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A new integrated evaluation method of heavy metals pollution control during melting and sintering of MSWI fly ash

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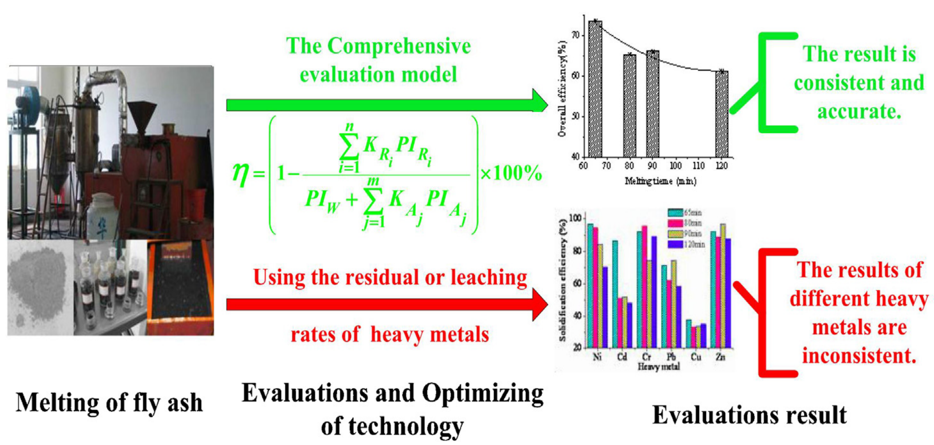
HIGHLIGHTS

- A new integrated evaluation method of heavy metals pollution control was proposed.
- An overall pollution toxicity index OPTI for this evaluation method was proposed.
- The method was used to evaluate melting and sintering technology of MSWI fly ash.
- The lowest efficiency of melting was 56.2% and the highest of sintering was 46.6%.
- The consistent, uniqueness and correctness of the method was demonstrated.

GRAPHICAL ABSTRACT



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ABSTRACT

Evaluations of technologies for heavy metal control mainly examine the residual and leaching rates of a single heavy metal, such that developed evaluation method have no coordination or uniqueness and are therefore unsuitable for hazard control effect evaluation. An overall pollution toxicity index (OPTI) was established in this paper, based on the developed index, an integrated evaluation method of heavy metal pollution control was established. Application of this method in the melting and sintering of fly ash revealed the following results: The integrated control efficiency of the melting process was higher in all instances than that of the sintering process. The lowest integrated control efficiency of melting was 56.2%, and the highest integrated control efficiency of sintering was 46.6%. Using the same technology, higher integrated control efficiency conditions were all achieved with lower temperatures and shorter times. This study demonstrated the unification and consistency of this method.

1. Introduction

Solid waste containing heavy metal accounts for a large proportion of all kinds of hazardous waste. Harmless treatment methods for those hazardous wastes mainly employ solidification and stabilization, including chemical stabilization, asphalt solidification, cement solidification, sintering, and melting [1–3]. Evaluations of

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technologies for heavy metal control mainly examine the residual and leaching rates of a single heavy metal [4]. However, because practical applications of the evaluation of different metals have shown inconsistent results [5,6], selecting a technology and optimizing processes for heavy metal pollution control are difficult. Establishment of an integrated evaluation method for heavy metal pollution control is therefore necessary; this evaluation method must consider the type, content, toxicity, and stability of heavy metals. The closest research that has been done in this area to date is the hazard evaluation of heavy metals in marine, river sediments and soil [7–10]. Several methods that tackle the various issues described from different angles have been proposed.

Common approaches for describing hazards include the pollution load index [11,12], potential ecological risk index [13], excess after regression analysis, theory of fuzzy subset, geoaccumulation index [12], face-graph, comprehensive pollution index, secondary phase enrichment factor [14]. The French Research Institute for Exploitation of the Sea (IFREMER) and the inter-ministerial group GEODE also realized the software GEODRISK which is based on two levels N1 and N2 to classify the risk of heavy metals in sediment [15]. However, these methods cannot be used directly in an integrated evaluation method of heavy metal pollution control because significant disparities from actual values have been observed. But the concept about Toxic Response Factor and integrated evaluation of heavy metal in those methods could be referenced for establishing an integrated evaluation method of heavy metals pollution control.

