EFFECTS OF OPERATING PRESSURE AND STAND-OFF DISTANCE ON COAL COMMINUTION BY WATERJET

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Abstract: Comminution of coal to ultrafine sizes by high-pressure waterjet coupled with cavitation cell provides a novel method for preparation of coal-water fuels for next generation, near-zero emission electric power generation. To establish the fundamental performance of the waterjet mill, the effects of the operating pressure and stand-off distance were comprehensively investigated using a high ash bituminous coal. The comminution products were evaluated in terms of the particle size, particle size distribution, and surface area change. The experimental results indicated that the waterjet-mediated comminution of coal was strongly affected by all these operating parameters. Higher operating pressure led to finer products, while the efficiency of the waterjet mill in terms of particle size strongly depended on the stand-off distance. This research provides a deeper insight into the high-pressure waterjet for coal comminution and a basis for process parameter optimization.

Keywords: coal, waterjet, comminution, particle size distribution

Introduction

Coal, as the most abundant energy resource with significant remaining reserves, will remain a key component in the power generation industry. However, coal is full of hazardous substances that, when burned, can contaminate air, land, and water. Environmentalists claim that coal burning is a leading cause of smog, acid rain, and introduction of toxic solid waste into the environment. In addition to environmental impact, ash/impurities from coal can form deposits on heat transfer surfaces as the coal burns. These deposits not only lower the efficiency of a boiler but may also cause safety hazards, e.g., explosion. As a result, removal of those toxins is the core issue for

effective utilization of coal for power generation. The successful reduction of those toxic components from coal depends directly on the degree of liberation from coal. The degree of liberation is known to improve with a decrease in particle size. Recent findings have already proven that most of the minerals in coal, down to the micrometer particle size range, can be liberated by fine grinding (Laskowski, 2001). As the cost of emission control has emerged as a new barrier for coal-fired power generation, reduction of coal to micrometer particle size for advancing coal cleaning technology has become increasingly important. Furthermore, the utilization of coal as the fuel for compression combustion engines has already shown its viability (Caton, 1992). The successful conversion of coal-water fuel (CWF) to a diesel fuel also strongly depends on effectively reducing coal to a micrometer size level. Clearly, the sustainable development and utilization of coal relies to a large extent on the comminution processes to produce ultrafine coal particles.

As a result of the mechanism employed, current comminution methods are recognized as being inherently inefficient processes for preparation of ultrafine coal particles (Austin, 1984; Fuerstenau and Abouzeid, 2002). It has been shown that more than 96.0% of energy spent in current comminution process is wasted (Cui et al., 2006). Based on the work of Zulfiquar et al. (2006), the current industrial scale comminution processes are typically less than 1.0% efficient based on the energy required for the creation of the new surface. Currently, ball mills are commonly used for coal pulverization. According to Cui et al. (2006), it takes at least two hours on average to reduce the coal particles from 20.0 μm to 2.0 nm using a conventional ball mill. When the coal particle sizes are reduced to about 15.0 μm in diameter, a dynamic balance between pulverization and aggregation occurs (Cui et al., 2008). As a result, when coal particles are smaller than 15.0 μm, there will be no further particle size reduction in ball mills, but the energy consumption dramatically increases. The inefficiency of the conventional comminution methods for ultrafine grinding attributes to the fact that conventional comminution devices rely too much on the exertion of compressive forces on the feed materials. However, most brittle materials are weaker in tension than in compression. This is particularly true for coal as a result of its internal structure, which is pervaded by small micro-cracks and fissures (Galecki et al., 2011). Thus, fragmentation of coal through the development of tensile stresses within the particles is more economical. However, this fact has not been utilized until high-pressure waterjets were applied for coal comminution in the 1980s (Galecki and Mazurkiewicz, 1987; Galecki and Mazurkiewicz, 1988).

