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Arvind Kumar Agnihotri
Krishna R. Reddy
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Environmental Geotechnology

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Preface

Geo-environmental engineering is an inclusive discipline which recognizes many environmental challenges that cannot be solved by one traditional discipline alone. The term geo-environmental engineering is a broad one covering the contributions that geotechnical engineers, environmental engineers, hydrogeologists, earth scientists, geochemists, water engineers, biologists and ecologists, amongst others, make to environmental management, site characterization, environmental risk assessment, waste disposal, soil and groundwater remediation, habitat protection and environmental rehabilitation. This book covers a variety of such multidisciplinary articles which will be very useful for students, working professionals, practitioners and researchers.

Since the nature of the problems addressed in geo-environmental engineering is diverse, the solutions to *geo-environmental problems* typically require the expertise of a variety of professionals who possess a similar diversity in terms of educational background and training. Because of this diversity, efficient and effective technical interaction among these professionals can be problematic. Thus, professionals who have attained a breadth of knowledge in a variety of the disciplines associated with geo-environmental problems can facilitate the professional interaction needed for the successful completion of geo-environmental projects within a *multidisciplinary setting*. Geo-environmental engineering is an emerging and exciting field that offers numerous technical challenges and great opportunities to understand multidisciplinary problems and develop solutions to protect public health and the environment and encourage sustainable development.

At present, the estimated worldwide population is in excess of 7.4 billion. According to the 'United Nations' prediction, conservative estimates give a population of 11.1 billion by the year 2100. Approximately 80% of this growth will be in developing countries. There are two major reasons for the development of environmental geotechnology. First is population growth, and the second is rising living standards. When the population increases, more land is needed; many soil deposits previously claimed to be unfit for residential housing and other construction projects are now being used. In a progressive society, rising projects are now being used. In a progressive society, rising living standards indicate an increase in industrial growth. As a consequence, hazardous pollution of air, water and land and urban refuse production become inevitable, thereby endangering the global environment. To cope with these problematic soil deposits and adverse environmental conditions, the present conventional construction technology has to take, by necessity, a new direction. Problematic soil deposits on the one hand and ground pollution problems on the other hand have challenged the current soil mechanics concepts and methods of analysing soil behaviour under varied environmental conditions. For this reason, the environmental aspects of geotechnology have been expanded and their subsequent response to engineering behaviour has paved the way for the emergence of environmental geotechnology.

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Role of Geochemistry in Sustainable Geotechnics

Krishna R. Reddy and Girish Kumar

Abstract The world in the twenty-first century is posed with unprecedented challenges such as rapid increase in world population, global resource depletion, increased waste generation, and increased greenhouse gas emissions, the consequences of which are unnerving. This, in fact, has triggered the geotechnical and geoenvironmental engineers to develop sustainable geosystems for civil infrastructure and for the protection of the environment. However, the solutions to these challenges are interdisciplinary. For geotechnical considerations, engineering properties of the soil and rock are influenced by several geochemical parameters and geochemical processes, which are usually not addressed in-depth by geotechnical engineers. However, it is crucial to understand these geochemical aspects of the soil and its environment so that they can be engineered to create favorable conditions for developing resilient and sustainable geosystems. This paper first presents the most significant geochemical properties and processes of soils, rock, and groundwater, followed by a discussion of recent advances that demonstrate the significance of geochemical processes toward an understanding and development of effective and potentially sustainable geosystems. The paper emphasizes on the need for studying the geochemistry and the geochemical factors affecting the performance and behavior of a geosystem.

Keywords Geochemistry · Sustainable geotechnics · Geosystem performance · Resiliency · Biocementation

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1 Introduction

Geochemistry in its fundamental sense deals with an understanding of the chemical composition, the physicochemical changes, and the principal mechanisms associated with the chemical interactions within and between the solid, liquid, and gases matter of the earth. Geotechnical and geoenvironmental applications are one of the most resource-intensive industries relying on earth's limited resources thus contributing a major proportion to the global environmental impacts (e.g., climate change, resource depletion, and increased waste generation). On the other hand, this provides a great scope for research in mitigating these environmental impacts by channeling the efforts toward building sustainable and resilient geosystems. The geosystems in geotechnical and geoenvironmental applications in almost all the cases happen to deal with earth and its environment (soil, water, and atmospheric air). Therefore, the performance of these systems is heavily influenced by the geochemistry between the constituents of the system. A thorough understanding of the geochemical processes and the geochemical parameters allows us to control the behavior of soil/rock minerals and groundwater, thus enabling us to design/develop innovative, resilient, and sustainable geosystems.

Geochemical processes such as adsorption–desorption, ion-exchange, oxidation–reduction, precipitation–dissolution, complexation, acid–base reactions, volatilization, and biodegradation processes are often complex with interrelated mechanisms influenced by several physical and chemical parameters including porosity, permeability, mineralogy, organic content, pH, temperature, among many others (see Fig. 1). Meanwhile, it is imperative to develop technologies that are technically robust, environmentally benign, and economically viable which are primary attributes of a sustainable and resilient geosystem. Utilizing and incorporating the natural biological processes/mechanisms and/or systems has become an attractive option to realize geosystems, which are less resource intensive yet being technologically sound. However, most of the emphasis on such systems is on understanding of the geochemical and biological interplay to get the desired behavior in soils and other waste materials. Understanding and leveraging on these fundamental biogeochemical processes provides a great scope to control the behavior of the materials and thus, the systems constituted by these materials.

