



Full Length Article

Mineral transformation and emission behaviors of Cd, Cr, Ni, Pb and Zn during the co-combustion of dried waste activated sludge and lignite



Ruikun Wang^{a,*}, Zhenghui Zhao^a, Qianqian Yin^a, Jianzhong Liu^b

^a Department of Power Engineering, North China Electric Power University, Baoding 071003, Hebei Province, China

^b State Key Laboratory of Clean Energy Utilization, Zhejiang University, Hangzhou 310027, Zhejiang Province, China

HIGHLIGHTS

- Co-combustion of lignite and waste activated sludge (WAS) is conducted.
- Mineral transformation and emission behaviors of heavy metals are determined.
- Anorthite, quartz, pyroxene, and albite are the main components of lignite-WAS ash.
- Effects of O₂ concentration and temperature on the volatilization of heavy metals.

ARTICLE INFO

Article history:

Received 9 January 2017

Received in revised form 20 February 2017

Accepted 13 March 2017

Available online 19 March 2017

Keywords:

Mineral transformation

Heavy metals

Elements volatilization

Co-combustion

Waste activated sludge

Lignite

ABSTRACT

Co-combustion of dried waste activated sludge (WAS) and lignite was conducted in a horizontal tube furnace system. The mineral transformation and emission behaviors of Cd, Cr, Ni, Pb, and Zn during combustion were examined. The above heavy metals (HMs) were selected because they are more abundant in WAS than in lignite. In the combustion condition of 1000 °C–21% O₂–30 min, the minerals in lignite ash were mainly anorthite (CaAl₂Si₂O₈), quartz (SiO₂), pyroxene [Ca(Mg,Fe)Si₂O₆], and albite (NaAlSi₃O₈). By contrast, the minerals in WAS ash were mainly quartz (SiO₂), anorthite (CaAl₂Si₂O₈), and hematite (Fe₂O₃). When 90% lignite and 10% WAS were co-combusted, hematite was hardly detected in the combustion product because hematite reacted with quartz and calcium oxide, which are abundant in lignite ash, and generated a large amount of pyroxene. Anorthite and pyroxene were generated continuously during the combustion process, but albite was mainly generated during the first 5 min of combustion. High temperature promoted the generation of complex components, such as sodian anorthite [(Ca, Na)(Si, Al)₂Si₂O₈ or (Ca, Na)(Si, Al)₄O₈]. High O₂ concentration promoted the reaction among the three main mineral elements, i.e., silicon, aluminum, and calcium, and generated a large amount of anorthite. During the co-combustion of WAS and lignite, the volatilization percentages of Cd, Pb, and Zn exceeded 30% after a combustion time of 30 min, and the order was Cd > Pb > Zn. By contrast, the volatilization percentages of Cr and Ni were lower than 15%. High temperature caused an increase in the volatility of HMs, especially Zn and Ni, although the volatilization percentage of Ni remained low. High O₂ concentration also caused an increase in the volatility of HMs, except for Cr and Ni, which showed a slight increase or decrease with increasing O₂ concentration in the inlet atmosphere.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Effective and economic handling of waste activated sludge (WAS) has become a practical problem that should be solved immediately because large amounts of salts, nutrients, heavy metals, pathogens, and organic pollutants are contained in WAS, and serious environmental pollution could occur if WAS is not treated

properly. Lignite reserves are very large, and its application is promoted in China. Its primary application mode is burning to generate power. WAS can be used as boiler fuel by co-firing with lignite. Waste handling is fulfilled simultaneously as energy is recovered, and the toxic organics are destroyed. Large amounts of volatile compounds in WAS are released and combusted easily in the early combustion stage [1]. The heat produced by volatile combustion increases the local temperature and promotes the further release of volatile compounds and carbon combustion [2,3]. High flame temperature is also beneficial for the burnout of co-combustion

* Corresponding author.

E-mail address: ruikun_wang@163.com (R. Wang).

[4,5]. Therefore, the co-combustion of WAS and lignite reduces the harmful effects of WAS on the environment and improves the combustion performance of lignite.

Flocculants are generally used during wastewater treatment processes to facilitate solid particle settling and enhance wastewater treatment efficiency. Flocculants are commonly macromolecules containing iron (Fe), phosphorus (P), and alkali metals. These elements are abundant in WAS. When WAS is used as a combustion fuel, these elements react with other mineral components and influence the mineral transformation behavior [6,7]. Mineral transformation behaviors are theoretically important in determining fouling and slagging properties during the co-combustion of WAS and lignite [8,9]. Many previous studies [7,10–12] have investigated the ash fusion characteristics of coal-sewage sludge blends by referring to ash chemical and mineralogical compositions. However, direct studies on mineral transformation behaviors during co-combustion are scarce.