Waterjet technology is one of the most efficient methods widely used in industry to machine materials. Pure waterjet method involves the use of high pressure water to machine the materials. An abrasive medium is added to the high pressure waterjet to increase the waterjet cutting ability in abrasive waterjet method (Kulekci, 2002). Galecki and Mazurkiewicz (1987) noted that most of the abrasive particles fracture during the mixing and acceleration process in waterjets cutting of materials. In addition to an alternation in failure-inducing forces from compressive to tensile,

waterjet-based mineral comminution offers other distinctive advantages. In a high-pressure waterjet mill, mineral particles are injected into a conventional abrasive cutting head and then exposed to high-speed waterjets. These small waterjets penetrate into the existing cracks of mineral particles, resulting in external stresses within existing flaws. Further crack growth is thus promoted by these external stresses and finally results in fragmentation. In this way, minerals are liberated along the grain boundaries of different constituents. Since these small waterjets move so fast that they can effectively penetrate into the material almost as quickly as the crack tip can propagate, most mineral particles in a high-pressure waterjet mill are broken into smaller ones rapidly (Galecki and Mazurkiewicz, 1987). For this reason, the original crystalline shapes and surface glossiness of minerals are retained without any surface modification and contamination. Consequently, the natural hydrophilic or hydrophobic properties of different components of coal are preserved. This will significantly benefit the subsequent separation process and greatly expand the application of this technique. Attracted by these unique advantages, several types of high-pressure waterjet mills have been developed and described in the literature (Huang, 1994; Mazurkiewicz, 2001; Sun and Hou, 2002; Liu and Sun, 2005). Based on these waterjet mills, much research has been conducted and many valuable views have been presented (Yashima et al., 1987; Gong and Fang, 1998; Fu et al., 2001; Hou and Sun, 2003; Cui et al., 2008; Hlavac et al., 2010; Galecki et al., 2012; Galecki et al., 2013). However, all findings on the waterjet-mediated comminution have been empirical so far. No model currently has been constructed to either predicatively or quantitatively assess the performance of the waterjet mill for coal comminution. The main reason for this is that the size reduction process in the high-pressure waterjet mill is strongly affected by a variety of feed properties and operating parameters. Moreover, effects of these factors are not constant but may undergo rapid changes with the parameters of the waterjet and feed properties. This phenomenon further complicates the comminution process of waterjets. As a result, an extensive and detailed study on the effects of these waterjet's parameters and feed properties is essential to fully understand the process of waterjet-based coal comminution.

Material and methods

Sample selection and preparation

A bituminous coal from Illinois (U.S.A) with 31% ash content was subjected to the comminution experiments. XRD analysis showed that the coal contains clay, quartz and pyrite as mineral matter. For sample preparation, a two-step crushing process was used. First, run-of-mine coal was crushed with a jaw crusher to minus 5.0 mm. It was then further crushed in a laboratory scale hammer crusher to minus 710 micrometer.

Experimental and apparatus

The comminution experiments were conducted in a high-pressure waterjet mill coupled with a cavitation cell designed by Greg Galecki based on his previous work (Galecki et al, 2013). This waterjet mill consists of a conventional abrasive cutting head and a cavitation cell. The schematic of the high–pressure waterjet mill is given in Fig. 1. A laser diffraction Microtrac S3500 series particle size analyzer, manufactured by Microtrac Incorporation, was employed to measure the particle size of the feeds and their resulting products.
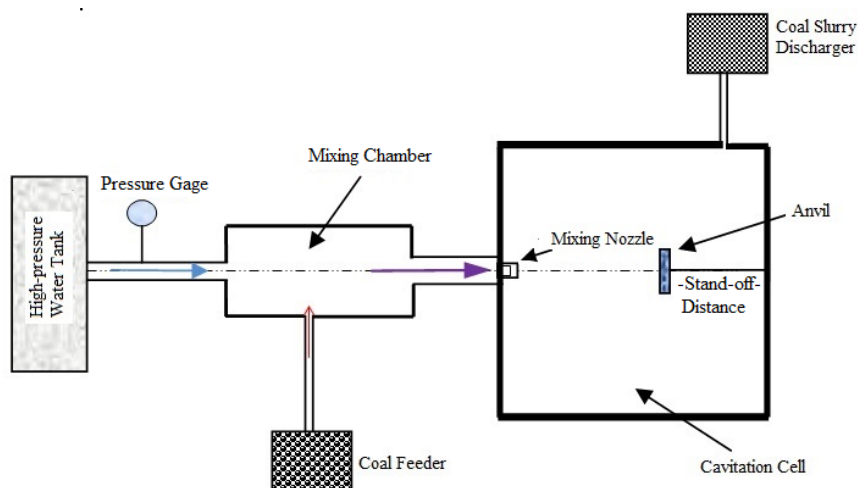
Fig. 1. Schematic of the high-pressure waterjet mill

