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Research article

Studies on carbon flotation from fly ash

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ABSTRACT

The separation of carbon from fly ash significantly improves the potential end-us of combustion byproducts. Froth flotation is the most effective separation technique for ultrafine material. Diesel dosages, conditioning time, and impeller rotating speeds' influences on carbon flotation performance were studied. From flotation products, +25 and −25 μm fractions were screened out to study their different flotation behaviors. At a given impeller speed, carbon recovery of +25μm fraction increased significantly from 38.46% to 74.22% over a range of diesel dosage from 0.5 to 4.5 kg/t, while that of -25 μm fraction was relatively constant at 85% over the same diesel dosage range. Morphologies and microstructures of coarse and fine carbon were studied by using scanning electron microscope. Porous structures of coarse carbon were observed. It's difficult for diesel droplets of several microns to penetrate the pores of coarse carbon particles, which increases diesel consumption. Increasing impeller speeds from 1200 to 1600 rpm during conditioning improved the carbon recovery and separation efficiency of +25 μm fraction by 79% and 110%, respectively, which significantly reduced diesel consumption. Flotation kinetic studies indicate that increasing impeller speeds during conditioning stage can improve the flotation rate constant and maximum carbon recovery for both +25 and −25 μm fractions.

1. Introduction

It has been estimated that 750 million tons of coal fly ash is generated on a global basis annually, and the global fly ash utilization figure is estimated to be 25% [1]. Carbon content in fly ash is within the range of 0.1–25% [2,3]. Fly ash is mainly used as a raw material for adsorbents, ceramics, glasses, geo-polymers, concretes, etc. There are limitations of the carbon content for these applications. For example, according to the ASTM C618-12a standard, the carbon content of class C, F, and N fly ash types used in concretes should be less than 6.0%, 6.0%, and 10.0%, respectively [4]. Altun et al. [5] pointed out that the carbon in fly ash used as raw materials of ceramics and glasses should be less than 1%. Since the implementation of the Clean Air Act of 1990, low-NO_x burners and catalytic reduction systems have been widely used, indicating that tuning the boiler to reduce carbon content in fly ash is impossible [1,3,5]. Meanwhile, utilizations of carbon from fly ash as metallurgical coke and activated carbon have appeared in iron making industry [1]. Therefore, efficient techniques of carbon recovery from fly ash are very important.

After its first significant industrial applications in early 20th century, flotation has been widely used in mineral processing industries. Many papers concerning carbon flotation from fly ash have been published since the 1970s. Hurst and Styron [6] used kerosene as a collector with 30 min of conditioning to obtain froth product with 70–80% carbon. Imhof and Henrich [7] found that using a modified pneumatic flotation cell could reduce residence time from more than 30 to 2 min. Grunewald and Ottersteter [8] achieved better separation with lower reagent consumption and shorter residence time by using a commercial flotation reagent. Hwang [9] obtained product with 80.21% carbon content by using fuel oil (No. 2) and strong stirring. Groppo et al. [10–12] conducted an extensive study using collectors which had been applied successfully in oxidized coal flotation and developed a reagent scheme to address the drawbacks of carbon flotation from fly ash, i.e., long residence time and high reagent cost.

Recently, significant work has been conducted using state-of-the-art flotation systems instead of conventional cells to recover carbon from fly ash. Niewiadomski et al. [13] used air sparged hydrocyclones and a commercial diesel collector to recover carbon from fly ash, and they obtained product with 35% carbon content and 54% carbon recovery. Gray et al. [14] used triboelectrostatic separation, ultrasonic column agglomeration, and column flotation to process the same fly ash sample. They determined that column flotation was the most effective method. Carbon concentrate with 61% carbon content and 62% carbon recovery was obtained. Huang et al. [15] successfully recovered 61.7% of the carbon from fly ash by using a flotation column with optimum parameter values, i.e., flotation time of 30 min, gas flow rate of 0.7 L/min, and kerosene dosage of 4 mL/L. Altun et al. [5] separated carbon from fly ash using a concurrent flotation column equipped with an additional bubble generator, and a clean ash product with less than 1% carbon was achieved.

