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Project Summary

Technologies of Delivery or Recovery for the Remediation of Hazardous Waste Sites

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Remediating techniques that involve recovering contaminants or delivering treating material are particularly attractive because they can be less expensive and more permanent than either containment or excavation. A few delivery or recovery techniques are in use today, but on the horizon are new technologies that offer improvements in both the rate and the ultimate effectiveness of remediation.

A review was conducted of in-situ delivery or recovery techniques that show promise for the remediation of contaminated ground or groundwater. Of the techniques reviewed, some are currently being investigated for remedial actions: others show promise but have yet to be investigated for remedial purposes. Current investigations are funded chiefly by the U.S. Environmental Protection Agency (EPA) or other government agencies. The promising technologies have been drawn from methods developed by the petroleum or solution mining industries.

The review examined 17 technologies. Twelve are currently being investigated in some way as remedial techniques; four are from the enhanced oil recovery industry, and one from the solution mining industry.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at the back).

Introduction

Definitions

Delivery and recovery technologies are processes that facilitate the transport of materials either into or out of the subsurface. Delivery technologies, in general, involve transporting materials into the subsurface. Liquids are the principal phase in most delivery operations, although some of the new techniques allow either vapor or solid phases to be delivered as well.

Recovery technologies, in general, include any process to remove material from the subsurface. Existing recovery technologies used for remediation are associated with fluid flows driven by hydraulic gradients. Some innovative technologies are driven by other types of processes, such as thermal methods, as well as processes to expedite recovery by employing chemical reactions that alter the behavior of contaminants.

An innovative delivery or recovery technology is a process that offers some improvement when compared with existing methods. For hazardous waste remediation, improvements either in the rate of recovery or in the amount of contaminants remaining in the subsurface are considered valuable. Improvements in delivery would occur with development of a method to deliver an increased volume of a liquid phase, or a method to deliver vapor or solid phases.

Limitations of Current Technologies

Delivery and recovery techniques have been used for many years to remediate contaminated sites. Most currently used techniques rely principally on pumping from wells to recover contaminated groundwater followed by treatment and injection at delivery wells. These pump and treat techniques reduce concentrations to acceptable levels for some contaminants under certain saturated site conditions. But these technologies are generally not applied to tight formations where hydraulic conductivities are less than 10^{-4} cm/sec.

Currently the delivery of remediating materials is limited to injecting liquids through wells. Methods of delivering solid or vapor phases are for the most part unavailable, although such methods would facilitate some remedial actions.

Existing technologies are usually not effective at sites with contaminants of low water solubilities or those that are readily adsorbed to soil. Current delivery or recovery methods are also usually ineffective for contaminated unsaturated soils. Low hydraulic conductivities and local stagnant zones in unsaturated media inhibit the rates and ultimate effectiveness of most delivery or recovery technologies. Furthermore, some current recovery methods applied to the unsaturated zone require an underlying impermeable barrier that precludes their use at some sites.

Another problem not addressed by current delivery and recovery technologies is the presence in some natural soils of preferred pathways of high conductivity separated by blocks of low conductivity. Delivery or recovery from such soils is limited by rates of diffusion through the soil matrix blocks to the preferred pathways.

Procedures

The innovative technologies reviewed were identified during a literature survey of topics related to the remediation of contaminated ground and groundwater, enhanced petroleum recovery, and solution mining. When published descriptions were insufficient to adequately describe a technology, interviews were conducted with researchers or developers.

Some of the technologies are currently being investigated as possible remediation methods, whereas others, principally the ones from the petroleum and mining industries, have yet to be investigated. They may, however, offer potential as remediation methods.

Results and Discussions

The 17 innovative methods of delivery or recovery identified during the review are listed in Table 1 and summarized below.

Colloidal gas aphrons (CGA) are microdispersions of gas in water. Typically, a CGA dispersion is 60 to 70 volume percent gas occurring in the form of minute bubbles or aphrons. The use of gas aphrons has been suggested as a technique to enhance the in-situ aerobic biodegradation of dissolved and dispersed organic contaminants. This suggestion is based on laboratory experiments showing that aphrons deliver a much greater concentration of gas when compared with other methods that deliver gases dissolved in water.