Many recent studies have advanced the fundamental understanding of geochemical processes in engineered geosystems. The author has investigated the fundamental geochemical processes and developed engineered systems to remediate environmental pollution in soils and groundwater. Al-Hamdan and Reddy (2008) and Cecchin et al. (2016) demonstrated that with proper understanding of soil composition, geochemical properties and geochemical processes (especially adsorption–desorption, precipitation–dissolution, and redox reactions), various strategies (e.g., soil washing, electrokinetics, stabilization, air sparging, oxidation, permeable reactive barriers, and biodegradation) can be implemented to favor geochemical conditions for effective remediation of heavy metals, organic contaminants, or when they coexist. Remediation strategies may be focused to remove,

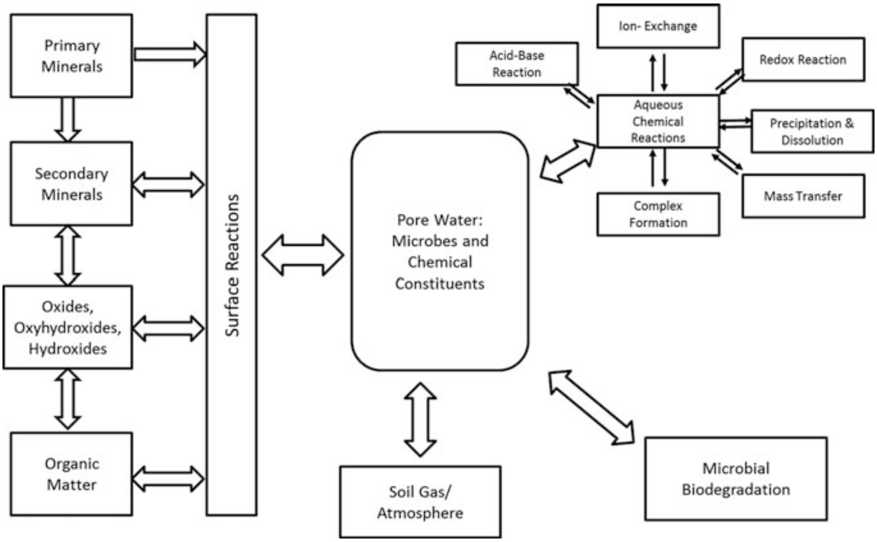

Fig. 1 Fundamental geochemical processes in soil and its surrounding environment

immobilize, or degrade the contaminants in the soils and groundwater. Yang et al. (2016) showed that appropriate amendment selection based on targeted geochemical processes can be effectively deployed in vertical barriers (e.g., soil–bentonite wall) to contain and simultaneously treat groundwater contaminants.

This paper discusses the importance of understanding the geochemistry in geotechnical and geoenvironmental applications to develop potentially sustainable and resilient geosystems. In addition, the various geochemical processes and the factors that control these geochemical processes within soil, water, and air are presented. Finally, some of the recent and innovative technologies that are driven by the geochemical processes are briefly discussed and the research challenges pertaining to geochemistry in these systems are highlighted.

2 Geochemistry for Sustainability and Resiliency

The exploding world population, rapid urbanization, increased use of earth and its resources, increased waste generation, increased global greenhouse gas emissions, and global climate change are some of the major world challenges of the twenty-first century. A major proportion of these problems can be ascribed to the civil engineering construction industry, since it involves highly resource and energy-intensive processes and activities. In particular, the geotechnical and geoenvironmental engineering applications often exploit the earth and its resources thus contributing significantly to the broader environmental, economic, and social impacts. In recent years, a major stride has been toward incorporating sustainable engineered systems, which are environmentally benign, economically viable and socially acceptable, into geotechnical and geoenvironmental practice. However, it is also crucial to make the sustainable engineered systems more resilient in order to recover and restore from natural and/or anthropogenic perturbations. A resilient system has the ability to return to its original functioning state within an acceptable period of time when subjected to unpredictable disruptions while an adaptive system is responsive to gradual and natural changes within itself and in its environment, and is flexible to modifications and alterations required to cope with such changes (Basu et al. 2013).

Development of sustainable and resilient geosystems demands an interdisciplinary and/or multidisciplinary approach. The use of any potentially beneficial waste material or other engineered materials in combination with soils to enhance the soil's engineering properties requires a thorough understanding of how these materials interact geochemically to produce the desired outcome. The geochemical processes within the soil minerals and other supplemental materials are influenced by several geochemical parameters. The control over these parameters in the real-field conditions is impractical in most of the cases. However, understanding the impacts of different factors on the fundamental geochemical processes aids in tuning the materials, hence the engineered geosystems, to adapt to the changing environmental conditions and maintain its performance. Likewise, understanding of the geochemical interactions between the groundwater and the soil is of utmost importance in geoenvironmental applications. Bioengineered geosystems have great potential to be resilient and sustainable, but they require an understanding of the fundamental biogeochemical processes. The ongoing research in geotechnical and geoenvironmental engineering to develop sustainable and resilient geosystems are focused on delineating the geochemical processes through experimental, numerical and field implementation. Recently, new biologically inspired strategies such as biocementation, bioclogging, bioremediation, and phytoremediation have received great attention from geotechnical and geoenvironmental engineers. All of these strategies rely on microbes and microbial processes that are highly sensitive to geochemical parameters/conditions as depicted in Fig. 2.

