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New Method of Coal Comminution to Ultrafine Size

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Abstract

Research into the use of coal for power generation has become more important to deliver next-generation solutions for advanced coal cleaning technologies required by near-zero emissions. Comminution of coal with waterjets to ultrafine particle size offers a new and promising method for producing coal-water fuel (CWF), which is a replacement for power generation products. In this paper the results of coal comminution in a waterjet-based mill are presented for the range of pressures up to 276 MPa using four groups of feed size ranging from minus 850 micrometers to less than 106 micrometers. The focus of studies was on particle size reduction and distribution. The results presented in this paper are part of ongoing studies of coal-water fuel optimization for power generation.

Introduction

As Antoine de Saint-Exupery said, "A civilization is built on what is required of men, not on that which is provided for them." Today's world requires affordable energy. Coal has always been one of the most reliable energy sources throughout history. However, developing advanced coal cleaning technology has become crucial for the sustainable use of coal today [1]. The use of coal in the form of slurry offers the potential to make the use of coal cleaner and comparable to heavy oil [2].

The coal-water slurry is a stable fluid that can be pumped and burnt as efficiently as conventional fuels. CWF has a great potential for efficient replacement of oil in boilers and furnaces. It has been successfully used in diesel engines. As reported by Lee [3], CWF is used in many countries, including US, Russia, Japan, China and Italy.

In the process of CWF preparation, the properties of solids are very important. Particle size and distribution provides the basis for production of high-concentration coal-water slurry [1]. The use of a small amount of additives stabilizes the coal-water slurry by uniformly dispersing the coal particles in the suspension, which helps maintain a concentration of up to 70% [2,4-9]. Depending on the application, there are different requirements for CWF. The term CWS (coal-water slurry) is often used interchangeably with CWF. In general, the coal particle size distribution for CWS should be wide, and preferably bimodal. Table 1 gives a typical particle size distribution of CWS for use in different applications.

Coal needs to be ground to an appropriate size for use in the preparation of coal water slurries. The energy requirements in conventional grinding processes dramatically increase with the desired ground product sizes. It has been shown that more than 96% of energy spent in current comminution processes is wasted [10]. The sustainable development and utilization of coal requires more efficient comminution methods. For that reason, a new generation of grinding mills has been introduced as alternate low energy comminution systems.

As introduced by Galecki and Mazurkiewicz [11,12], waterjets can be efficiently used for grinding of coal. The slurry is injected into the cavitation chamber to enhance the particle size reduction during combination with waterjets [11,13-15]. The process provides size reduction of minerals by inducing failure under tensile stresses, and is reported as a selective and efficient crushing process by different researchers for different materials. Size reduction is achieved by the combined effects of rapid dynamic shear stress, cavitation bubble growth and collapse, and the direct impact of particles against a rigid anvil. The degree of the forces involved in grinding determines the product properties [16-21]. Hlavac et al. [18] studied material comminution by waterjets using various mixing chamber configurations. Hlavac et al. [18] then proposed a model to quantitatively assess the particle size reduction. The effects of different parameters on grinding of coal using a high pressure waterjet mill were investigated individually by Cui et al. [10] based on fractal dimensions of the products. Later, the use of high pressure waterjet comminution techniques in preparation of ultra-clean micronized coal slurry was studied by Cui et al. [22].

In this study, coal samples were ground using a water jet mill consisting of an abrasive cutting head/cavitation cell set up under different operational conditions to determine the size reduction behavior of coal particles in the waterjet mill. For the purpose of the study, the product distributions were evaluated in terms of the equivalent volume mean diameters and calculated surface area values.

Materials and Methods

Two different bituminous coal samples were used in this study and are referred to as IC with 11% of ash and WC with 2.83% of ash. Run-

Property	Current CWS for boiler	Gas turbine	Diesel engine
Mean Particle Size (μm)	10-20	4-6	5-15
Particle Size (μm)	% Mass passing		
-5	5	60	30
-10	35	100	60
-20	50		100
-75	75		
-250	95		
-500	100		
Coal content (w/w)	65-70	55-60	50-55
Viscosity, mPaS @100^{S-1}	500-1000	400	300

Table 1: Some properties of high concentration CWS (8).