Results and discussion

As important methods to assess the performance of grinding circuits, the cumulative volume under size plots, calculated surface area ratios, and particle size distribution plots were used to characterize the feeds and comminution products. Mean diameter in micrometers of the "volume distribution" representing the center of gravity of the distribution was set as a criterion to represent the fineness of the products. The comminution efficiency of the waterjet-based comminution was compared based on the calculated surface area change provided in units of M^2/cc. The operating pressure is the pressure of the water stream entering into the mixing tube. In this research, the operational pressure ranged from 69 to 276 MPa with a 69 MPa increment at 2 mm and 98 mm stand-off distance. The stand-off distance is the distance from the mixing nozzle to the anvil. It can be adjusted by varying the placement of the anvil in the cavitation cell. The results obtained from the experiments were presented in Fig. 2a and Fig. 2b
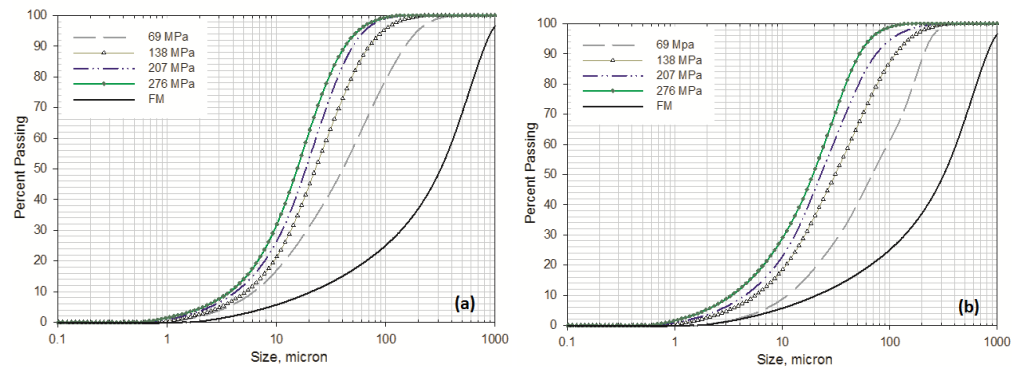
Fig. 2. Cumulative passing plots of products for -710 micrometer feed comminuted
at different operational pressures; feed material is abbreviated FM.
a) 2 mm stand-off distance, b) 98 mm stand-off distance

Experimental results presented in Fig. 2a and Fig.2b indicate that the decrease in stand-off distance from 98 to 2.0 mm resulted in an increase in the efficiency of size reduction process for all pressure values. In the comminution process of the high-pressure waterjet mill, the primary collision of the waterjet and coal particles takes place inside the abrasive cutting head. During this collision, the coal particles are accelerated by absorbing partial kinetic energy of the waterjet and mixed with it together and then coal water slurry jet travels into the cavitation cell and impacts against the anvil. A further size reduction therefore results. The efficiency of this impact comminution is determined by the kinetic energy of the coal-water slurry jet when it impacts the anvil. As the stand-off distance increases, the impact energy decreases. Therefore, the size reduction ratio reduces with increasing stand-off distance.
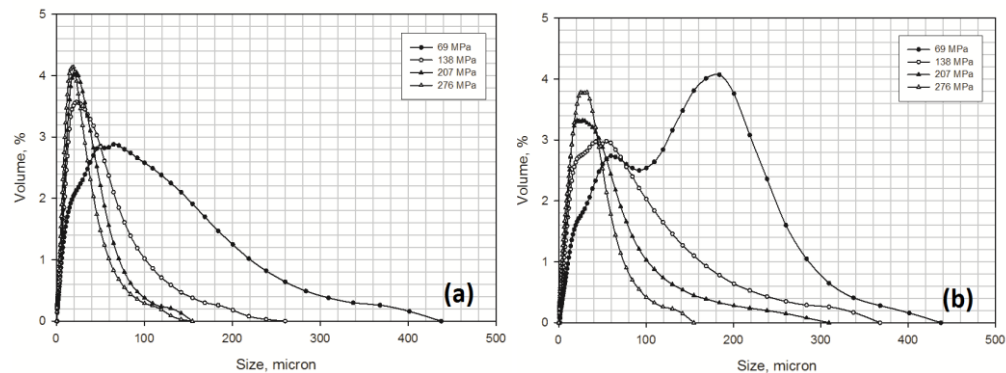