Figure 2 illustrates how different geochemical factors combine to influence microbial activity by way of dictating energy availability for a given reaction in a system (Gibbs free energy, determined based on analysis of solution/system geochemistry using laws of thermodynamics), and thus which reactions a microbe can use for energy. All bio-based geotechnologies involve studying the microbial ecology in varying subsurface environments (the microbial types, abundance, and metabolic activities), the coupled biogeochemical processes in the subsurface environment, the influence of potential extreme climatic conditions, soil mineral composition, and pore water constituents on the performance of the geosystems. The long-term impacts of using these innovative biogeotechnologies are not always apparent. Hence, a sustainability and resiliency assessment is essential before these technologies can be used at a large-scale field implementation.

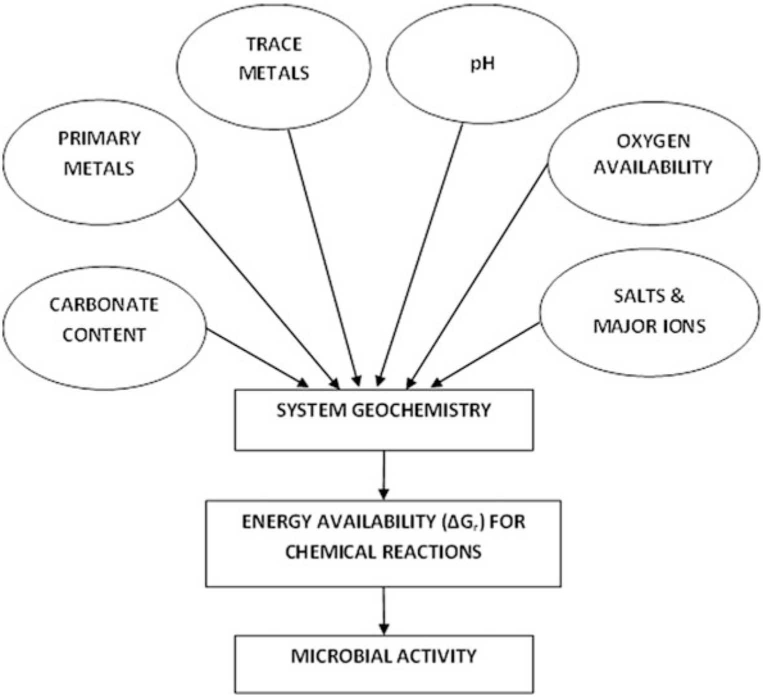

Fig. 2 Role of geochemistry on microbes and microbial processes

3 Recent Advancements

3.1 Biocementation by Microbially Induced Calcite Precipitation (MICP)

A new and innovative technology, known as microbially induced calcite precipitation (MICP) has been the subject of interest for several industrial applications of which soil stabilization is of particular interest to geotechnical engineers. MICP is a microbially mediated process that involves injecting aerobically cultivated bacteria that produce urease enzyme into the soil, then utilizing the urease enzyme to catalyze the hydrolysis of urea to produce ammonium and carbonate ions, and finally, precipitate calcium carbonate in the presence of calcium (Ca^{2+}) source (see reactions 1 and 2). The precipitate binds the soil particles by cementation and thereby alters the soil characteristics such as the strength and stiffness.

$$CO(NH_2)_2 + 2H_2O \quad 2NH_4^+ + CO_3^{2-} \tag{1}$$

$$\mathrm{Ca}^{2+} + \mathrm{CO}_3^{2-} \quad \mathrm{CaCO}_{3(s)} \qquad (2)$$

The concept of MICP is promising, however, there are some major technical challenges associated with the practical implementation of the technology which largely related to the geochemistry of the entire process. In order to have the desired strength and stiffness in the treated material (soil), there has to be a control on the MICP process and the factors affecting it. Several factors (including geochemical parameters) have been identified that control the carbonate precipitation such as moisture content (degree of saturation) of the soil during treatment, microbial type, their population and distribution, pH for optimum microbial activity (7.5–8), nutrients, temperature, O_2 availability, concentration of the chemical reactants, and methods to introduce the reactants to the reaction media (Stocks-Fischer et al. 1999; Qabany et al. 2011; Cheng et al. 2013).

Thus, there are a range of physical and chemical parameters that influence and control the calcite precipitation of microbes. However, in order to implement MICP on a field scale, it is essential to determine under what in situ environmental conditions is the desired performance maintained. Moreover, the extreme weather patterns and the exposure to acidic conditions can significantly reduce the crystalized carbonates by its dissolution and thereby the strength and stiffness of the treated soil.