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of-mine coal samples were crushed to minus 5 mm by a jaw crusher and the particle size of the material was then reduced to 0.850 mm by secondary crushing. After homogenization, the sample was classified into different particle size fractions (850-355, 355-212, 212-106, 106 micron) using dry sieving.

The experiments were carried out using a specially designed cavitation cell coupled with a conventional abrasive cutting head. The parameters used were the upstream pressure and feed particle size. A Microtrac S3500 series particle size diffractometer was employed to determine the comminution product properties. The particle sizes of the ground products presented in this paper were all given in terms of "equivalent volume mean diameter".

Results and Discussions

During the test, mono size and original feed samples were exposed to waterjet action in the mill at various pressures. Then, the grinding products were evaluated based on particle size volume distribution and equivalent mean particle size. The distribution profiles of ground products obtained from minus 106 microns mono size fraction (feed) at different pressures are shown in figures 1a and 2a. It can be seen that the higher applied pressure results in finer products. However, it should be noted that limited size reduction can be obtained for these fine feeds which had equivalent volume mean diameters of 51.66 (IC) and 50.28 (WC) microns. The calculated surface area ratios were very low for both coal samples (Figure 3a, 3b).

The equivalent volume mean diameters for the mono size feeds of 212-106 microns were found to be 140.4 microns for the IC and 161 microns for WC. The mean particle size of the grinding products obtained from IC coal varied between 75.39 and 32.80 microns for the lowest and highest applied pressures (Figure 1b). Under the same conditions, finer products were generated from WC coal which had 46.99 microns and 21.30 microns for the lowest and highest applied pressures. Overall surface area ratios were found to be higher than those obtained from minus 106 micron feed. For this size fraction, the process seems to be more effective on grinding of WC coal (Figure 3a, 3b).

The mono size feed materials of 355-212 had equivalent mean diameters of 325 microns for the IC and 293.1 microns for the WC. As shown in figures 1c and 2c, a limited amount of fines were generated at 69 MPa. However, the incremental increase of pressure from 69 MPa to 276 MPa resulted in the production of finer particles. Higher surface area increases were obtained for WC again. The coarsest mono size feeds used in this study were 850-355 microns with equivalent mean diameters of 611.6 microns for the IC and 504.9 microns for the WC. Depending on the applied pressures, the mean particle size of the ground products varied between 119.4 microns (at 69 MPa) and 41.08 (microns at 276 MPa) for WC coal. Under the same conditions the coarsest products had a mean diameter of 149.6 microns for IC coal.

