Basic Study on Electrochemical Remediation of Heavy Metal Contaminated Water and Soil

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Abstract: Heavy metal pollution of soil is one of the major environmental problems at this stage, and soil pollution itself has the characteristics of accumulation and irreversibility, which is difficult to completely recover from the root. Therefore, the research work on soil remediation technology and practice has become the main work content. The research progress in recent years includes physical remediation, chemical remediation, bioremediation, agricultural remediation and other models. It is also imperative to study its technical characteristics and application scope.

1 Introduction

In recent years, the continuous reduction of cultivated land has become an important obstacle to the development of agriculture. At the same time, the problem of soil pollution still exists in China, especially under the premise of a large population, the improvement of food demand and economic development is undoubtedly a severe form for soil environmental protection, and the importance of soil remediation technology and practice is also obvious. With the continuous development of China's economy, people's quality of life is getting better and better, but the phenomenon of heavy metals polluting the soil has occurred from time to time, especially some heavy industrial enterprises such as metallurgy and petrochemical industry have aggravated the environmental pollution. In particular, the sewage and waste residue generated during the production of heavy industrial enterprises are left in the soil, thus causing soil pollution[1]. Heavy metal pollution sources have the characteristics of long storage time, concealment and irreversibility. If these pollutants cannot be completely removed, it will cause difficulties in soil development and bring many problems to land use.

2 Physical and chemical soil remediation technology

2.1 Traditional repair technology

Physical remediation and chemical remediation are mainly used to separate or fix heavy metals by physical and chemical means and chemical means based on the difference between physical and chemical properties and characteristics of heavy metals[2]. Relatively speaking, this technology has higher efficiency of pollutant treatment, lower risk level, more convenient and flexible implementation, and is also applicable to various types of heavy metal treatment schemes. However, the actual technology quotation needs to take into account the engineering quantity and technology cost to prevent these factors from affecting the technology.

![Figure 1 Flow Chart of Soil Vapor Extraction Restoration System](https://example.com/figure1.png)

2.1.1 Engineering repair technology

The engineering repair method has been used for a long time, with distinct advantages and disadvantages[3]. The advantages are relatively thorough and stable, but the amount of work is large, the investment is high, the structure of the land itself is destroyed, and the waste soil replaced still needs to be stockpiled and treated.

(1) Foreign soil law: it refers to adding uncontaminated soil and contaminated soil together to reduce the proportion of pollutants in the upper soil, so as to reduce the absorption of pollutants by plant roots and reduce the harm to human beings[4].

(2) Soil replacement method: It refers to digging out
the contaminated soil and transporting it to another place for disposal, and then filling the site where the contaminated soil is removed with clean soil.

(3) Deep ploughing method: refers to deep ploughing of soil to disperse pollutants in shallow soil to deep soil to dilute soil pollution.

The application of the above engineering remediation technology can effectively reduce the content of pollutants in the soil, reduce the toxicity of the soil plant system caused by pollutants, and reduce the rate of leaching. Hence, the remediation technologies include chemical passivation, solidification stabilization, in-situ chemical oxidation, leaching, electrokinetic remediation and soil performance improvement.

Chemical passivation. This method can effectively stabilize the heavy metals in the soil and reduce their biological activity and migration capacity by adding a passivating agent to the heavy metal contaminated soil[5]. The curing agents used include various phosphorous substances, clay minerals, biochar and oxides. Figure 2 Flow chart of heavy metal curing and stabilization technology in soil.

Figure 2 Flow chart of soil heavy metal curing and stabilization technology repair

(2) Curing stabilization technology. The cost of this treatment technology is very low, which can reduce the cost of contaminated soil treatment in some non-particularly sensitive areas. Lime, zeolite, Portland cement and asphalt are common stabilizers, among which cement is the most widely used. The buried depth of pollutants, pH value of soil and organic matter content in soil will affect the effectiveness of this technology.

(3) Elution technology. This technology will accelerate the dissolution and migration of pollutants in the soil, inject the solvent into the polluted soil layer through water pressure, and then extract the liquid with pollutants from the soil for treatment. The key point of soil leaching technology is to select extractants. A good extractant can extract pollutants on the one hand, and on the other hand, it will not damage the soil structure. However, it is difficult to find extractants. Moreover, improper use of extracts will lead to secondary pollution. Therefore, the main task of this technology is to develop efficient surfactants, reduce costs, and improve repair efficiency.

