JOURNAL OF ENVIRONMENTAL SCIENCES XX (2016) XXX–XXX

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JES
JOURNAL OF ENVIRONMENTAL SCIENCES
www.jesc.ac.cn

Phytotoxicity and groundwater impacts of leaching from thermal treatment residues in roadways

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ARTICLE INFO

Article history:
Received 29 April 2016
Revised 13 November 2016
Accepted 18 November 2016
Available online xxxx

Keywords:
Thermal treatment residues
Bottom ash
Flue gas desulfurization residue
Heavy metals
Phytotoxicity
Groundwater impact

ABSTRACT

The use of coal fly ash (CFA), municipal solid waste incinerator bottom ash (MSWIBA) and flue gas desulfurization residue (FGDR) in road construction has become very common owing to its economical advantages. However, these residues may contain toxic constituents that pose an environmental risk if they leach out and flow through the soil, surface water and groundwater. Therefore, it is necessary to assess the ecotoxicity and groundwater impact of these residues before decisions can be made regarding their utilization for road construction. In this study, the physico-chemical characteristics, leaching and phytotoxicity of these residues were investigated. Specifically, multivariate analyses were used to evaluate the contributions of the leaching constituents of the CFA, MSWIBA and FGDR leachates to the germination index of wheat seeds. B, Ba, Cr, Cu, Fe and Pb were found to be more toxic to the wheat seeds than the other heavy metals. Furthermore, the leached concentrations of the constituents from the CFA, MSWIBA and FGDR were below the regulatory threshold limits of the Chinese identification standard for hazardous wastes. Analyses conducted using a numerical groundwater model (WiscLEACH) indicated that the predicted field concentrations of metals from the CFA, MSWIBA and FGDR increased with time up to about 30 years at the point of compliance, then decreased with time and distance. Overall, this study demonstrated that the risks resulting from MSWIBA, CFA and FGDR leaching could be assessed before its utilization for road construction, providing crucial information for the adoption of these alternative materials.

Introduction

Rapid urbanization has led to demands for construction materials that are exceeding the availability of natural materials. At present, several countries are attempting to replace natural materials with residues produced by thermal treatments (Ore et al., 2007) such as municipal solid waste incinerator bottom ash (MSWIBA), coal fly ash (CFA) and flue gas desulfurization residue (FGDR). More than 10 million tonnes of MSWIBA (National Bureau of Statistics of China, 2015), 550 million tonnes of CFA (Yu et al., 2015), and 7.1 million tonnes of FGDR (Wang et al., 2013) are produced annually in China, showing great potential for resource reuse (Cheng et al., 2007; Córdoba, 2015). However, the types and quantities of solid residues vary according to the waste composition, thermal treatment process, flue gas cleaning

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http://dx.doi.org/10.1016/j.jes.2016.11.009
1001-0742/© 2016 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V.

technology and residue handling at various facilities (Seshadri et al., 2010).

CFA, MSWIBA and FGDR are usually considered non-hazardous wastes that can be utilized as alternative construction materials, especially in roadways. The mineral compositions and engineering characteristics of these residues are similar to those of natural sand or aggregates. In China, sustainable waste management policies are encouraging reutilization of these residues (Geng et al., 2009; Wang et al., 2010). The environmental benefits include lowering the amounts of waste being sent to landfills and replacing natural materials. Thus, reuse of the residues could save landfill capacity and reduce the environmental impacts arising from exploitation of natural materials as well as transport of these residues to landfill sites and of virgin aggregates to points of use.

However, when CFA, MSWIBA and FGDR are used in construction, hazardous constituents contained in the residues may be leached out by runoff, surface water or groundwater that may come in contact with the materials. Such leaching represents a potential threat to the environment (Cheng et al., 2008; Liyanage et al., 2013; Yu et al., 2013). The compositions of CFA, MSWIBA and FGDR have been described for many different incineration plants and countries (Shim et al., 2005; Rendek et al., 2007; Hua et al., 2010; Rocca et al., 2012; Chen et al., 2014; Córdoba, 2015; Phoungthong et al., 2016a). To assess the environmental impacts arising from use of these materials, information is needed not only on the total contents of constituents in the residue materials, but also on the amounts of these constituents that might reach the surrounding environment. Therefore, the leaching behavior of alternative materials under field site conditions and during standardized laboratory tests has been discussed by several researchers. It was reported that the impacts of leaching from MSWIBA and CFA used in road construction on the soil and groundwater were low (Schreurs et al., 2000; Bruder-Hubscher et al., 2001). Badreddine and François (2009) assessed the fate of PCDD/Fs from municipal solid waste incineration residues that were used in four road construction sites (>10 years) as surface, base, and sub-base courses, and found that the materials posed little harm to the quality of road soils. In another study (Lidelöw and Lagerkvist, 2007), however, higher concentrations of Cr and Cu were observed in MSWIBA than in crushed rock used in a construction site.