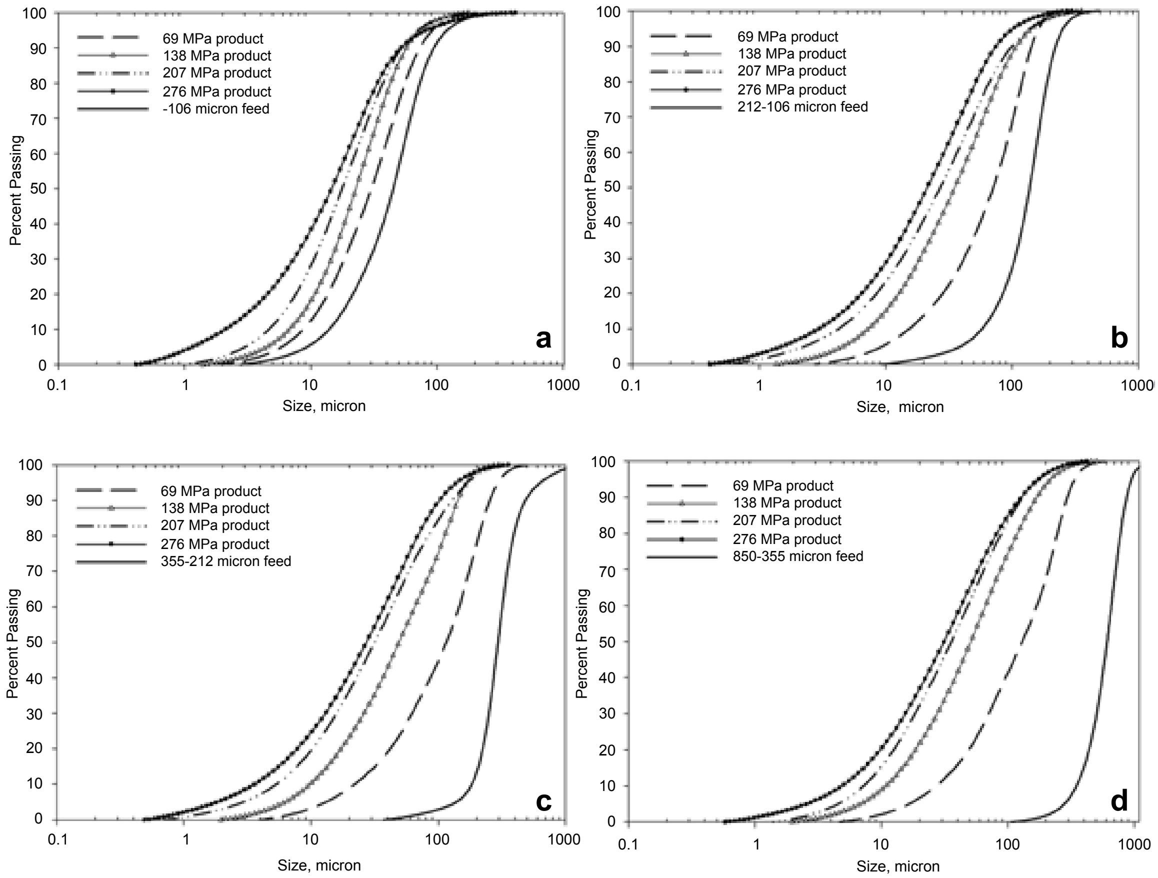

Figure 1: Product size distribution of the grinding products of IC obtained from different feeds at varying applied pressures.

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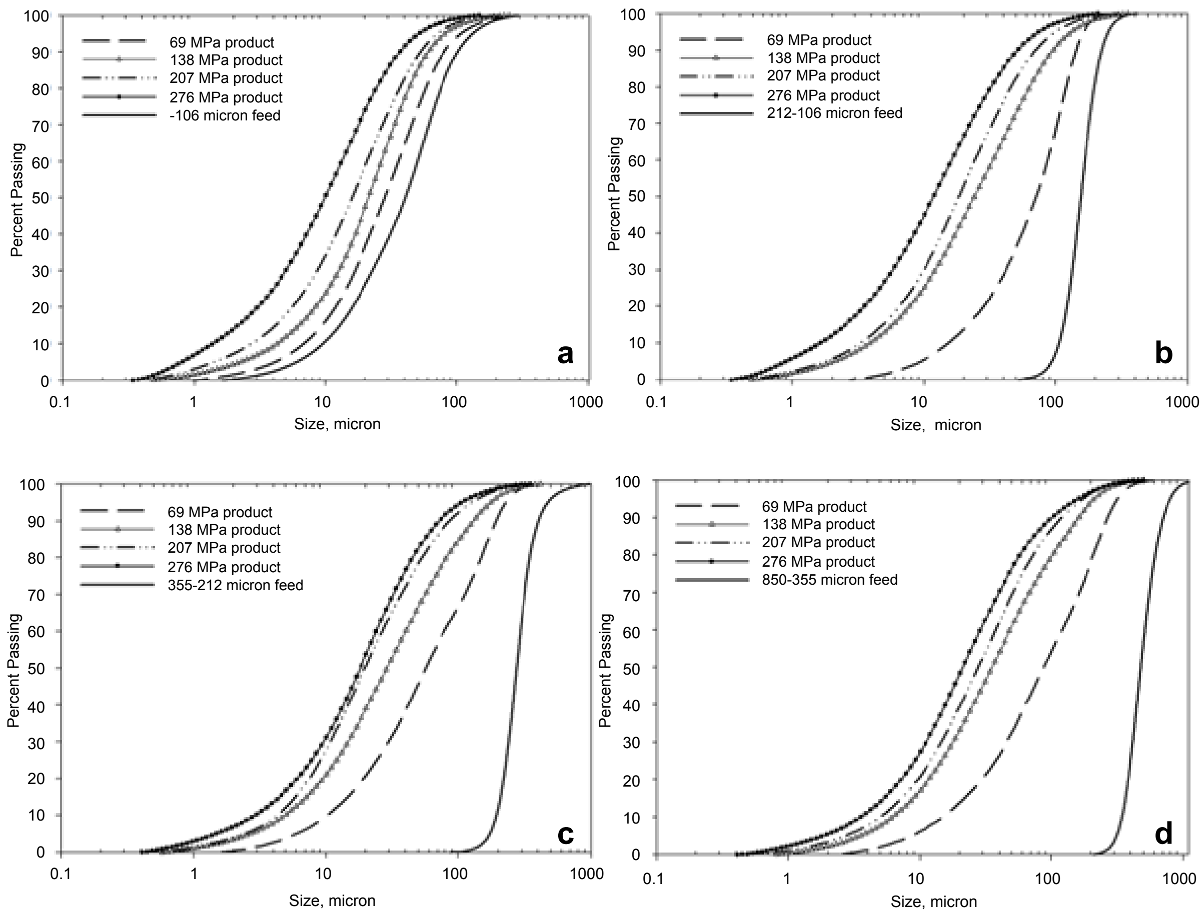

