A2L03: Committee on Physicochemical Phenomena in Soils
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Physicochemical Phenomena in Soils

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Geoenvironmental and geotechnical engineers are concerned with the composition and fabric of natural soils, their surface and pore-fluid chemistry, the physicochemical and biological processes that govern soil behavior, and the ways in which these fundamental characteristics and processes affect the hydrologic and geotechnical properties of soils. These professionals focus on identifying and promoting research on fundamental processes that affect soil and related materials, as well as the relationship of these processes to material behavior. The goal is to provide practitioners with a knowledge base on physicochemical phenomena in the subsurface environment. Such a knowledge base is needed in all geotechnical and geoenvironmental engineering activities associated with transportation facilities, including foundations, earthworks, contaminated site remediation, and brownfield restoration.

PROBLEM

The transportation industry faces a challenge in dealing with chemical effects on subsurface structures. These challenges range from the need to remediate contaminated subsurface profiles to the impact of corrosion on the metallic components of subsurface elements. More recently, brownfield rehabilitation has emerged as a critical need to be addressed by the profession. In general, properties acquired for highway realignment or expansion or for construction of new maintenance facilities may have contaminants in place from past practices. The remediation of these facilities continues to be a challenge to the profession.

Petroleum and heavy metal contaminants, including fuels, lubricants, and solvents, are associated with activities of the transportation industry. Uncontrolled releases of these compounds into soil and groundwater are frequent as a result of accidents or poor control practices. Underground storage tanks and piping containing gasoline, diesel fuel, heating oil, and used oil may leak. Even newly installed dispensers can leak fuel through loosened pipe unions. Spills during product delivery can contaminate soils in fill areas. Hydraulic lift systems can fail, releasing hydraulic oil into soils and groundwater beneath buildings. In the heavy metal category, lead contamination continues to pose a challenge to the transportation industry.

Most contaminated sites pose significant environmental consequences and require remediation. While remediation options abound, the objectives remain to clean up the site at a minimum cost and as quickly as possible. Accordingly, understanding the physical, chemical, and biological phenomena that characterize soils and groundwater is essential for the remediation of transportation facilities.

PAST AND CURRENT ACTIVITIES

The Transportation Research Board served as the focal point for research on the physicochemical properties of soils from the 1950s to the late 1970s. Much of the knowledge generated through these efforts was directly and indirectly applicable to understanding the physicochemical role played by contaminants in impacting soil properties. During the 1980s, the focus shifted to the geoenvironmental properties of soils and the movement of dense nonaqueous phase liquids and light nonaqueous phase liquids within the subsurface environment. In the late 1980s and early 1990s, research was focused on landfills, waste containment, and characterization of contaminated sites and groundwater. Information on innovative and cost-effective remediation techniques and their efficacy is generally lacking in the literature.

STATE OF THE PRACTICE

The state of practice in remediation techniques is guided largely by regulatory requirements. The regulatory approach to soil petroleum contamination has ranged from requiring removal of all impacted soil to leaving the soil in place to naturally biodegrade, and everything in between. Excavation of the contaminated area and replacement with clean fill frequently have been used in practice. However, treatment options for remediating the impacted soil have changed. Treatment methodologies allowed by regulators have been determined not only by technological advances, but also by policy changes, which often are driven by public comments. The method of treatment is chosen not only according to the contaminant type and the volume of contaminated soil, but also on the basis of geographic location, local politics, and economic considerations.

The Minnesota Department of Transportation (MnDOT), for example, has used several techniques to treat petroleum-contaminated soil during the past 10 years. These treatment techniques have included landspreading, thinspreading, roadbase incorporation, asphalt incorporation, thermal treatment, bioremediation, and in situ natural attenuation. During the late 1980s and early 1990s, MnDOT depended heavily on landspread treatment and roadbase/shoulder application. Some of these options are no longer allowed by regulators in the state of Minnesota. Landspreading has been virtually eliminated in some parts of the state by local government. The number of permitted thermal treatment facilities in operation changes constantly. The number depends on both the economic climate and the regulatory structure, which can render the excavate and replace option difficult to implement.

With cost often being a driving consideration, the U.S. Environmental Protection Agency (EPA) is encouraging innovative technologies and risk-based corrective actions. To best apply remedial funding, EPA has embraced a defensible approach to intrinsic remediation and natural attenuation. As an example of such an approach, changing environmental regulations and public opinion resulted in MnDOTs pioneering work with low-technology bioremediation techniques in the early 1990s. Since the early 1990s, MnDOT has routinely used the biomound approach to treat petroleum-contaminated soil. To date, MnDOT has used biomounds successfully to treat approximately 13,000 cubic yards of petroleum-contaminated soil at 25 sites.

