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Capture efficiency of coal/biomass co-combustion ash in an electrostatic field

Jianyi Lu [a,*], Lili Fu [a], Ximei Li [a], Eric Eddings [b]

[a] School of Environmental Science and Engineering, North China Electric Power University, Baoding 071003, China
[b] Department of Chemical Engineering and Institute for Secure and Clean Energy, University of Utah, Salt Lake City 84112, USA

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ABSTRACT

Ash samples from corn stalk and coal co-fired at 0%, 5%, 10%, 15%, 20%, and 100% biomass were collected by a 4-stage wire-pipe type electrostatic precipitator (ESP), and the ratio of $^{14}C/^{12}C$ in ash samples from the 0%, 20%, and 100% co-firing scenarios were measured by an accelerator mass spectrometer. The differential capture efficiency in electrostatic fields for coal ash, coal/biomass co-combustion ash (co-ash), and pure biomass ash was studied separately based on the ratio $^{14}C/^{12}C$. Other factors that may influence capture efficiency were analyzed, including microscopic morphology, resistivity, dust density, and particle size distribution. The results indicate that co-ash may be efficiently captured by ESP, while pure biomass ash could not. Co-ash capture was mainly concentrated in the first two electrostatic fields in the lab-scale ESP, and the overall capture efficiency exceeded 90%. Biomass addition decreased the resistivity of co-ash, and enhanced its surface adsorption capacity to form agglomerates, facilitating the capture of co-ash. The capture efficiency of coal ash in co-ash was higher than that of pure coal ash in the first electrostatic field of the ESP. Co-firing biomass can aid the removal of both coal ash and biomass ash when using an ESP.

1. Introduction

Energy is an important factor in the development of a national economy, and the shortage of sufficient energy supply has become an important factor restricting economic development (Chen & Wu, 2017). China's energy structure is characterized by "rich coal, lack of oil, less gas", which shows coal as the main energy source in China (Xie, Li, & Zhao, 2010). In recent years, there has been an increased interest in biomass energy use around the world, and there has been a corresponding upsurge in the development and utilization of new technologies for biomass-based energy production. Therefore, optimizing energy infrastructure to improve the proportion of renewable energy use is an important direction for China's energy development. Biomass is a unique carbon source that is abundant and renewable (Al-Hamamre et al. 2017). CO_2 absorbed by biomass during photosynthesis corresponds to the amount of CO_2 emitted by the biomass when it burns, leading to a net "zero discharge" of CO_2 vis-a-vis the combustion process (Bassano, Deiana, & Girardi, 2014). Replacing traditional fossil fuels with biomass can not only lessen the problem of energy depletion but also reduce CO_2 emissions that contribute to the greenhouse effect. However, owing to the low calorific value of biomass, very large quantities are required for use in utility-scale power production. Because of challenges associated with large-scale growth, harvesting, and shipping of biomass, an attractive alternative for biomass utilization is the co-combustion of biomass with coal, which offsets a portion of fossil-based CO_2 emissions. In addition, studies have indicated that ash deposition problems often attributed to biomass combustion are manageable when co-firing the biomass with coal at low biomass percentages (e.g. 10%) (Sami, Annamalai, & Wooldridge, 2001; Eddings, McAvoy, & Coates, 2017).

At present, the primary technology used for dust removal at coal-fired power plants in China is electrostatic precipitation (ESP). If a traditional coal-fired power plant boiler is considered for retrofit to co-combust biomass and coal, an important question is whether the ESP can be used for efficient removal coal/biomass co-combustion ash (co-ash). Biomass alters combustion characteristics during co-combustion and can make charge and electrostatic field characteristics of the co-ash in the ESP different from those of pure pulverized coal ash (Lu, Xu, Lu, Deng, & Eddings, 2017). The capture efficiency of biomass/coal co-ash in ESP has not been

* Corresponding author.
E-mail address: lujianyi@tsinghua.org.cn (J. Lu).

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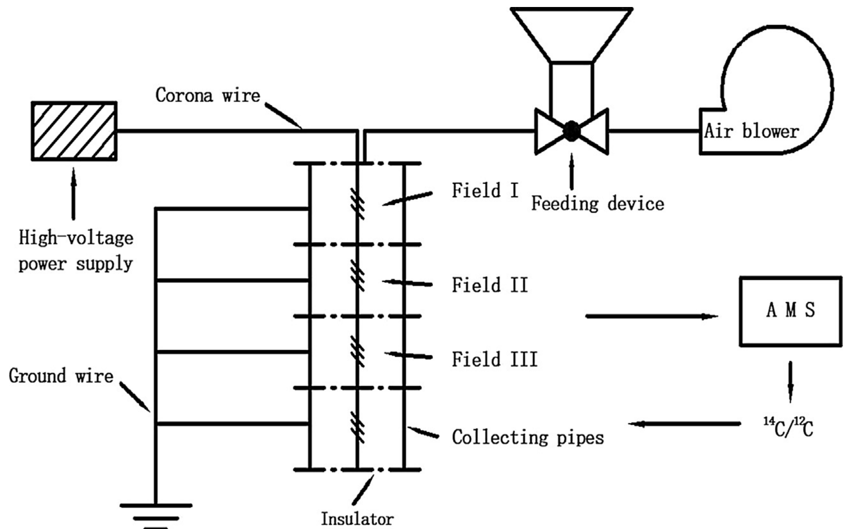

Fig. 1. Schematic of experimental setup.

widely researched, so it is an interesting and urgent problem to be addressed.