3.2 Liquefaction Mitigation by Microbially Induced Desaturation and Precipitation (MIDP)

Traditional methods to mitigate the potential for liquefaction include compaction/densification, solidification of the group, drainage, and desaturation. These techniques are disruptive, energy intensive and involve high implementation costs. In recent years, desaturation techniques have gained more prominence due to their ability to mitigate liquefaction potential significantly even with a small change in saturation (Eseller-Bayat et al. 2012; O'Donnell et al. 2017a). MIDP has been recently investigated for an environmentally sustainable and economically viable means to mitigate liquefaction potential.

MIDP is a similar process as MICP is discussed earlier except that it involves dissimilatory reduction of nitrate through microbial denitrification. The concept of MIDP is to utilize the naturally available denitrifying microorganisms in the subsurface to reduce nitrates to large amounts of carbon dioxide and nitrogen gases, which further lead to desaturation of the soil thus increasing liquefaction resistance (Kavazanjian and O'Donnell 2015). The quick desaturation of the soil provides short-time mitigation and the slow rate continued MICP provides long-term resistance to liquefaction. The MICP via denitrification is more environmentally sustainable in comparison to the usual MICP by hydrolysis of urea since MIDP generates nontoxic N_2 and CO_2 as by-products while MICP via ureolysis

(O'Donnell et al. 2017b) produces ammonium, which needs to be flushed after soil treatment.

It should be recognized that the successful implementation of this technology relies on the underlying geochemistry and the factors that influence those geochemical processes. The amount of substrates and nutrients that needs to be supplied, the time scales of the treatment are highly dependent on the accurate prediction of the biogeochemical processes under a given set of environmental conditions.

3.3 Biosealing/Bioclogging

Seepage through water-retaining structures (e.g., dam, dikes), leaks from the piping systems, and migration of contaminants is some of the most prominent problems in geotechnical and geoenvironmental engineering. Traditional methods to address these problems include grouting and construction of vertical barriers and a few others to reduce the permeability through the soil. There are several disadvantages to these technologies, which include high cost, low accessibility to the subsurface leaks, and require lots of chemical compounds for grouting. In recent years, biosealing/bioclogging has been sought as an effective and sustainable way to prevent seepage/leakage in the porous media at the leaking locations by reducing the permeability of the media. Clogging can occur due to microbiological growth caused by the presence of nutrition or changes in redox conditions. Accumulation of bacterial biomass, insoluble bacterial slime, and biogenic gas bubbles in the soil will make the soil less permeable for fluids (Blauw et al. 2009).

Biosealing essentially stimulates the microbial activity and involves the injection of nutrition for bacteria near the location of the leak. As the injected nutrients mix with the stored water/groundwater, the nutrients and the microbes are automatically transported toward the leak by the flow of water. The addition of nutrients enhances the biomass growth and the extracellular polymeric substances (EPS) released from the microbes.

Both the biological techniques are governed by microbial activities which are in turn dependent on the right chemical conditions. The bioclogging is suitable under the presence of right kind of microbes (extensive bioclogging induced by anaerobic bacteria) and optimum conditions (pH, temperature, and nutrients) for microbial activity. Some of the large-scale laboratory experiments and field-scale demonstrations of biosealing and bioclogging can be found in Van Paassen (2011), Liao et al. (2007) and Van Beek et al. (2007).

3.4 Bioreactor Landfills for Waste Management

The conventional municipal solid waste (MSW) landfills are designed as per the regulatory requirements to effectively contain the waste using the bottom liner system and the top cover system. These components limit the moisture infiltration and help maintain very dry conditions within the waste to prevent excess leachate. The absence of adequate moisture hinders the microbial activity and lowers the rate of biochemical reactions associated with the anaerobic decomposition of waste. This leads to several problems including, low gas generation and settlement rates, prolonged waste stabilization time, extensive leachate treatment and disposal requirements, increased post-closure monitoring, and increased methane (CH_4) and carbon dioxide (CO_2) emissions over the prolonged monitoring period.

In this regard, bioreactor landfills are being considered as a promising technology for sustainable management of waste. The bioreactor landfill essentially involves recirculation of the collected leachate from the bottom of the landfill back into the waste mass, through various leachate injection systems, usually under pressurized conditions. The enhanced moisture levels by the introduction of leachate promote rapid decomposition of waste thus leading to early waste stabilization. In addition, it offers several other benefits such as high gas generation and settlement rates, low leachate treatment and disposal costs, landfill space reclamation, among many others. The concept of bioreactor landfills is appealing; however, the design of such landfills for safe and effective operations is challenging due to many reasons.

The MSW in landfill is highly heterogeneous and anisotropic which makes the injection of leachate uniformly across the entire landfill highly uncertain. One of the major reasons which make the landfill system highly complex to understand is the biodegradation of waste. The conversion of biodegradable solids to gas influences the engineering properties of the waste and thereby the mechanical response (e.g., settlement) and hydraulic flow of leachate within the waste. In order to design a stable and effective bioreactor landfill, it is imperative to understand the fundamental system processes during the course of landfill construction and operation. More importantly, the biodegradation of the waste involves various biochemical reactions mediated by the microbial activity which are sensitive to various parameters (moisture, pH, and temperature). A schematic of a simplified anaerobic digestion process as presented by McDougall (2007) is shown in Fig. 3.

