Fuel 107 (2013) 848–851

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Mechanism of the effect of alkali metal on the electrostatic precipitability of fly ash

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HIGHLIGHTS

- Ash samples with different alkali contents were prepared using three methods.
- The effects of sodium and potassium content on the specific resistance in fly ash were reported.
- The mechanisms of sodium and potassium on volume and surface resistivity were discussed.

ARTICLE INFO

Article history:
Received 17 December 2012
Received in revised form 1 February 2013
Accepted 3 February 2013
Available online 18 February 2013

Keywords:
Fly ash
Specific resistivity
Alkali element
Electrostatic precipitability

ABSTRACT

The alkali element content is second only to the sulfur content as the most important factor affecting dust-specific resistivity. Size sieving, soaking in distilled water, and ion migration at a high voltage are effective methods of changing the sodium and potassium contents in fly ash. Ash samples with different alkali contents were prepared by the aforementioned methods. The effects of sodium and potassium contents and morphosis on the specific resistance of fly ash were analyzed. Based on the morphosis of alkali compounds in coal and on the analysis of the combustion process, the mechanisms underlying the effects of sodium and potassium on volume resistivity and surface resistivity were determined. Sodium and potassium were related to the specific resistance in fly ash, i.e., a higher alkali content resulted in a lower specific resistance of fly ash. However, the instability of sodium causes it to react easily with water vapor, HCl, and SO_3 in a boiler to produce Na_2SO_4 and NaCl. In an electrostatic precipitator, the electrically conductive component is distributed outside the particle and makes contact with water vapor to form a liquid film, which in turn becomes the charge carrier for fly ash conduction. These reactions significantly improve the conductivity and decrease the surface resistance of fly ash.

1. Introduction

Coal is a dominant energy source in China, and this status is not projected to change in the coming years. However, the amount of fly ash discharged from existing coal-fired power plants has been increasing and has reached over 300 million tons per year in China. In particular, the particulate matter emission standards has increased from 50 mg/m^3 to 30 mg/m^3, with the new emission standard of air pollutants for thermal power plants (GB 13223-2011) promulgated in China. Thus, the country has become more serious in controlling pollutant levels.

An electrostatic precipitator (ESP) is a particulate control device used in modern pulverized-coal-fired power plants and in the cement industry to collect fly ashes from flue gas. Compared with mechanical ash separators such as gravitational settling devices and cyclones, ESP achieves high overall mass collection efficiencies usually above 99% [1,2]. However, the collection efficiency of ESPs in some power plants (Jungar 96.9%, Tuoketuo 96.7%) has decreased after burning Jungar coal in Inner Mongolia, China. The fly ash from the Jungar Power Plant in Inner Mongolia, China is unique because it has a high concentration of alumina ($Al_2O_3 > 50\%$) and a low concentration of Alkali elements (Na_2O and $K_2O < 0.50\%$).

The Na_2O content is the second only to the sulfur content as the most important factor affecting dust-specific resistance. Na_2O can conduct electricity in its ionic form. The Na_2O content also contributes to the decrease in specific resistance and dust precipitation [3,4]. K_2O is believed to have the same effect, but the larger ionic radius of potassium (K) ion and easier transformation into the glass phase make the effect of K_2O weaker than that of Na_2O.

The main purpose of this paper was to develop a method of changing the lithium (Li), sodium (Na), and K contents of fly ash. Other elements that affect the dielectric property of fly ash cannot be controlled, and the structure and existential form of chemicals cannot be changed. By measuring the specific resistance, the effect of alkali metals on electric conduction can be clearly explained.

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0016-2361/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2013.02.004

2. Specific resistance of a fly ash sample that contains different alkali metal contents

The specific resistivity was examined using a dust electrical resistivity test instrument invented by our group. This instrument adopts a lifting dish electrode and a specific circuit design method which enable the concentricity and parallelism of the top and bottom electrode to be adjusted. After the device lifts and puts down the dish, the pressure on the surface of fly ash can be accurately stabilized at 10 g/cm^2, and the reliability is enhanced [5].

To determine the effect of alkali element contents in fly ash on the collection efficiency and resistivity of an ESP, fly ash with various alkali element contents must first be obtained. In changing the alkali metal content of fly ash, the structure of every chemical compound should be maintained to determine the exact effects of alkali metals on the specific resistance of fly ash.

2.1. Size sieving method

Some papers [6–8] have reported that the mineral components and contents differ among coal dust with different particle diameters. The contents of the chemical components of coal ash are also related to the particle size of coal dust combusted in the boiler. Thus, the ash sample can be screened through 100, 140, and 200 mesh sieves to obtain ash samples with particle sizes of <76 , 76–105, 105–154 , and >154 μm, respectively. The specific resistance and elemental contents of the four samples with different particle sizes were then measured with a high-pressure dust resistivity test bench. The data are shown in Table 1 and Figs. 1 and 2.

