Review

Environment

Remediation Technology for the Restoration of Polluted Soil

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One of the most serious environmental issues is soil pollution. With the increase in contaminated sites, how to safely and effectively remediate these contaminated soils has become an urgent environmental problem in our country. This paper summarizes the most commonly used remediation technologies and research progress for contaminated soil in the United States and abroad, including physical remediation, chemical remediation, and bioremediation. Each repair technique has advantages and disadvantages. To get around the problems with a single method and make the most of the benefits of different remediation technologies, it was suggested that research and development of comprehensive remediation technologies for contaminated soils be stepped up.

Keywords: Soil; Heavy Metal Pollution; Petroleum Hydrocarbons; Persistent Organic Pollutants; Soil Remediation Technology

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Introduction

ONE of the most significant natural resources for human survival is soil, which is also a crucial component of the human ecological environment. The solid, liquid, and gas phases of soil include minerals, organic matter created by the breakdown of plant and animal remains, soil organisms; water; and air, respectively. The soil medium is an aggregate that has a complicated heterogeneous structure. Numerous colloids and oxides, both organic and inorganic, are entangled and combined. On the medium's surface, there are electric fields and residual force fields with enormous surface energies. The biological system in soil is also quite diverse and includes microflora, microfauna, and fauna, the most active of which are microorganisms (1). In addition to playing a significant role in soil formation, nutrient transformation, material migration, and pollutant migration and transformation, soil organisms make soil biologically active. Additionally, the soil has a complicated redox mixed system made up of both organic and inorganic oxidizing and reducing molecules (2). When these components work together, the soil displays specific redox-reduction characteristics. The transport and transformation of compounds in soil are significantly influenced by the oxidation-reduction characteristics of soil (3). These characteristics of the soil, such as volatilization, diffusion, dilution, adsorption, biodegradation, redox, etc., provide the soil with a certain degree of self-purification ability and reflect a certain capacity for the entry of foreign chemicals.

Although the purification effect of the soil itself can reduce the pollution degree of pollutants in the soil, if the quantity and speed of pollutants entering the soil exceeds the soil's self-purification capacity, that is, exceeds the soil's environmental capacity, it will eventually lead to soil pollution. The presence of the contaminated soil creates a dual problem: on the one hand, they pose environmental and health risks; on the other hand, they impede urban construction and local economic development.

Soil Remediation Technology

Typical Soil Pollution Problems

Heavy Metal Pollution

Soil heavy metals come from a variety of sources, including the three wastes and automobile exhaust emitted by industries such as mining, metallurgy, and chemical industries, as well as pesticide and fertilizer application (4). Heavy metal elements in soil can be classified into two types based on their biochemical properties. One is that the content of elements that are harmful to crops, humans, and animals, such as mercury, cadmium, lead, and metalloid arsenic, and they should be reduced so that it does not exceed the environmental capacity. The other type of element is one that is beneficial to crops and the human body under constant conditions but is harmful in excess, such as copper, zinc, chromium, manganese, and metalloid selenium. Controlling what is in them is important if they are to help crops grow and people stay healthy.

Oil Pollution

Oil pollution is caused by the release of crude oil and various petroleum products into the environment during the extraction, refining, storage, transportation, and use of oil. The oil pollutants in the soil are mostly concentrated in the top 20 cm of the soil (5). The landing oil produced during the extraction process and the oil field transfer station, oil tank, sedimentation tank, sewage tank, and bottom sludge of oil separator in the oil field, as well as the oil sludge produced by the oily sewage treatment facility in the refinery, are all sources of oil pollution. The main parts of petroleum in polluted soil are C15-C36 alkanes, polycyclic aromatic hydrocarbons, alkenes, benzene series, phenols, and other pollutants, of which up to 30 are under environmental priority control (6).

Fertilizer Pollution

Chemical fertilizers are the basis for increasing grain production and the mainstay of agricultural production materials in modern agriculture, and they have become the main exterior nutrients in agricultural production. The main components of polluted soil are toxic heavy metals, inorganic acids, and organic substances found in chemical fertilizers. Heavy metals include chromium, cadmium, mercury, arsenic, lead, zinc, nickel, copper, cobalt, manganese, and others, with phosphate fertilizers having the highest content; organic pollutants include phthalates, nitrobenzenes, chloroalkenes, and others. Most fertilizers contained almost all of the dimethyl phthalate, n-butyl phthalate, and phthalate diester; hexachlorocyclopentadiene; and 2,6-dinitrotoluene (7).