Several researchers have performed experimental investigations to delineate the possible biodegradation mechanisms in MSW. Many researchers have also formulated mathematical models to simulate the biochemical reactions (Gawande et al. 2010; Haarstrick et al. 2001; Young 1989). However, most of these models do not speak of its influence on the hydraulic and mechanical response mathematically and the ones which do involve simulating the coupled interactions between different processes, do not holistically assess the influence of these processes on the overall performance (landfill stability and integrity of landfill components) of the bioreactor landfill. MSW is a geomaterial and understanding its behavior is crucial in

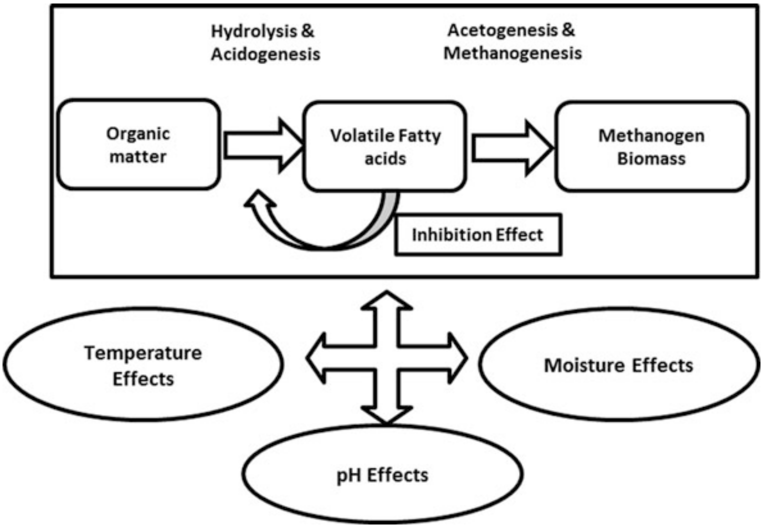

Fig. 3 Two-stage anaerobic biodegradation process (McDougall 2007)

understanding the landfill system itself. The sustainable management of waste through bioreactor landfill can only be realized if the biogeochemical reactions within the waste can be manipulated as required. The control over these reactions is possible only by detailed experimental investigation of the biochemical behavior and trying to simulate it mathematically to understand its long-term impacts on the other processes within the landfill.

3.5 Biocovers for Mitigation of Landfill Gas Emissions

MSW in landfills undergoes anaerobic decomposition and generates CH_4 and CO_2 gases predominantly. The gas extraction wells installed at the landfills can capture most of the gases generated and use it for several purposes (e.g., thermal energy, electricity). However, there is always some portion of these gases that escape the influence of the extraction wells and gets released into the atmosphere through the landfill covers. In the U.S., these emissions from the landfills are one of the largest sources of greenhouse gas emissions into the atmosphere. The cover soil in the landfill covers naturally consists of microbes called as methanotrophs, which can feed on the CH_4 passing to the cover and oxidize it to CO_2 thus mitigating some of the CH_4 emissions into the atmosphere. However, the microbial oxidation in cover soil is limited due to the lack of favorable conditions for the microbial activity.

In recent years, biocovers, which involve the addition of organic matter to the cover soil in order to enhance microbial activity, have gained more prominence. The addition of organic matter enhances the microbial oxidation of CH_4 thus

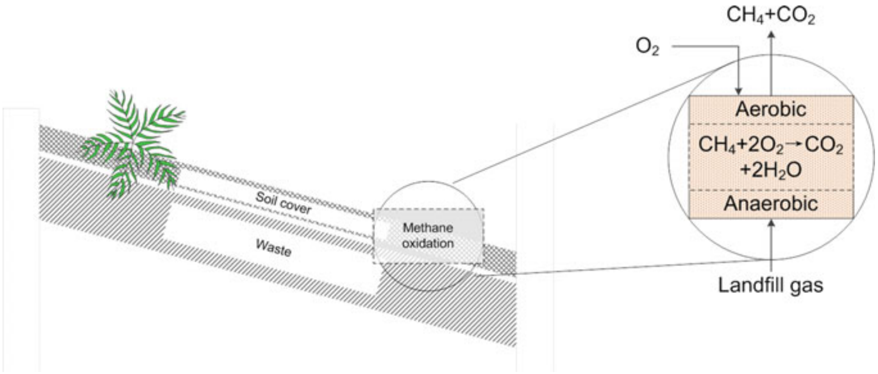

Fig. 4 Microbial oxidation of methane in biochar-amended soil cover system

alleviating the CH_4 emissions. However, the organic matter such as compost, sewage sludge, and biosolids may undergo anaerobic degradation in the cover soil emitting CH_4, thus, exacerbating the emissions. In this regard, biochar, a solid byproduct derived out of gasification or pyrolysis of biomass, has shown great promise. The addition of biochar as an amendment to the soil promotes microbial growth and activity due to its unique characteristics such as high internal porosity and specific surface (see Fig. 4). In addition, biochar is a stable form of carbon and it does not undergo any degradation or creates odor. Several recent investigations on the biochar-amended soils for landfill cover systems have shown the effectiveness of mitigating the CH_4 emissions (Yargicoglu et al. 2015; Yargicoglu and Reddy 2017a, b, 2018).