WAS contains a higher content of heavy metals (HMs) than lignite. Co-combustion of WAS and lignite results in potential HM emissions. Therefore, studying HM emission behaviors during the co-combustion of WAS and lignite is necessary. Several studies [13–16] have examined HM emission behaviors during the co-combustion of sewage sludge and coal. However, bituminous coals were mostly adopted in these studies, and lignite was rarely involved. Lignite, which is widely distributed and has large reserves in China, has become the most important primary energy and chemical material. Large amounts of WAS are generated yearly with the industrialization of and population increase in China. Co-combustion of WAS and lignite has broad application prospects in China. Considering the large differences in coal quality and combustion properties between lignite and bituminous coal, further research on HM emission behaviors during the co-combustion of WAS and lignite is required.

During actual combustion in a boiler or furnace, temperature and atmosphere are generally unevenly distributed in space. Temperature and atmosphere significantly affect combustion [1,17]. Therefore, investigating the influences of temperature and atmosphere on mineral transformation and HM emission behaviors is crucial. In this study, combustion experiments were performed at different temperatures (800 °C, 1000 °C, and 1200 °C) and O₂ concentrations (10%, 21%, and 30%), and the effects of temperature and O₂ concentration on mineral transformation and HM emission behaviors were studied.

2. Experiments

2.1. Materials

Lignite was collected from Xinjiang District, China, and WAS was collected from a municipal wastewater treatment plant located in Hangzhou, China. This plant treats approximately 500,000 m³/d of industrial and domestic wastewater using anaerobic–anoxic–oxic technique. Lignite and WAS were dried at 105 °C for 24 h. The dried samples were ground and sieved to the desired size (less than 74 μm). This particle size is consistent with that in actual applications.

2.2. Co-combustion equipment and methods

Combustion experiments on lignite, WAS, and their blend were conducted in a horizontal tube furnace system, as shown in Fig. 1. The lignite–WAS blend was prepared with 10% dried WAS and 90% dried lignite. This blending ratio is generally adopted in actual applications [18] according to the heat value of the blend fuel and the combustion pollution emission concentration.

In an actual industrial application, fuel is fed into a boiler or furnace operated at a relatively stable temperature. In this study, the temperature of the tube furnace was increased to the desired value. Subsequently, the sample was pushed into the tube furnace (Fig. 1a) rather than the opposite, which was adopted by most thermogravimetric analyses in which the sample was first placed in the combustion chamber before the temperature of the furnace was increased.

When the appointed time was achieved, the sample was removed from the tube furnace and placed in the cooling position (Fig. 1b). Atmosphere flow, which was simulated with N₂ and O₂ controlled by an individual mass flowmeter, was fed into the quartz tube in the tube furnace through combusting and cooling. The sample was removed and sealed for subsequent determination after being cooled down to room temperature.

Approximately 2 g of fuel powder was used for each test, and the combustion times were 1, 5, 10, and 30 min. The temperatures were 800 °C, 1000 °C, and 1200 °C. Three atmospheric conditions, namely, oxygen lean, standard and oxygen enriched with reference to air, were created by allocating the inlet proportions of N₂ and O₂ at N₂–O₂ ratios of 90:10, 79:21, and 70:30, respectively. The total atmosphere flow was 1 L/min. The experiment was conducted in triplicate, and three parallel samples were obtained for the measurement of HM and chlorine concentrations.

2.3. Measurement of the phase compositions of combustion products

The phase compositions of the combustion products after different combustion times were determined with an X-ray diffractometer (XRD) (PANalytical Co. X'pert PRO, Netherlands) operated at a voltage of 40 kV and a current of 40 mA.

2.4. Measurement of the HMs of combustion products

The combustion products after different combustion times were collected for subsequent elemental determination to evaluate the emission behavior of HMs during the co-combustion of WAS and lignite. Approximately 0.1 g of combustion products were acid digested with an 27 mL acid solution (HCl: HNO₃: HF = 6: 2: 1) on an electric heating plate at 210 °C for 15 min. The digested solutions were diluted with deionized water to 25 mL (the acid solution was concentrated during the heating process). Subsequently, the solutions were sealed and allowed to stand for 24 h. The supernatants were filtrated through 0.45 μm membranes. The concentration of the targeted HMs (Cd, Cr, Ni, Pb, and Zn) in these filtered supernatants was determined through inductively coupled plasma mass spectrometry (ICP-MS) (XSENIES, Thermo Electron Co., USA). Dried lignite/WAS was used during acid digestion for the determination of HM concentration.

2.5. Measurement of chlorine (Cl) in the combustion products

The chlorine in the combustion products was measured with an integrated energy dispersive X-ray spectrometer equipped in a SIRION-100 field-emission scanning electron microscope (FEI, Netherlands). Three measurements were conducted at different locations on each sample, and the results are presented as mean values.

3. Results and discussions

3.1. Characterization of materials

The proximate and ultimate analyses and calorific values of lignite and WAS on a dry basis are shown in Table 1. The ash contents

Download English Version:

<https://daneshyari.com/en/article/6474837>

Download Persian Version:

<https://daneshyari.com/article/6474837>

[Daneshyari.com](https://daneshyari.com)