

AVAILABILITY AND ASSESSMENT OF FIXING ADDITIVES FOR THE IN SITU REMEDIATION OF HEAVY METAL CONTAMINATED SOILS: A REVIEW

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Abstract. The use of low-cost and environmental safety amendments for the in situ immobilization of heavy metals has been investigated as a promising method for contaminated soil remediation. Natural materials and waste products from certain industries with high captive capacity of heavy metals can be obtained and employed. Reduction of extractable metal concentration and phytotoxicity could be evaluated and demonstrated by the feasibility of various amendments in fixing remediation. In this review, an extensive list of references has been compiled to provide a summary of information on a wide range of potentially amendment resources, including organic, inorganic and combined organic-inorganic materials. The assessment based on the economic efficiency and environmental risks brought forth the potential application values and future development directions of this method on solving the soil contamination.

Keywords: availability, assessment, fixing additive, heavy metal, in situ remediation

1. Introduction

Heavy metal contamination of soil environment has been occurring for centuries but its extent has increased markedly in the last fifty years due to technological developments and increased consumer use of materials containing these metals. In recent years, widespread concern has arisen over the implications of human health problems from increasing heavy metals in soils (Majid and Argue, 2001; Zhou, 2003). Unlike organic contaminants, most metals in soil environment do not undergo microbial or chemical degradation and therefore the total concentrations and ecotoxicity of metals persist in soils for a long time after their introduction. The remained heavy metals in various ecosystems would seep into groundwater or even channel into the food chain by crops growing on such a soil (Lin *et al.*, 1998). These heavy metals may adversely affect the soil ecosystem safety, not only agricultural product and water quality, but also the human health (Adriano, 2001; Zhou *et al.*, 2004). With lessons of catastrophic heavy metal contamination in the history, greater

public awareness was focused on the implication of contaminated soil environment on human and animal health, and there has been ever-increasing interest amongst the scientific community in developing technologies for remediating contaminated sites (Mulligan *et al.*, 2001; Namkoonga *et al.*, 2002; Bolan and Adriano, 2003a). Many methods such as vitrification, phytoremediation, earth-swap, soil flushing, solidification were used to remedy the metal contaminated soils. Among them, in situ fixation of heavy metal using exterior amendments is a promising technology for cleaning up contaminated soils and wastes (Ma *et al.*, 1993; Zhou and Song, 2004). *In situ* application of soil additives modifying the physicochemical properties of the contaminating heavy metals combined with the development of biological communities and plants for further metal immobilization was shown to be a very promising alternative remediation method based on risk reduction and time and cost efficiency (Vangronsveld *et al.*, 1995; Diels *et al.*, 2002).

In situ fixation had been originally depicted in water or solution contaminated with metals using different sorbents in the middle of last century. In the 1950s to 1970s, it began to realize that the total content was not sufficient to assess the metal contamination; growing awareness of the strong dependence of the toxicity of heavy metals upon their chemical forms had led to an increasing interest in the qualitative and quantitative determination of specific metal species (Tessier and Campbell, 1979; Zhou and Sun, 2002). Fraction-based studies on the fixation of heavy metals in sediments and soils had been greatly carried out with different unitary additives, such as zeolite, cements, and limes. In the following two decades, many synthetic amendments such as synthetic zeolites and phosphate-induced products, and byproducts such as quarry waste, biosolids and sewage sludge were used in the metal immobilization (Ma *et al.*, 1993; Ortego *et al.*, 1998; Cao *et al.*, 2003; Ciccu *et al.*, 2003). And fixation treatment in soils with heavy metal contamination has been greatly developed with the increasingly available resources of different additives. Both in water and soil, the fixation treatment is based on the reduction of metal mobility and availability as a result of applying additives. And consequently, the detrimental effects of heavy metals to environmental receptors such as microorganisms, plants, animals, water bodies and humans are reduced.

Screening out the fixing additives and application assessment are the two major aspects in the further fixation study. In recent years, a lot of fixing additives including bio-absorbent, byproducts, synthetics were often used in the immobilization remediation according to their different costs and fixation efficiency. Low-cost additives are critically required to the improvement of fixing efficiency. The natural or waste materials are considered as the important resources for the fixing remediation. Meanwhile, application assessment is another necessary component for the safety utilization of selected amendments with the lowest environmental risks. In this paper we classified the additives into organic, inorganic and organic-inorganic types according to the different availability in nature. Application assessment and the remediation standard were the other parts of this review.

