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Statistical study on distribution of multiple dissolved elements and a water quality assessment around a simulated stackable fly ash

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ABSTRACT

This study reports the leaching and transport behaviors of sixteen elements in fly ash taken from coal-fired power plant stations. A total of 480 water samples were collected from 20 simulative monitoring wells at three different times. Concentrations of elements in water samples were detected to know the spatial variability of substance, contamination level and quality of groundwater around stackable fly ash. The results of the water quality index (WQI) indicate that the water around a stackable fly ash is unsuitable for drinking. Sixteen parameters (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mg, Mn, V, Pb, Sb, Ni and Zn) were analyzed using different multivariate statistical approaches to assess the origins of elements in groundwater around stackable fly ash, identified five factor types that accounted for 75.66% of the total variance. Based on drinking water guidelines, As, Sb, Pb, Al and Cd were the dominant contaminants in groundwater around stackable fly ash. The quality of fly ash were considered to contribute much of the Mn, V, Ba and Mg (Cd, Cr and Ni for leaching time; Sb and Pb for leaching intensity; Al and Fe for water depths; B for flow velocity). Co, Cu and Zn had natural and random origins from crustal materials and upper reaches. Cluster analysis (CA) was adopted to classify the 20 simulative monitoring wells into two groups of water pollution, high pollution and low pollution, reflecting influences from leaching solution and upper reaches activities, respectively. The results of Hazard quotient and index (HQ/HI) suggests that As, Sb, Cd, Pb, V and Cr are the largest contributors to health risks in monitoring sites around stackable fly ash.

1. Introduction

Coal is an important fuel source of power generation in China with increasing demand of electricity (Tang et al., 2013). It is estimated that China has occupied more than 50% of world coal production and consumption, in which billion tons of coal have been burned in thermal power plants (Fu et al., 2016). Many studies reported that toxic elements with weaker bound in fly ash could be leached out and return into the environment when exposure or soaked by surface water and groundwater (Zhou et al., 2012; Li et al., 2015). As far as today, there is still a lot amount of ash to fill up in ponds or landfills even large amounts of fly ash (80%) are used as additive to make cement and brick in some place of China (Wang et al., 2016). A lot of reports demonstrate that the secondary pollution caused by conventional waste like fly ash is still a severe problem for our environment (Wang et al., 2016; Jankowski et al., 2006).

As a result, hazardous leachable trace elements such as As, B, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Se, Sr, Ti and Zn, as well as a great deal of major element compounds as oxides, hydroxides and sulfates of iron, aluminum and calcium in fly ash are the most sensitive population segment compared with other elements (Yılmaz, 2015; Bhattacharyya et al., 2009; Medina et al., 2010). The leaching and transport behavior of elements in fly ash relates to the particle size, surface area, elemental abundance and pH of fly ash, initial property of the liquid, leaching time, quantity of fly ash, leaching intensity, leaching medium and morphological structure of the elements. In the interaction process, the elements from fly ashes will be dissolved in leachate and the elements concentrations are highly precarious which in consistent with the long solid–liquid equilibrium time. However, short-period leaching behaviors of elements in fly ash and their activities are important for both optimized selection of pollution monitoring points and goal-directed decrease of preconceived monitoring elements' number in the system. In addition, at present, research on the leaching and transport behaviors of element contamination from fly ash mainly concerns simple comparison or the qualitative assessment from data in situ sampling and simulation study (Li and Zhang, 2010a, 2010b). Little multivariate statistical information on element contamination, influence factor analysis, source identification, health risk evaluation, or water quality assessments around a simulated stackable fly ash is available, although such information is critical for waste management or water management. In addition, it could provide important information regarding diverse element sources and sample point types that were not available

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at first glance (Wang et al., 2017). Thus, the transformation characterization of sensitive elements and the environmental property of surrounding groundwater around stackable fly ash are discussed systematically in this study.

The main objectives of the study are to present the elements characteristics of fly ash and to compare their leaching and transport behaviors. For this reason, soil column and sand tank were designed to simulate the leaching and transport behaviors of elements in laboratory. The leaching concentrations of Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mg, Mn, V, Pb, Sb, Ni and Zn in fly ash were determined. Based on the result, the spatial and temporal distribution patterns of dissolved elements in leaching were analyzed; influence factors and elements sources were explored by multivariate statistics; contamination level and quality of groundwater around stackable fly ash were evaluated; and hazard quotient and index (HQ/HI) posed by elements were calculated, respectively. The outcome of this study is expected to provide some information for the management efficiency increasing of waste and groundwater, and utilization of useful elements in fly ash rationally in the course of leaching process.

2. Materials and methods

2.1. Simulation experiments

There are various standard test methods for the investigation of leaching behavior of the materials. In this study, short-term leaching and transport tests (during 12 h) were done for elements (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mg, Mn, V, Pb, Sb, Ni and Zn) to find out more strategic analysis of the factors if they are key or not when fly ash being exposed to normal environmental conditions in initial stage. Fig. 1 shows the mesh frame and indoor sand tank. Mesh frame that used to place fly ash was 30 cm × 25 cm × 20 cm. Device of sand tank (including soil column) is supported by organic glass plate with the thickness of 6 mm. As designed, the body of sand tank (120 cm × 60 cm × 60 cm) is mainly divided into four parts (infall area, leaching area, migration area, outfall area). Running water was used to imitate real rain during the whole leaching process. Some factors need to consider: leaching time, quantity of fly ash, leaching intensity and flow velocity.

