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Research on Soil Chromium Pollution and Chemical Bioremediation Technology

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ABSTRACT

This thesis analyzes the source of soil chromium pollution, its harmfulness, the occurrence form, migration and transformation of chromium in soil in detail. At the same time, the mechanism of chemical and bioremediation technology to treat soil chromium pollution was also discussed. From the statistical data analysis of soil chromium pollution sources, the main sources of soil chromium pollution are atmospheric sedimentation, agricultural fertilization, sewage irrigation, non-ferrous metallurgy and the geochemical cycle of chromium in nature. In nature, chromium mainly exists in two stable forms of trivalent chromium and hexavalent chromium, Cr(VI) is a toxic chromium valence state, which can penetrate deep into the soil, destroy the soil structure, and cause serious pollution to the soil. Therefore, the key to the remediation of chrome-contaminated soil is to remove the free Cr (VI).

KEYWORDS

Chromium pollution; Repair technique; Biochemical remediation technology; Heavy metal pollution hazards; Presence of chromium.

1. INTRODUCTION

Soil is the foundation of life on Earth and its importance is reflected in the following aspects: Maintaining biodiversity: Soil is the habitat of many living things, including microorganisms, plants and animals. It provides the environment and conditions necessary for biological growth, thus maintaining biological diversity and ecological balance. Supply of nutrients and other resources: Soil is a key factor in determining the success of agricultural production, it provides the water, nutrients and air necessary for plant growth. Through agricultural production, people are able to obtain food and other agricultural products to meet basic human needs. In addition, organic matter and microorganisms in the soil can also have an impact on the climate by releasing carbon dioxide and other gases through respiration. Protect the environment: soil can absorb and fix harmful substances in the atmosphere, reducing environmental pollution. At the same time, soil can also provide water conservation, water and soil conservation and other functions, which is of great significance for environmental protection. However, in recent years, the intensification of human activities has caused soil pollution and degradation, in which chromium pollution in soil is particularly harmful to the natural environment and biological health. [1] According to the Agency for Toxic Substances and Disease Registry, Agency for Research on Cancer, and National Toxicology According to the Program, chromium ranks 7th among the 20 highly toxic pollutants, belongs to the first class carcinogen, and is also one of the 18 air pollutants. [2] Chromium is a heavy metal element with strong biological toxicity. When the soil is exposed to heavy metal chromium, chromium will gradually accumulate and enter the plants and animals through the circulation of the ecosystem, and when it reaches a certain amount, it will cause harm to human life safety. Under normal natural

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conditions, environmental exposure to chromium does not have a significant effect on human health. However, in various industrial production processes, chromium-containing compounds are often discharged into the atmosphere, water, soil and other environmental media along with waste gas, wastewater, waste residue, resulting in the concentration of chromium in these environmental elements exceeding the standard. In order to protect the ecological environment and human health, China promulgated the "Soil Environmental Quality Agricultural Land Soil Pollution Risk Control Standard (Trial)" in 2018, if the detected chromium content exceeds the risk screening value, there may be a risk of soil pollution. If the content exceeds the risk control value, then the edible agricultural products grown by the land are likely to fail to meet the quality and safety standards, which means that the pollution risk of agricultural land soil is already quite high, and strict control measures should be taken in principle. [3].

2. SOURCES OF SOIL CHROMIUM POLLUTION

The sources of soil chromium pollution can be divided into anthropogenic sources and geochemical cycles. Anthropogenic sources are often associated with agriculture, industry and ore smelting. [4] Agricultural activities, such as the use of chromium-containing fertilizers, pesticides, or cropland irrigated with chromium-contaminated irrigation water. Industrial activities: In the industrial production process such as electroplating, chemicals containing heavy metals such as chromium will be used, if not properly treated, these chemicals will enter the soil through waste water, exhaust gas and other ways to cause pollution. In addition, some industrial activities also produce a large amount of solid waste, if not properly treated and disposed of, it will also cause soil pollution. Ore smelting: For example, chromite is calcined at high temperature to oxidize Cr(III) to Cr(VI) in the ore, which may cause chromium to enter the soil. On the other hand, the natural geochemical cycle of chromium may also lead to chromium contamination in the soil. During the soil-forming process, if chromium containing minerals in the earth's crust are weathered and released into the soil, it may lead to an increase in chromium content in the soil. Overall, the sources of soil chromium pollution are diverse and may come from natural processes or human activities. When understanding the sources of soil chromium contamination, these different sources need to be considered and appropriate measures taken to reduce.

