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Effects of various parameters on ultrasonic comminution of coal in water media

Ercan Sahinoglu, Tuncay Uslu *

Karadeniz Technical University, Department of Mining Engineering, 61080, Trabzon, Turkey

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ABSTRACT

This paper investigates the potential use of ultrasonic treatment in comminution of coal in water media. A laboratory type, high intensity ultrasonic generator (750 W, 20 kHz) equipped with a horn transducer system and a titanium alloy horn tip (13 mm in diameter) was used as a source of ultrasonic treatment. The tests were performed at different levels of variables including ultrasonic power level (9.5–113.6 W/cm^2), ultrasonic treatment times (5–20 min) and solid ratio of pulp (5–20% w/w). Temperatures of pulp atmosphere during ultrasonic treatment at different solid ratios and ultrasonic power levels were recorded. Particle size distribution curves were used to determine the degree of comminution. It was observed that ultrasonic treatment improved size reduction of coal significantly. Higher ultrasonic power levels and treatment times provided coal particles to be reduced to finer sizes. In addition, scanning electron microscope (SEM) and stereo microscope examinations were carried out to support test results. Selective comminuting ability of ultrasonic treatment was revealed from pyritic sulfur analysis for different size fractions of treated coal.

1. Introduction

Comminution of coal is essential for any kind of its effective utilization, be it through combustion, carbonization, gasification [1–3], the incorporation of coal injection in cement kilns to make cement clinker or in blast furnaces to assist in economic iron making [3]. In addition, coal slurry technology in which comminution is an important requirement has been also emerging rapidly [1,4].

Although comminution of coal to very fine sizes before cleaning is not required generally and coal cleaning is carried out after size classification following to comminution at great size, comminution to finer sizes can be imperative sometimes if the gangue disperses finely in the coal [4].

The sustainable development and utilization of coal require more efficient comminution methods. For that reason, a new generation of mills has been introduced as alternate low energy comminution systems [5]. Apart from the advanced mills, comminution of coal has been tried to be enhanced by using different systems. One of these systems is ultrasonic treatment [6]. Ultrasonic comminution has been reported as one of the promising candidates for improving comminution due to its high capacity to cause breakage at boundaries within the coal compounds by using low energy [7].

Ultrasonic treatment causes cavitation, that is, the formation, growth and collapsing of bubbles in a liquid. Collapsing of bubbles produces small areas of high pressure differences, resulting in micro turbulence [8–10]. When the ultrasound is applied to a mixture of particles–liquid and the bubbles collapse near the solid surface, a high speed jet of fluid is driven into the particles and this jet can deposit enormous energy densities at the site of impact [11]. This energy causes many chemical and physical effects on the particle. Particle comminution which is the focus of this study is one of these effects [12].

Use of ultrasound in comminution can be divided into two groups. The first one is use of ultrasound to drive the plates of comminution machine in which the ore is comminuted. In other words, ultrasound is not applied on the material to be comminuted. In the second group including also this study, ultrasound is itself a comminution energy which is introduced to solid materials in water media.

Several studies were undertaken on ultrasonic treatment for comminution of different minerals in water media. Gartner [13] was the first to apply ultrasounds to the fragmentation of particles in suspensions. The effect of ultrasound on the breakage characteristics of aluminum oxide particles suspended in water and identification of breakage mechanism was reported [12,14]. Size reduction of sodium chloride by using ultrasonic treatment in aqueous phase was undertaken [15]. Ultrasonic comminution in water media has been studied recently for clays due to its selective and gentle nature without affecting the mineralogical and morphological structure [16–19].

A few studies mentioned briefly and roughly about size reduction effect of ultrasounds for coal in water media. However, their purpose was to improve the coal processing methods such as flotation, agglomeration, and leaching by cleaning coal surface using ultrasonic treatment [20–22]. Very limited studies, relating directly on ultrasonic-based coal comminution have been undertaken [23,24]. Therefore, another works are required to fill the gap in this area. The present study focuses directly

* Corresponding author. Tel.: +90 462 3773530; fax: +90 462 3257405.
E-mail address: tuncay43@ktu.edu.tr (T. Uslu).

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Table 1
Proximate, sulfur and calorific value analyses of the coal sample.

	Air dried	Dried
Proximate analysis		
Moisture (%)	2.25	–
Ash (%)	34.85	35.65
Volatile matter (%)	10.73	10.98
Fixed carbon (%)	52.17	53.37
Sulfur analysis		
Sulfate sulfur (%)	0.99	1.01
Pyritic sulfur (%)	5.44	5.57
Organic sulfur (%)	1.3	1.33
Total sulfur (%)	7.73	7.91
Calorific value analysis		
Calorific value (kcal/kg)	4970	5084

Fig. 2. Experimental setup.

on the comminution of coal in water media by ultrasonic treatment and effects of ultrasonic power, ultrasonic treatment time, solid ratio and pulp temperature on comminution. In addition, unlike the limited number of previous studies, very detailed SEM and stereo microscope examination on ultrasonically treated coal samples were presented in the study.

