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Mineral matter and trace elements in ashes from a high-arsenic lignite fired power plant in Inner Mongolia, China

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ABSTRACT

The distribution, enrichment, and environmental influence of trace elements and mineral matter in fly ash (FA), bottom ash (BA), and flue gas desulfurization gypsum (FGDG) from a high arsenic coal-fired power plant in Inner Mongolia, China were studied by X-ray diffraction spectrometry (XRD), X-ray fluorescence spectrometry (XRF), field scanning electron microscopy equipped with energy dispersive X-ray spectrometry (FSEM-EDX), atomic fluorescence spectroscopy (AFS), and inductively coupled plasma-mass spectrometry (ICP-MS).

The results showed that mineral matter in FA included quartz, mullite, and gypsum, and that in BA included quartz, enstatite, magnetite, and hematite. The arsenic content in the lignites reached 44.4 μg/g, which was much higher than the global average content of lignite. Most of the trace elements in lignite, except for Mo, Sb, and W, had enrichment trends in the fine grade samples. Arsenic is a toxic element enriched in FA compared with the world lignite ash, while there are several elements of environmental concern are depleted elements (Mo, Cd, Ba, and U). The Cs and Hf are also enriched elements in FA, where Hf showed a significant enrichment. The contents of most trace elements in the smaller particles of FA were higher than those in the larger particles, except for Y and Re. The arsenic content in BA was evidently lower than that in FA, which was 24.4 μg/g, and the trace elements enriched in the smaller particles of BA included Li, Zn, Ga, Rb, Mo, Cd, In, Sb, Cs, Nd, Tl, Pb, Bi, and Th. With the exceptions of As, Sr, Cd, and Sb, the amount of trace elements in flue gas desulfurization gypsum was much lower than that in average Chinese soil. Because the fly ash was stacked for a long time, arsenic and several other trace elements leached into soil surrounding the fly ash dump. As a results the elemental content of old fly ash is less than those collected in this study, which indicates the soil in vicinity need to be monitored continuously for their possible environmental effect.

1. Introduction

Coal-fired power plants are major power generators in China, which consume large amounts of coal annually (Yao et al., 2015). Fly ash is the greatest by-product of coal-fired power plants and the amount of which was increasing annual year in China (Gong et al., 2016; Saikia et al., 2015; Yao et al., 2014; Zhang et al., 2010; Zhao et al., 2006). Several trace elements in fly ash are considered as environmentally sensitive elements; if not properly disposed of, fly ash can cause potential hazards to the environment (Choi et al., 2002; Swaine and Goodarzi, 1995, Goodarzi, 2004, 2006a and d; Goodarzi and Huggins, 2001, 2004, 2005a, 2005b; Nyale et al., 2014; Patra et al., 2012; Sushil and Batra, 2006; Yang et al., 2014; Yao et al., 2015; Zhao et al., 2017; Zhao et al., 2012). Therefore, it is necessary to study the migration and transformation of trace elements in coal ash.

The distribution of trace elements in combustion products largely depends on element volatilization, the modes of occurrence of trace elements in coal, the operation parameters of boilers, and pollution control equipment (Swaine and Goodarzi, 1995; Gentzis and Goodarzi, 2000; Goodarzi 2006a and 2009; Goodarzi and Huggins, 2005a, 2005b; Guedes et al., 2008; Huggins and Goodarzi, 2009; Mardon et al., 2008; Mokhtar et al., 2014; Vassilev and Vassileva, 2007; Xu et al., 2004). Quan et al. (2013) studied the distribution of trace elements in coal and coal-fired products from two power plants in Huainan, China and found that most of the trace elements were present in fly ash, and Fe and Mn enriched bottom ash. Guo et al. (2004) determined the partition arsenic

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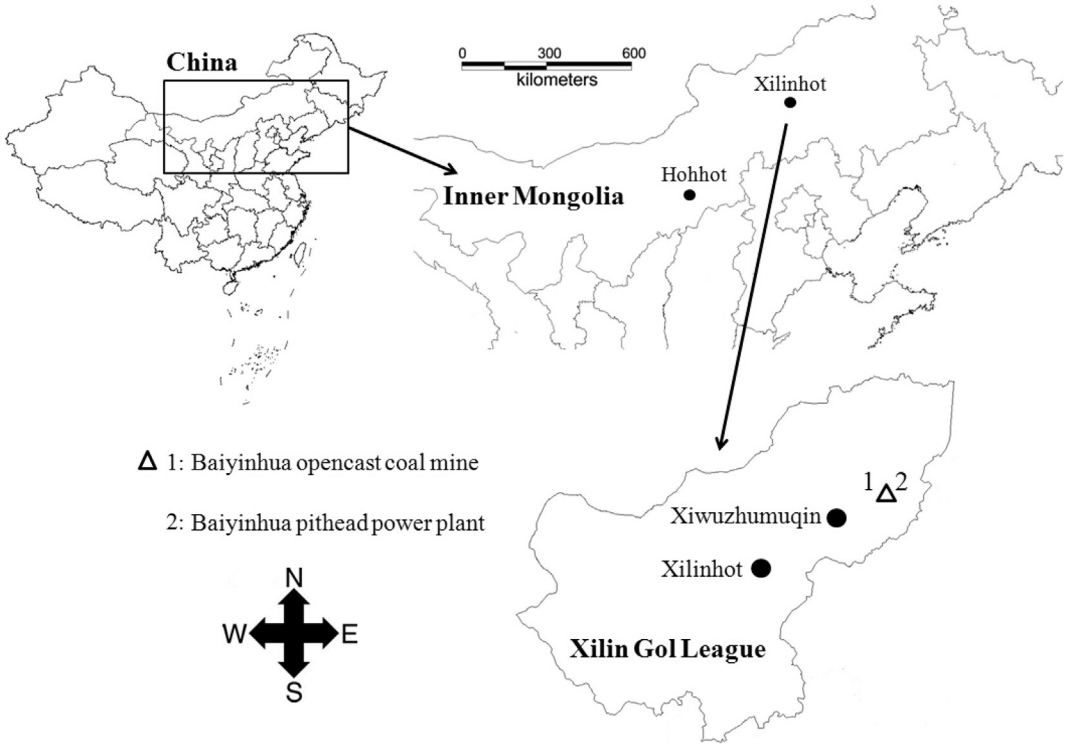