This paper establishes an overall pollution toxicity index of heavy metals in hazardous waste using the residual rates and heavy metal toxicity coefficients of Hakanson's potential ecological risk index method as references [16]. An integrated evaluation method of heavy metal pollution control based on the developed index was established. Sintering and melting experiments on municipal solid waste incinerator (MSWI) fly ash were also carried out in this paper. This study investigates the effects of operational conditions, such as temperature, time, and additives, on the residual and leaching rates of heavy metals (Pb, Zn, Cu, Cr, Ni, and Cd) in the atmosphere. Then, the integrated evaluation method was used to evaluate the heavy metal pollution control efficiency during sintering and melting treatments in different operational conditions.

2. Material and methods

2.1. Method description

The integrated method evaluates the overall pollution toxicity index (OPTI) of heavy metals during the technical treatment process of hazardous wastes containing heavy metals and focuses on changes in the overall pollution toxicity of the heavy metals. The integrated control efficiency (η) of heavy metals can be defined as follows:

$$\eta = \left(1 - \frac{\sum_{i=1}^{n} \mathrm{K}_{R_i} \mathrm{OPTI}_{R_i}}{\mathrm{OPTI}_W + \sum_{j=1}^{m} \mathrm{K}_{A_j} \mathrm{OPTI}_{A_j}} \right) \times 100\% \quad (1)$$

where W is the hazardous waste, OPTI_W is the overall pollution toxicity index of heavy metals in the hazardous waste, R_i is a type of product obtained after the technical treatment of the hazardous waste, n is the products number, K_{R_i} is the mass percent of R_i, OPTI_{R_i} is the overall pollution toxicity index of the heavy metals in R_i, the A_j is a type of additive used during the technical treatment process, m is the additives number. K_{A_j} is the mass percentage of A_j, and OPTI_{A_j} is the overall pollution toxicity index of heavy metals in A_j.

Table 1
The background values of heavy metal in topsoil in China and the toxic response factor of heavy metal.

Heavy metal	Ni	Cd	Cr	Pb	Cu	Zn
C_k^0 (mg/kg)	27	0.10	61	26	23	74
T_k^r	5	30	2	5	5	1

Notes: C_k^0 is the reference value of heavy metals concentration, T_k^r is the toxic response factor of heavy metals.

The key to this method is the calculation of the overall pollution toxicity index of heavy metals, which indicates their potential risk to the environment and considers the following parameters:

Quantity – Reflects the integrated influence of heavy metals to the environment. The hazards of multiple heavy metals should be higher than only by a single or a few heavy metal hazards.

Intensity – Directly reflects the hazardous effects of heavy metals on the environment. The higher the concentration of heavy metals is, the greater the pollution intensity. The heavy metal pollution intensity (C_k^I) can be calculated as follows:

$$C_k^I = C_k - C_k^0 \quad (2)$$

where k is the type of heavy metal used, C_k is the heavy metal concentration, and C_k^0 is the reference value for heavy metal concentration, Usually, the reference value for the evaluation use the highest background values of heavy metals are found in topsoil before industrialization, as shown in Table 1 [17].

Toxicity – Reflects the toxicity of heavy metals and the sensitivity of organisms toward these heavy metals. Toxicity can be indicated by the toxic response factor (T_k^r) in Hakanson's potential ecological risk index method as references [13]. The T_k^r of several heavy metals are shown in Table 1 [18,19].

Stability – Reflects the releasability of heavy metals in different forms. Stability can be determined by leaching characteristics. Only heavy metals that are released to the environment can cause ecological risk. Heavy metals usually dissolve in water prior to harming the ecological environment. Thus, the leaching rate (L_k) may be defined to characterize the stability of a heavy metal:

$$L_k = \frac{m_k^1}{m_k^0} \times 100\% \quad (3)$$

where k is the type of heavy metal considered, m_k^1 is the mass of heavy metal in the leaching solution, and m_k^0 is the mass of heavy metal in the leaching sample.

Using these four parameters, the overall pollution toxicity index (OPTI) of heavy metals can be calculated as follows:

$$\mathrm{OPTI} = \sum_{k=1}^{o} T_k^r C_k^I L_k \quad (4)$$

where o is the number of heavy metals.

2.2. Melting and sintering experiment of fly ash

Two kinds of MSW incinerator fly ash (designated as FA1 and FA2) were obtained from the bag filter of two incineration plants located in South China. Fly ash samples were uniformly mixed, ground to an average particle size of less than 150 mesh (106 micrometers), and then dried. Following US EPA 3050, the fly ash samples were digested with HNO_3-HF-$HClO_4$, and their heavy metals contents were analyzed by an AAS 200 system (PerkinElmer Company). The measured heavy metal contents are reported in Table 2.