Fuel 216 (2018) 673–680

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Measurement and prediction of fly ash resistivity over a wide range of temperature

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ARTICLE INFO

Keywords:
Wide temperature region
Fly ash resistivity
Chemical composition
Prediction model
High-temperature electrostatic precipitator

ABSTRACT

Resistivity is a key factor in the efficient and stable operation of electrostatic precipitators. Sixty types of typical industrial fly ashes were collected for this study. Subsequently, fly ash resistivity at the temperature range of 303–1073 K, and the chemical compositions, micrographs, and size distributions of the samples were measured. The joint influence of chemical composition and temperature on resistivity was also investigated. The main components of the fly ash samples were Fe (0.8–5.0%), K + Na + Li (0.3–5.1%), Ca + Mg (0.5–4.0%), and Al + Si (10–34%), respectively. Fe, K, and Na were highly sensitive to fly ash resistivity. Resistivity decreased with the increase in Fe, K, Na, and Li contents; by contrast, resistivity increased with Ca and Mg contents. The effects of Si and Al on fly ash resistivity were weak. Resistivity initially increased first and then decreased with the increase in temperature. Maximum resistivity was observed at 373–473 K. Based on the experimental data, a prediction model for fly ash resistivity over a wide range of temperature (303–1073 K) was established. The resistivity diagrams generated specifically for this study suggest that typical fly ash samples from different industries can be estimated using chemical composition and temperature data.

1. Introduction

Particulate matter adversely affects human health and the environment [1]. Coal-fired power plants, biomass power plants, waste plants, cement kilns, steel factories, glass kilns, coal gasification structures, and other modes of consumption in the energy industry were identified as the main sources of pollutant emissions. The characteristics of dust, gas temperature, and gas composition differ for each industry (e.g., fly ash particles produced in the power industry, ore particles in the metallurgical industry, and high aluminum/silicon particles in cement plants and glass kilns) [2–4]. Electrostatic precipitators (ESPs) are widely used in collecting fly ash samples because of their low cost and technical advantages, such as low-pressure drop, stability, and adaptability features [5,6].

Fly ash resistivity is an important parameter in ESP design and operation [7]. Particle migration, as well as anti-corona and dust removal on collecting plates, affects fly ash resistivity. Accordingly, these factors considerably affect ESP efficiency in principle and practical use [8]. Previous studies have shown that the most suitable range in measuring fly ash resistivity is at $10^4 - 5 \times 10^{10}$ Ω·cm. However, for low resistivity (i.e., below 10^4 Ω·cm), serious back mixing is common; for high fly ash resistivity (i.e., above 10^{11} Ω·cm), back corona and secondary blowing of fly ash occurs [9,10]. Fly ash resistivity can also be affected by temperature and humidity of gases, chemical composition of ashes, and the sulfur content of burning coal [11]. Xu studied fly ash samples in the range of 673–1273 K and found that resistivity decreases at high temperatures [12]. Resistivity also decreases with the increase of Na, K, and C contents [13–15]. In addition, fly ash resistivity rises with an increase in Al. When Al_2O_3 is above 50%, resistivity exceeds 10^{12} Ω·cm [16], Maximum resistivity has been studied mostly with Li_2O, Na_2O, Fe_2O_3, and water vapor [17]. Biekelhaupt measured the fly ash resistivity of a coal-fired power plant, after which a prediction model of fly ash resistivity called Biekelhaupt model was established at the temperature range of 363–673 K. Although fly ash resistivity has been studied considerably, most focused only either at a narrow temperature range or for coal-fired power plants while ignoring the ash components from other industries [18,19]. Given that ESPs are commonly used by industries to analyze different temperature ranges and atmospheres, further research is thus required to understand resistivity. Chemical composition (e.g., Si, Al, Mg, Li, Fe, K, Na, and Ca) of fly ash samples from various industries should also be analyzed at a wide temperature range to study the influence of temperature and chemical composition on resistivity.

A measurement system was designed and built to study fly ash resistivity in different atmospheric and high-temperature conditions. The study focused on typical industrial fly ashes. Subsequently, the