3. ATMOSPHERIC SEDIMENTATION

Atmospheric subsidence is one of the pollution pathways. The gas and dust produced by the electronic component manufacturing and metallurgical plating industries contain a large number of pollutants, and enter the soil in the form of aerosol through dry and wet settlement, resulting in soil destruction. [5]

4. SEWAGE IRRIGATION

Soil chromium pollution caused by sewage irrigation is a serious problem. Sewage irrigation refers to the use of sewage for irrigation, although this method can solve the problem of water shortage, but if used improperly, it will cause serious pollution to the soil. Heavy metal elements such as chromium in sewage irrigation will enter the soil with sewage, accumulate in the soil, affect the growth and quality of crops, and even enter the human body through material circulation, which has a negative impact on health. When carrying out this irrigation method, it is necessary to strictly control the quality of sewage and the amount of irrigation to ensure that it will not cause excessive pollution to the soil. At the same time, it is also necessary to strengthen soil monitoring and management, and timely detection and treatment of pollution problems. In the process of unreasonable stacking or disposal of solid waste, hexavalent chromium may enter the soil in the form of ions after rain washing and weathering leaching. [5]

5. AGRICULTURAL FERTILIZER

The application of various products such as fertilizers, livestock manure and sludge compost is also one of the sources of soil chromium pollution. For example, spraying pesticides (e.g. Bordeaux, dorin, basic copper chloride, zinc forme, etc.) can lead to the deposition of some heavy metals (e.g. Cadmium, chromium, copper, zinc, nickel, lead) in the soil. The misuse of chemical fertilizers not only causes soil compaction, but also introduces heavy metal pollution. For example, the maximum chromium content in phosphate fertilizer is 70 to 150 mg·kg-1, and long-term application of phosphate fertilizer will lead to the accumulation of chromium in the soil. [6] In recent years, the use of chrome-containing additives in livestock and poultry feed is directly related to the excessive chromium content in agricultural machinery fertilizer. In addition, due to the addition of lead, chromium and other insulation agents in the production process of crop mulch, excessive abuse of mulch will not only cause white pollution, but also cause an increase in the content of heavy metals in the soil.

6. METALLURGICAL INDUSTRY

All kinds of waste substances (waste rock pile, tailings pile and smelting slag pile, etc.) and chromium-containing wastewater (beneficiation wastewater and smelting wastewater, etc.) produced by ore mining and smelting. The accumulation and discharge of these waste residues and wastewater will cause the migration and diffusion of free chromium, which will seriously pollute the surrounding soil and rivers. [7]

7. OCCURRENCE, MIGRATION AND TRANSFORMATION OF CHROMIUM IN SOIL

Chromium has three valence states, Cr(III), Cr(IV) and Cr(VI). These three valence chromium causes different pollution to soil. Cr(III) is a stable chromium valence state that does not pollute the soil. Cr(IV) is a neutral chromium valence state, although it will not cause serious pollution to the soil, but it will be converted into Cr(VI), increasing the risk of soil pollution. Cr(VI) is a toxic chromium valence state, which can penetrate deep into the soil, destroy the soil structure, and cause serious pollution to the soil. The occurrence, migration and transformation of chromium in soil is a long and complicated process. Chromium in the soil is water-soluble, exchangeable, carbonate, organically bound and residual. Chromium can be converted into each other in the soil and is affected by many aspects at the same time.

