REMEDIATION TECHNIQUES FOR SOIL AND GROUNDWATER

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Summary

Rapid development of China in social and economic areas has created an environment of serious contamination of soils and groundwater. Major contamination sources from industry, agriculture and urban areas have not been put under strict control. The accumulation, mobilization and toxicity of various contaminants in soils and groundwater are threatening the natural environment as well as the sustainable development of China.

Remediation is the only way to clean up the contaminants in soils and groundwater. General technical methodologies include transfer of contaminants solely by themselves, with contaminated soils, or groundwater to other places for final treatment or disposal; confinement of contaminants in place; and destruction of contaminants in place. Mechanistic principles are physical, chemical and biological processes. Remediation techniques which have been commonly used include: containment, pump-and-treat, extraction, stabilization/solidification, soil washing, air stripping, precipitation, vitrification, thermal desorption and biological remediation.

Among the remediation techniques currently in use, physicochemical processes can

quickly remove contaminants from soils and groundwater but usually considerable energy consumption are required. Biological processes can save energy but often it takes longer time to reach desired remediation level. Remediation techniques with low cost and high efficiency are being developed in China.

1. Introduction

The contamination of soils and groundwater is becoming a serious problem in China since the contamination sources have not been controlled in an effective manner. These major sources are from industrial activities, agricultural practices and consumption actions. Every year, there are about 600 million tons of solid wastes produced as a result of industrial production and resident consumption, which is still increasing at a rate of 10% per year. It is estimated that more than 64% of the entire groundwater has been contaminated in urban areas. Agricultural activity also accounts for a major pollution source. About 0.8 million ton/year plastics is left in soils after being consumed, 25% of the total nitrogen fertilizer is released to groundwater through permeation or runoff, a significant portion of pesticides applied is not functional and left in soil. In addition, industrialization in the rural areas poses an ever increasing threat to soil and groundwater. For a quite long period of time, the town and village enterprises in rural areas will be operated with less not up-to-date technologies and unskillful management practice will soon be vanished before they can fully developed or be eliminated through market competition. Currently about 280 million tons of solid wastes are discharged in the countryside every year by those town and village enterprises.

The presence of contaminants in soils and groundwater at concentrations above background levels demonstrates a high potential health and ecological risk. Common contaminants include a variety of volatile hydrocarbons-such as benzene, toluene, ethylene, and xylene (BTEX compounds)-found in fuels; heavy paraffins and chlorinated organic compounds including polychlorinated biphenyls (PCB); inorganic compounds e.g. lead, chromium, cadmium, arsenic and mercury; and radionuclides such as tritium. Often, soil is contaminated with a mixture of contaminants. The nature of soil, the contaminant's chemical and physical characteristics, and environmental factors as climate and hydrology interact determine the accumulation, mobility, toxicity, and overall significance of the contaminant in any specific instance.

Remediation techniques play a key role in fully cleaning up the contaminants in soils and groundwater. Remediation refers to the process of environmental cleanup of contaminated sites and the techniques to reduce or eliminate contamination from soil or groundwater. Remediation pathways include transfer of contaminants alone, or with contaminated soils or groundwater to other place for final treatment or disposal, confinement, and destruction of contaminants in place. Technical principles for remediation can be divided into physical, chemical and biological processes. Techniques frequently used are: containment, pump-and-treat, extraction, stabilization/solidification, soil washing, air stripping, precipitation, vitrification, thermal desorption, and bioremediation.

2. Containment

Containment is a common technique adapted to contain contaminated ground waters or soils within a site; or to divert ground or surface waters away from that contaminated site, for the purpose of limiting their contact with people, the ecosystem on the sites, and minimizing the potential for further contamination to happen.

The objective of containment is achieved by the construction of low-permeability or impermeable cutoff walls. Most of the walls are built with soil, bentonite, and water mixture; walls of such composition provide a barrier with low permeability and chemical resistance at low cost. Other wall compositions of cement, bentonite, and water may be necessary if additional structural strength is required or if chemical incompatibilities between the bentonite and site contaminants exist. The desired permeability of the completed wall is typically 1×10^{-3} cm/sec to 1×10^{-6} cm/sec.

Wall construction is often performed in a continuous manner with the simultaneous processes of trench excavation, support slurry fill, backfill mixing, and backfill emplacement. Slurry walls are typically placed at depth less than 50 m and are often 0.6 to 1.5 m in thickness. There is a substantial cost increase for walls deeper than 30 m. Depending on the site conditions and contaminants, the trench can be either excavated to a level below the water table to capture chemical "floaters" or extended into a lower confining layer. Similarly, on the horizontal plane, the slurry wall can be constructed around the entire perimeter of the contaminated site or sections thereof.

Soil-bentonite walls are the most popular and less costly. Attapulgite may also be used in cases where the bentonite is not compatible with the waste. A newer development in technology is the use of fly ash as a high carbon additive not only to lower the permeability of the soil-bentonite but also to increase the adsorption capacity of the soil-bentonite with respect to the transport of organic chemicals. Recent advances have extended to include the use of microfine cement, mineral wax, sodium silicates and colloidal silica gel. Montan wax is a fossilized plant wax with properties similar to that of natural plant waxes. Soils or slurry walls permeated with these agents show a significant reduction in permeability.

Composite slurry walls incorporate an additional barrier, e.g. a geomembrane, within the trench to improve impermeability and chemical resistance. The geomembranes often are plastic screens which are comprised of high-density polyethylene pile plank sections. The membrane is easy to install, having a long life; and is resistant to animal and vegetation intrusion, microorganisms, and decay. Combining the membrane with a bentonite slurry wall may be the most effective combination. It is usually effective to construct the bentonite-cement slurry wall and then install the membrane in the middle of the wall.

