



Leaching of elements from bottom ash, economizer fly ash, and fly ash from two coal-fired power plants

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ARTICLE INFO

Article history:

Received 25 July 2011

Received in revised form 4 October 2011

Accepted 8 October 2011

Available online 15 October 2011

Keywords:

Coal combustion products

Fruitland Formation

Leaching

Pittsburgh coal

TCLP

SGLP

ABSTRACT

To assess how elements leach from several types of coal combustion products (CCPs) and to better understand possible risks from CCP use or disposal, coal ashes were sampled from two bituminous-coal-fired power plants. One plant located in Ohio burns high-sulfur (about 3.9%) Upper Pennsylvanian Pittsburgh coal from the Monongahela Group of the Central Appalachian Basin; the other in New Mexico burns low-sulfur (about 0.76%) Upper Cretaceous Fruitland Formation coal from the San Juan Basin, Colorado Plateau. The sampled CCPs from the Ohio plant were bottom ash (BA), economizer fly ash (EFA), and fly ash (FA); the sampled CCPs from the New Mexico plant were BA, mixed FA/EFA, FA, and cyclone-separated coarse and fine fractions of a FA/EFA and FA blend. Subsamples of each ash were leached using the long-term leaching (60-day duration) component of the synthetic groundwater leaching procedure (SGLP) or the toxicity characteristic leaching procedure (TCLP, 18-hour duration). These ashes were all alkaline. Leachate concentrations and leachabilities of the elements from the CCPs were similar between corresponding CCP types (BA, EFA, and FA) from each plant. The leachabilities of most elements were lowest in BA (least leachable) and increased from EFA to FA (most leachable). Ca and Sr were leached more from EFA than from either BA or FA. Leachability of most elements also increased as FA particle size decreased, possibly due in part to increasing specific surface areas. Several oxyanion-forming elements (As, Mo, Se, U, and V) leached more under SGLP than under TCLP; the opposite was true for most other elements analyzed.

Published by Elsevier B.V.

1. Introduction

Coal combustion by coal-fired power plants, cement plants, and steel plants produces large quantities of coal combustion products (CCPs), which include ashes, slag, and flue-gas desulfurization residues. Coal-fired power plants in the USA produced 135 million tons of CCPs in 2009 (ACAA, 2011); bottom ash (BA) and fly ash (FA) make up about 60% (80 million tons) of these. Combustion of coal concentrates many of its minor and trace elements in the resulting CCPs. Some of the elements that are concentrated in CCPs relative to the source coal (e.g., As, Cd, and Pb) are potentially hazardous to human health or the environment, and may enter the environment under some CCP use or disposal conditions.

Coal ashes can be classified as BA, FA, or a specific kind of FA called economizer fly ash (EFA). BA is noncombustible material that is too heavy to be entrained in the flue gas stream and falls to the bottom of the furnace during coal combustion. Particles of BA are typically angular, irregularly shaped, and sand- to gravel-sized (Meawad et al., 2010). FA is composed of vaporized and combusted material entrained in the flue gas stream. At least some of this vaporized material

condenses, as flue gases cool, into mainly fine-sand-sized and smaller, glassy, hollow silicate spherules called cenospheres. A portion of the FA can be captured by electrostatic precipitators (ESPs) or by fabric filters in baghouses (Meawad et al., 2010). Economizer fly ash (EFA) is FA that is captured at the economizer unit, located along the flue gas pathway between the furnace and the ESPs or baghouses. As a result, EFA contains some small, angular, non-volatilized particles entrained in the flue gas stream and some spherules that condensed from flue gas at higher temperatures than those at the ESPs or baghouses. EFA is also coarser than FA collected at ESPs or baghouses. Of the BA and FA produced in the USA, about 80% is FA and 20% is BA (ACAA, 2011).