The migration and transformation of chromium in soil is mainly carried out through the following ways:

The first is solution-precipitation. Chromium in soil can enter the soil solution through dissolution, and then be redeposited in the soil through precipitation, or be absorbed by plants.

The second is Adsorption-desorption. Chromium in the soil can be adsorbed by soil particles, and can also desorption down from soil particles. This adsorption-desorption effect will affect the distribution and migration of chromium in the soil.

Besides, Oxidation-reduction is also one source. Chromium in soil can undergo REDOX reactions, such as hexavalent chromium can be reduced to trivalent chromium, or trivalent chromium can be oxidized to hexavalent chromium. This REDOX action affects the chemical form and migration capacity of chromium.

The last is Biological action. Microorganisms and plants in the soil can absorb, transform and release chromium. For example, certain microorganisms can reduce hexavalent chromium to trivalent chromium, while certain plants can absorb chromium from the soil and accumulate it in their bodies.

The process is affected by a variety of indicators, including soil structure, pH, organic carbon content, and water content. It is of great significance to understand the occurrence form, migration and transformation of chromium in soil for assessing soil pollution risk and formulating soil pollution control measures.

8. HAZARDS OF CHROMIUM POLLUTION IN SOIL

Chromium (Cr) will have an inhibitory effect on organic matter in the soil, have a negative effect on the growth of plants, affect the absorption and storage of nutrient elements by plants, and cause the top of the plant to wither. At the same time, chromium causes the root tip to lose the ability to divide, resulting in the plant root can not continue to grow and supply the required nutrients, and eventually can not survive and wilt.

When chromium enters the organism, it interferes with various biochemical processes in the body, resulting in protein inactivation and the formation of precipitated nucleic acids and nuclear proteins. Chromium also interferes with the normal function of the enzyme system. Once chromium enters the bloodstream, it affects the oxygen-carrying capacity of red blood cells. In addition, hexavalent chromium (Cr(VI)) in the water body will also harm the growth and reproduction of aquatic organisms and microorganisms. [8]

Hexavalent chromium enters human cells with the help of carbonate, sulfate, etc. These carrier systems act as "transport vehicles" for hexavalent chromium, helping it enter the interior of the cell. Once inside the cell, hexavalent chromium produces active intermediates. These intermediates can wreak havoc on DNA denaturating it and becoming toxic to cells. After contact with chromium (VI), the following symptoms may occur: Skin symptoms: Chromium compounds are irritating to the skin, if frequent contact with chromium, the accumulation of chromium in the skin is too much, may cause allergic reactions, skin will appear erythema, edema, blisters, ulcers and other symptoms. Respiratory symptoms: Chromium compounds can cause serious damage to the respiratory tract, and when patients inhale chromium compounds for a long time, chromium compounds can irritate and damage the respiratory tract, and even have the risk of cancer. Digestive system symptoms: chromium compounds have strong irritation to the human body, if the patient is exposed to chromium compounds for a long time, chromium compounds accumulate in the mouth, with saliva into the gastrointestinal tract will stimulate the gastrointestinal mucosa, so that patients appear nausea, vomiting, abdominal pain and other symptoms, some patients will also appear hematemesis, black stool and other symptoms. [9]

9. CHEMICAL BIOREMEDIATION TECHNOLOGY FOR SOIL HEAVY METAL CHROMIUM CONTAMINATION

9.1. Technical principle of chromium pollution remediation

The principle of chromium pollution remediation technology is mainly divided into two parts: solidification and stabilization. [10] Curing: It mainly refers to mixing chromium metal pollutants with certain substances to make them appear large particles, thereby reducing the surface area of chromium metal in the soil and improving the soil's resistance to chromium metal pollution. This can effectively prevent the risk of chromium contamination. Stabilization: Mainly using chemical methods, the use of stabilizers to change the properties of the soil, strengthen the effective adsorption of the soil to chromium metal, so as to achieve the precipitation of pollutants, and ultimately reduce the biological availability of chromium metal.

