HEAVY METAL REMOVAL FROM CONTAMINATED SOIL BY SOIL WASHING – A REVIEW

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ABSTRACT: Soil washing is one of the few permanent treatment alternatives for removing heavy metal contaminants from soils. This paper reviews the various technology and full-scale field applications of soil washing applicable to soils highly contaminated with heavy metals. Soil remediation technologies have been monitored by their general function, feasible environment, target contaminants, removal efficiency, environmental impact, overall cost and compatibleness with other remediation options. Heavy metals constitute an ill-defined group of inorganic chemical hazards, and those most commonly found at contaminated sites are Lead (Pb), Chromium (Cr), Arsenic (As), Zinc (Zn), Cadmium (Cd), Copper (Cu), Mercury (Hg), and Nickel (Ni). Remediation of heavy metal contaminated soils is necessary to reduce the associated risks with an aim to make the land resource available for agricultural production, enhance food security and scale down land tenure problems arising from changes in the land use pattern.

Keywords: Soil washing; Heavy metals; Soil remediation

1. INTRODUCTION

In recent trends due to pollution, soils are generally very much contaminated and have several types of contamination from accumulation of toxic heavy metal emitted from widely spreaded industrial areas, mine tailings, chemical fertilizers, animal manures, pesticides, deposition of high metal waste and residues of petrochemicals, coal combustion, gasoline and paints etc as well as sewage sludge. The concern over the soil contamination is important due to the associated health risks either in the form of direct contact with soil or secondary contamination via water supplies and food. Soil is the major place at which heavy metals and other contaminants are being dumped due to the anthropogenic activities.

Heavy metals are one of the major pollutants of the soil. These are defined as the any kind of metal or metalloid which is of environmental concern due to its hazardous nature and harmful effects. Heavy metals generally constitutes group of inorganic chemical substances. Most common heavy metals present in soil of contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni). The organic contaminants are better than the inorganic contaminants because they are oxidized to carbon (IV) oxide and degraded by the microbial actions so they are washed away from soil after some duration. However, Inorganic contaminants i.e. heavy metals persist in soils for the longer time because they did not undergo microbial as well as chemical degradation. Only possible things which could be done are changes in their chemical forms (speciation) and the bioavailability. Even the biodegradation of organic contaminants is also inhibited by the presence of the toxic metals. Heavy metal contamination severely affects the human health and ecosystem directly as well as indirectly. Contamination of soil increases toxicity in the proper food chain (soil-plant-human or soil-plant-animal-human), drinking water and ground water which reduces the safety and marketability of food, quality of drinking water and land reusability for agriculture purpose. These all factors increase the risk of various diseases in humans both at national and international levels. Thus, in current scenario heavy metal removal or remediation of soil is very important mainly at the nearby places where lots of industries are running. Restoration of the heavy metals contaminated soil requires soil characterization and selection of appropriate remediation technologies. Soil characterization provides the clear cut situation about the source of contamination, basic chemical properties of contamination, their bioavailability and speciation. Based on these characteristics, selection of best remediation technology can be adopted. Selection of the most suitable technique depends on the type, characteristics and concentration of pollutants as well as on the characteristics of soil.

In this review, we focus on the heavy metal contamination of soil, their characterization and available remediation technologies and their selection of best method in the cost effective manner.

2. SOIL CHARACTERSTICS AND HEAVY METALS IN SOIL

Soil is the non-homogeneous natural mixture of mineral grains obtained mainly from the physical and chemical weathering process and of constituents of inorganic origin. Soil classification is based on various parameters and one important parameter is the grain size. On the basis of grain size, gravel, sand, silt and clay soil are defined (Sposito, 1989). Immobilization potential of metal contaminants and their transport ability in soil is affected by the void structure within the soil which is highly dependent on the distribution of grain size and degree of compaction.

Several metals and heavy metals are released as a waste regularly from the various industries where metals or metallic compounds are used during the production or manufacturing of the products. Table 1 shows the major heavy metals released from the metal coating industries. However waste from this industry also having common metals such as aluminum, arsenic, cadmium, chromium, nickel and silver etc. In 1989, Traver et.al observed that concentration of heavy metals from the industrial and municipal waste in soil and sludge are generally several magnitudes higher than their concentration in nature (Table 2).