About 32 million tons, or 40%, of BA and FA produced in the USA are used, for example, as agricultural soil amendments, abandoned mine fill, or in wallboard, concrete, or highway construction (ACAA, 2011). The remaining 48 million tons are stored in piles, landfills, monofills (landfills that contain only ash), or holding ponds (ACAA, 2011). Use rates of CCPs elsewhere in the world range from about 30% in India and China (Asokan et al., 2005; Pei-wei et al., 2007) to near 100% in Germany and the Netherlands (Barnes and Sear, 2006).

In the USA, CCPs are classified as non-hazardous solid wastes under Subtitle D of the Resource Conservation and Recovery Act (RCRA, Public Law 94-580, 1976), so CCP disposal in lined impoundments is allowed. However, in June 2010, the U.S. Environmental Protection Agency (EPA) proposed two options to regulate CCPs destined for impoundments,

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including storage, settling, and aeration pits, ponds, and lagoons; the proposed rule does not include mine fills or beneficial use (e.g., as wall-board or cement additives) of CCPs. The first option is to list CCPs as special wastes under the more stringent RCRA Subtitle C, which essentially labels them as hazardous. Under this option, all CCPs, from the point of generation through the closing of any landfill, along with related surface water run-on and run-off controls, dust controls, groundwater monitoring, financial assurance, and post-closure care would require permits and inspections (U.S. EPA, 2010). The second option is for CCPs to remain listed as RCRA Subtitle D non-hazardous solid waste, but to establish national standards to ensure that landfills are properly sited, constructed, monitored, and closed: composite liners, groundwater monitoring, corrective action for any releases, and closure and post-closure care standards would be required.

Many researchers (e.g., de Groot et al., 1989; Gitari et al., 2009; Jankowski et al., 2006; Karupiah and Gupta, 1997; Kosson et al., 2002; Popovic et al., 2005; Prahara et al., 2002; Sheps-Pelleg and Cohen, 1999; Wang et al., 1999, 2009; Ward et al., 2009) have investigated the possible leaching of elements from CCPs into the environment under various CCP use or disposal scenarios. Many leachants have been used in these studies, from pure water to strong acidic and alkaline solutions. However, as several researchers have discussed (Hassett, 1994; Hassett et al., 2005; Kim and Hesbach, 2009; Kosson et al., 2002; Zandi and Russell, 2007), some of these leachants are unrealistic, simulating conditions atypical for CCP use or disposal and these leaching results should be interpreted cautiously.

For example, researchers sometimes use the toxicity characteristic leaching procedure (TCLP; U.S. EPA, 2004) to investigate CCPs. This procedure quantifies the “toxicity characteristic” of elements in a waste, used by the EPA to assess whether a waste is considered hazardous due to its toxicity. The TCLP uses a buffered acetic acid solution as the leachant to simulate disposal intermixed with garbage in a municipal landfill. CCPs are rarely, if ever, disposed in such a setting, although this low-pH leaching could be relevant to CCPs used to remediate acid mine drainage. In fact, water mixed with some CCPs forms alkaline solutions, in contrast to the acidic leachant used in the TCLP (Hassett, 1994). Although TCLP results regarding CCPs are informative, they are unlikely to provide an analog for most environmental conditions in which CCPs are used or disposed.

To better understand CCP leaching and its possible environmental impacts, we investigated the leaching of trace metals from several kinds of ash resulting from combustion at two power plants of bituminous coals, one high-sulfur (about 3.9%) and one low-sulfur (about 0.76%). We used two standard batch leaching procedures. The first was the synthetic groundwater leaching procedure (SGLP; Hassett, 1998), which simulates the interaction of ash with groundwater, using as the leachant reagent water, sampled groundwater, or a solution similar to groundwater. Such an interaction could occur as a result of disposal of ash in a monofill if its walls or liner failed. The second was the TCLP, selected to allow direct comparison of our results with similar TCLP-based studies by others. The primary goal of our research was to assess the extent to which trace elements leach from coal ashes, in order to understand possible risks from their use or disposal. A secondary objective was to assess differences in leaching between ashes from high-sulfur and low-sulfur coals and between different types and particle sizes of coal ashes.