In order to solve the problem of excessive hexavalent chromium, ferrous sulfate solution can be used to reduce the hexavalent chromium in the soil to trivalent chromium. In actual use, ferrous sulfate heptahydrate is selected as a stabilizer and quick lime as an auxiliary agent. Ferrous sulfate has a strong reducibility, can reduce the hexavalent chromium in the soil to trivalent chromium, and then use quick lime to adjust the PH to weak alkaline, at this time, quick lime is used as a bonding agent, will not be reduced hexavalent chromium adsorbed on the soil surface, while lime can react with trivalent chromium to produce stable hydroxide precipitation, chromium ions from the soil completely removed.

9.2. Remediation technology of soil heavy metal chromium pollution

Remediation technologies for soil heavy metal chromium pollution mainly include chemical reduction stabilization remediation technology, soil leaching remediation technology, microbial remediation technology, electric remediation technology, biochar remediation technology, and joint stage remediation technology. Among them, the application of biochar remediation technology, electric remediation technology and combined remediation technology is low, and the operation and utilization conditions of the technology are not mature, so they are not widely used in China. [8]

9.3. Chemical reduction stabilization repair technique

Chemical reduction technology is an effective method to repair heavy metal chromium pollution in soil. By adding reducing agents to contaminated soil, hexavalent chromium is transformed into trivalent chromium. This method has the advantages of short processing time and high removal efficiency, so it has been widely used in engineering restoration.

However, chemical reduction techniques also have some potential environmental impacts. First, the added reducing agent may have an impact on the soil environment. Some reducing agents may change the pH value of the soil, affecting the activity of soil microorganisms and soil quality. In addition, reducing agents may react with other substances in the soil, creating new pollutants or altering the nutrient balance in the soil. Secondly, chemical reduction techniques may have an impact on groundwater and surface water. During the soil remediation process, some wastewater containing chromium and other contaminants may be created, which can contaminate groundwater and surface water if discharged directly into the environment without proper treatment. \

In order to reduce the impact of chemical reduction technology on the environment, the following measures can be taken: Select the right reducing agent: Choose a reducing agent that is friendly to the environment and has little impact on the soil to reduce the impact on the soil environment. Iron and sulfur reducing agents are effective in the remediation of chromium-contaminated soil, but the effect of single reducing agent is far less than that of multiple reducing agents combined. [11] In the actual application of soil treatment, it is also necessary to consider whether the characteristics and properties of the reducing agent will react with the components of pollutants to produce harmful substances, and select the most suitable reagent for soil remediation to make the best recovery of soil. This includes understanding the chemical properties, reaction mechanisms, environmental impacts and other factors of the different reducing agents to ensure that the selected repair method is both cost-effective and environmentally friendly. At the same time, it is also possible to consider the combined use of a variety of reducing agents to make use of their respective advantages and make up for the shortcomings of a single reducing agent. For example, a combination of iron and sulfur reducing agents can be tried to improve the efficiency of remediation and reduce the cost and environmental impact. Control the amount of reducing agents: according to the degree of soil pollution and restoration objectives, reasonable control of the amount of reducing agents to avoid excessive use of adverse effects on the environment. Wastewater treatment: The wastewater generated during the restoration process is properly treated to ensure that the pollutants in the wastewater meet the discharge standards before being discharged. Long-term monitoring: Long-term monitoring of the restored soil to ensure that the chromium content is no longer excessive, but also to pay attention to changes in soil quality and other environmental indicators.

In conclusion, although chemical reduction technology plays an important role in soil chromium pollution remediation, its impact on the environment should be considered comprehensively in practical application, and appropriate measures should be taken to reduce the negative impact. In addition, long-term monitoring of the restored soil is needed to ensure that chromium levels are no longer excessive, and to pay attention to changes in soil quality and other environmental indicators. If it is found that the repair effect is not good or there are other problems, remedial measures should be taken in time or a backup plan should be adopted.