Carbon in fly ash can be recovered efficiently by using proper reagents and equipment. However, some drawbacks such as large reagent consumption exist. In this publication, collector dosages, conditioning

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Table 1
Chemical composition of the sample.

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	MgO
%	50.84	26.77	6.75	3.57	2.07	1.54	0.85
Element	P_2O_5	SO_3	NaO_2	SrO	BaO	MnO	LOI
%	0.50	0.32	0.31	0.11	0.10	0.02	6.24

time, and impeller speeds' influences on the flotation of both coarse (+25 μm) and fine (−25 μm) carbon are presented. To explain the different flotation behaviors of the coarse and fine carbon, morphologies and microstructures were studied. The test results reveal the potential of reducing reagent dosage by manipulating operating parameter values such as impeller speeds. Flotation kinetic studies were conducted to determine the studied parameters' influences on whole flotation process.

2. Material and methods

Representative fly ash samples were collected from the electrostatic precipitators of an eastern U.S. coal powered facility. Feed coal of the plant is of high volatile A bituminous rank. Chemical composition of the fly ash determined by X-ray fluorescence (XRF) is reported in Table 1. By drying the sample in a 100 °C furnace for 12 h, moisture of the sample was calculated to be 0.83 ± 0.07%. According to the ASTM C618-12a standard, this fly ash was classified as class F fly ash [4]. X-ray diffraction (XRD) was used to identify main mineral phases in the sample. XRD pattern of the fly ash shows that mullite, quartz, and sillimanite are three major minerals. Diesel and F940 were used as collector and frother, respectively. F940 is a commercial glycol-based frother.

Size distribution of the fly ash was determined by using wet screening and following sieve sizes: 100 (0.15 mm), 200 (0.075 mm), 325 (0.045 mm), 400 (0.038 mm), and 500 (0.025 mm) mesh. Before screening, ultrasonic treatment was used to thoroughly disperse the fly ash particles. To determine the flotation performance of +25 and −25 μm fractions, concentrates and tailings were subjected to wet screening using a 500 mesh sieve. A Field Emission-Scanning Electron Microscope (HITACHI™, S-4300) was used to study particle morphology and microstructure.

Flotation tests were accomplished by using a Denver flotation machine equipped with 1 L cell. For each flotation test, 100 g of the as received fly ash sample was added directly into the cell. The slurry was stirred for 1 min with 1200 rpm impeller speed to mix thoroughly. Then, 1 kg/t collector and 0.75 kg/t frother were added into the cell successively, and conditioned for 5 and 1 min, respectively. After conditioning, airflow was introduced to the cell at a rate of 3.6 L/min. The concentrate was continuously removed over a period of 3 min. For parametric studies, the corresponding parameters will be changed accordingly. For flotation kinetic tests, froth concentrate was collected throughout the following time periods: 0–5 s, 5–15 s, 15–30 s, 30–45 s, 45 s–1 min, 1–2 min, and 2–3 min. The remaining slurry in the cell was collected as tailings.

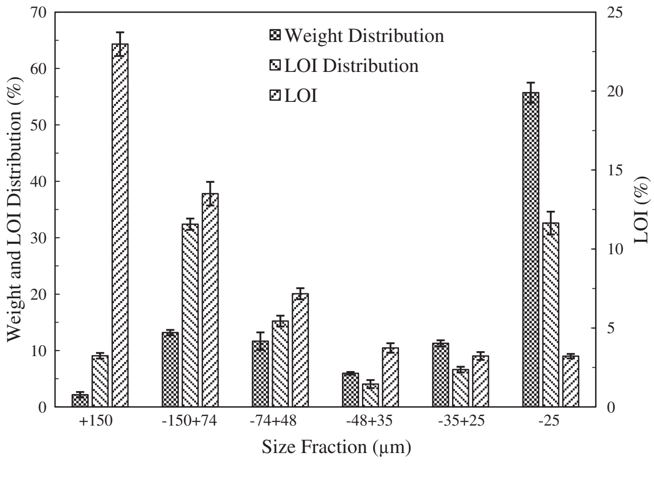

Fig. 1. LOI, LOI distribution, and weight distribution in different size fractions of the feed fly ash.