2. Types and Availability of Fixing Additives

In the fixation processes of amendments, cation exchange, adsorption, surface complexation and precipitation are the general phenomena that can reveal the primary mechanism in immobilization of heavy metals. Comparing with the former research works, the different efficiency of the selected amendments was apparently stated. The fixation efficiency depends on not only the amount of the amendments mixed to the soil, but also the patterns of them. The physical and chemical properties of metals and amendments themselves are also the corresponding factors in the fixation. Most of the metals are characteristic of their special chemical properties. Cation mobility is one of the most important properties that can evaluate their environmental fate and biological toxicology. Different metals have the distinct mobilities and certainly it is not easy to find the uniform fixation agents to reduce the bioavailability of heavy metals. Among the numerous treatment agents, some are eligible for several metals, depending on the amount that will be admixed to the soil based on the previous studies, such as limes, phosphates, organic matter induced additives and industrial co-products based synthetics which are the typical fixation agents in the field study. According to the source situation of different fixing reagents, there are the three resources including natural materials, artificial synthetics and co-products used for fixing study. Natural materials that are available in a large quantity, or certain waste products from industrial or agricultural operations may have potential as inexpensive sorbents. Due to their low cost, after these materials have been expended, they can be disposed of without expensive regeneration. Generally, we also classify these available fixing additives into organic, inorganic and combined organic-inorganic resources.

2.1. FIXING ADDITIVES BASED ON ORGANIC MATTER

Organic waste such as sewage sludge and domestic refuse or manure compost can be used as soil amendments and to certain extent as a slow release nutrient source, and simultaneously could be used to lower metal availability. Most of organic additives are mainly from the farmyard manure, poultry manure, sewage sludge, domestic refuse and straws (Table I).

Bark and sawdust are effective because of their high tannin content. The polyhydroxy groups of tannin are considered as the active species in the adsorption process of heavy metals. And it was easily forming a chelate when the ion exchange happened in the adjacent phenolic hydroxyl groups (Vazquez *et al.*, 1994).

2.2. FIXING ADDITIVES BASED ON INORGANIC MATTER

In addition to organic amendments, inorganic amendments are used to improve substrate characteristics. These included quarry waste, pulverized refuse, and pulverized fuel ashes (Table II). Inert materials including colliery spoils and steel slag

TABLE I
Types and resources of organic amendments for metal immobilization

Material	Heavy metal	Resources	Reference
Bark sawdust	Cd, Pb, Hg, Cu	By-product of the timber industry	Suran and Beiley (1999) Bryant <i>et al.</i> (1992)
Xylogen	Zn, Pb, Hg	Waste water of paper mill	Rei (2000)
Chitosan	Cd, Cr, Hg	Waste product of the crab meat canning industry	Suran and Beiley (1999)
Bagasse	Pb	Sugarcane	Janusa <i>et al.</i> (1998)
PM ^a	Cu, Zn, Pb, Cd	Poultry farm	Ihnat and Fernandes (1996)
CM	Cd	Poultry farm	Bolan <i>et al.</i> (2003c)
Rice hulls	Cd, Cr, Pb	Rice cultivation	Roy <i>et al.</i> (1993)
SS, milorganite	Cd	Cd uptake decrease with amount additive	John and Laerhoven (1976)
Leaves	Cr, Cd	Senna, redwood, pine	Suran and Beiley (1999)
Straw	Cd, Cr, Pb	Cotton, rice, maize	Suran and Beiley (1999)

^aPM: poultry manure; CM: cattle manure; SS: sewage sludge.