9.4. In situ vitrification technology

By inserting electrodes, the contaminated soil is treated with high temperature, volatilizing or pyrolyzing organic pollutants and some inorganic compounds (such as nitrate and carbonate, etc.), thereby removing them from the soil. The resulting pyrolysis products are processed by a gas collection system. After melting and cooling, the contaminated soil will form a chemically inert, non-dispersive hard glass body, and harmful inorganic ions will be fixed. This technology is suitable for soils with low water content and no more than 6 meters of contaminants.

9.5. Soil washing technology

Soil washing is an effective soil remediation technology, through the use of leaching liquid or chemical additives combined with soil pollution components, so that contaminated soil can be repaired. The effect of soil leaching is affected by many factors, such as solid-liquid ratio, leaching agent, pH value, leaching time and soil particle size. [12] For the removal of hexavalent chromium and total chromium, soil leaching technology can completely remove these contaminants from the soil. However, this technology is suitable for soil with high Cr pollution concentration and good permeability, but not for soil with soil particle content higher than 22.5%. Currently commonly used eluents include water, acid, alkali, ED-TA and citric acid. The choice and use of these drenches needs to be determined according to the specific soil conditions and the degree of contamination.

9.5.1. In situ leaching technique

In situ leaching technology is a remediation technology to purify soil and groundwater in situ at contaminated sites. The principle is to inject the leaching agent (such as active agent, water or other solvents, etc.) into the contaminated soil or groundwater, and the pollutants are separated from the soil or groundwater through the physical and chemical interaction between the leaching agent and the pollutants, and are discharged with the leaching solution. [13] In-situ leaching technology is suitable for various types of contaminated sites, including heavy metal, organic matter, petroleum hydrocarbon pollution. The technology has the advantages of simple operation, high treatment efficiency and small impact on the environment. In the implementation of in-situ leaching technology, it is necessary to conduct detailed investigation and analysis according to the specific situation of the contaminated site, and determine the appropriate leaching agent and process parameters. At the same time, it is also necessary to properly handle the eluent to avoid secondary pollution to the environment. It should be noted that in-situ leaching technology is not a universal remediation technology, and for some complex or deep contaminated sites, it may be necessary to combine other remediation technologies for comprehensive treatment.

9.5.2. Ectopic elutriation technique

Ectopic leaching technology is a kind of remediation technology for contaminated soil. Its main principle is to dissolve and transfer the pollutants in the soil through leaching, so as to achieve soil purification. [14] Specifically, ectopic leaching involves cleaning and filtering contaminated soil after it has been dug up to remove harmful substances from the soil. After the soil is dug up, it needs to be briefly classified according to the particle size and then treated. The advantage of ectopic leaching technology is that it can effectively remove pollutants from the soil, and it is also suitable for contaminated sites with large depths. However, the technology requires that contaminated soil be dug up and treated, which may have a certain impact on the environment.

9.6. Electrokinetic repair technique

Electrokinetic remediation is a technique that uses electric field to make contaminated ions in soil solution accumulate near the electrode and then be removed. Its principle mainly includes ion electromigration, charged particle electrophoresis, electroosmosis and diffusion.

Electromigration refers to the movement of ions and ionic complexes to the opposite electrode under the action of external direct current electric field, and the speed of ion migration in the unit electric field gradient is called ion mobility.

The second is Charged particle electrophoresis. Under the action of an electric field, charged particles in the soil (such as heavy metal ions) will be affected by the electric field force and will move in a directional manner. By controlling the direction and strength of the electric field, charged particles can be separated from the soil, thus achieving the purpose of removing pollutants.

Besides, Electroosmosis is also included. Under the action of an electric field, the water in the soil will move in a directional way. By controlling the direction and strength of the electric field, water can be discharged from the soil, and pollutants can be discharged with the water, so as to achieve the purpose of removing pollutants.

The last if Diffusion. Under the action of an electric field, the molecules in the pollutant will have thermal motion and spread around. By controlling the direction and intensity of the electric field, the diffusion of pollutants can be promoted, thereby increasing the removal efficiency of pollutants.