2. Materials and methods

Coal combustion products were sampled from two pulverized-coal-fired power plants in Ohio and New Mexico, USA. The Ohio plant burns bituminous high-sulfur (about 3.9%) locally available Upper Pennsylvanian Monongahela Group Pittsburgh coal from the central Appalachian Basin. *Tewalt et al. (2001)* discuss the geology of this coal in detail. From this plant, feed coal, bottom ash (BA), economizer fly ash (EFA), and fly ash (FA) were collected as separate

composite samples twice weekly over an eight-week period in 2007 for a total of 16 coal samples and 48 ash samples. In this study, we leached two of these BA, EFA, and FA sample suites (the fourth and the tenth), a total of 6 samples, and characterized the corresponding feed coals. These two sample suites were chosen randomly from the suites in which all samples were complete and were successfully collected on the same day. *Fig. 1* schematically shows the sampling locations for the Ohio plant. BA was collected from a storage pond. EFA was collected from the economizer unit. FA was collected from all ESP hoppers and combined into a single sample. Flue gas temperature at the ESPs is about 160 °C (330 °F) in this power plant.

The New Mexico plant burns a bituminous low-sulfur (about 0.76%) coal blend from three locally available coal beds in the Upper Cretaceous Fruitland Formation, San Juan Basin, Colorado Plateau. *Fassett (2000)* discusses the geology of this formation. Feed coal, BA, FA mixed with EFA, and FA without EFA were collected from the plant on 18 consecutive days in July and August, 2007. In this study, we used two days of samples, collected on 27 July and 8 August. These dates were selected randomly from the days on which all samples were successfully collected. *Fig. 2* schematically shows the sampling locations for this plant. During plant operation, BA is dumped into a storage area, and still-warm BA samples were collected from the center of this area. At this plant, FA is captured in two baghouses; one collects solely FA and the other collects roughly equal amounts of FA and EFA. Ash samples were collected from each baghouse. At the power plant, a blend of ashes from the two silos undergoes cyclone particle-size separation so that the fine portion can be sold, primarily for use in concrete. We sampled the coarse (generally >40 µm) and fine (generally <40 µm) fractions of the FA/EFA mixture that resulted from this separation. In all, five kinds of ash samples were collected from the New Mexico plant: 1) BA, 2) a FA and EFA mixture, 3) FA, 4) the coarse fraction of a mixture of types 2 and 3, and 5) the fine fraction of a mixture of types 2 and 3. Flue gas temperature in this power plant is about 430–450 °C (800–850 °F) at the economizer unit and about 105 °C (220 °F) at the baghouses.

Proximate analyses (moisture, volatile matter, ash, and fixed carbon) of the feed coals were performed using ASTM method D3172 (*ASTM International, 2007*). Total S contents of the feed coals were measured using the direct combustion and infrared absorption method (ASTM method D4239, *ASTM International, 2007*). These and all other analyses and leaching procedures in this study were performed at a single commercial laboratory.

Total concentrations (all valences) of Al, As, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Ni, Pb, Sr, Ti, V, and Zn in subsamples of each

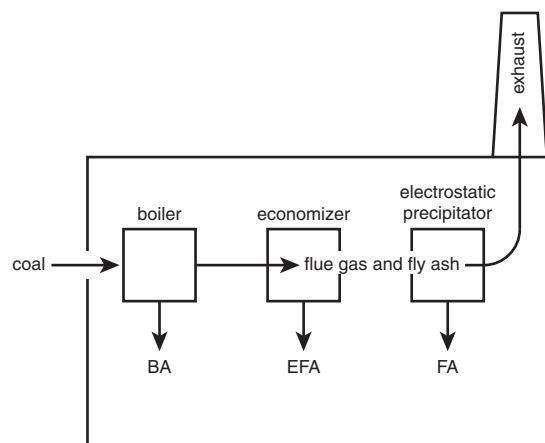


Fig. 1. Schematic diagram showing CCP sampling locations at the Ohio power plant. This plant also contains a flue gas desulfurization system (not pictured) that captures additional trace elements in the flue gas. Abbreviations: BA = bottom ash, EFA = economizer fly ash, FA = fly ash.

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