(4) Electrodynamic repair technology. Soil electrokinetic remediation technology has been widely used in the treatment of heavy metal pollution. Its principle is to enrich pollutants to the electrode area through electrochemical and electrokinetic actions, and then conduct centralized treatment. Compared with traditional technologies, this technology has the characteristics of low cost, wide application range, strong controllability, high treatment efficiency and more thorough (generally more than 90% of heavy metals can be removed), and maintaining the original ecological environment. As shown in Figure 3 below.

Figure 3 Schematic diagram of soil remediation by the E-K method

(5) In situ chemical oxidation repair technology. Add oxidants to contaminated soil with different burial depths to oxidize heavy metal pollutants in soil into substances with low toxicity. The commonly used oxidants are FeSO4, NaHSO3, SO2 and Na2S2O3.

(6) Soil performance improvement technology. This technology is an engineering technology that uses improvers or artificially changes the oxidation reduction potential of soil according to the nature of the soil and the type of pollutants. The improvers applied to the soil include lime, phosphate, compost, sulfur, blast furnace slag, iron salt, etc. This technology can fix pollutants to a certain extent within a certain period of time and control their harm. It is one of the more economical and effective ways to repair heavy metal contaminated soil, but it cannot remove pollutants.

2.2 Electric power technology

Electrodynamic remediation is also known as electroremediation. Electrodynamic soil process and soil electrochemical pollution control are its main features. Its technical characteristics are that heavy metal pollutants can be recovered, and its cost consumption is relatively low compared with traditional remediation technologies. This scheme was used in the 1990s. Through the action of electric field force, the pollutants in the soil can be moved out of the soil directionally for the purpose of pollution remediation. In the process of electrodynamic remediation, there will be ion migration, free diffusion
and other material migration phenomena, especially ion migration directly affects the final results of soil remediation. In the process of electrodynamic remediation, the pH value and ionic strength of the soil will constantly change, and the electric field strength and conductivity of the soil in different regions will also change, especially the conductivity of the soil near the cathode will be significantly reduced, generally because the electric field strength is increased, the pH value of the soil near the cathode is significantly increased, and heavy metals are settled. Therefore, when the ion concentration in the soil solution reaches a certain range and the conductivity decreases rapidly, the amount of ion migration and pollutant migration will also decrease. In the experiment of some soil samples, other factors such as soil temperature should also be considered to improve the effectiveness.

2.3 Curing and stabilization technology

Solidification technology refers to the key technology of adding solidification agent to the heavy metal soil to prevent the release of toxic heavy metals in the soil and keep the soil in a relatively stable state. Similarly, stabilization technology has also been effectively used to adsorb and precipitate heavy metals through stabilizing agents. When heavy metals are controlled through similar technologies, their adverse effects on groundwater and deep soil will be reduced. In general, the selection of curing and stabilizing agents should comply with certain principles, that is, the agents themselves should not contain heavy metals to prevent secondary pollution, and the agents should maintain a certain degree of continuity. The research results of relevant remediation practices show that ferromanganese compounds, apatite, montmorillonite, etc. can be used as effective curing materials to reduce the bioavailability of heavy metals. In addition, in the process of project construction, this type of passivation technology will also be used to remove soil, but daily results monitoring is required to reduce the activation of heavy metals.

3 Bioremediation technology

3.1 Microbial remediation

Because there are many microorganisms in the soil, some bacteria and fungi can adsorb heavy metals and reduce the toxicity of pollutants in the soil. Relevant studies have shown that the strains in cattail can reduce the content of Cu and other elements in the soil, especially in the exchangeable state. In addition, through some pot experiments and field experiments, the results also show that mycorrhizal inoculation plays a very significant role, and the resistance of plants to heavy metals is very critical. Biological treatment of contaminated soil is a new technology in recent years, and also a promising technology in the future. The technology is to use plant metabolism and microbial life metabolism function to absorb and degrade pollution sources, so as to reduce damage to soil. Through this technology, the form of heavy metals in soil can be changed, which can play a role in reducing, accumulating and fixing heavy metal pollution in soil. Through the implementation of this technology, heavy metals can be absorbed by biotechnology, and then treated reasonably, which can effectively reduce the pollution to the soil. The electrokinetic bioremediation methods are shown below in Figure 4.

