-clean CWS) as a fuel for diesel engines and boiler is the typical clean coal technology and has been the subject for years, but little progress had been achieved in industrial application. It is because of the difficulties in desulphurization and ash removal. Coal water slurry is a clean coal fuel, which is prepared by grinding raw coal into coal fines in micron size, separating impurities of sulfur and ash from it, finally mixing with additives such as water, oil and methanol, etc. The conventional mechanical crushing principle based mill, such as ball mill, has been widely used in grinding raw coal for preparation of super-clean CWS. It pulverizes materials by repeatedly crushing effect between the grinding media (i.e. balls) and materials, and tends to make the fines over-ground, as well as makes the following separation a difficult task.

Before made into a fuel, the coal fines need to be cleaned by flotation process which is used for coal-minerals separation by utilization of surface characteristic differences between coal and minerals. Froth flotation is a fine particle separation process based on the difference in surface hydrophobicity of different components. It is often very effective for coal cleaning since coal is naturally hydrophobic and minerals are hydrophilic [2]. Fractured coal by long-time repeatedly crushing will damage the surface of coal and impurities and lowered the floatability of coals.

Mazurkiewicz and Galecki [3] investigated tensile and cleavage pulverizing materials with high pressure water jet. They comminuting coals with the aid of water jet and found that the coal particle fracturing relies on the penetration of the jet into microcracks, microcracks pressurization, and subsequent propagation of the micro fracture to erode the material; the micro fracture propagates along the path of least resistance, consequently, liberating individual grains at the surface of the rock; as well as the crushing principle commonly used at present is changed to one in which particles are fragmented by the tensile growth of pre-existing internal flows or cracks.

The aim of this investigation was to use high pressure water jet mill instead of widely used ball mill at present for ultra-fine grinding coal, liberate the components of the raw coal from one another at their common boundary, and separate the different components based on their surface characteristics, the differences in their surface hydrophobicity, and the differences in their specific gravity. This research work was undertaken as part of efforts to make coal cleaning operations achieve high ash rejection and sulfur rejection, while high combustible recovery can be maintained, with the fully making use of the achievements in preparation of super-clean CWS in CUMTB (China University of Ming and technology Beining), which has been supported by various funds at different level and carried on for years.

2. EXPERIMENTAL

A schematic representation of the experimental setup is given in Figure 1. The setup is composed of high pressure pump and its control system, the water jet mill which is based on the principle of AWJ with a self-resonator in the mixing chamber, the hydrocyclone, and the froth flotation testing equipment.

The high pressure pump kept running at 40 MPa and flow rate of 70l/min during the test, and the flow rate was 70 liter per minute. The size of coal feed is less than 1mm, see Figure 2. The feed particles were entrained into the mixing chamber and accelerated by the jetting water through the accelerating tube. The accelerated particles were colliding upon the target inside the grinding chamber and fragmented into coal fines by the joint action of cavity and water hammer pressure. The embedded resonator was conducive to improve the particle-waterjet mixing effect and achieve higher grinding efficiency.

The 75 mm diameter hydrocyclone was used for classification operation. The classifying experiments were conducted using the ground coal as feed (for particle size seeing Figure 3). The ground coal is a mixture of coal fines and water with density of 30%. It was pumped into the hydrocyclone at a varying inlet pressure which was adjusted with an inlet and bypass valve. Timed samples of the overflow and underflow collected were used to compute average product flow rates. Size distribution of the products was determined using Mastersizer analyzer. All the parameters of the classification system were adjusted for the expected product size of -10μm in the overflow. Figure 4 illustrates the size of the coal fines in overflow after classification by the hydrocyclone at the inlet pressure of 0.2 MPa. Figure 5 illustrates the size of the coal fractures as discharge in the underflow, which was sent back to the water jet mill as feed.

A laboratory-used small ball mill with input power of 370W was employed to grind coal at the same expected product size of -10μm. The ball mill grinding test had been running repeatedly in different time interval, and finally the 3 hours long grinding time achieved finer product size, seeing Figure 6. The ball-mill ground coal fines (expected size) and the waterjet-mill ground fines (expected size) were used for flotation experiments under the identical testing conditions. Diesel oil based surfactant was used as frother and alcohol based reagent as collector in the flotation tests. The concentrates and tailings were weighed, dried and weighed and assayed for ash rejection.