In order to improve the repair effect of electric repair technology, the following measures can be taken: Control soil pH value: Soil pH value has a great impact on the effect of electric repair. By adjusting the soil pH value, the solubility of pollutants in the soil and the ability of ion electromigration can be changed, thereby improving the efficiency of electric remediation. Improve the solubility of pollutants in the soil: By increasing the water content in the soil or adding chemical reagents and other methods, the solubility of pollutants can be improved, thereby increasing the efficiency of electric remediation. Combining electric repair with other technologies: Electric repair can be combined with other technologies such as adsorption technology, permeable reaction barrier mixing systems, etc. Through the combined application of these technologies, the efficiency of electric repair can be further improved. [3]

In short, electric remediation is an effective soil remediation technology. By controlling soil pH value, improving the solubility of pollutants in soil, and combining electric remediation with other technologies, the remediation effect and efficiency can be greatly improved.

9.7. Bioremediation technology

9.7.1. Phytoremediation

Phytoremediation refers to the use of various biochemical reactions carried out by plants themselves to remove pollutants from the environment or make them harmless, including plant volatilization, plant extraction, plant stabilization and super accumulation. [15] In the process of repairing the soil contaminated by chromium 6, plants can absorb chromium 6 ions in the soil through the roots and transfer them to the plant body.

Through plant growth and metabolic processes, hexavalent chromium can be converted into low-toxic or non-toxic forms, thus achieving soil purification. Improve plant resistance to chromium by analyzing the mechanism of chromium detoxification at the molecular level, including chrome-activated reactive oxygen species (ROS) signaling, antioxidant response, defense proteins such as phytochelin (PCs), metallothionein (MTs) and glutathione transferase (GSTs). Then plant separation is carried out to enhance the bioaccumulation of plants [16] At the same time, phytoremediation can also achieve the transformation of hexavalent chromium valence state by cultivating plant root microorganisms. These microorganisms can form a symbiotic relationship with plants and promote the absorption and transformation of hexavalent chromium in plants. Common plants used to repair chromium hexavalent soil are mustard grass, wolftail, reed, cattail and so on. These plants have good tolerance and repair ability, and can effectively absorb and remove hexavalent chromium from the soil. Phytoremediation is a way to fundamentally solve the problem of soil pollution, which has a special role and significance. It can not only remove pollutants from the soil, but also improve soil quality and promote the restoration and reconstruction of ecosystems. Therefore, phytoremediation has a broad application prospect in soil pollution control.

9.7.2. Microbial remediation

The role of microorganisms in the removal of toxic metals mainly includes bioadsorption, bioaccumulation and biotransformation. [17] Bioadsorption: This is the passive absorption of metals by microorganisms. In this process, microorganisms adsorbed metal ions through various functional groups on the cell surface and fixed them on the cell surface. This adsorption is usually non-specific and can adsorb a variety of metal ions. Bioaccumulation: This is the process by which microorganisms actively absorb metals. In this process, microorganisms actively absorb metal ions into the cell through mechanisms such as transporters inside the cell. This absorption process is specific, and different microorganisms may have different absorption capacities for different metal ions. Bioconversion: This is the process of enzymatic reduction of metals by microorganisms. In this process, microorganisms reduce metal ions to elemental metals or cheaper compounds through their own metabolic pathways. This conversion process reduces the toxicity of the metal, making it easier to remove. These processes play an important role in toxic metal removal. By understanding these processes, we can better understand and apply the use of microorganisms in toxic metal removal.

9.8. Biochar remediation techniques

Biochar is indeed rich in active organic functional groups and aromatic structures, and this unique property makes biochar have a high cation saturation. In addition, the specific surface area of biochar is large, which makes its adsorption capacity for pollutants significantly improved, and the negative anionic charge attached to the surface has a high impact on performance characteristics. [18] Biochar is produced from a variety of raw materials, including woody biomass, animal manure, sludge and organic waste. After pyrolysis treatment, these raw materials can be converted into biochar with special properties. [19] The mechanism of interaction between biochar and Cr is mainly manifested in the adsorption of chromium by carboxyl, carboxyl, hydroxyl and other oxygen-containing functional groups in biochar, which changes the hexavalent chromium into trivalent chromium, and biochar provides hydrogen ions for chromium to generate electrostatic attraction and thus complexation occurs.