![Figure 4 A Schematic diagram of the electrokinetic bioremediation](image)

3.2 Phytoremediation

Phytoremediation can control pollutants from many aspects, including plant extraction, plant solidification, plant volatilization, root filtration, etc. Plant extraction is to use plants to absorb heavy metals in the soil, and then harvest the aboveground part of the soil. Generally, continuous plant extraction is the mainstream technology. At present, there are many types of plants, which can also play a good enrichment capacity for different heavy metals. Relevant studies have studied the adsorption capacity of Pteridopsis crassipes and Pteridopsis farinosa, proving that they are arsenic enriched plants. This technology makes use of planting highly decontaminated, high-yield and beautiful plants to extract, fix, degrade and volatilize heavy metal pollutants in the soil, reduce the content of heavy metals in the soil, and also play a role in water and soil conservation. Phytoremediation technology has a wide range of applications, which can not only remove soil pollution, but also be used in the construction of artificial wetlands. This method requires less technology and cost, and is easy to operate. Figure 5 below shows the schematic diagram of heavy metal phytoremediation in the soil.

![Figure 5 The principle of phytoremediation of heavy metals in the soil](image)
Plant solidification is the process of fixing heavy metals in soil by plant roots, which is helpful to prevent them from diffusing underground. Plant volatilization mainly uses some substances secreted by plant roots to change the form of metal elements and remove pollution in volatile form. Compared with physico-chemical remediation technology, phytoremediation technology has a lower cost, and it can repair the soil and surrounding polluted water at the same time, but there is a gap in the speed of repair.

3.3 Electrochemical remediation of heavy metal contaminated soil

Combined with soil leaching and electro-adsorption technology, small molecular organic acids were used to extract heavy metals from contaminated soil, and then the extracted heavy metals were removed by activated carbon electrode adsorption. The remediation mechanism and the effects of pH value, eluent type and voltage sum were investigated, and the remediation effect was further evaluated by potted rape. The results showed that after 7 days of sodium citrate extraction with initial pH of pHi 8.3 and electrochemical adsorption with cell pressure of 0.9V, the total amount and available content of Cu in contaminated soil decreased from 1090 and 281 mg kg⁻¹ to 391 and 52 mg kg⁻¹, and the total amount and available content of Zn decreased from 262 and 39 mg kg⁻¹ to 208 and 30 mg kg⁻¹. Cu²⁺ and Zn²⁺ are mainly electrodeposited on the cathode and adsorbed on the anode surface respectively, which makes the concentration of heavy metals in the extract less than 1 mg L⁻¹. The promotion effect of three organic acids on soil remediation is citric acid > oxalic acid > acetic acid. Reducing the initial pH value of citric acid solution improves the removal rate of Zn, but has little effect on the removal of Cu. With the decrease of cell pressure from 0.9 to 0.3V, the removal of heavy metals gradually decreased. Pot experiments of rape showed that soil remediation significantly reduced the toxicity of contaminated soil to rape growth process, and the contents of heavy metals Cu and Zn in the roots and stems of rape planted in soil decreased by more than 50%.

4 Concluding remarks

There are many remediation technologies for heavy metal pollution in soil. When selecting remediation technologies, the most appropriate remediation technology or combination should be selected according to factors such as pollutant nature (type, concentration, form, etc.), soil nature (pH, permeability, etc.), pollution degree, remediation objectives, remediation costs, and the applicability of remediation technologies, so as to achieve high efficiency and low consumption. In the heavy metal contaminated soil, there is a widespread phenomenon that multiple pollutants are combined and mixed to pollute the soil. Single remediation technology is difficult to achieve the remediation goal. It needs to work with more than two technologies to jointly repair the soil. Joint remediation technology can not only improve the remediation rate and efficiency of contaminated soil, but also overcome the limitations of single remediation technology.

Reference