3. RESULTS AND DISCUSSION

Table 2 shows the grinding results obtained using water jet mill and small laboratory mill, Figure 3 and Figure 6 illustrate the ground coal particle size by water jet mill and ball mill respectively. Calculation was made by the output of less than 11.55μm coal fines. The results show that the output per hour for the water jet mill is much higher than that of the ball mill, and the power consumption much lower than that of the latter. It should be taken into account that the small ball mill is just for the experiments in the lab and there may be some deviation in the results. Further experiments have been undergoing for more accurate results and evaluation.

Flotation is a complex mineral beneficiation process that depends on a large number of physical and chemical parameters. There are limits beyond which the success of the process is reduced, and one of the well known limits is in fine particle flotation [4]. The intergrowth of mineral ore deposits has necessitated fine grinding for liberation. Froth flotation is one of the most widely accepted industrial practices for separation of valuable components from associated gangue materials in mineral ores. It is a process that exploits the differences in surface hydrophobicity between minerals. During flotation, the particles of a hydrophobic surface adhere to air bubbles and report to the froth product while hydrophilic particles stay in the cell and discharge as tailings [5].

The outstanding features of water jet comminution lie in its tensile crushing principle and the cleavage ability. The shock waves created by high velocity water jet attack penetrate the crystal grain boundary and result in tensile stress in between the grains, consequently lead to disintegration of the crystal aggregate of minerals [6,7]. The different components such as coal, pyrite, and other associated gangue minerals are liberated form one another along their common boundary, i.e. cleavage, thus the surface and the original crystalline form of the individual grains are well preserved. It was well known that coal is naturally hydrophobic and the minerals such as pyrite are hydrophilic, the liberated mineral and coal fine grains with well preserved original form and clear surface will enhance the difference in surface hydrophobicity of the different components and improve the kinetics of fine particle flotation. The floatability of the water jet ground coal fines, therefore, can be improved by modifying surface characteristics and/or enhancing particle-reagent interactions.

The results of the flotation and subsequent ash test were well proved above expectation, seeing Table2. From table2, we can see that the combustible recovery (concentrates) for the water jet ground coal is as much as 80%, whereas the ball mill ground coal is only 57%. The ash content of the concentrates for water jet mill ground coal is as little as 13.67%, in contrast, the ash content of the concentrates for ball mill is 27.08%.

It was observed that the raw coal for water jet grinding and ball mill grinding were just the same, however, the ash content in the samplings of the ground coal fines is so different. The ash content of water jet ground coal fines before flotation is 29.70%, a little bit higher than the ash content of 27.33% of the ball mill ground before flotation (seeing table 2).

4. CONCLUSIONS

By high pressure water jet mill grinding coal in conjunction with the normal flotation processing, a much higher combustible recovery (i.e. the concentrates) was achieved with much lesser ash content in it, compared with the identical chemical conditions using ball mill for fine grinding coal.

As the collector, the frother and the impeller were all the same during the flotation test for coal fines ground by ball mill and water jet mill, the higher recovery and lower ash content can be attributed to the cleavage principle of water jet grinding. The kinetics of fine particle flotation and surface hydrophobicity are greatly improved for liberated fines grains of different components in the raw coal.

The power consumption for water jet mill is much lower than that of the ball, which was partly due to the small laboratory ball mill used in the experiment. But compared with the conventional mechanical grinding technology, the achieved results have already proved that high pressure water jet comminution is a energy saving one [3,7].

The present study focuses on the circuits of coal cleaning process with water jet grinding and conventional mineral processing technology. With the aid of the cleavage disintegration of coal by high pressure water jet, the utilization of hydrocyclone classification technology for separation of the pyrite and other mineral impurities from coal is feasible.

6. ACKNOWLEDGMENT

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8. TABLES

Table1 Grinding results obtained using water jet mill and laboratory small ball mill

Mill type	Input power (kW)	Output of -11.55μm fines (ton/h)	Power consumption (kW·h/ton)
Water jet mill	46.67	0.6988	66.79
Ball mill	0.37	10^{-5}	37000

Table2 Flotation and ash test results

Mill	Sampling of ground coal fines: 50g	Flotation yield: (%)		Ash specification: Percentage of ash (%)
Water jet mill	Fines in overflow SeeingFig.4: D_{50}=5.43μm Specific surface area: 102852 sq.m./gm Ash percentage before flotation: 29.70%	concentrates	80	13.67
		tailings	20	65.93
Ball mill	3 hours long grinding time Seeing Fig. 6: D_{50}=24.52μm Specific surface area: 0.4256 sq.m./gm Ash percentage before flotation: 27.33%	concentrates	57	27.08
		tailings	43	27.32