Fig. 1 shows that the Na, Li, and K contents initially decreased and then increased. The alkali metal in the coal organic matter can volatilize during combustion. When the temperature decreased to below 982 °C, sodium vapor accumulated on the escaped ash. Thus, fly ash that consisting of small particles contained high alkali metal contents.

However, fly ash with different particle diameters had different porosities and specific areas. Small particles had small stacking densities and large porosities, which resulted in increased volumetric ratio between air and the particles. These small particles reduce the ability to conduct electricity; in other words, these particles had high specific resistance. Fig. 2 shows that the volume resistance of fly ash with diameters below 76 μm was significantly low mainly because the alkali metal-induced decrease in the specific resistance was greater than the particle size effect.

2.2. Soaking by distilled water

Some studies [9,10] have shown that alkali metals in fly ash are generally in the form of salts and oxides. Some of these metals exist on the surface of vitreous bodies. The activities of Li, Na, and K were significantly higher than those of Si, Ca, Fe, and Al. Thus, the method of soaking in distilled water was used to lixiviate some alkali metals.

A specific experimental method was to add fly ash to distilled water followed by stirring the mixture using a magnetic stirrer. The stirring speed and ash weight were fixed, but the stirring and soaking times were varied. The cement–water mixture was then filtered three times. After drying the ash, the chemical component and specific resistance were measured. The results are shown in Table 2 and Fig. 3.

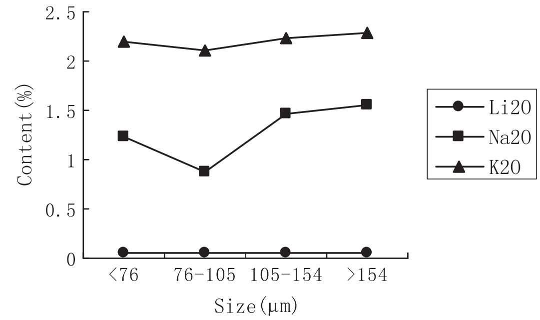

Fig. 1. Alkali content in fly ash with different particle size.

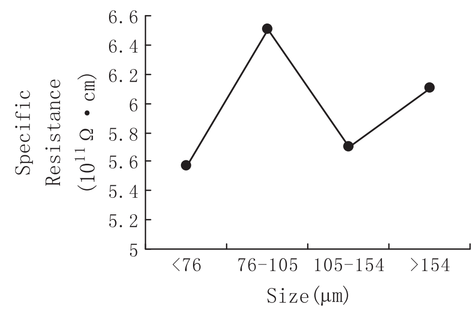

Fig. 2. Specific resistance in fly ash with different particle size.

Fig. 3 shows that the Na content in the ash sample significantly decreased from 1.42% in the original ash to 0.69% in the ash soaked in distilled water for 24 h because of the low Na concentration in ash. The decrease in K was not as high as that in Na after soaking in distilled water. This result was mainly due to the higher activity of Na than K. The K ion is also large, K can easily transform into the glass phase, and elemental K in ash rarely exists as an ion. The Li content decreased from 0.048% to 0.033%, which meets the purpose of the experiment.

Table 2 shows that the Si, Ca, Fe, and Al contents of the ash soaked in distilled water showed negligible changes compared with the original ash. No chemical reagents was added, and no chemical reaction occurred. Thus, soaking in distilled water was a physical lixiviation process that changed the Li, Na, and K contents but did not affect the form and structure of other elements.

With increased soaking time, the extracted alkali metal contents increased, whereas the Li, Na, and K contents decreased in the ash sample. Fig. 4 shows the corresponding increase in the specific resistance of the ash sample soaked in distilled water. Therefore, specific resistance was associated with the Li, Na, and K contents, i.e., the specific resistance increased with decreased alkali metals in fly ash.

2.3. Ion migration at a high voltage

At high temperatures, electrical conduction is due to volume conduction and is associated with the ash component. Electrical

Table 1
Chemical component and volume–resistance in fly ash with different particle size.

Coal particle (μm)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	Li_2O (%)	Na_2O (%)	K_2O (%)	Specific resistance (Ω cm)
<76	46.8	7.3	34.4	1.8	0.047	1.5	2.3	5.6×10^{11}
76–105	47.6	7.4	33.8	1.7	0.046	0.9	2.1	6.5×10^{11}
105–154	48.5	7.6	33.0	1.7	0.048	1.4	2.1	5.7×10^{11}
>154	49.7	7.7	31.7	1.7	0.046	1.2	2.1	6.1×10^{11}