Slurry walls have the potential to provide an effective, long-term, low-cost, and low-maintenance solution to the control of contaminant migration in soil and groundwater. Such walls are typically quick to be constructed and can provide for a fast-response solution to an acute groundwater contamination problem. However, the slurry walls along do not eliminate the source of the contamination or reduce its toxicity, and additional techniques are required to permanently eliminate or reduce the threat of contamination.

3. Pump-and-Treat

Pump-and-Treat is a primary technique for groundwater and soil remediation. In this process, groundwater is pumped to the surface, and contaminants are removed by a variety of treatment methods, including air-stripping, activated carbon, ultraviolet or ozone treatment, precipitation and biodegradation.

This technique is accomplished through one or more pumping wells, with the water being treated by any one of physical and biological methods or their combinations. Pump and treat systems are relatively easy to design, install and operate using standard hydro-geologic and engineering practices. For successful remediation, surface treatment of pumped groundwater must be in consistence with the type and concentration of contaminants.

Pump-and-treat is typically used for contaminants which are dissolved in groundwater. The pumping systems can accomplish rapid mass-removal from areas of the groundwater plume where contaminants are most heavily concentrated. The technique also allows full capture of a plume at its leading edge, and prevents further migration. For this reason, pump-and-treat will continue to be the principal method of choice for plume containment and control.

Nevertheless, pump-and-treat is not so effective in area with low permeability soils as clays and silts. Further, long-period operation is often expensive due to the high rate of energy used to pump and treat large volumes of water, and the effluent disposal costs.

4. Soil Vapor Extraction

Extraction uses vapor extraction wells to remove volatile contaminants from the soil. Vacuum blowers are often installed to supply the driving force by inducing airflow through the soil matrix.

The extraction wells are prepared within the contaminated area. Wells are typically constructed of plastic pipe which is screened through the zone of contamination. The screened pipe is placed in a permeable packing; the unscreened section is sealed in a cement/bentonite grout to prevent a short-circuited air flow direct to the surface. The pumped air strips the volatile compounds from the soil and carries them to the screened extraction well. Gases are collected in perforated pipe wells or trenches and transported above-ground to a vapor-liquid separator, where entrained water is separated and contained for subsequent treatment. The contaminant vapors are moved by a vacuum blower for the vapor treatment process. Vapors produced by that process are conventionally treated by carbon adsorption or thermal destruction. Other methods including condensation, biological degradation, and ultraviolet oxidation have been applied thought to a limited extent.

In some cases, air-injection wells are installed in-situ. These wells may enhance the process efficacy by actively using forced airflow. The system must be designed in a way that any air injected into the system does not allow the escape of volatile organic compounds to the atmosphere.

Steam is often can be used in extraction to remove volatile and semi-volatile hazardous contaminants from soil and groundwater. It is injected into the ground to raise the soil temperature and drive off volatile contaminants. Steam injection can form a displacement front by its condensation to displace groundwater. Steam can enhance the stripping of volatile contaminants from soil and be used to displace contaminated groundwater under some conditions. The steam extraction process is applicable to organic wastes but has not been applied for removing insoluble inorganics and metals. The contaminated liquid and steam condensate are collected for further treatment.

In-situ extraction has been demonstrated effectively for removing volatile organic compounds from the vadose zone. In general, the process works the best in well drained soils with low organic carbon content.

Soils exhibiting low air permeability are difficult to treat by in-situ vapor extraction. When there is a high organic carbon content in soil and exerting a high sorption capacity for VOCs is more difficult to be remediated successfully with the soil-vapor extraction technique. Low soil temperature decreases a contaminant's vapor pressure, making volatilization more difficult. Sites that contain a high degree of soil heterogeneity will have variable flow pattern and make remediation difficult.

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Biographical Sketch

X.H. Zhang, obtained his Ph.D. in 1991 from Tsinghua University, and worked in the capacity of a faculty member from 1991 to 1995 at the Department of Environment Science and Engineering, Tsinghua University, he was honored as an excellent young faculty member. From 1995 to 1999, Professor Zhang was in the United States of America, as a postdoctorate fellow, and had received a senior research award from the National Research Council of USA. His major research interests include engineering treatment of micro-polluted water and remediation of soils and groundwater. In the fields of water treatment, extensive research activities have been conducted involving enhancement of conventional treatment processes, advanced technologies, pretreatment of raw water, and pollution control of water resources. More than 15 research projects have been completed as principal or co-principal investigators. In the fields of remediation of contaminated soils and groundwater, the researches have been focused on modeling of microbial co-metabolism of persistent organics in soils and groundwater and the development of innovative technology which combines bioremediation with electro-kinetics. A comprehensive model has been developed by Professor Zhang for the co-metabolism of chlorinated solvents based on key enzyme induction, toxic inactivation, self-recovery and energetics. An innovative remediation technology has been developed in this author's laboratories based on rotated transportations of microbial cells in subsurface soil pores, and this technology has been patented. More than 30 research papers have been published in the past decade. The author is also served as the member of the editorial board for Journal of Environmental Science and Health (Part A) in the USA. A Special Issue has been edited on Environmental Simulation and Pollution Control in China in 2000. Major courses taught by Professor Zhang include Physicochemical Treatment of Water and Wastewater; Biological Treatment of Water and Wastewater; Advanced Principle of Water and Wastewater Treatment; Design of Water Treatment Plant, and Internship of Water and Wastewater Engineering. At present, the author is an Associate Professor in the Department of Environment Science and Engineering, Tsinghua University, Beijing, China.