2.1.1. Leaching

Concentration of elements in the fly ash before leaching was showed in Table S1. In these tests, leaching time was generally applied as 2 h, 6 h and 9 h. In a typical run, 800 g, 1500 g, or 2500 g of fly ash was placed in mesh frame and leached with spraying flowing water (pH = 6.68) at different rates of 140 ml/min, 150 ml/min and 160 ml/min for some time. The whole piece of Whatman No.42 filter paper was lined in mesh frame to prevent the erosion of fly ash. If leachate's flow rate was above hydraulic conductivity of fly ash, some fly ash in mesh frame will be soaked. Data obtained from tests will be a mixture of soaking liquid and drench filtrate, which could be treated as a case that frequently occurred in the study region.

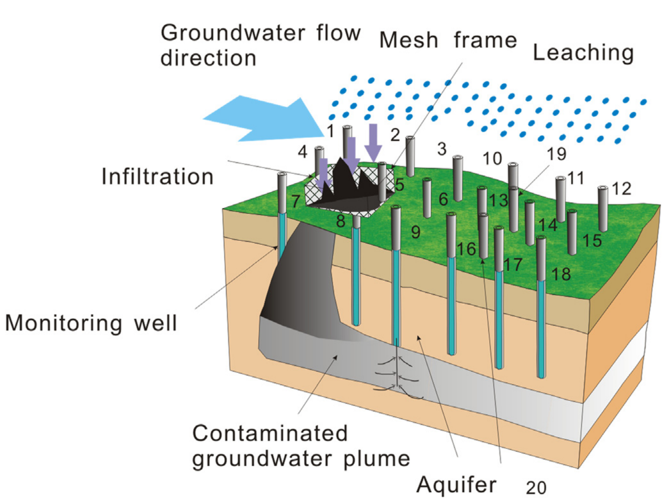

Fig. 1. The location and number of monitoring well around stack coal fly ash in simulation sand tank.

2.1.2. Transport of leaching

Twenty simulative monitoring wells monitoring wells were distributed at different positions as showed in Fig. 1 to simulate the migration of elements in longitudinal or transverse direction. All simulative monitoring wells were located on leaching area and migration area. Both the horizontal and vertical distances between adjacent simulative monitoring wells were 15 cm (except 7.5 cm for #19 and #20). Depth of wells from the surface of sandy layer were 31.75 cm (#1, #4 and #7), 32.5 cm (#2, #5 and #8), 33.25 cm (#3, #6 and #9), 34 cm (#10, #13 and #16), 34.375 cm (#19 and #20), 34.75 cm (#11, #14 and #17) and 35.5 cm (#12, #15 and #18). Water table of wells from the bottom slab of the tank were 28.25 cm (#1, #4 and #7), 27.5 cm (#2, #5 and #8), 26.75 cm (#3, #6 and #9), 26 cm (#10, #13 and #16), 25.625 cm (#19 and #20), 25.25 cm (#11, #14 and #17) and 24.5 cm (#12, #15 and #18). Water samples at different depth of 10 cm and 20 cm were collected. Fresh drench filtrate of fly ash would be directly used to study the migration and evolution of elements. Based on the analysis of natural stackable fly ash, soil column and sand tank were designed to simulate elements transportation in laboratory. Materials from aeration zone and gravel aquifers were collected and then placed in sand tank in turn (8 cm of soil, 8 cm of fine sand, 8 cm of coarse sand and 16 cm of sandy pebble) to simulate real conditions according to the actual order of soil layers with the thickness ratio of 1: 30. The whole sandy layer was packed to a thickness of 40 cm to attain 90 × 60 × 40 cm^3. Mesh frame was put on the soil layer of leaching zone. The whole piece of Whatman No.42 filter paper was lined in mesh frame to prevent the erosion of fly ash. In order to prevent blocking up problem happened, pebble around 5 cm thick was stacked in both infall area and outfall area respectively. In this part, flow velocity was set as 219 ml/min, 353 ml/min, 513 ml/min and water level was kept as 28.5 cm (11.5 cm below the surface of sandy layer). A relationship in which the sampling time of one simulative monitoring well corresponds to the sampling time of another simulative monitoring well. Thus, the transport characteristic of leaching can be reflected by real-time dynamic change of elements concentration in a series of simulative monitoring wells.

2.1.3. Sample collection and treatment

Water samples from simulation monitoring wells were collected in sand tank. A total of 480 effective water samples were collected from 20 simulative monitoring wells at three different times (2 h, 6 h, 9 h) and at different sites around stackable fly ash. Samples from 20 sites, labeled #1–#20, that reasonably reflect the groundwater quality around a simulated stackable fly ash were collected at the same time from two different depths of 10 cm and 20 cm at each site, respectively, for assessment of the element characteristics. Four batches of experiments were carried out on different combinations of quantity of fly ash, leaching intensity and flow velocity with 2500 g, 140 ml/min, and 219 ml/min; 2500 g, 150 ml/min, and 513 ml/min; 1200 g, 160 ml/min, and 353 ml/min; 800 g, 160 ml/min, and 353 ml/min. The samples were analyzed after one hour' standing by using inductively coupled plasma-atomic emission spectrometry (Optima 7300 DV, Perkin-Elmer Cooperation, USA).

2.2. Analysis method and theoretical basis

2.2.1. Test and statistics of data

The temporal variations of the water quality parameters at different