Pesticide Pollution

Preliminary data indicates that the arable land is pesticide-polluted. The two primary categories of soil pesticide pollution are organophosphorus and organochlorine pesticides. Pesticides make up the majority of the 20 potential persistent organic pollutants listed in the Stockholm Convention on Persistent Organic Pollutants, which the United Nations Environment Programme (UNEP) adopted in 2001. Of the 12 priority control persistent organic pollutants (POPs) listed, 9 (aldrin, six chlorobenzene, chlordane, mirex, dieldrin, toxaphene, DDT, endrin, and heptachlor) are pesticides (8).

Combining the numerous pollution types stated above, it is easy to come to the conclusion that heavy metals and organic matter, such as petroleum hydrocarbons, organic fertilizers, and persistent organic pollutants in pesticides, are today's predominant types of pollution in the soil.

Remediation Technology for Contaminated Soil

Physical remediation, chemical remediation, and bioremediation are the three main technologies now used to treat oil-contaminated soil. The three primary methods for remediation are: (i) lowering the concentration of pollutants in the soil; (ii) altering the form of the pollutants to fix or passivate them in order to minimize their mobility in the environment; and (iii) eliminating the pollutants from the soil.

Physical Maintenance

Before the 1980s, only physical and chemical procedures were used to treat contaminated soil. The early physical treatments, such as the burning method, thermal repair method, soil replacement method, isolation method, and mechanical method, require high temperatures, mechanical equipment, and additional labor, and do not solve the pollution issue fundamentally. The pollutants have been transported, and they now require additional treatment. Currently, these physical procedures are predominantly employed during sudden emergencies. Rather, a number of economically viable novel processes and technologies, such as the electrical remediation method, the thermal desorption method, the soil gas phase extraction method, and the CSP method, i.e., soil purification technology, have emerged as research hotspots.

Electroremediation involves the placement of electrodes in areas of contaminated groundwater and soil (9). After applying direct current, a direct current electric field is formed, causing directional electrodialysis, electromigration, and electrophoretic movement of soil pore water and ions and particulate matter in the water along the direction of the electric field, resulting in the migration and movement of water and charged ions or particles in soil pores. By heating the soil, the thermal desorption technique decomposes the volatile contaminants and collects them for treatment. It is primarily utilized for restoring biological substances (10).

To remove of volatile or semi-volatile petroleum components from petroleum-contaminated soil through physical methods, using carbon-containing materials (such as coal and coke) as adsorbents, the CSP technique powerfully adsorbs hydrocarbon-based pollutants through the coal surface at 90 ℃ with vigorous stirring, and then separates clean soil and adsorbed organic pollutants using gravity separation or flotation.

Electric soil remediation has the advantages of less labor, less exposure to dangerous compounds, great economic gains, and minimal damage to the site's ecological environment as compared to conventional soil remediation methods. It is more appropriate for treating dense soil with a low permeability coefficient. Thermal desorption is an energy-intensive process that is prone to destroying soil organic matter and structural water while also releasing hazardous vapor into the sky and causing secondary pollution. Soil gas phase extraction has many benefits, such as being easy to use, being able to remove a wide range of contaminants, being able to use standard equipment, not damaging the soil structure, and recycling waste (11).

Bioremediation

Bioremediation is the process of restoring polluted soil to a healthy state by reducing the concentration of toxic and harmful substances in the soil through biological metabolic activities. There are three main types of bioremediation technologies that can be used to clean up polluted soil: microbial remediation, phytoremediation, and animal remediation.

Microbial Restoration

Microbial remediation is the process of using specific soil microorganisms to absorb, precipitate, oxidize, and reduce one or more pollutants in order to stop soil from absorbing heavy metals, break down complex organic matter, and clean up polluted soil (12).

Various environmental factors can have a significant impact on microbial remediation. Temperature, oxygen, moisture, pH, and other factors can all influence microbial activity and thus the remediation effect. Tolerance to biological factors that affect growth and metabolism varies by microbial strain. When several microorganisms are involved in bioremediation in the same environment, the tolerance range is greater than when only one remediation microorganism is present. But if the environment gets too bad for all the microorganisms that live there, microorganism remediation will stop (13).

Phytoremediation

In 1983, American scientist William Chaney proposed phytoremediation technology, which used plants that can enrich heavy metals to remove heavy metal pollution in soil. Plant extraction, plant volatilization, plant stabilization, and plant degradation are the four basic types of phytoremediation technology for polluted soil, according to the mechanism and action process of phytoremediation. Plant extraction is the use of plants that tolerate and accumulate pollutants to absorb pollutants in the soil environment, transport and store pollutants in their aerial parts, and remove pollutants from the soil by planting and harvesting plants. Plant volatilization is the use of special substances secreted by plant roots to convert pollutants in soil into volatile states; or plants absorb pollutants in soil into their bodies and convert them into gaseous substances that are then released into the atmosphere, thereby purifying the soil. Plant stabilization occurs when plants, through a biochemical process, reduce the mobility of pollutants in contaminated substrates, thereby decreasing bioavailability. Plant degradation is a biochemical process in which plants break down pollutants with the help of their roots, exudates, and microorganisms in the rhizosphere.

