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Review

# The mechanisms of heavy metal immobilization by cementitious material treatments and thermal treatments: A review

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ABSTRACT

Safe disposal of solid wastes containing heavy metals is a significant task for environment protection. Immobilization treatment is an effective technology to achieve this task. Cementitious material treatments and thermal treatments are two types of attractive immobilization treatments due to that the heavy metals could be encapsulated in their dense and durable wasteforms. This paper discusses the heavy metal immobilization mechanisms of these methods in detail. Physical encapsulation and chemical stabilization are two fundamental mechanisms that occur simultaneously during the immobilization processes. After immobilization treatments, the wasteforms build up a low permeable barrier for the contaminations. This reduces the exposed surface of wastes. Chemical stabilization occurs when the heavy metals transform into more stable and less soluble metal bearing phases. The heavy metal bearing phases in the wasteforms are also reviewed in this paper. If the heavy metals are incorporated into more stable and less soluble metal bearing phases, the potential hazards of heavy metals will be lower. Thus, converting heavy metals into more stable phases during immobilization processes should be a common way to enhance the immobilization effect of these immobilization methods.



**Contents**



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## 1. Introduction

Many solid wastes are identified as hazardous wastes due to the fact that they contain leachable heavy metals, such as metallurgical slag, galvanic sludge, tannery sludge, municipal solid waste incinerators ash. Unlike organic pollutants, heavy metals cannot be destroyed but are infinitely persistent (Akcil et al., 2015; Bolan et al., 2014; Fu and Wang, 2011; Koptsik, 2014). If these solid wastes containing heavy metals (SWCHM) are not properly disposed, they will lead to secondary pollution to the air, soil and water (Audry et al., 2004; Conesa et al., 2009; Xiao et al., 2008; Zhou et al., 2007). The contaminated environmental factors are known to have adverse effects on individual biological recipients and populations (Bolan et al., 2014; Komarek et al., 2013; Koptsik, 2014; Porter et al., 2004). Therefore, assuring safe disposal of SWCHM is an important task of environment protection (Vespa et al., 2006a, 2007).

Immobilization treatment is an effective solution to address the potential hazards that SWCHM pose to the environment. This technology can reduce the potential migration of heavy metals by changing the physical and chemical properties of the wastes. Many immobilization methods have been developed in the past several decades, such as cement based solidification/stabilization (S/S) (Ucaroglu and Talinli, 2012), geopolymer based S/S (Guo et al., 2017), vitrification (Coruh and Ergun, 2006), carbonation (Li et al., 2007), Colloidal silica medium to obtain safe inert (COSMOS) (Benassi et al., 2016) etc. Fig. 1 shows the classification of various immobilization methods. Among these methods, cementitious material treatments and thermal treatments are two types of attractive methods due to that the heavy metals could be isolated in their dense and durable wasteforms. The wasteforms can provide a stable environment for the contaminations. The other chemical additive stabilization methods, such as carbonation, almost have no isolation effect on heavy metals. Fig. 2 shows the number of articles of each method from 2000 to 2016. The number of articles of each method was obtained as follows: 1. Keywords related to the SWCHM immobilization treatment were screened. 2. The keywords were used to search the databases of Science Citation Index (SCI) and the Science Citation Index Expanded (SCIE). 3. Unrelated and repetitive articles were excluded. The records were selected within the time span 2000–2016 where 2401 records were obtained. Then, the papers were classified by immobilization methods according to title and keywords of the papers.

As show in Fig. 2, cementitious material treatments and thermal treatments are always the research hotspots among various

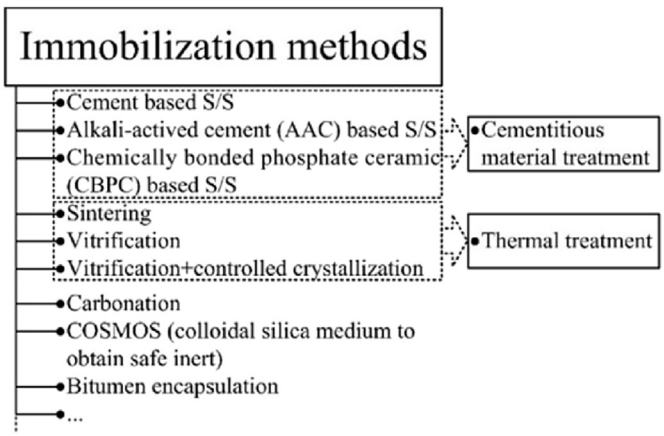


**Fig. 1.** The classification of various immobilization methods.

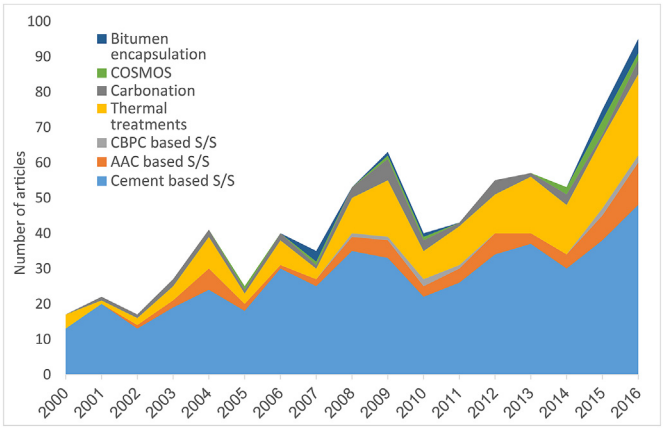


**Fig. 2.** The number of articles of each method from 2000 to 2016.

immobilization methods. The immobilization mechanisms of these methods are crucial to elucidate the mobility decline of heavy metals. In order to further enhance the immobilization effects of each method, it is necessary to understand the immobilization mechanisms. To the authors' knowledge, there is no previous review article focusing on the immobilization mechanisms of cementitious material treatments and thermal treatments. There are many similarities in the immobilization mechanisms of these methods. The aim of this article is to discuss the immobilization mechanisms of these methods in detail.

## 2. Immobilization methods

### 2.1. Cementitious material treatments

Cementitious material treatments are to encapsulate the SWCHM by mixing them with cementitious materials that solidifies and bonds the particles of SWCHM. After the mixture hardens, monolithic wasteforms with structural integrity and long-term stability are produced (Batchelor, 2006; Sullivan et al., 2010). The wastes are isolated in the wasteforms, whereas the mass and volume of the wastes are increased (Wang et al., 2012). As results, the leaching of heavy metals is inhibited and the environmental risks are reduced. Cement, alkali-activated cement (AAC) and chemically bonded phosphate ceramic (CBPC) are three popular binders for SWCHM treatment over the past decade.

#### 2.1.1. Cement based S/S

Cement based S/S has been widely used to treat SWCHM for several decades (Batchelor, 2006; Conner, 1990). Portland cement, the primary binder used in this method, consists of four major crystalline clinker phases (Gougar et al., 1996; Shi and Spence, 2004). Portland cement was first to be used in the field of nuclear wastes S/S (Conner and Hoeffner, 1998). Conner et al. summarized the reasons why cement based S/S are popular in researches and practical applications for SWCHM treatments (Conner and Hoeffner, 1998): (a) The composition of Portland cement is consistent from source to source. (b) The setting and hardening processes of cement are clearly understood.

Table 1 shows the clinker phases of Portland cement and the hydration products of these phases. Solid wastes may act as aggregates or partially react with the components of cement during the immobilization process. Immobilization treatment of SWCHM by cement based S/S may be complicated by the fact that the components of wastes interfere with cement hydration. Many solid wastes are reported to accelerate or retard the hydration of cement

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