TABLE II
Types and resources of inorganic amendments for metal immobilization

Material	Heavy metal	Resources	Reference
Lime and quicklime	Cd, Cu, Ni, Pb, Zn, Cr, Hg	Lime factory and stone pulverization	Dermatas and Meng (1996) Bolan <i>et al.</i> (2003b)
Phosphate salt	Pb, Zn, Cd, Cu	Phosphate fertilizer plant Phosphorite	Naidu <i>et al.</i> (1994) Cao <i>et al.</i> (2003) Basta and McGowen (2004)
Hydroxyapatite	Zn, Pb, Cu, Cd	Phosphorite	Ma <i>et al.</i> (1993)
Rock phosphate	Pb, Zn, Cd	Phosphorite	Basta <i>et al.</i> (2001)
Fly ash	Cd, Pb, Cu, Zn, Cr	Thermal power plant	Ciccu <i>et al.</i> (2001) Lau and Wong (2001)
Slag	Cd, Pb, Zn, Cr	Thermal power plant	Deja (2002)
Ca-montmorillonite	Zn, Pb	Mineral	Auboiroux <i>et al.</i> (1996)
Beringite	Zn, Cd	Bauxite mineral	Vangronsveld <i>et al.</i> (1995)
Bauxite residue	Cd, Pb		Lombi <i>et al.</i> (1998)
Portland cement	Cr ³⁺ Cu, Zn, Pb	Cement plant	Diet <i>et al.</i> (1998) Li <i>et al.</i> (2001)
Bentonite	Pb	Pozzolana	Geebelen <i>et al.</i> (2002)
Gravel sludge	Zn, Cu, Cd	Stone pulverization	Krebs <i>et al.</i> (1999)
Ettringite	Cd, Cu, Pb, Zn, Cr	Bauxite	Albino <i>et al.</i> (1996)

are very often necessary to serve as an insulation layer, to avoid migration of toxic elements to the plants and groundwater (Wong, 2003).

It is a common practice to apply liming materials to overcome some of the problems associated with acidic conditions. The liming materials including CaO, Ca (OH)₂, CaMgCO₃, and CaCO₃, and the phosphate induced materials including CaHPO₃, Ca (H₂PO₃)₂, K₂HPO₄, H₃PO₄, and (NH₄)HPO₄ were the typical amendments used for the in situ immobilization in order to decrease the metal concentration in soil solution and extractability, to decrease metal mobility and leachability, to transform from soluble metals to residual and to reduce the metal concentration in plant tissues (Dermatas and Meng, 1996; Gray *et al.*, 1999; Bolan *et al.*, 2003b; Kreutzer, 1995; Brown *et al.*, 1997; Wang *et al.*, 2001; Theodoratos *et al.*, 2002; Pearson *et al.*, 2000; Cao *et al.*, 2003; Chen *et al.*, 2003). Wang (2001) reported that Ca (H₂PO₄)₂ could replace CaHPO₄ due to lower cost and higher solubility in the field study. The combination of Ca (H₂PO₄)₂ and CaCO₃ significantly reduce the extractable metal concentration and successfully immobilize heavy metals on the site. Dermatas (2003) considered that the quicklime (CaO) was a more effective additive because it is readily soluble and available for reactions, and its addition to a soil material results in larger pH increases. Moreover, in the case of the in-situ stabilization of deep layers by slurry injection, lime due to its high solubility in water, permeates the porous media much more effectively, and therefore has a much larger radius of influence than the other additives.

2.3. FIXING ADDITIVES BASED ON THE COMBINED ORGANIC – INORGANIC MATTERS

The development of the additives used as metal fixation in soils is placing more emphasis on the reuse potential of the stabilized materials and the cost efficiency. Previous research had only concentrated on the reducing leachability efficiency of heavy metals after comparing with different additives. Many amendments used in the stabilization of metal in MSW (municipal solid waste) were introduced in contaminated soil remediation. The in situ remediation of contaminated soils by the fixation method requires accurate cost assessment. And the reuse of stabilized material is of great consideration as well as the efficiency. Inexpensive, effective, readily available materials can be used in place of activated carbon or ion exchange resins for the removal of heavy metals in soils. A wide range of combined organic – inorganic amendments including low-cost sorbents such as xanthate sorbent had been studied (Table III). Cement based and lime based additives were considered as the most cost-effective in fixation. As for the fixation of metals in soil, the lowest releases of the previously immobilized toxic heavy metal components could be the foremost factor in choosing the additives for fixation.