^{14}C isotope techniques have been used in medical, archaeological, geological, and other disciplines (Jun,Takao, Jun, & Tomohiro, 2004; Megens, Van der Plicht, De Leeuw, & Smedes, 2002). In recent years, ^{14}C technology has also been used in research into atmospheric pollution. The carbon isotope ratio technique is used to quantitatively estimate the relative contribution of particulate matter derived from fossil and non-fossil fuels. This method can be used to estimate the contributions of carbon dioxide emissions from coal, motor vehicle exhaust, and biomass sources to urban atmospheric CO_2, to help provide an overall assessment of the distribution of carbon emissions in the atmosphere (Piletic et al., 2013; Zhang et al., 2014, 2015; Shi, Guo, Jiang, Rui, & Zeng, 2016). Megens et al. (2002) analyzed the composition of stable and radioactive carbon in organic matter with different particle sizes. Fine particles (<20 μm) were found to have a higher ^{14}C content, and their $\delta^{13}C$ values were also higher, illustrating that the organic matter had different origins.

It is generally accepted that fossil fuels do not contain radioactive carbon, whereas modern biomass has very high ^{14}C content (Li, 2010). Based on this characteristic, elemental C in co-ash would contain ^{12}C from coal and ^{14}C from biomass, and thus the capture efficiency of biomass ash or coal ash could be calculated by the ratio $^{14}C/^{12}C$ in co-ash collected by an electrostatic field. Therefore, ^{14}C technology can be used to determine whether the addition of biomass affects overall capture efficiency, whether the differential capture efficiency is the same for biomass ash and coal ash in different electrical fields, and to identify which factors influence capture efficiency. In the present work, co-ash samples from mixtures of corn stalk and coal co-fired at different ratios were collected in a 4-stage wire-pipe type ESP, and $^{14}C/^{12}C$ in ash samples from 0%, 20%, and 100% co-firing were measured by an accelerator mass spectrometer (AMS). Based on $^{14}C/^{12}C$, the capture efficiencies of coal ash, co-ash, and pure biomass ash in electrostatic fields were separately studied. ^{14}C technology was introduced in the study and used to determine whether and how the addition of biomass affects the capture efficiency of co-ash in an ESP.

2. Experimental

2.1 Ash sample preparation

Biomass briquettes (corn stalk) and coal (from Kaifeng power plant) were used in the co-combustion experiments. The coal and biomass were ground and sieved before co-combustion. The resulting ash samples were also sieved by screen to separate particles into a size range of 80–120 mesh (177–125 μm), in order to produce ash samples that were similar in size for the tests. The ash samples were prepared as follows (Lu et al., 2017). Biomass was mixed with coal at ratios 0% (pure coal), 5%, 10%, 15%, 20%, and 100% (pure biomass) on an energy basis, followed by co-combustion. Pure coal ash and biomass/coal co-combustion ash samples were prepared according to the test method for analysis of coal ash (GB/T 1574, 2007). The fuels were put into a muffle furnace and burned in air for 30 min at 500 °C, and then burned in air for 1 h at 815 °C. Pure biomass ash was prepared according to the standard test method for ash in biomass (ASTM, 2007). The biomass fuel was put into the muffle furnace and burned in air for 1 h at 250 °C, and then heated to 600 °C within 30 min and burned in air at that temperature for an additional 3 h. The ash samples were taken out and placed on a heat-resistant asbestos board, cooled in the air, and then transferred to a desiccator and cooled to room temperature for preparation.

2.2 Ash classification and capture

To measure the differential capture efficiency of co-ash samples in an electrostatic field, a four-stage, high-voltage wire-pipe-type ESP was used. The setup is shown in Fig. 1. As shown, this ESP comprised an air blower, power feeding device, corona wire, collecting pipes, high-voltage power supply, and grounded wires. The device consists of four electric fields, each of which was separated by insulating material between the pipes. At room temperature, ash samples were added to the powder feeding device, and the high-voltage power supply was adjusted to about 20 kV (greater than the corona voltage but less than the breakdown voltage). Then, the air blower and powder feeding device were switched on to initiate the experiment. After mixing with the air, the ash particles entered the electrostatic trap at a velocity magnitude of ~1.0 m/s. The ash particles were then classified and captured by the electrostatic fields. At the end of an experiment, the air blower and power supply were turned off and the ash samples were collected from the dust-collecting poles within the electrostatic trapping device.

2.3 AMS assay and calculation of ^{14}C

Based on theory for the ^{14}C dating method (Jun et al., 2004), we hypothesized that we could use the principle to distinguish between carbon derived from biomass and carbon derived from