Hydraulic fracturing is a process of cracking rock in the neighborhood of a borehole. The cracks are formed by injecting a fluid, usually water, at pressures exceeding the confining stress at the bottom of the borehole. Sand pumped into the fracture at the time of its creation holds the fracture open forming a high-permeability channelway. Hydraulic fracturing could be used to increase the rates of either delivery or recovery to contaminated soil or rock from a well.

Radial well drilling is a technique used to place horizontal wells radially outward from a central borehole (4.5 inches in diameter or larger). The horizontal radial is cut by high velocity water pumped out of a conical jet nozzle. The nozzle is fed from the surface through steel tubing and cuts a borehole with a diameter several times larger than the tubing. Completed radials can be used to enhance access, for either delivery or recovery, to a contaminated formation or aquifer for groundwater control and in-situ treatment.

Ultrasonic vibration is used extensively by soil scientists to disperse clay and silt particles in the laboratory. Most commercial ultrasonic probes contain a transducer that converts electrical energy to mechanical energy and results in a mechanical disturbance of the sample. Possible applications of ultrasonic vibration to remedial actions include: (1) dispersing clay particles clogging soil pores adjacent to wells, (2) reducing adsorption of contaminants onto the surfaces of clays, and (3) eliminating microorganisms clogging soil pores adjacent to wells.

Kerfing (or borehole notching) is a technique to cut a slot either normal or parallel to the axis of a borehole. Kerfi uses a high pressure jet of water, wa with entrained air, water and bentonite, water and an abrasive material to cut t slot. Although recent interest in kerfi has been as a technique to help stop t migration of pollutants from uncontroll waste sites, it may also have applicati as a recovery technique.

Electro-kinetics (electro-osmos occurs when a liquid migrates through charged porous medium under the acti of an electric field. The electric field applied through the anodes that cau the cations to migrate through t saturated medium towards the negativ charged cathodes. Viscous drag of t water molecules by the cations causes net flow of water towards the cathod Basically, this is how the flow of wa can be induced from the application of electric field. Electro-kinetics has t potential for delivering remediati materials and recovering spent solutic or contaminants, principally metals, fr contaminated soil.

The jet-induced slurry method is technique used to excavate an ore bo at depth without removing t overburden. A borehole-mining tool lowered down a predrilled borehole. T borehole-mining tool generates a hig velocity hydraulic jet that erod subsurface material and then pumps t slurry through a well to the surface processing. This technology could of the unique capability of recoveri contaminated material from t subsurface without removing t overburden.

Carbon dioxide flooding is an enhanc oil recovery technique. Carbon dioxide injected into oil-bearing formations maintain pressure and displace Carbon dioxide injection mobilizes oil reducing oil viscosity and increasing t pressure in the reservoir. Carbon dioxi flooding to recover groundwat contaminants would likely be limited applications where carbon dioxide either dissolved in water or contained aphrons. In either case, carbon dioxi flooding could be used to decrease t viscosity and increase the recovery hydrocarbons.

Water-soluble polymers added waterfloods are used to enhance recovery. Water-soluble polymers a used to decrease the viscosity contr between the oil and fluids in waterfloc or to homogenize reservoir permeabili The homogenezation of permeability one possible application of polymers the recovery of contaminan Temporarily filling high-permeabil

Table 1. *Summary of the Development Status of Innovative Delivery or Recovery Technologies*

Technology	Delivery		Recovery	
	General	Remedial	General	Remedial
1. Colloidal gas aphrons	E*	E	A	NA
2. Hydraulic fracturing	E	E	A	E
3. Radial drilling	E	E	D	D
4. Ultrasonic methods	NA	NA	A	C
5. Kerfing	E	E	A	E
6. Electro-kinetics	D	D	A	D
7. Jet slurrying	NA	NA	A	C
8. Co_2 injection	NA	NA	A	C
9. Polymer injection	NA	NA	A	C
10. Vapor extraction	NA	NA	A	D
11. Steam stripping	NA	NA	A	D
12. Hot-brine injection	NA	NA	C	C
13. In-situ combustion	NA	NA	A	C
14. Radio frequency heating	NA	NA	D	D
15. Cyclic pumping	C	C	A	C
16. Soil flushing	NA	NA	A	D
17. Ground freezing	NA	NA	A	D

*Level of development
A - available fully proven and in routine use;
D - developed, passed bench- and pilot-scale testing;
E - emerging, research in progress;
C - conceptual, applicable but unevaluated;
NA - not applicable.

channelways with polymer gels could be used to induce flow and transport contaminants out of local zones of low permeability.