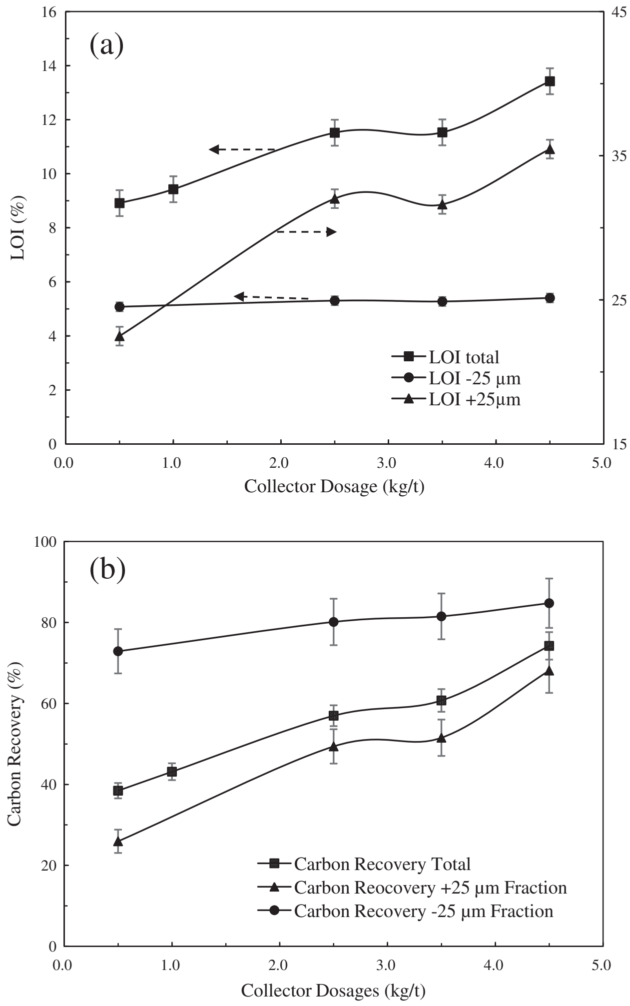

Fig. 2. Effects of diesel dosages on flotation performance of the total concentrate, +25, and −25 μm fractions. (a) LOI; (b) carbon recovery.

Carbon content was represented by loss of weight on ignition (LOI), which was measured following the ASTM D7348-08 standard [16]. LOI, carbon recovery, ash recovery, and separation efficiency were used to evaluate the experimental results, which were calculated as follows:

$$W_p(\%) = M_p/M_F \times 100 \tag{1}$$

$$\text{Carbon Recovery}(\%) = \left(W_p \times LOI_p\right)/LOI_F \tag{2}$$

$$\text{Ash Recovery}(\%) = \left[W_p \times \left(100 - LOI_p\right)\right]/\left(100 - LOI_F\right) \tag{3}$$

$$\text{Separation Efficiency}(\%) = \text{Carbon Recovery} - \text{Ash Recovery} \tag{4}$$

where M_P is the weight of dry products (g), M_F is the weight of dry feeds (g), LOI_P is the LOI of products (%), and LOI_F is the LOI of feeds (%). To evaluate the flotation results of +25 and −25 μm fractions, weights and LOI were quantified individually. Repeated tests were conducted for each series of experiments. Average values and uncertainties were utilized in the data analysis. The uncertainty analysis was performed according to Bell [17].