Table 1: Heavy Metal Generator industries (Traver et.al, 1989)

Industries	Copper	Lead	Zinc
Mining and Metallurgy	X	X	X
Paints and Dyes	X	X	
Pesticides		X	X
Electrical and Electronic	X	X	
Cleaning and Duplicating	X	X	
Chemical Manufacturing	X		
Explosives	X	X	
Rubber and Plastics			X
Batteries		X	
Textiles	X		
Petroleum and Coal		X	

Table 2: Typical Superfund Soil and Sludge Contaminants. (Traver et.al, 1989l)

Heavy Metal	Average (mg/kg)	Maximum (mg/kg)	TTLC [a] (mg/kg)
Pb	3,100	61,000	1,000
Zn	5,000	67,000	5,000
Cd	180	3,000	100
As	90	950	500
Cu	2,100	52,000	2,500
Cr	370	9,000	2,500
Ni	200	1,900	2,000

3. TRENDS FOR HEAVY METAL TOXICITY IN SOIL

Heavy metal contamination in soil occurs through the natural process such as flooding, weathering, erosion as well as by anthropogenic activities such as industrilization, urban waste discharge i.e. the most significant source of contamination.

Over the last few decades, annual worldwide release was estimated upto 22,000 t (metric ton) for cadmium, 9,39,000 t for copper, 7,83,000 t for lead and 1,350,000 t for zinc (Singh et al., 2003). According to European Enviornment Agency, it is estimated that about 3 miliion sites in the European countries are potentially polluted by anthropogenic activities, however around 2,50,000 sites require proper cleanup actions to be taken. By considering these trends, EEA estimated that number will increase with about 50% upto 2025 (EEA 2007; Weber et al. 2008). Similar trends of heavy metal contamination in soil have been observed in countries like USA, England, China and in our country. Urbanization and industrialization imbalances the natural flow of materials and introduces the novel toxic chemicals by increasing the rate of toxic effluent discharge into enviornment. Mining and millitary activities as well as farming and waste practices also contaminate the large areas of developed countries with high concentrations of organic and inorganic pollutants.

4. CURRENT REMEDIATION TECHNOLOGIES FOR THE HEAVY METALS CONTAMINATED SOILS

There are several technologies available for the remediation of heavy metal contaminated soil. There is two tier system for the remediation of soil depending on the where action have taken place in which first tier is based on the In situ treatment and second tier is based on ex situ treatment. Insitu (in place) treatment relies on the application of physical, chemical and biological processes on the subsurface of soil without removing bulk soil from its original place to degrade, remove or immobilize the heavy metal contaminant from the soil. Insitu treatment has some benefits such as generally less cost and deep contamination remediation. Exsitu treatment relies on the removal of bulk contaminated soil from its original place and remediation of contaminants by physical, chemical as well as biological treatment either for off site disposal or for onsite treatment and its return to subsurface. Unlike insitu treatment, it requires much cost however less time for treatment. But the advantage is the certainty of the treatment due to its ability to screen, homogenize and mix the soil.

There are several remedies available for the treatment. Soil washing, soil flushing, stabilization/sodification and phytoremediation are some of the in situ and exsitu treatments available which are described below:

4.1 SOIL FLUSHING

Soil flushing is the insitu process for the extraction of the contaminants from the soil via an appropriate washing solution. Washing solution may be water, surfactants, chelating or complexing agents, reducing agents and acid/alkaline solution. Soil flusing can be potentially applied on all types of contaminants (Holdenet et al., 1989). It enables permanent removal of contaminants and especially effective in case of permeable soils such as sandy soil. There is no necessity for any additional treatment if soil flushing process is successful. In, (Chamber et al., 1990) mentioned that there are some disadvantages of soil flushing process such as (1) it introduces toxic chemicals into the soil system around the site. (2) Possibility of transport of the contaminants via solvents away from the site into uncontaminated areas. (3) Chances of incomplete removal due to heterogeneity of soil permeability. Water or washing solutions are injected or sprayed into area of contamination. The contaminants are mobilized by solubilization, chemical reaction with washing solutions and formation of emulsions. After passing through a contaminated zone, contaminated eluent is collected and pumped to the surface for removal, recirculation or onsite treatment or to the surface of disposal. Efficiency of this extraction process for contaminants depends on the hydraulic conductivity of soil. A high permeability always favors the process i.e. greater than $1*10^{-3}$ cm/s. Water solubility of the contaminants is the controlling mechanism behind the process so the additives are used to enhance the efficiency. It is showed in a study that chemical flushing requires only 4 yrs. whereas only water flushing requires around 400 yrs. So the chemical enhanced flushing is mainly used for the heavy metal removal from the soil.