Fig. 3. Particle size distribution plots of the products for -710 micrometer feed comminuted
at different operational pressures. a) 2 mm stand-off distance, b) 98 mm stand-off distance

Analysis of the Fig. 2a and Fig. 2b indicates that the particle size change of coal exposed to the waterjet also strongly depends on the operational pressure. The dependence on the operational pressure was acutely correlated to the development of fine particles. More directly: the higher the operational pressure the finer the product is generated. This statement is connected with the observation from Fig. 3a and Fig. 3b that, as the pressure increased, the size distribution of products became narrower. Simultaneously, sizes of particles shifted to smaller values. A distinct accumulation peak around 10 micrometer could be observed.
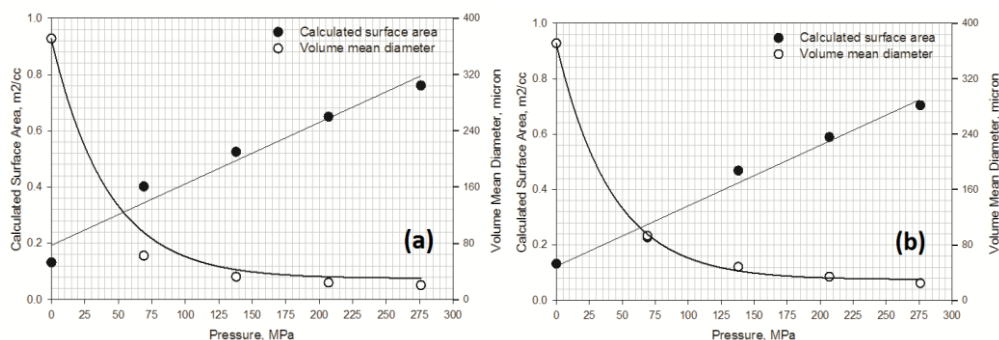

Fig. 4. Volume mean diameter and calculated surface area plots of the products for -710 micrometer feed comminuted at different operational pressures. a) 2 mm stand-off distance, b) 98 mm stand-off distance

Figure 3 and Fig. 4 also visualize that the use of 2 mm stand-off distance provides the generation of finer particles with a narrow size distribution compared to 98 mm stand-off distance. This also can be attributed to the influence of the stand-off distance on the impact energy. The major kinematic parameter in the impact comminution is the impact velocity. An increase in the impact velocity fractures smaller coal particles. Higher impact energy resulted in higher impact velocity. Consequently, sizes of particles subjected to milling at a shorter stand-off distance are smaller than those at larger stand-off distance in a situation where applied pressure is equal.

Conclusions

High-pressure waterjet coupled with cavitation cell offers a promising method for advancing clean coal technology and preparation of ultrafine particles for coal-water fuel. The results showed that waterjet-based comminution method can effectively produce ultrafine coal particles below 10.0 μm with a narrow size distribution. The waterjet-mediated coal comminution was strongly affected by the operating pressure and stand-off distance. Utilization of higher operating pressure smaller stand-off distance led to finer products due to increasing kinetic energy that coal-waterjet impacts against the anvil.

Acknowledgments

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