Most studies conducted to date have focused on the physico-chemical properties and constituents of residue leachates. Chemical analysis is used to quantify pollutant concentrations and cannot account for the interaction among the pollutants in complex mixtures (Fan et al., 2006), thus providing insufficient comprehensive risk information. On the contrary, ecotoxicity is the result of the combination of several factors, such as heavy metals, ammonia, salts and volatile fatty acids. Therefore, to reveal the feasibility of utilizing MSWIBA, CFA or FGDR as a construction material, an ecotoxicity risk assessment of leachates derived from these residues needs to be conducted in addition to traditional chemical analyses. A few studies have included ecotoxicological analysis of MSWIBA and CFA leachate using methods such as the Microtox® toxicity test, *Daphnia magna* immobility test, *Ceriodaphnia dubia* death test, worm mortality (Quilici et al., 2004; Tsiridis et al., 2006; Ribé et al., 2014; Phoungthong et al., 2016a), and plant assays (Radetski et al., 2004; Phoungthong et al., 2016b). Different levels of toxicity have been recorded from the various tests, and the toxicity was greatly influenced by the pH status of the solid samples, the types of the leachants, as well as the concentrations of heavy metals and carboxylic acids in the residues' leachates. Therefore, the residues need to be formally tested with ecotoxic and genotoxic sensitive tests before recycling. Little is currently known about the phytotoxicity of CFA and FGDR.

The ecotoxicity of the residues is highly dependent on the leachability of the constituents and the leaching environment

Table 1 – Physico-chemical characteristics of the coal fly ash (CFA), municipal solid waste incinerator bottom ash (MSWIBA) and flue gas desulfurization residue (FGDR).

Properties	CFA1	MSWIBA1	MSWIBA2	FGDR1	FGDR2	FGDR3	FGDR4	FGDR5
LOI (%wt, at 600°C)	3.13	3.31	1.14	2.25	9.56	3.64	6.73	6.06
Density (g/cm^3)	1.66	2.12	1.83	1.82	1.66	1.54	1.53	1.33
d_{50}	30 μm	3.10 mm	3.80 mm	–	–	–	–	–
Elemental content (mg/kg)								
As	44.2	57.1	85.4	34.7	31.5	41.3	63.0	51.0
B	ND	ND	ND	1407	574	1086	3090	774
Ba	359	1240	2090	2183	2799	3073	3013	3030
Be	6.42	1.78	2.68	ND	0.13	0.17	ND	0.75
Bi	ND	ND	ND	52.6	48.9	51.3	52.3	55.0
Cd	1.01	4.91	7.52	ND	ND	ND	ND	ND
Co	ND	ND	12.4	ND	ND	ND	ND	ND
Cr	65.8	330	676	ND	4.73	ND	ND	6.71
Cu	56.0	1670	1710	ND	0.29	1.38	0.76	18.1
Mn	213	705	1080	8.01	342	370	136	429
Ni	26.8	131	2107	2.58	22.9	22.9	9.93	23.9
Pb	86.9	482	609	1.49	7.29	3.13	1.29	14.1
Se	16.8	1.60	3.13	ND	ND	ND	ND	ND
Sr	544	219	366	256	1501	1706	886	1168
V	140	44.7	54.0	0.47	27.4	28.7	19.1	58.2
Zn	81.9	2100	2370	354	335	390	458	468

ND: not detectable.

Please cite this article as: Phoungthong, K., et al., Phytotoxicity and groundwater impacts of leaching from thermal treatment residues in roadways, J. Environ. Sci. (2016), http://dx.doi.org/10.1016/j.jes.2016.11.009