Figure 2: Product size distribution of the grinding products of WC obtained from different feeds at varying applied pressures.

As shown in figure 3, the ratios between the calculated surface area of the comminution products and feed materials are directly proportional to the applied pressure for both coals. It is important to note that the highest increase in the calculated surface area was achieved for the coarsest feeds.

For reference purposes, figure 4 shows the comminution products of the original feed materials without classification. As determined with the use of the Mictrotrac S3500, the mean particle size of the original feeds were 257.5 microns (for the IC) and 127.8 microns (for the WC). The mean particle size of the comminution products at the highest applied pressure of 276 MPa were determined as 33.68 microns for the IC and 22.60 microns for the WC. These changes clearly show the effect of pressure on the particle sizes and distribution.

The other property of the particles, other than their sizes and distribution, was the transition of the particle shape as a function of applied pressure. Figure 5 shows SEM pictures of the original feed material. The observed particles present a characteristic morphology of crushed coal with well-defined edges and angles with a variety of shapes, suggesting breakage along the grain boundaries.

Figures 6 and 7 shows the comminution products that result from various upstream pressures. The increase in the amount of fine particles is visible. The details about the transition of particle size, distribution and shape are given in the analysis of comminution products resulting from each pressure applied. At 69 MPa, particles retained their angular and flaky shape, with low sphericity as shown in Figures 5a and 6a. When the pressure was increased to 138 MPa, Figures 5b and 6b show the increasing amount of fines but particles are still coarse, flaky and maintain low sphericity. When the pressure was increased to 207 MPa, Figures 5c and 6c show rounded sharp edges of the particles. There is a noticeable increase in the number of subangular shaped particles with medium level sphericity. At the highest pressure applied in this series of experiments, 276 MPa, the ground product consists mostly of fine particles with sub-rounded and rounded shapes associated with medium sphericity (Figures 5d and 6d).

Conclusions

In the quest for a new method of coal comminution, the use of a waterjet for low ash coal grinding to ultrafine sizes proves to be efficient when size reduction is taken into consideration. It was found that the use of higher pressure resulted in reduction of the mean product diameter. A SEM study of the comminution products showed the transition in the shapes of the particles from very angular with low sphericity achieved at low pressures to sub-rounded particles with medium sphericity with the pressure increase within the range for these experiments.