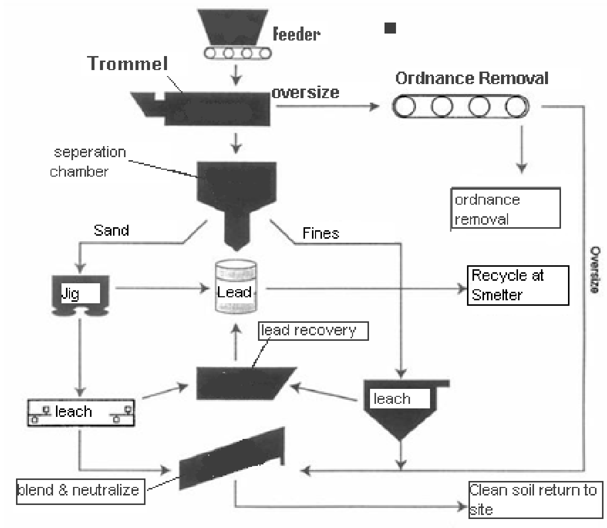

Figure 1: Overview of the Soil flushing process (Holdenet et al., 1989)

4.2 SOLIDIFICATION/STABILIZATION

This technique is widely applied for the disposal of the low-level radioactive waste. Now the application for the hazardous waste is also becoming more common. Many industries are focusing on the study and development of the processes applicable to this technology. In case of the in situ application of solidification/stabilization for the contaminated soil, most significant challenge is the achievement of the complete and homogeneous mixing of the solidifying and stabilizing agents with the soil. There are different types of stabilization processes in which binding mechanisms are different. Binding mechanism depends on the type of primary stabilizing agent which is used such as cement-based, pozzolanic-based or silicate-based, thermoplastic-based or organic polymer-based. The SS techniques are generally successful on the inorganic wastes streams. Waste slurry or sludge is pretreated to adjust the pH and insolubilize the heavy metals for reducing their mobility before treatment. The high alkalinity of cement and setting agents neutralizes the acidic leachate and keeps the heavy metals in their insoluble form thus less mobile.

The disadvantage of this technology is as follows: (Chambers et al., 1990).

1. Increase in the volume of treated materials by the addition of reagents.
2. Difficulty in achieving uniform mixing and in situ treatment and delivery reagents to the subsurface.

4.3 SOIL WASHING

Soil washing is used for both the organic and inorganic contaminants exist in soil, sludge as well as in sediments. Soil washing is the extraction process of contaminants from soil or sludge matrices by using a liquid medium such as water or any other washing solution depending on the type of contaminants to be removed. This process involves the high energy contact between the washing solution and the contaminants. Washing fluid used may be water, organic solvents, water/chelating agents, water/surfactants, acids or bases depending on the type of contaminants. Soil washing is essentially the volume reduction and waste minimization process. It may be performed by both exsitu on the excavated soil (physically removed) and insitu (on-site). In this review, soil washing refers only to the exsitu techniques in which physical and chemical extraction of heavy metals from the soil occurs.

During soil washing:

1. Soil particles covering the major contaminant of the soil are separated from the bulk soil fractions by the physical separation.
2. Contaminants are separated by the use of chemical aqueous solutions which are recovered on solid substrates (Chemical Extraction).
3. A combination of both physical and chemical separation.

In all the cases, separated contaminants are then discarded at the hazardous waste sides landfill or sometimes further treated by chemical, thermal and physical process.

After removal of major contaminants from the soil, remained bulk fraction can be:

(i) Recycled on the site being remediated as relatively inert backfill,
(ii) Used on another site as fill, or
(iii) Disposed off relatively cheaply as nonhazardous material.

