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A risk-based approach for assessing the recycling potential of an alkaline waste material as road sub-base filler material

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ABSTRACT

In this work we present an integrated risk-based approach that can be used to evaluate the recycling potential of an alkaline waste material such as incineration bottom ash (BA) as unbound material for road sub-base construction. This approach, which is aimed at assessing potential risks to the groundwater resource (in terms of drinking water quality) and human health associated to the leaching of contaminants from the BA, couples the results of leaching tests for the estimation of source concentrations with the fate and transport models usually adopted in risk assessment procedures. The effects of weathering and of the type of leaching test employed to evaluate eluate concentrations were assessed by carrying out different simulations using the results of laboratory leaching tests. Specifically, pH-dependence and column percolation leaching tests were performed on freshly collected and 1-year naturally weathered BA samples produced from a grate-fired incineration plant treating Refuse Derived Fuel (RDF). To evaluate a broad span of possible scenario conditions, a Monte Carlo analysis was performed running 5000 simulations, randomly varying the input parameters within the ranges expected in the field. In nearly all the simulated conditions, the concentrations of contaminants in the groundwater for the specific type of BA tested in this work were well below EU and WHO drinking water quality criteria. Nevertheless, some caution should be paid in the case of the establishment of acidic conditions in the field since in this case the concentration of some elements (i.e. Al, Pb and Zn) is expected to exceed threshold values. In terms of risks to human health, for the considered utilization scenario the probability of exceeding the acceptable reference dose for water ingestion was usually less than 1% (except for Cr and Pb for which the probability was lower than 3.5% and 7%, respectively).

1. Introduction

The recycling potential of alkaline waste materials (e.g. residues from thermal treatment processes, steel slag and construction and demolition waste), as secondary aggregates for civil engineering applications has been increasingly investigated in the last few years (e.g.: Forteza et al., 2004; Petkovic et al., 2004; Das et al., 2007; Huang et al., 2007). The recycling of these materials is aimed at reducing both the amount of landfilled waste and also the consumption of virgin raw materials, in line with the circular economy strategy recently promoted by the European Commission (EU Commission, 2014). However, the use of the above mentioned types of residues as construction materials or as fillers for different applications (e.g. for road sub-base construction) is still limited in many European countries, or carried out only under restricted conditions, due to concerns related to potential long-term environmental impacts, especially in terms of the leaching of inorganic constituents (Kosson et al., 2002; Engelsen et al., 2009). Thus, the suitability of a specific recycling option for these waste streams should be evaluated on the basis of a detailed assessment of the potential impacts to the environment and human health caused by the release of pollutants contained in the waste, which should take into account of the actual field conditions expected for the specific application scenario.

During the past decades, risk-based approaches have been increasingly applied in the field of waste management as a valuable decision support tool to identify environmentally-sound solutions concerning the recycling of granular waste materials (e.g. Hartlen et al., 1999; Petkovic et al., 2004; Chen and Ma, 2006). A scientifically sound risk-based approach allows to model several

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Nomenclature

AT	averaging time [y]
BW	body weight [kg]
C(L/S)	leaching concentration estimated from the column test [mg/L]
C_{poc}	concentration at the point of compliance [mg/L]
CR	water ingestion rate [L/d]
C_{source}	leachable concentration from the source [mg/L]
d	source thickness [m]
d_a	groundwater thickness [m]
DAF	dilution attenuation factor [–]
ED	exposure duration [d]
EF	exposure frequency [d/y]
HI	hazard index [–]
i	groundwater gradient [m/m]
I	net water infiltration rate [–]
I_{eff}	effective water infiltration rate [m/y]
K_{sat}	soil hydraulic conductivity [m/y]
LDF	leachate dilution factor [–]
LF	leaching factor [–]
L_f	water table depth [m]
P	precipitation [m/y]
POC	point of compliance [m]
RfD	reference dose [mg/kg·d]
R_T	total risk [–]
R_i	risk calculated to a generic i-th time interval [–]
SAM	soil attenuation model [–]
SF	slope factor $[mg/kg{\cdot}d]^{-1}$
S(pH)	leaching concentration estimated from the pH-dependence test [mg/L]
S_w	width of the source orthogonal to the groundwater flow [m]
t	time [y]
v_{gw}	Darcy velocity [m/y]
W	width of the source longitudinal to the groundwater flow [m]
α_x	longitudinal dispersivity [m]
α_y	transversal dispersivity [m]
α_z	vertical dispersivity [m]
δ_{gw}	groundwater mixing zone height [m]
θ_e	effective porosity of the soil [–]
ρ_{mat}	waste material dry bulk density [kg/L]

utilization scenarios for granular waste materials. These scenarios should take into account of the transport of leaching substances from the source (the waste material) following a pathway (through its surrounding environment) towards the receptor (generally a surface or groundwater body or human receptors). Model calculations result in time-dependent concentration curves of the leached substances that reach the receptor over the whole exposure duration (Saveyn et al., 2014).