TABLE III
Types and resources of combined organic – inorganic amendments for metal immobilization

Material	Heavy metal	Resources	Reference
LSB ^a	Cd, Pb, Zn	Lime and organic matter	Basta <i>et al.</i> (2001)
MSW	Cd, Pb, Zn, Cr	Municipal solid waste	Bolan <i>et al.</i> (2003c)
SS, Milorganite	Cd	Artificial synthetic	Snyman <i>et al.</i> (1998)
Living earth	Cd	Sewage sludge	Bolan <i>et al.</i> (2003c)
Peat	Cd, Cr, Hg, Pb	Complex soil material with organic matter in various stages of decomposition	Kertman <i>et al.</i> (1993)
Peat moss			Sharma and Forster (1993)
Xanthate sorbent	Cd, Hg, Cr	Fibrin, amyllum and carbon bisulfide	Suran and Beiley (1999)

^aLSB: lime stabilized biosolid; SS: sewage sludge; MSW: municipal solid waste.

3. Assessment of the Fixation Treatment

Generally, the assessment of in situ fixation includes economic efficiency and environmental risk. As seen in Figure 1, soils in intervention value (formally, integration of human toxicological and ecotoxicological serious soil contamination concentration) are in the remediation urgency. The aim of the remediation treatment by the fixing method is to get the target value which was related to the negligible risk for the ecosystem.

3.1. ECONOMIC ASSESSMENT

Prior to the in-situ application of additives, economic efficiency would be assessed to estimate the cost acceptance of this method. Economic assessment is generally including two parts: comparing with previous productivity and the cost of other remediation methods. Product quantity and quality, corresponding with the competition in the market business, are the basic indexes for assessing the application of amendments to the remediation of contaminated soils, especially for the arable soils with low metal contamination. This aspect would also be stated in the parts of the phytotoxicity in environmental risk assessment. Input and output comparison in the soil remediation gives the fundamental information for selecting the proper method. Previous studies had shown the cost evaluation of several methods in the contaminated site, specific in point pollution, see Table IV.

Table IV shows the estimated cost, time and risk advantages between the phytoextraction, in situ fixation, excavation and landfilling in a public approved hazardous waste facility, and soil extraction. Phytoremediation is far less expensive, but it requires more than 5 years rather than shorter periods for the competing technologies. It also greatly depended upon both the contamination extent and phytoextraction efficiency. The trade off is the large amount of time that is required to

TABLE IV
Advantages of different remedial treatments^a

Type of treatment	Cost t/m ³ (\$)	Time required (month)	Additional factor/expense	Safety issue
Fixation	90–200	6–9	Transport/excavation, long-term monitoring	Leaching
Landfilling	100–400	6–9	Long-term monitoring	Leaching
Soil extraction/ leaching	250–500	8–12	5000 m ³ minimum chemical recycle	Residue disposal
Phytoextraction	15–40	18–60	Time/land commitment	Residue disposal

^aRevised after Schnoov (1998).