STATE OF THE ART

State-of-the art technologies for the remediation of contaminated soil and groundwater can be categorized as in situ or ex situ. In situ refers to remediation of the contaminated subsurface without excavating or moving the soils. Ex situ refers to the removal of contaminated soils and groundwater to the surface.

Examples of in situ treatment techniques include soil flushing, electrokinetics, bioremediation, vacuum or air stripping, and immobilization. In the case of in situ bioremediation, one or more organic compounds are biochemically degraded within the contaminated subsurface. Air or steam stripping is feasible if the Henry's Law constant of the organic compound(s) is greater than 3×10^{-3} atm/m^3 mol. In the case of immobilization techniques, contaminants are tightly bounded within a solid matrix that minimizes their migration. Solidification, stabilization, and vitrification are the principal immobilization techniques. In contrast with immobilization, soil flushing promotes contaminant solubilization and migration in the liquid phase so the contaminants can easily be flushed from the soil matrix. Examples of ex situ techniques include soil washing, biological landfarming, and excavate and replace. Considering all remediation approaches, only soil flushing and stripping remove contaminants from the contaminated zone without requiring excavation of the soil.

In general, the area of remediation technologies is still in its infancy, and current state-of-the-art methods are still under development. For hydrocarbon compounds such as fuels, lubricants, and solvents, bioremediation offers a means of accomplishing remediation. However, additional knowledge is needed, particularly in terms of applicability to specific compounds and mixtures, field conditions, and field performance. For example, certain chlorinated compounds may degrade naturally into more toxic compounds (vinyl chlorides) and necessitate modification of normal bioremediation approaches. Furthermore, aromatic and aliphatic metabolites of incomplete fuel degradation have been shown to accumulate in oxygen-limited aquifers. This is a potential problem since many hydrocarbon metabolites are potentially toxic.

With regard to soil flushing, which applies to hydrocarbons as well as heavy metals, water has been the primary washing fluid, with emerging chemical additives now being used to promote contaminant solubilization. This process is referred to as surfactant-enhanced aquifer remediation (SEAR). Nonionic and ionic surfactants, acids, and solvents are examples of chemical additives. The soil flushing process involves a number of steps: contaminant solubilization by the wash fluid (surfactant), extraction of the solubilized contaminants from the subsurface, treatment of the spent flushing water, and disposal/reuse of the treatment residuals. Information and data are needed for examining the effectiveness of chemical additives in extracting soil-bound contaminants during the soil flushing process and for determining the end point of remediation with this process.

The state of the art of soil and groundwater remediation reflects many technical advances. Nevertheless, a greater challenge is posed by the need to make the transportation industry aware of the potential role of these state-of-the-art technologies in treating the dominant contaminants within the industry's sphere of operations.

VISION FOR THE 21st CENTURY

Emerging state-of-the-art techniques address a wide range of environmental challenges facing transportation facilities. Basic understanding of the physicochemical phenomena of soils and groundwater will play an ever-increasing role in the development and implementation of innovative environmental remediation measures. Powerful computing, nondestructive techniques, image processing, and advanced electronic tools will provide the impetus for understanding pollutant-chemical interactions and intricacies; they also will improve the efficiency of the remediation effort. The progressive development of directional drilling, electrokinetics, and innovative injection/extraction systems, together with utilization of the real-time sampling response, will enhance the delivery of remediation media and performance monitoring. The integration of several functions on a chip will allow for multitasking, provide the opportunity to perform complete analysis of a contaminated area, and enable decision support systems that can assist in identifying efficient and cost-effective alternatives, as well as reduce uncertainties associated with the outcomes. Innovative polymers and genetically engineered bacteria will emerge for addressing the specific level of hazard associated with a given site. A treatment train, rather than a single technology, will provide integrated and effective remediation measures based on a comprehensive understanding of the physical, chemical, and biological properties of the media and compounds of concern. The greater challenge of the 21st century perhaps will be meeting the need for a multidisciplinary knowledge base integrating the physical, chemical, and biological disciplines—as well as the political and socioeconomic factors—involved in environmental cleanup efforts by transportation facilities.