9. GRAPHICS

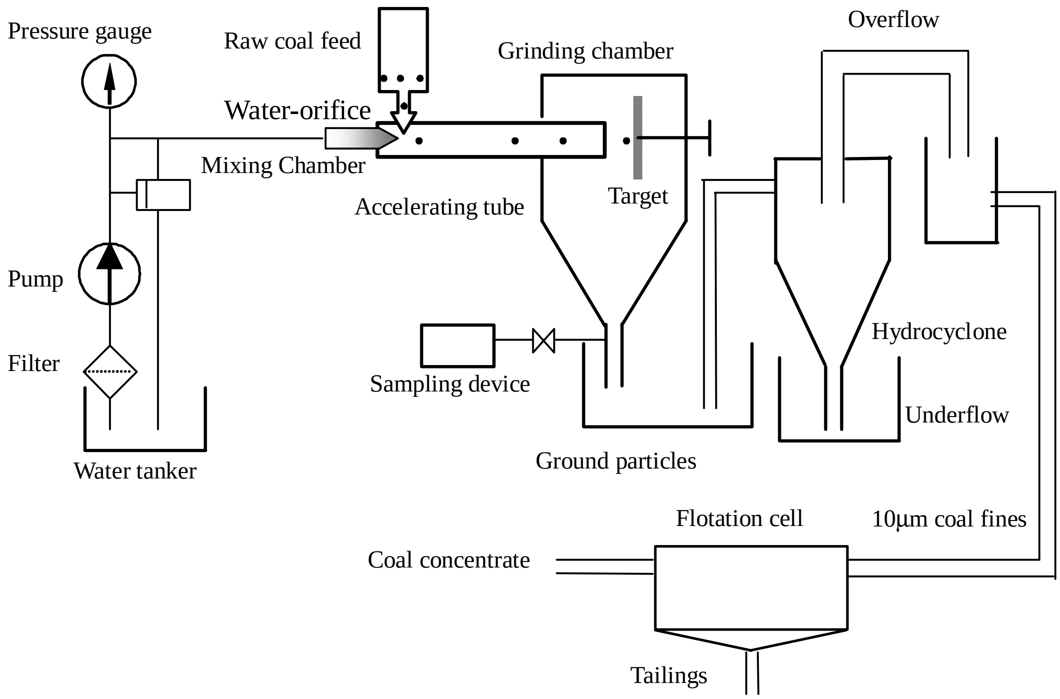

Fig. 1 Schematic diagram of Experimental setup

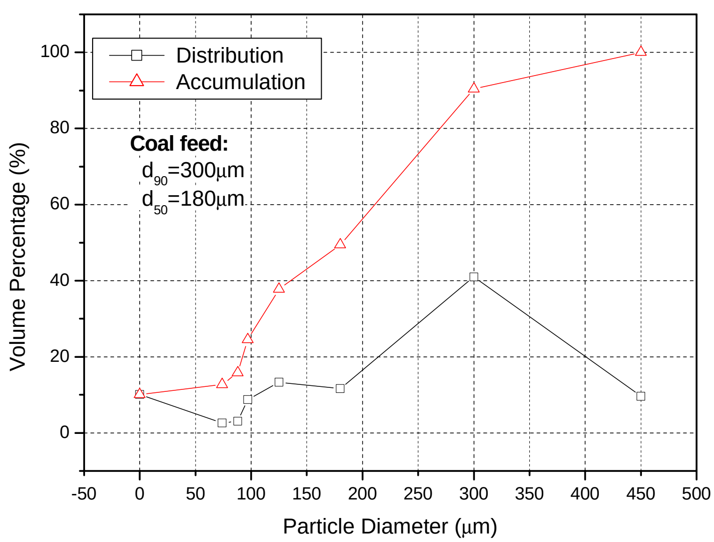

Fig.2 Particle size of the coal feed

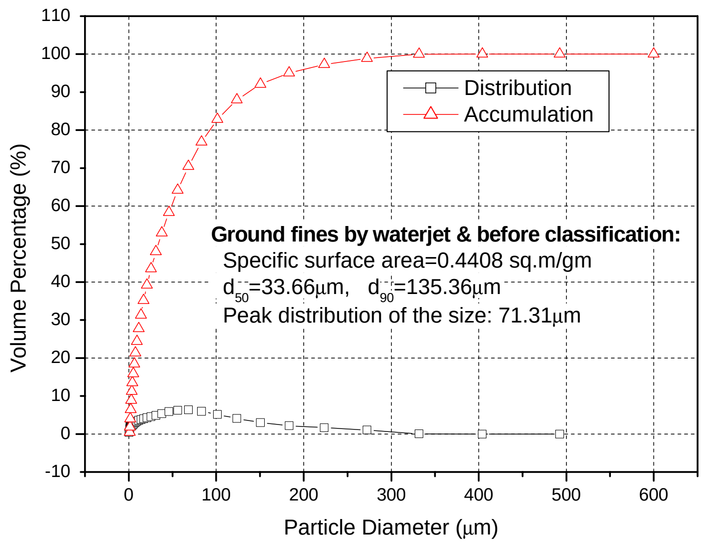

Fig.3 Waterjet-ground coal particle size before classification