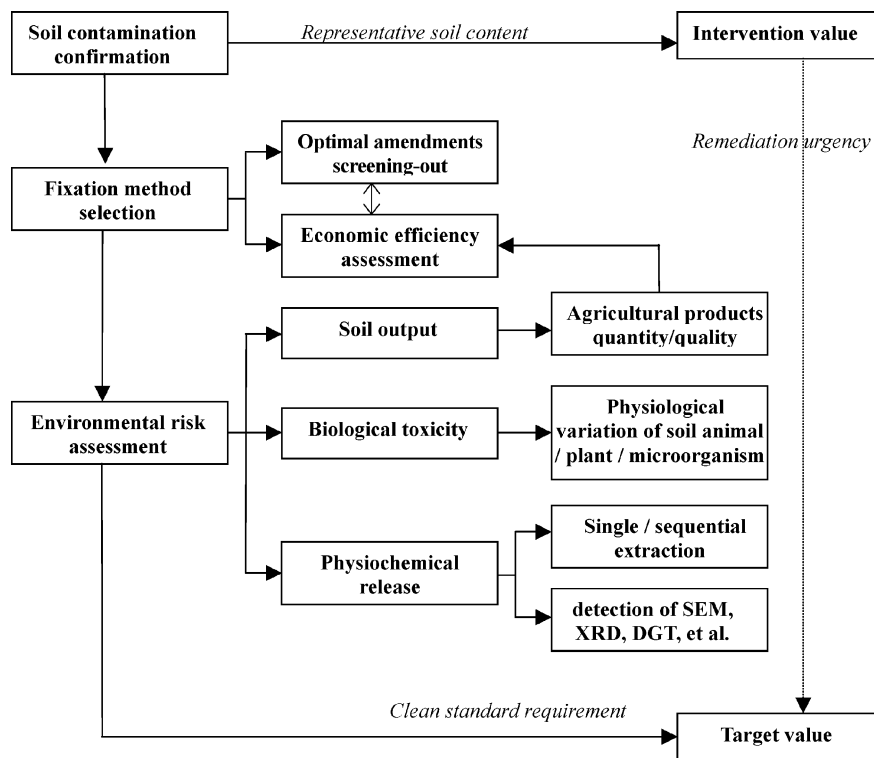


Figure 1. The flow chart of fixation assessment. (SEM: scanning electron microscopy, XRD: X-ray diffraction, DGT: Diffusive gradient in thin film technique).

achieve treatment to action levels in a heavy or multiple contamination site. As for the arable soil with non-point pollution, the plant selected for metal extraction could not enter the food chain and consequently this would result in the economic lost in agricultural production. Fixing remediation sometimes is the most comparable with the in situ remediation based on its time advantage and wide utilization in the arable

soil without changing the cultivating pattern. Proper screening on the amendments and efficient achievement to action level would contribute to cost saving.

3.2. ENVIRONMENTAL RISK ASSESSMENT OF FIXING TREATMENT

As a selected method in the soil contamination remediation, environmental risk assessment could be necessary for estimating the remediation efficiency. It was widely accepted that no uniform standard had been found to assess the remediation efficiency (Zhou, 2004). Due to the different contaminated extent and assessing methods, most of the studies on the remediation efficiency were concentrated on the results after finishing remediation. Different methods and standards were suggested according to their results. Here we stated the general flow of environmental risk assessment in the fixation remediation. We classified the environmental risk assessment into two processes of before treatment and after treatment.

3.2.1. Assessment Before Fixing Treatment

Prior to the *in-situ* treatment of fixing additives, laboratory experiment could be conducted to screen out the most efficient additives for the field remediation. The batch test was one of the most common used methods to evaluate the metal extraction and leachability in the laboratory study. Firstly, the batch-screening test was to select the best additives and combinations of additives. Secondary, the batch experiment was used as a quick test to obtain a preliminary evaluation of extractable or leachable metal concentration. Results of the reduction of metal concentration in the stabilized matrix would show the general fixation information of the exterior amendments. In the batch test before the *in situ* application of fixing additives, the soils used for the microcosmic experiment could be incubated under the expected condition for the imitation study. The toxicity characterization leaching procedure (TCLP) developed by US EPA (Environmental Protection Agency) was usually used to determine the mobility and leachability of metals in solid and multiphase wastes (US EPA, 1986). After the batch test, the following equations can be used to evaluate the efficiency (K) and capacity (Cap) of different additives for immobilization and field application (Jang and Choi, 1998):

$$K = 1 - \frac{C_e}{C_i} \quad (1)$$

and

$$\text{Cap} = (C_i - C_e) \frac{V}{W} \quad (2)$$

where K = efficiency of additive immobilization; Cap = capacity of additive immobilization; C_e = equilibrium extractable concentration of single metal in the immobilized soil (mg/L); C_i = initial extractable concentration of single metal

in pre-immobilized soil (mg/L); V = volume of metal salt solution (mg/L); W = weight of chemical additive (g). The high value of K and Cap represents the perfect efficiency and capacity of an additive that can be used in the field study of metal immobilization.

After screening out the best efficient additive, another experiment could be conducted to determine the best ratio (soil/additive) for the field fixing treatment. This was also corresponding with the economic efficiency in the low cost of big ratio (soil/additive) in the field application.

3.2.2. Assessment After Fixing Treatment

After the fixing treatment of contaminated soils, a lot of methods including biological and physiochemical experiments could be used to assess the remediation efficiency. Environmental risk could also be estimated after confirming the immobilized efficiency and possible release.