9.9. Combined repair technique

Combining multiple repair methods may be more effective than a single repair method. This is because different remediation methods may target different forms or different locations of heavy metals in the soil, resulting in more comprehensive removal of contaminants. [21] For example, some remediation methods may change the pH of the soil or add certain chemicals to precipitate or convert heavy metals to a more stable form. Other methods may remove heavy metals through absorption or transformation by plants or microorganisms.

Combining multiple repair methods can also reduce the possible negative effects of a single repair method. For example, some remediation methods may damage the structure of the soil or alter the soil's microbial community, while combining other methods can reduce these negative effects. Wang [22] demonstrated the potential of combining different remediation methods to deal with heavy metal pollution in soil. Chemical leaching removes both water-soluble and acid-soluble components, thereby reducing the amount of FexCr1−x(OH)3 or Fe2Cr2−xO3, making it easier for electrons to enter the soil. Next, the use of reducing agents to react with residual or deep Cr(VI) in the soil can further remove pollutants. In electrokinetic repair (EKR), Zheng [23] found that the synergistic effect of Ca and zero-valent iron (ZVI) also helps to enhance the removal effect of chromium. Ca can help to reduce the hindrances of Cr electromigration caused by co-precipitation of iron and chromium, and the final product Fe(III) of ZVI can catalyze the reduction of Cr(VI). However, high concentrations of Ca (> 0.15 mol L−1) will hinder the reduction of Cr(VI), while excessive ZVI (> More than 10 g) is not conducive to energy saving. Cao Xiaoya [24] converted all the hexavalent chromium in the supernatant into non-toxic and stable trivalent chromium through various methods such as leaching, and the chromium remaining in the soil was converted from exchangeable state to stable state by plants. These findings provide valuable experience and knowledge to guide the development of more effective soil remediation strategies in the future.

In conclusion, combining multiple remediation methods may be a more effective and sustainable remediation strategy for soil heavy metal pollution.

10. CONFLICTS OF INTEREST

The future development plan of heavy metal chromium pollution remediation technology includes the following points.

The first is joint remediation technology, that is, combining a variety of remediation technologies, such as microbial remediation, phytoremediation and nanotechnology, to achieve a more efficient and stable chromium pollution remediation. This combined repair technology can maximize the advantages of various technologies, make up for the shortcomings of a single technology in some aspects, and improve the quality of repair.

The second is application of new materials and new technologies. Continue to research and develop new repair materials and new technologies, such as nanomaterials with higher reducing properties, and genetically engineered hyperenriched plants. The application of these new materials and technologies can improve the efficiency and effect of chromium pollution remediation and reduce the remediation cost.

Besides, application of intelligent and automated technology is also important. Intelligent and automated technology is applied in the process of chromium pollution remediation, such as the use of drones, robots and other equipment for sampling, monitoring and repair operations. The application of this technology can improve the repair efficiency, reduce the labor cost, and improve the accuracy and consistency of the repair.

Furthermore, interdisciplinary cooperation is also needed. Remediation of chromium pollution involves multiple disciplinary fields, such as environmental science, biology, chemistry, materials science, etc. Strengthening interdisciplinary cooperation and exchanges can promote the generation and development of new technologies and new methods, and promote the progress of chromium pollution remediation technology.

Lastly, policy support and improvement of regulations are effective. the government should increase its support for chromium pollution remediation technology, strengthen supervision and law enforcement, crack down on violations of environmental regulations, and provide a strong guarantee for the development and application of chromium pollution remediation technology.

In short, with the continuous progress and innovation of science and technology, the pollution remediation technology of heavy metal chromium will continue to develop and improve, providing more options and solutions to solve the problem of soil pollution.

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