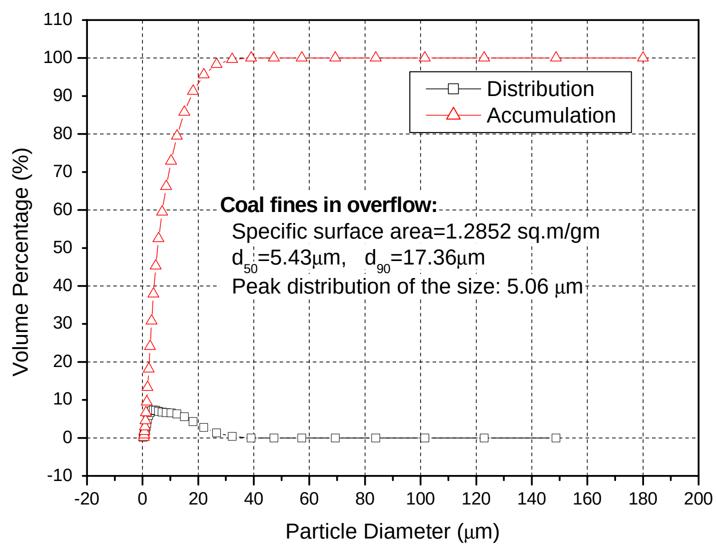

Fig.4 Waterjet-ground coal particle size in overflow of the hydrocyclone

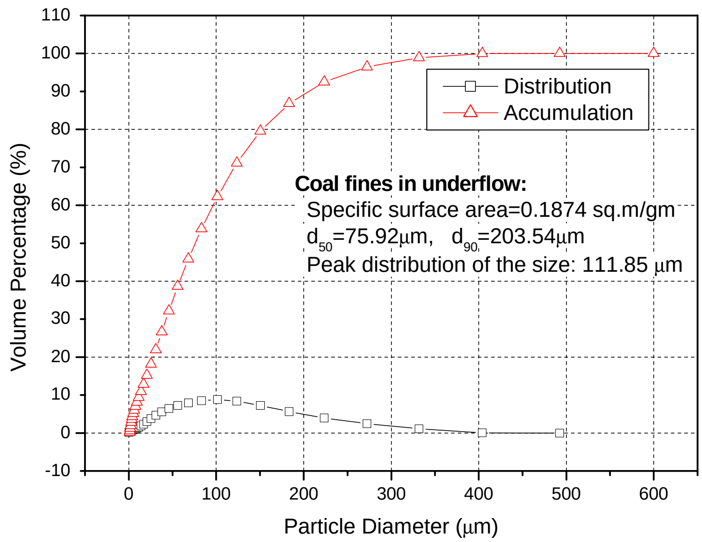

Fig.5 Waterjet-ground coal particle size in underflow of the hydrocyclone

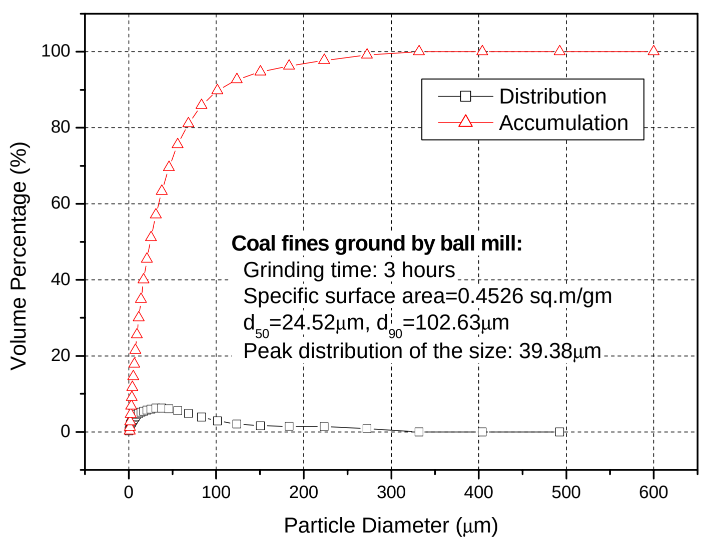

Fig.6 Ball mill ground particle size