As described by Townsend et al. (2006), in risk assessment-based studies the evaluation of the leachable fractions of a waste material can be performed following basically two different types of approaches. The first one is based on the use of literature values for solid-water partition coefficients (K_d), specific to each contaminant, that on the basis of the total concentration of the pollutant in the waste allow to estimate the concentration in the leachate. This is the approach commonly applied for soils contaminated by organic compounds; however, for inorganic contaminants, it is widely recognized that the use of literature K_d values may lead to predictions that are not representative of the site-specific leaching scenario (U.S. EPA, 2005). To overcome this limitation, experimental leaching tests can be used to assess the potential behaviour of the specific waste material in the considered utilization scenario (Townsend et al., 2006; Tiruta-Barna et al., 2007; Susset and Grathwohl, 2011). This second type of approach is applied in European Countries (e.g. in Denmark, Norway and Sweden) for the evaluation of recycling and reuse strategies for solid mineral waste (e.g. Hartlen et al., 1999; Petkovic et al., 2004; Saveyn et al., 2014) and it was the basic principle followed at the EU level for the development of leaching criteria for landfill acceptance of waste (EU Council, 2003).

Several types of experimental leaching methods have been developed for both characterization and regulatory purposes and many efforts have been made in order to harmonize leaching test procedures (e.g. Kosson et al., 2002; van der Sloot and Dijkstra, 2004; van der Sloot and Kosson, 2012). It is well known that the liquid-to-solid ratio (L/S) and pH represent the most important parameters influencing the leaching behaviour of contaminants from granular waste materials in any recycling/disposal scenario (e.g. Saveyn et al., 2014). To this end, the most relevant leaching tests which are employed to characterize the environmental behaviour of alkaline waste materials are pH-dependence tests (e.g. CEN/TS 14429 or 14997; EPA Method 1313) and column percolation tests (e.g. prEN 14405 and EPA Method 1314). pH-dependence tests can be used to assess the influence on the leaching behaviour of pH changes which the material may undergo during disposal or recycling (van der Sloot and Kosson, 2012). Percolation column tests provide information on release under hydraulically dynamic conditions (Kalbe et al., 2008; López Meza et al., 2008; Grathwohl and Susset, 2009). Both methods can be used to provide estimates, within defined uncertainty levels, of maximum field leachate concentrations, extent of leaching and expected leaching response over time and as a consequence of changes in environmental conditions (Kosson et al., 2014).

When examining the recycling potential of a granular waste material, also other important factors, such as carbonation, redox potential and complexation processes should be taken into account, since they can affect the leachability of different constituents. For instance, especially for alkaline waste materials (e.g. combustion residues, steel slag and construction and demolition waste), carbonation plays an important role. Indeed, Ca bearing (hydr)oxides and/or silicate phases in contact with atmospheric air and humidity may partially dissolve and react with CO_2 leading to the formation of carbonate precipitates. This process leads to decreases in pH (e.g. from above 12 to values below 10) and as direct consequence, or in relation to other mechanisms (e.g. co-precipitation or adsorption), may affect the solubility and leachability of several contaminants (Meima and Comans, 1999; Chimenos et al., 2000).

In this work, a risk-based approach is presented for evaluating the recycling potential of an alkaline waste material. In particular, Bottom Ash (BA) produced by a grate-fired incineration plant treating Refuse Derived Fuel (RDF) was selected as alkaline material on which to carry out the assessment. The physical-chemical and mineralogical characteristics, as well as leaching behaviour, of this specific type of BA was analysed in depth in previous studies (Di Gianfilippo et al., 2016; Rocca, 2011; Rocca et al., 2012). This type of BA in general, and the analysed sample in particular (see Baciocchi et al., 2010b; Rocca et al., 2012; Di Gianfilippo et al.,