Fig. 1. Sampling locations.

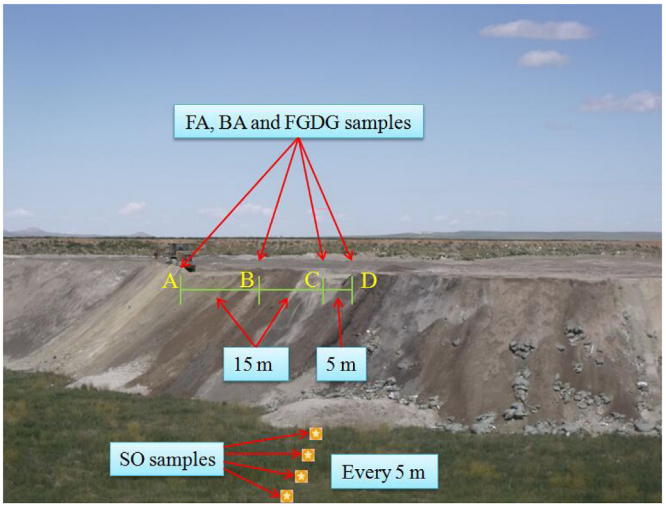

Fig. 2. Sampling sites of the ash dump. FA, fly ash; BA, bottom ash; FGDG, flue gas desulfurization gypsum; SO, soil.

Table 1
Proximate and ultimate analyses of lignites (wt%).

Samples	Proximate analysis				Ultimate analysis (daf)				
	Mad	Vd	Ad	FCd	N	C	H	S	O[a]
RC-1	2.15	46.76	24.71	26.38	1.13	50.24	3.85	0.60	44.18
RC-2	2.70	49.12	18.61	29.58	1.17	54.36	4.37	0.38	39.72
RC-3	11.46	43.48	23.44	21.62	0.89	45.04	3.89	0.67	49.52
RC-4	13.50	47.70	8.37	30.43	1.23	55.85	4.78	0.57	37.57

RC: lignite; M: moisture; ad: as received; V: volatile matter; d: dry base; A: ash; FC: fixed carbon; daf: dry ash-free basis.
[a] By difference.

in bottom ash, gas, and fly ash in a coal-fired power plant in China and found that the As distribution ratios were 0.53%, 2.16%, and 84.6%, respectively. The results of Goodarzi and Huggins (2005a) and Goodarzi (2006a) indicated that the concentration As increased progressively from feed coal to bottom ash and then fly ash. Goodarzi (2006c) showed that concentration of As in fly ash from Canadian power plants increased from the large particle (PM > 10) towards PM 10 and 2.5, at rate 0.18/0.37/1.27 (g/h).

Fly ash is considered to be a potential source of release for many environmentally sensitive elements (Goodarzi, 2006a, 2006b, 2006c; Goodarzi and Sanei, 2009). Reservoir or landfill with fly ash may be in contact with aqueous environments, which may cause a considerable amount of trace elements to leach out. Several elements can potentially harm the environment, even at very low concentrations, such as V, Cr, Ni, Cd, and Pb (Swaine and Goodarzi, 1995; Goodarzi, 2006a; Goodarzi and Huggins, 2001, 2005a, 2005b; Patra et al., 2012). Nyale et al. (2014) studied the leaching behaviors and geochemical distributions of several trace elements in a coal ash dump and found that As, Zn, Pb, Ni, Mo, Cr, and Cu were easily leached from the coal ash dump, which would posed a threat to surface water, groundwater, soil, and food production. Neupane and Donahoe (2013) analyzed the leaching characteristics of As, Co, Cr, Ni, Sb, Se, Ti, V, and Zn through leaching experiments, and the results showed that an unlined landfill with fly ash can potentially pollute the environment. Arsenic is a toxic element in coal, it can be released into the atmosphere during coal combustion and enriched in coal-fired by-product, which would be leached into the soil and water, and do harm to the environment and people's health eventually (Goodarzi, 2006a; Goodarzi and Huggins, 2005a; Goodarzi and Huggins, 2001; Goodarzi et al., 2008; Huggins and Goodarzi, 2009; Linak et al., 2011; Zhang et al., 2002; Zhao et al., 2008).

Inner Mongolia is one of the main areas of coal production in China, and the local coal-fired power plants discharge a large amount of fly ash every year. In this work, high-arsenic lignites were collected from the Baiyinhua (BYH) opencast coal mine, and high-arsenic fly ash (FA), bottom ash (BA), and flue gas desulfurization gypsum (FGDG) samples were collected from the Baiyinhua pithead power plant coal ash dump