2. Materials and methods

A coal sample from coal deposit located in Muzret (Artvin, Turkey) was used in this study. A fine coal sample of ≈150 kg was taken from coal deposit. A large portion of the sample was below 0.5 mm. The remaining little amount of sample whose size was over 0.5 mm was reduced to −0.5 mm by controlled dry grinding. The sample was divided by repeated coning and quartering until one fourth of initial sample (≈37.5 kg) was obtained. Then, chute rifflers having different chute opening sizes were used as repeated cycles for further dividing and mixings until the feed amounts (≈46 g) were obtained. The final sample was completed to ≈50 g by adding small samples taken from squares of chessboard placed samples. Proximate and sulfur analysis of the sample showed that Muzret coal had high ash and pyritic sulfur contents (Table 1). Pyrite is the primary mineral in the coal sample as seen from the polished section examination of coal (Fig. 1). Kaolinite, montmorillonite, illite, calcite, gypsum, and quartz were determined to be other mineralogical components of the sample.

Coal–water mixtures were subjected to ultrasonic treatment to ensure particle size reduction of coal. A laboratory type, high intensity ultrasonic generator (750 W, 20 kHz) equipped with a horn transducer system and a titanium alloy horn tip (13 mm in diameter) was used as a source of ultrasonic treatment. In an earlier study [25], actual intensity of power outputs (W/cm^2) at various amplitude settings of equipment used in this study, had been calculated calorimetrically. In an amplitude–power graph drawn according to this calculation, power levels corresponding to amplitude settings of 20%, 40%, 60%, 80%, and 100% were 9.5, 28.5, 45.7, 72.8, and 113.6 W/cm^2, respectively. The tests were performed at different levels of ultrasonic power levels (9.5, 28.5, 45.7, 72.8, and 113.6 W/cm^2), ultrasonic treatment times (5, 10, 15, and 20 min) and solid ratios of slurry (5%, 10%, 15%, and 20%). In addition, temperatures of pulp were measured and recorded during the ultrasonic treatment. Photo of experimental setup is illustrated in Fig. 2. Particle size analysis of original coal sample (Table 2) and ultrasonically treated coal samples were carried out. Size analyses were carried out by using standard sieving procedure in which automatic sieving machine was used. Results of the particle size analysis were used to draw the size distribution curves. Coals of different size fractions were analyzed for pyritic sulfur before and after ultrasonic treatment.

3. Results and discussion

As seen from Figs. 3–10, it is clear that ultrasonic treatment causes particle breakage of coal samples. While the weight percent of −0.5 + 0.3 mm fraction was decreased from 22.16% to 8.93%, weight percent of −0.053 mm fraction increased from 20.16% to 39.96% by ultrasonic treatment. In other words, maximum decrease in amount of coal in size fractions of −0.5 + 0.3 and maximum increase in amount of coal with particle size of −0.053 mm realized as 59.70% and 98.21%, respectively. Size reduction of coal particles can be attributed

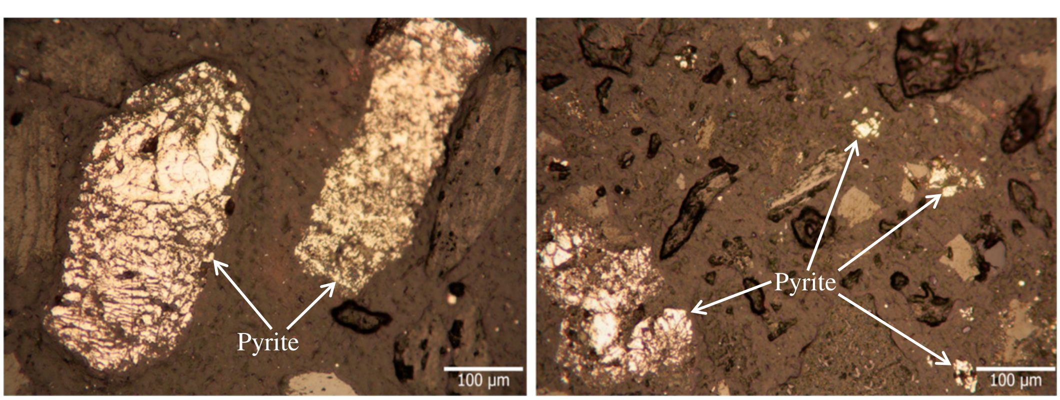

Fig. 1. Pyrite particles in the coal sample.