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https://doi.org/10.1016/j.fuel.2017.12.047
Received 14 September 2017; Received in revised form 8 December 2017; Accepted 12 December 2017
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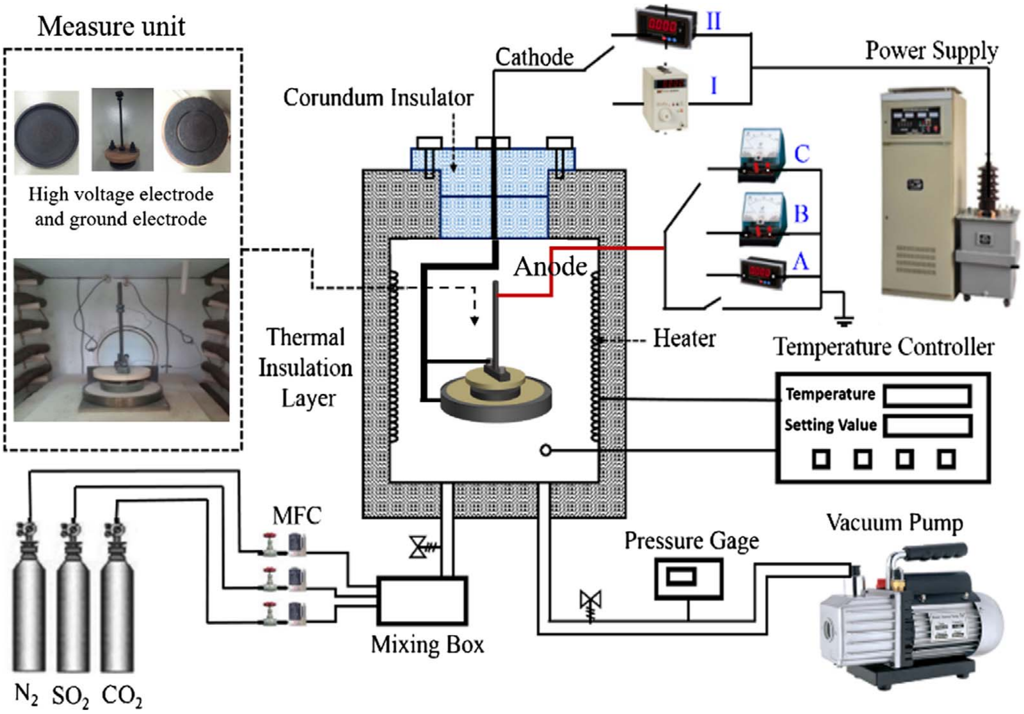

Fig. 1. Schematic of the measurement system of fly ash resistivity.

morphological characteristics and chemical composition were analyzed, and the resistivity in a wide temperature range was measured. The influence of temperature and chemical composition on resistivity was studied vigorously. The resistivity prediction model was established statistically, and the relationship of resistivity with chemical composition and temperature was determined. The diagram curves of the fly ash resistivity model changed with temperature and chemical composition, further suggesting that the present study can intuitively predict resistivity values.

2. Experimental

2.1. Experimental apparatus

Fly ash resistivity is normally measured using leakage currents, fly ash layers, and high-voltage conduction cells [13]. Following this principle, the measurement system of the present study was designed to obtain resistivity values over a wide temperature range (Fig. 1). The facility comprised systems for temperature control, atmosphere adjustment, high-voltage measurement, and current measurement.

The system for temperature control, composed of the electric heater and regulator, can accurately operate at specific temperatures from ± 1 K to a maximum of 1073 K. The units for 300 K and 873 K are shown in Fig. 2. For the atmosphere adjustment system, the gas was controlled by a flowmeter attached to a buffer tank and a chamber. A negative DC high-voltage power supply was used to provide 0–30 kV to the units. The voltage is detected by a high-voltage meter (CC1940-3, AC/DC = 30 kV) and a digital voltmeter (DF4, DC = 1000 V), corresponding to I and II in Fig. 1, respectively. The current is detected by three parallel ammeters, namely, an ammeter (0–1 mA, 1 μA), a DC reflow galvanometer (AC15/1, 0–13 μA, 2.0×10^{-9} A) and a DC reflow galvanometer (AC15/4, 0–1.3 μA, 2.0×10^{-9} A) corresponding to A, B, and C in Fig. 1, respectively.

2.2. Fly ash preparation and measurement

Fly ash resistivity was measured following IEEE 548-2002 and Chinese JB/T 8537-2010 standards [20]. The fly ash sample was screened by an 80-mesh sieve and heated for 2 h at 110 °C. The sample was naturally spilled onto test plates in a grounded environment chamber. The upper electrode was gently placed onto the ash with a defined pressure. The oven was started, and once the desired temperatures were reached, the readings for temperature, voltage, and current were taken using the instrumentation provided in the test facility. Fly ash resistivity can be calculated from the standard relation

$$\rho = \frac{AV}{hI} \tag{1}$$

where ρ is the resistivity of the particle (Ω·cm), *A* is the cross-sectional area of the particle layer (cm^2), *h* is the cross-sectional thickness of the particle layer (cm), *V* denotes voltage (kV), and *I* represents current (A).

2.3. Fly ash characterization

Sixty types of fly ash samples from six emission-polluting industries were gathered for the present study. Particle size distribution was measured by a laser particle size analyzer (Mastersizer 2000). The microstructure and morphological characteristics of the samples were observed by high-resolution field-emission scanning electron microscopy (FESEM). X-ray fluorescence was used to detect the chemical composition of each sample. The Li content of the samples was measured by atomic absorption spectrometry [21,22].

3. Results and discussion

3.1. Fly ash characterization

In the present study, fly ash resistivity was influenced by chemical composition and particle size distribution; based on past works, the shape fly ash particles can also affect the separation process and collection efficiency of ESPs [23,24]. Consequently, the chemical compositions, surface structures, and particle size distributions of the samples were investigated.

Table 1 presents the weight percentage of the chemical components of the samples from different industries. The 60 types of fly ash were collected nationwide. To meet the study requirements, samples with observable differences at a wide temperature range were collected. The

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