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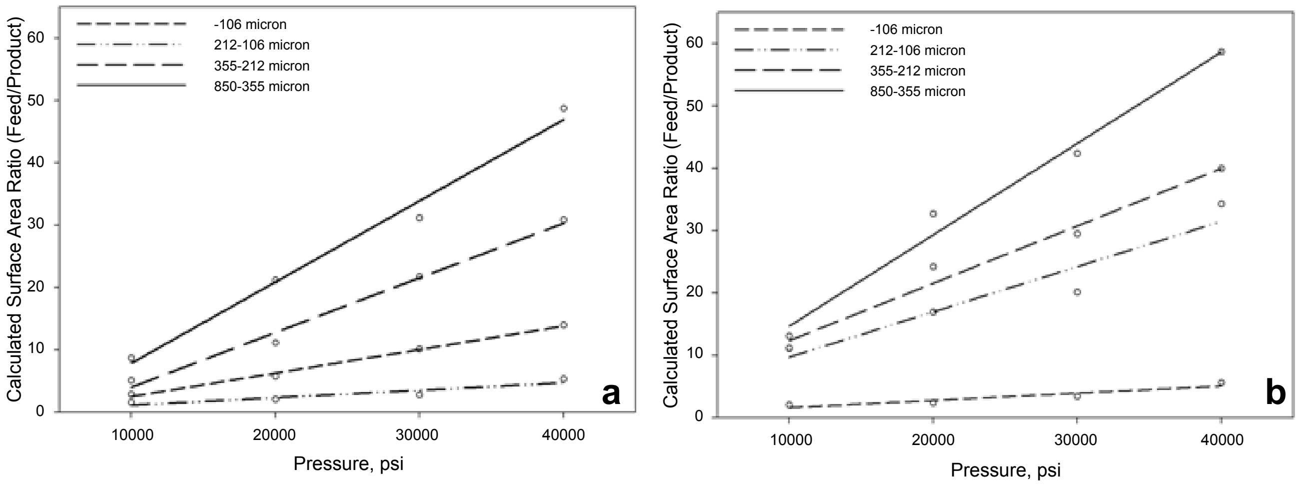

Figure 3: Calculated surface area ratios versus applied pressure for IC and WC.

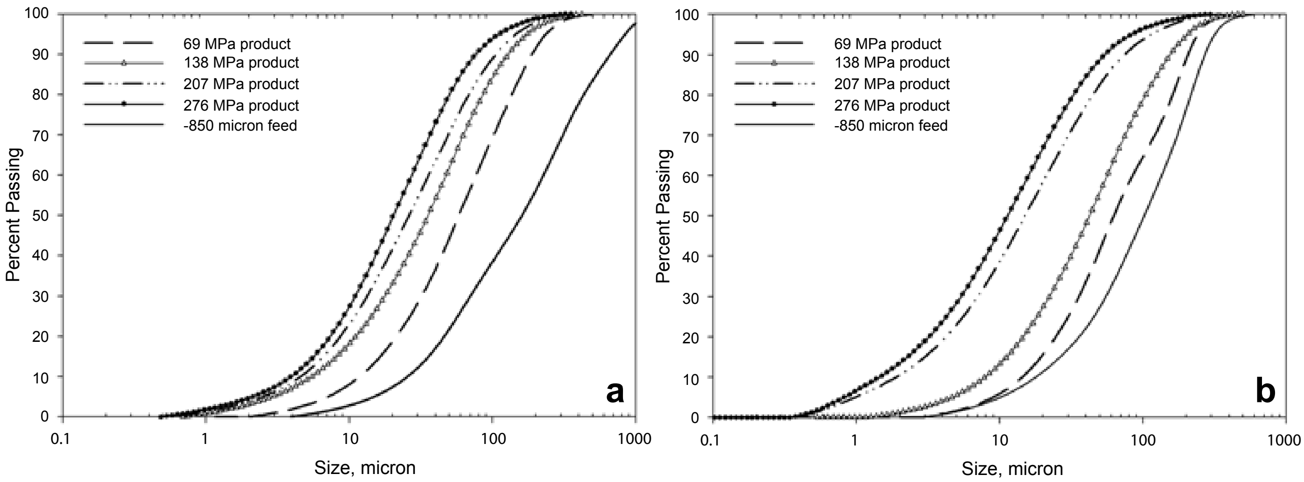

Figure 4: Size and distribution plots of products obtained from -850 microns feeds of IC and WC.