3.2.2.1. Biological Assessment. Generally, phytotoxic assessment is the most effective method for the in situ assessment of additive efficiency. Phytotoxic variation could be demonstrated by their physiological changes after the fixing treatment. The apparent variation of leaf and stem color, individual height, weight and some other properties could be observed with/without the stress of heavy metals in contaminated soils.

Phytotoxic variation can be also demonstrated by the decrease of heavy metal concentrations in the plant issues and the increase of biological quantity and quality. Superabundant metal ions in soil are fixed in the stabilized structure of additive mixture. The combining and bounding with the special reagent largely limit the mobility of metal ions and reduce the plant uptake concentration and biotoxicity. The proper screening on the plant cultivated in a contaminated site is help to the further evaluation of the fixation efficiency. Hyperaccumulative plants or the one, which is more sensitive to the variation of metal concentration in soil, could more accurately reveal the general information of phytotoxicity (Zhou *et al.*, 2004).

In addition, soil animals and microorganisms can be used as indicators of soil contamination both before and after remediation (Haimi, 2000). Effects of metals on living organisms must be considered within a context of communities, livabilities, sizes, weight and some other microcosmic indexes such as enzymes activities, DNA damage (Guo and Zhou, 2003; Youn *et al.*, 2004).

3.2.2.2. Physiochemical Assessment. Fraction scheme and micro-detection were often used as physiochemical methods to assess the remediation efficiency. In the fraction scheme, single and sequential extractions were the two basic component parts that are often used separately for different purposes. Single extraction is proposed to determine one speciation of metal in soils using a specific extractant. Single extraction is often demonstrated the exchangeable or the leachable fraction change which is estimated by TCLP in the batch experiment and the column test. The

progressive of TCLP and the column test were also introduced as single extraction methods in order to further expound environmental behaviors of metal contaminants in the immobilization materials (Li *et al.*, 2001). The procedure of each step was the same as the standard TCLP test. After each extraction, the residues from the filtering process were returned to the extraction bottles to repeat the extraction using a fresh portion of the leachant. The column test can be carried out particularly for assessing the leachability and/or mobility of metals from surface to subsurface. Columns with the in-situ contaminated soil were saturated with counter flows, drained several times in order to release air bubbles. Then the continuous flow was conducted to leach in column with different leaching reagents. Detail variation of metal concentration in leachate and soil in different depth of column was obtained to evaluate the influence on the downward movement of metals by an additive.

Sequential extraction methods have often been used to study the speciation and possible associations between metals and soil or sediment components (Tessier *et al.*, 1979; Lo and Yang, 1998; Agata *et al.*, 2000; Kaasalainen and Yli-Halla, 2003). The chemical partitioning of metals is operationally defined according to the reagents used and the matrix of the samples. For exterior additive-based immobilization waste, this method can be useful to evaluate the metal distribution in the different phases of the immobilization waste matrix, potential binding mechanisms and leaching behaviors (Lo and Yang, 1998; Li and Poon, 1998). At present, a number of schemes have been proposed to fractionate metals on the basis of extractability in various chemical reagents either discretely or sequentially (Maiz *et al.*, 2000; Ngiam and Lim, 2001). Of these methods, the sequential extraction presented by Tessier *et al.* (1979) has been widely used in soil studies.

The study of interactions between the waste and the binder by means of the complexation analysis allows us to verify that the binder mixture in the presence of the waste and the mechanisms of the waste fixation. The scanning electron microscopy (SEM) and the X-ray diffraction (XRD) are frequently used to determine the new mineral phases, investigate the possible mechanism involved in the sorption of heavy metals and the differences in those arising from the fixation treatment, and confirm different species transformation in the sequential extraction (Ma *et al.*, 1993; Thevenin and Pera, 1999; Illera *et al.*, 2004). The approach to understand immobilization mechanisms and identify reaction products involves in other methods. The neutron activation analysis (NAA), the X-ray fluorescence (XRF), and the X-ray photoelectron spectroscopy (XPS) are used for quantifying elements. The field-emission scanning electron microscopy (FESEM) is used to examine the structure and morphology of the discrete particle. The scanning-transmission electron microscopy and X-ray microanalysis (STEM-XRM) are used to interrogate discrete particles, examine discrete particle morphology and determine elemental composition and possible mineral formula in discrete particles. The secondary ion mass spectroscopy (SIMS) is used to examine stabilization reaction mechanisms. The X-ray powder diffraction (XRPD) is used to identify bulk crystalline phase minerals. XPS is principally used to identify crystalline and amorphous speciation

and abundance at particle surfaces (Eighmy *et al.*, 1997). The diffusive gradient in thin film technique (DGT) is used to measure the flux of heavy metals which is supplied by diffusion through the soil solution and release from the solid phase (Lombi *et al.*, 2002).