Phytoremediation is the most widely used and promising phytoremediation technology for soil pollution. Phytovolatile remediation technology is used to remediate polluted soil and can effectively remove pollutants in soil. However, it is limited to volatile substances, has a limited application range, and transfers pollutants into the atmosphere. More research is needed to determine whether there are environmental risks. As a result, when employing plant volatilization remediation techniques, extreme caution should be exercised. Stabilized phytoremediation does not remove pollutants from the soil, but rather fixes them temporarily. When the soil environment changes, the pollutants may be reactivated, and their toxicity restored. As a result, the problem of soil pollution has not been fully resolved (14).

Animal Restoration

The process of remediating soil pollution through the direct (absorption, transformation, and decomposition) or indirect effects of soil fauna is referred to as animal remediation technology (improving soil physical and chemical properties, enhancing soil fertility, and promoting the growth of plants and microorganisms). Animal remediation technology has two components: (i) feeding plants, grains, and other organic matter grown on polluted soil to animals and studying soil pollution through the biochemical variation of animals; and (ii) directly feeding soil animals, such as earthworms and nematodes, in contaminated soil research. This technology is currently widely used in petroleum pollution.

Chemical Restoration

Chemical remediation is the process of reducing pollutant mobility or bioavailability in soil through adsorption, dissolution, redox, antagonism, complex chelation, or precipitation. Curing, stabilization, extraction, chemical oxidation, and leaching are all common chemical repair methods. Solidification is the process of mixing heavy metal-contaminated soil with a solidifying agent in a specific proportion, then curing the mixture to form a solid mixture with low permeability in order to solidify the pollutants in the solidified body, isolate the connection between the contaminated soil and the external environment, and achieve pollution control. The reason for migration Stabilization is the process of transforming pollutants into less soluble, less migratory, or less toxic states or forms by adding chemicals to soil that change the form or valence of heavy metals. The extraction method employs an organic solvent to extract crude oil from oil-contaminated soil using a similar compatibility principle. It then separates the organic phase. The solvent is separated and recycled, and the recovered oil is used in the refining process. Spraying or injecting chemical oxidants into polluted soil causes them to chemically react with the pollutants, resulting in purification. To get rid of the pollutants, the rinsing method involves washing the polluted soil with clear water rinsing solution or an aqueous solution with chemical additives.

The curing technology can be used quickly and is simple to use, but it will harm the soil's structure and use a lot of curing ingredients. Only small, badly contaminated soils are suited for it. Oil resources can be recycled using the extraction method, although there are now issues with the length, complexity, and expense of the process. Soils with a significant concentration of oil pollution are suited for this approach. The soil washing method has a low energy need, low processing expense, and the ability to recover eluted crude oil, which not only allows for the preliminary cleansing of oil-contaminated soil but also has significant economic advantages. The chemical oxidation method can be used to get rid of many different types of contaminants without having to dig up the land or hurting the structure of the soil, but the process is not easy (15).

Conclusion

Technology for soil remediation spans a variety of fields, including geology, chemistry, physics, materials science, biology, and environmental science. The rehabilitation of soils contaminated with oil has been the subject of numerous studies in recent years. Plans for the cleanup and remediation of oil-contaminated soils have been developed by nations all over the world, and they have advanced significantly. Technologies for remediating soil heavy metal pollution are currently being explored. Technologies for bioremediation, chemical repair, and physical repair all have clear limitations. Physical remediation technology consumes a lot of energy, necessitates specialized equipment, is expensive to process, requires a lot of work, and can only treat a small area of contaminated soil. Chemical remediation is more likely to cause secondary pollution and is more likely to damage the aggregate structure of the soil. Some intermediary compounds whose pollutant breakdown is sluggish are significantly more harmful than the original pollutants. The effectiveness of the restoration is greatly influenced by site characteristics and environmental circumstances, and the effect of the restoration is unstable. Research and development of comprehensive soil pollution remediation technologies are especially crucial in order to overcome the drawbacks of a single approach and fully exploit the benefits of several remediation technologies. Emphasis is placed on the development of integrated physical, chemical, and biological remediation procedures as well as the thorough usage of various biotechnologies.■

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