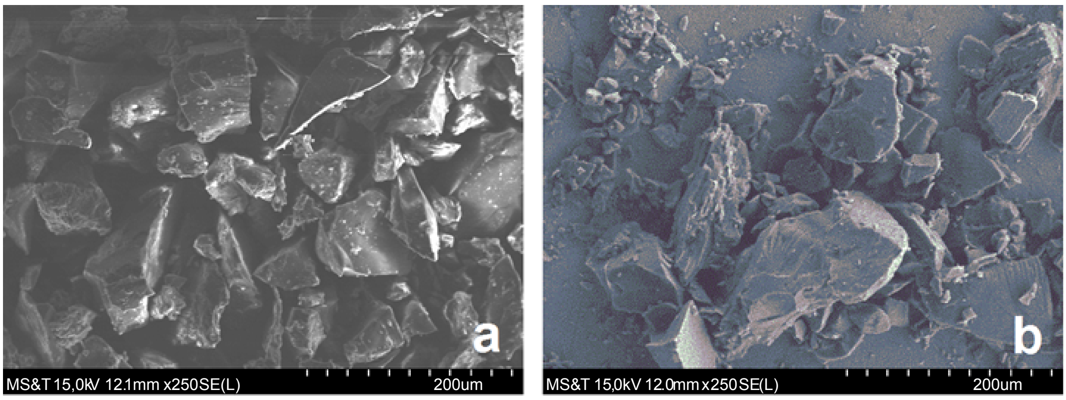

Figure 5: SEM pictures of original feed materials (-850 micron) without classification – note the flaky and angular particles with low sphericity.

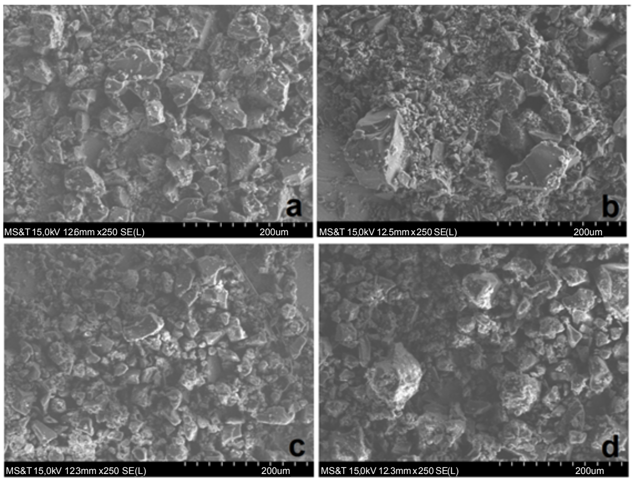

Figure 6: SEM pictures of the comminution products obtained from -850 micron feed of IC (a: 67 MPa, b: 138 MPa, c: 207 MPa, d: 276 MPa).

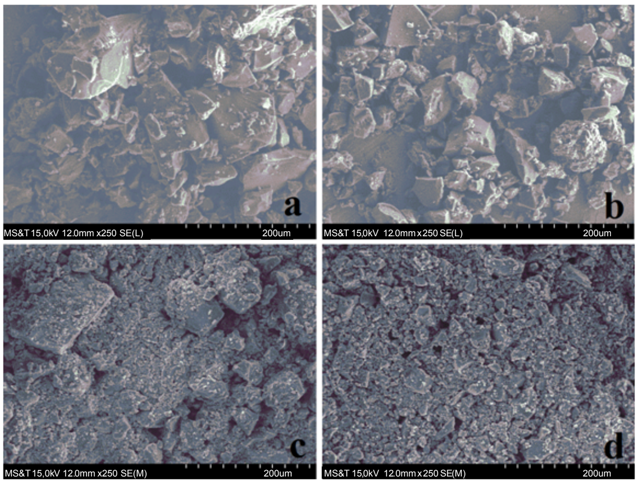

Figure 7: SEM pictures of the comminution products obtained from -850 micron feed of WC (a: 67 MPa, b: 138 MPa, c: 207 MPa, d: 276 MPa)

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