The addition of biochar into the cover soil induces beneficial physical and chemical characteristics into the soil. However, one of the most critical aspects in the biochar-amended soil cover system is to maintain the physical and more importantly, the chemical environment within the soil cover that favors the microbial growth and activity. The availability of O_2 for the microbes, gas fluxes out of the waste gas flow into the soil cover, retention time for the chemical reactions to occur, adequate moisture content, pH, and temperature play a crucial role in the geochemical processes that take place within the cover system. Thus, investigation of the abovementioned geochemical factors on the microbial activity and the biogeochemical interactions in the soil cover is of utmost importance for optimal CH_4 oxidation.

3.6 Phytoremediation for Decontamination of Soils

The geoenvironmental remediation involves active or passive treatment of contaminated air, water, and soil to protect the human health and the environment. The nature of the problem addressed in geoenvironmental remediation is diverse and requires multidisciplinary solutions. Several technologies for the remediation of contaminated soils have been developed over the past three decades. These methods include soil vapor extraction, soil washing, chemical oxidation, thermal desorption, and bioremediation, but they are often limited to a particular type of contaminant (Sharma and Reddy 2004). Most of the traditional remediation technologies are highly energy intensive leading to more problems indirectly. In recent years, biological-based technologies or bioengineered systems have gained wide attention due to their passive yet effective performance in remediation of contaminated sites. In the case of contaminated sites with mixed contamination, few technologies have proven to be efficient, but they also have major limitations and their application for large field sites can be very expensive (Reddy 2010). In this context, phytoremediation has the potential to be a benign, cost-effective alternative for the treatment of contaminated sites with mixed contamination (Cameselle et al. 2013; Chirakkara et al. 2016).

Phytoremediation is the use of plants to degrade (phytodegradation), extract (phytoextraction), and contain or immobilize (phytostabilization) contaminants from soil (Sharma and Reddy 2004). This green and sustainable remedial option can be adopted to remediate soils with a mixture of organic and inorganic contaminants that can be removed by the plants through different mechanisms (Reddy and Chirakkara 2013). Some mechanisms target certain types of contaminants over others, e.g., several organic compounds (e.g., tetrachloroethylene and trichloroethylene) can be completely degraded by the plant, while inorganic contaminants tend to be sequestered or accumulated within the plant. However, the effectiveness of the phytoremediation at a contaminated site highly depends on the physical and chemical properties of the soil. Figure 5 shows the comparison of three areas at the same contaminated site. The difference in the chemical properties of the soil underlying those areas dictates the survival of plants.

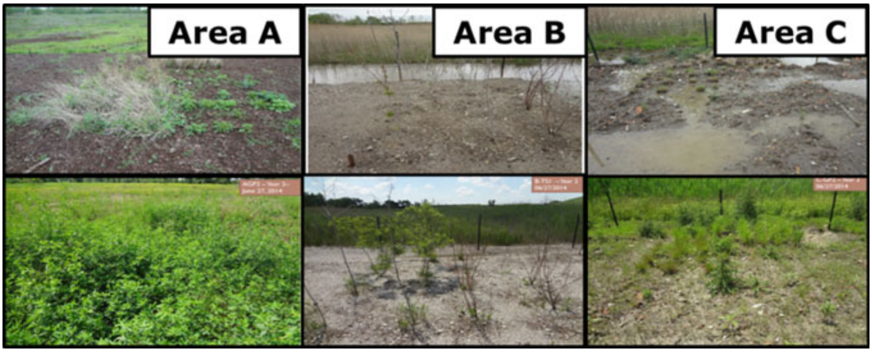

Fig. 5 Effect of varying physical and chemical conditions of soil in three areas at the same site on the growth and survival of plant species used in phytoremediation

The ability to remain resilient to adverse chemical conditions (e.g., unfavorable pH) depends on the adaptability of the plants growth to changing environmental conditions. In addition, the contaminant mobility, microbial activity, availability of the nutrients also limits the contaminant uptake in plants. The addition of organic matter to the soil was found to enhance the remediation of contaminated areas while increasing the chances of growth and survival of the plants (Reddy and Amaya-Santos 2017; Amaya-Santos and Reddy 2017; Reddy et al. 2017a, b). The geochemistry within the roots of the plants and the soil can immobilize, uptake or degrade the contaminants, but the concentration levels and the speciation of the contaminants significantly impact the contaminant reduction. The fundamental issues that need to be addressed for an effective phytoremediation are the selection of potential plant species, understanding the effect of different soil conditions, contaminant type, and its concentrations on growth and survival of plants. Furthermore, identifying suitable soil amendments for enhanced contaminant uptake and bioaugmentation of microbial degradation of contaminants is most desirable.