Exsitu soil washing is frequently used method for the soil remediation because it removes contaminants completly as well as ensures the rapid cleanup of the contaminated site. This process is the most cost effective solution, meets the specific criteria, eliminates the long terms liability and specially produces the recyclable materials and energy.

There are also some disadvantages of this process such as movement of contaminants from one place to another place so there must be risk of spreading contaminated soil and dust particles during transport and removal. Therefore the whole process must require the strict monitoring results in relatively higher cost. In case of large amount of contaminated soil which is disposed as hazardous waste, excavation can be the most expensive option. In recent scenario, soil washing involves insitu soil flushing in which washing solution forced through soil matrix then exsitu extraction of heavy metals from soil slurry in reactors and soil heap leaching.

There are two types of soil washing, physical washing i.e. based on the differences between the particles grain size, settling velocity, specific gravity and the magnetic properties used to separate the contaminant from the bulk soil. For this washing, standard mineral processing equipment is used which is generally used in the mining industry. Another one is the chemical washing, in which contaminants are removed from soil into solution by the chemical agents.

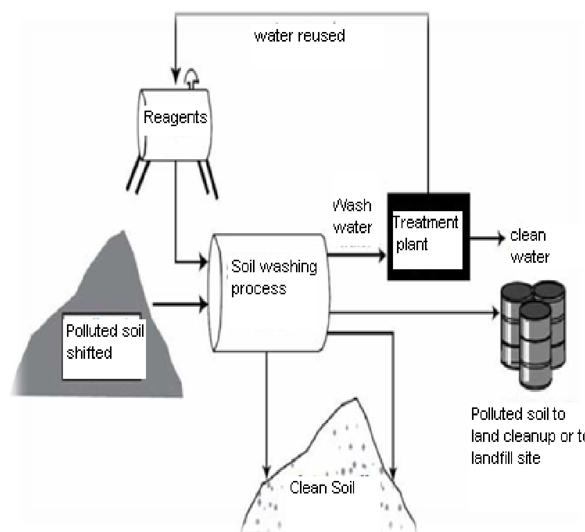

Figure 2: Overview of soil washing technique (Griffiths, Richard A.,1995).

Since heavy metals are sparingly soluble and occur generally in sorbed state so it is not sufficient to wash the soil by the water alone as it may remove very low amount of the contaminant. Some chemical agents have to be added in the washing solution to enhance the efficiency of the removal. Effectiveness of the washing depends on the solubility of the heavy metals in the extracting solution, so the strong bonds between the soil and metal particles creates difficulty in cleaning process. Therefore, the ultimate goal of the remediation is to remove the large quantity of contaminants by the proper choice of extractant and to retain the natural properties of the soil.

5. PREFERENCE OF SOIL WASHING OVER OTHER TECHNIQUES

Soil washing can be used as a remediation technology alone but it is generally used in the combination of other techniques. Cost effective washing technology can be applied if the material to be processed contained larger proportion of coarse sand and gravel in the material. There are several advantages of using soil washing techniques described as follows:

It provides a closed system which is unaffected by external conditions which permits the control of conditions such as pH level and temperature under which soil particles are treated.

1. Allows the excavation and on-site treatment of soil containing the hazardous chemicals.
2. Capability to remove the wide variety of contaminants from the soil.
3. Works in cost effective manner by the pre-processing step which significantly reduces the quantity of material to be treated.

Since soil washing is performed on-site, large portion of soil which is not contaminated can be reused and filled back at the site. Thus, this system saves money as well as time and generally the process can be performed at a very high rate of around 100 cubic yards per day (US EPA 1996). Soil washing can remove both the organic and inorganic form of contaminants simultaneously at the same time.

6. SUMMARY AND CONCLUSIONS

Remediation of heavy metal contaminated soil is generally carried out by the physical removal to a landfill or by the ex situ destructive soil washing using acids and alkalies. None of these options available retain the healthy state of the soil. The technologies discussed in this paper are non-destructive in nature; however the final goal is to remove the bioavailable and leachable metal contamination with the maintenance of a healthy system. Several questions and uncertainties exist for these technologies however our major concern is the production of the residual streams and the long term stability of the treatment of the soil. Additional research and development is needed to better understand the fundaments of some processes and to solve the uncertainties behind the technologies or the processes. Soil contamination is the major area of the interest as it affects the major health of the people living around the industrial areas.

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