3.2.2.3. Release Assessment. Heavy metal release from synthetic waste is an inevitable process with different environmental stress such as weathering, leaching, aging and depleting. Little is actually known, though, about the mechanism involved with the release of contaminants from the fixed waste. The two empirical models proposed to describe the release of contaminants are the bulk diffusion and shrinking unreacted core (SUC) models. Most studies on leaching behavior of cement based systems have assumed that the bulk diffusion is the main driving force for contaminant release. The bulk diffusion model, based on the Fickian diffusion, was originally developed according to the following equation (Baker and Bishop, 1997):

$$\frac{\partial C}{\partial t} = D_e \frac{\partial^2 C}{\partial x^2} \quad (3)$$

where D_e = effective diffusion coefficient, corrected for porosity and tortuosity ($\text{cm}^2 \text{S}^{-1}$); C = concentration of a contaminant (g cm^{-3}); t = time (s); x = distance (cm).

The primary failure of the bulk diffusion model is that the effect of acidity on the leaching process is not addressed. And the bulk diffusion model cannot accurately predict long-term leaching behavior. Baker and Bishop (1997) considered that leaching of contaminants was actually a result of the dissolution of the outer shell of the waste form, which resulted in a solubilization and release of contaminants from the leached shell. And the SUC model can account for the better understand of the role this mechanism playing in contaminant release. The potential release factor (PRF) equation derived from the SUC model was introduced as a means of assessing metal ions releasing efficiency from the fixed specimen:

$$\text{PRF} = \frac{\sqrt{2D_{e,s}f_{mo}^2C_m^2}}{\beta_c} \quad (4)$$

where PRF = potential release factor; $D_{e,s}$ = effective diffusion coefficient (for acid species) ($\text{cm}^2 \text{S}^{-1}$); f_{mo} = leachable fraction (dimensionless); C_m = solid contaminant concentration (mol cm^{-3}); β_c = acid neutralization capacity (kmol eq m^{-3}).

4. Prospect

To some extent, fixation of heavy metals in soils is different from that in water because of the different iron mobility and matrix structure. Low percentage of the soluble parts and unstable transformation of different metal species in soils

resulted in the difficulty in fixation of heavy metals. But that was also contributed to the plausible reaction of metals in soil through stabilization or solidification. An effective control of heavy metals in soil is impossible without an understanding the mechanism of the fixation. How can the amendments fix the irons? Precipitation and adsorption were once used to formulate the entrapment of heavy metal ions, but these could not accurately describe the interior reactions between metal ions and amendments. The study of universal mechanism that could be responsible for the entrapment of the heavy metal species in the fixation matrix could be important issues in the future study.

Although the bioavailability is the key factor for the remediation strategy, the in situ fixation with exterior amendments in low content of metal may offer a promising option, especially for the non-point and light extent pollution derived from agricultural sources. Regulatory acceptance of in situ immobilization as a secure reclamation method depends on the solution of the following problem: how to assure and monitor efficiency of metal immobilization on the long term. The possible release of metal ions from the fixed complexations under different environmental stresses, such as acidic flows, temperature fluctuation, and other accelerated weathering processes could be simulated in a kinetic way in order to get the detail information for the environmental risk assessment. All of the methods stated in the environmental risk assessment had provided the general way to estimate the fixing efficiency. Meanwhile, the consulted standard for the comparison of biological toxicity and extraction results is also needed to enact in the remediation study.

The novel amendment, which is cost-effective and environmentally safe, is also required. This type of amendment could be capable of its long-term performance and multiple pollution remediation. The novel amendment corresponding with different land utilization and pollution types and extents could stimulate the acceptance of this method in contaminated soil remediation and be contributed to the high quantity/quality output of the soils.

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