3.7 Bioremediation for Soil/Groundwater Remediation

Several remediation technologies have been developed over the past few years to remediate contaminated groundwater. In addition, these technologies are applicable under specific environmental conditions that favor the chemical reactions essential for contaminant removal. However, most of these technologies are energy intensive. Bioremediation, on the other hand, is often sought as a passive remediation technology since it relies on the in situ microorganisms to degrade the contaminants and reduce its concentration or transform it into nontoxic forms. But, the microbial activities are optimum only at a certain environmental condition and are otherwise slow and ineffective in the absence of favorable conditions.

One of the ways to enhance the microbial activity is by providing essential nutrients to the microbes to grow and proliferate. However, the availability of nutrients can take part in the surface reactions of the mineral and the contaminant adsorbed to it, thus changing the sorption capacity of the soil. A recent study by

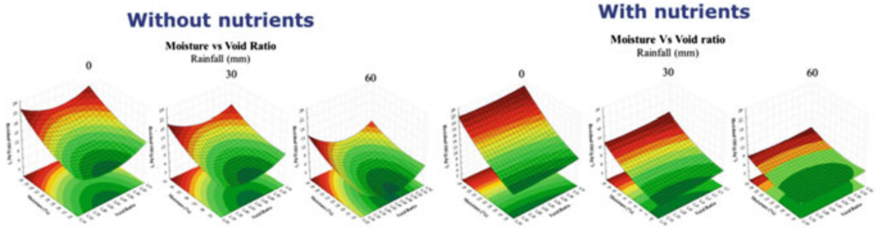

Fig. 6 Distribution of contaminant concentration with and without the addition of nutrients

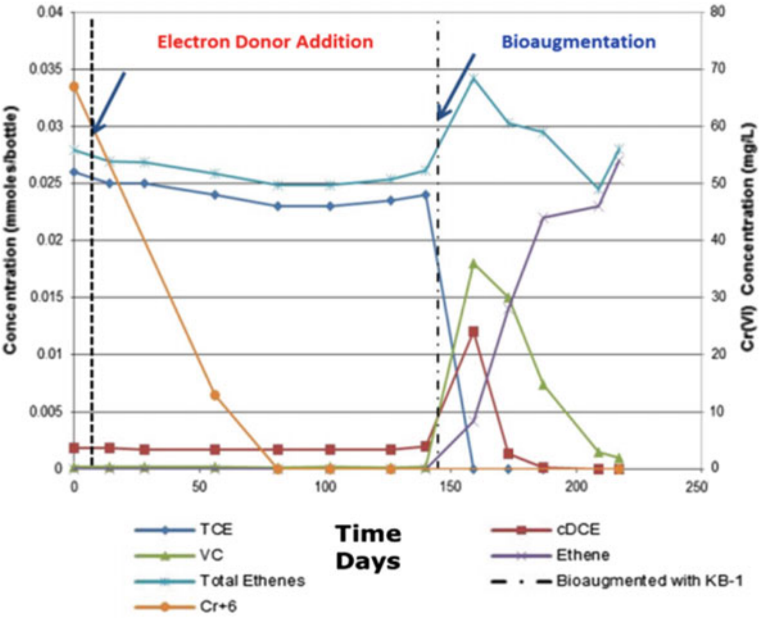

Fig. 7 Bioremediation of groundwater contaminated with Cr^{6+} and TCE: Biostimulation and bioaugmentation (*Source* Jeff Roberts, SiREM)

Cecchin et al. (2014) showed that the addition of nutrients can give a false impression of contaminant reduction at the place of nutrient injection, while the contaminant is actually mobilized by the geochemical surface reaction of the nutrients with the minerals thus transporting the contaminant to a different location and not actually reducing it (see Fig. 6). This is an appropriate example to say that the importance of understanding the geochemical process could aid in the reliable performance of the technology.

Bioremediation relies on the biogeochemical processes for contaminant reduction through a combined effect of microbial and chemical processes. The microbial activity involved in the bioremediation is sensitive to the contaminant types in the media (e.g., soil, groundwater). For example, in Fig. 7, it is observed that in the presence of appropriate electron donors Cr^{6+} could microbially be reduced to acceptable levels (by converting into Cr^{3+}). However, it does not degrade other contaminants such as TCE that may coexist. The addition of suitable microbes into the system at a later stage degraded the TCE concentrations. This emphasizes the fact that the right biogeochemical conditions such as the right nutrients and microbial inoculum are essential for addressing diverse contaminants in an environmental media.

4 Conclusions

Bio-based processes and technologies have the potential to be resilient and sustainable geosystems. However, an in-depth fundamental understanding of geochemical processes in complex subsurface conditions is necessary to make these processes/technologies effective and efficient. Many innovative bio-based processes/technologies are being envisioned and investigated through comprehensive laboratory studies, but field-scale investigations are needed to assess scale-up issues and variable field conditions.