Vapor extraction involves the recovery of vapor-ladened air from unsaturated soils by applying a vacuum at extraction wells. The pore space of unsaturated soils is composed of liquid and vapor phases. Compounds with moderate to high vapor pressures will be partitioned more strongly into the vapor phase than will compounds of lesser vapor pressure. Vapor extraction techniques make use of the strong partitioning by removing the vapor phase from the soil through the application of a vacuum at well points. Pressure gradients are established within the soil to induce convective air flow through the porous media. The process appears to be limited to those contaminants that exhibit significant volatility at ambient temperatures.

In-situ steam stripping is a method intended to recover highly volatile and also moderately low vapor pressure organic compounds from contaminated soil. The steam is injected into the contaminated soil through wells where it releases heat to the soil when it condenses. The steam has two main functions: it vaporizes the contaminants that would be immobile at ambient temperatures and it becomes the transport medium for the vaporous materials. The rate of vaporization and transport of these compounds increases with increasing soil temperature following contact with the steam.

Hot-brine injection is being developed to recover natural gas from solid and liquid gas-hydrate deposits. Hot-brine injection increases both the temperature and salinity of a reservoir thereby promoting dissociation reactions that drive solid or liquid gas-hydrates into a vapor phase and water for easier recovery. Hot-brine injection could be used at uncontrolled hazardous waste sites to recover certain contaminants whose dissociation temperatures decrease with an increasing salinity of pore fluid. The applicability of this method will require a salinity dependence on the dissociation temperature of the contaminant species to be recovered.

In-situ combustion methods are used to recover crude oil from tar sands and other deposits of viscous hydrocarbons. In-situ combustion uses an injection and production well system to create and migrate a thermal front through an oil-bearing formation. As the front advances and the formation temperature increases, lighter oil fractions are mobilized through volatilization and reduced viscosity. Similar techniques could possibly be used to recover hydrocarbons from uncontrolled hazardous waste sites.

Radio-frequency (RF) heating was developed in the 1970's for the thermal recovery of hydrocarbons. Electromagnetic energy is applied to the contaminated soil through bound-wave exciter electrodes. In this way molecular agitation rather than thermal conduction is used to heat the soil. RF heating techniques may have two general applications as a remedial technique: (1) thermal vaporization and recovery of contaminants with low boiling points and (2) the improvement of reaction rates between contaminants with high boiling temperatures and applied reagents.

Cyclic pumping is a delivery or recovery technique that systematically varies rates of either injection or extraction. Pumps are turned on during an active cycle and turned off during a rest cycle. The rest cycle allows time for diffusion between high-permeability pathways and the low-permeability blocks between them. Treating solutions diffuse from the pathways into the blocks, or contaminants diffuse from the blocks to the pathways. The active cycle is designed to deliver the minimum volume of nutrients or reactants or to remove the maximum possible concentration of reaction products. The optimization of pumping practices has the potential to

reduce remediation costs at hazardous waste sites by minimizing pumping costs.

In-situ soil flushing is a technology designed to accelerate the movement of a contaminant through unsaturated materials. The efficacy of soil flushing is related to two processes: (1) the increase in hydraulic conductivity that accompanies an increase in water content of unsaturated soil and (2) the engineering of treatment solutions to the composition of the contaminants and the contaminated medium. A treatment solution is applied to the soil and allowed to percolate downward and interact with contaminating chemicals. Contaminants are mobilized and transported downward to a saturated zone where they are pumped to the surface.

Ground freezing is a technique with the potential to migrate and concentrate solutes. When pore water freezes slowly, crystals of nearly pure ice form, and any dissolved species are concentrated in pockets or thin films of liquid around solid particles. The film around the particles can be very mobile allowing ion movement to occur through diffusion. Artificial ground freezing potentially can concentrate contaminants ahead of freezing fronts reducing the volume of contaminated soil at a site and thereby facilitate remediation.

Conclusions

Innovative technologies of delivery and recovery offer a range of potentially valuable new methods of remediati contaminated sites. Furth investigations that would develop t appropriate technologies to a level routine field application should certai enhance the remediation of sor problematic uncontrolled hazardo waste sites.

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The complete report, entitled "Technologies of Delivery or Recovery for the Remediation of Hazardous Waste Sites," (Order No. PB90-156 225/AS; Cost: $23.00 subject to change) will be available only from:
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