References

Al-Hamdan AZ, Reddy KR (2008) Electrokinetic remediation modeling incorporating geochemical effects. J Geotech Geoenvironmental Eng 134(1):91–105

Al Qabany A, Soga K, Santamarina C (2011) Factors affecting efficiency of microbially induced calcite precipitation. J Geotechn Geoenvironmental Eng 138(8):992–1001

Amaya-Santos, Reddy, KR (2017) Phytoremediation of heavy metals and PAHs in alkaline slag fill at wet meadow site. J Hazard Toxic Radioact Waste 21(4)

Basu D, Misra A, Puppala AJ, Chittoori CS (2013) Sustainability in geotechnical engineering. In: Proceedings 18th international conference on soil mechanics and geotechnical engineering, Paris, pp 3171–3178

Blauw M, Lambert JWM, Latil MN (2009) Biosealing: a method for in situ sealing of leakages. In: Proceedings of the international symposium on ground improvement technologies and case histories, ISGI (Vol. 9, pp. 125–130)

Cameselle C, Chirakkara RA, Reddy KR (2013) Electrokinetic-enhanced phytoremediation of soils: status and Opportunities. Chemosphere 93(4):626–636

Cecchin I, Reginatto C, Colla LM, Thomé A (2014) Bioestimulação Aumenta a Propagação De Contaminantes Oleosos Em Solos. Ciência & Engenharia 23(1):93–101

Cecchin I, Reginatto C, Thome A, Colla LM, Reddy KR (2016) Influence of physicochemical factors on biodiesel retention in basaltic residual soil. J Environ Eng ASCE, 142(4):1–8, 04015093

Cheng L, Cord-Ruwisch R, Shahin MA (2013) Cementation of sand soil by microbially induced calcite precipitation at various degrees of saturation. Can Geotechn J 50(1):81–90

Chirakkara RA, Cameselle C, Reddy KR (2016) Assessing the applicability of phytoremediation of soils with mixed organic and heavy metal contaminants. Rev Environ Sci Bio/Technol 15 (2):299–326

Eseller-Bayat E, Yegian MK, Alshawabkeh A, Gokyer S (2012) Liquefaction response of partially saturated sands. I: Experimental results. J Geotech Geoenviron Eng 139(6):863–871

Gawande NA, Reinhart DR, Yeh GT (2010) Modeling microbiological and chemical processes in municipal solid waste bioreactor, part I: Development of a three-phase numerical model BIOKEMOD-3P. Waste Manage 30(2):202–210

Haarstrick A, Hempel DC, Ostermann L, Ahrens H, Dinkler D (2001) Modelling of the biodegradation of organic matter in municipal landfills. Waste Manage Res 19(4):320–331

Kavazanjian E Jr, O'Donnell ST (2015) Mitigation of earthquake-induced liquefaction via microbial denitrification: a two-phase process. In IFCEE 2015 (pp 2286–2295)

Liao H, Zhao K, Lambert JW, Veenbergen V (2007) Experimental study on biosealing technology for seepage prevention. Age, 1000:3

McDougall J (2007) A hydro-bio-mechanical model for settlement and other behaviour in landfilled waste. Comput Geotechn 34(4):229–246

O'Donnell ST, Rittmann BE, Kavazanjian E Jr (2017a) MIDP: liquefaction mitigation via microbial denitrification as a two-stage process. I: Desaturation. J Geotech Geoenviron Eng 143(12):04017094

O'Donnell ST, Kavazanjian E Jr, Rittmann BE (2017b) MIDP: liquefaction mitigation via microbial denitrification as a two-stage process. II: MICP. J Geotech Geoenviron Eng 143 (12):04017095

Reddy KR (2010) Technical challenges to in-situ remediation of polluted sites. Geotechn Geol Eng J 28(3):211–221

Reddy KR, Chirakkara RA (2013) Green and sustainable remedial strategy for contaminated site: case study. Geotechn Geol Eng J 31(6):1653–1661

Reddy KR, Amaya-Santos G (2017) Effects of variable site conditions on phytoremediation of mixed contaminants: field-scale investigation at Big Marsh site. J Environ Eng 143 (9):04017057

Reddy KR, Amaya-Santos G, Yargicoglu E, Cooper DE, Negri MC (2017a) Phytoremediation of PAHs and heavy metals at slag disposal site: three-year field investigation. Int J Geotechn Eng, 1–16

Reddy KR, Amaya-Santos G, Copper D (2017b) Field-scale phytoremediation of mixed contaminants in upland area at Big Marsh site, Chicago, USA. Indian Geotechn J, 1–16

Sharma HD, Reddy KR (2004) Geoenvironmental engineering: site remediation, waste containment, emerging waste management technologies. Wiley, Hoboken, New Jersey

Stocks-Fischer S, Galinat JK, Bang SS (1999) Microbiological precipitation of $CaCO_3$. Soil Biol Biochem 31(11):1563–1571

Van Paassen LA (2011) Bio-mediated ground improvement: from laboratory experiment to pilot applications. In: Geo-Frontiers 2011: advances in geotechnical engineering, pp 4099–4108

Van Beek VM, Den Hamer D, Lambert JWM, Latil MN, Van Der Zon WH (2007) Biosealing, a natural sealing mechanism that locates and repairs leaks. In: Proceedings of the 1th international conference on self healing materials, Noordwijk aan Zee, The Netherlands, pp 18–20

Yang YL, Du YJ, Reddy KR, Fan RD (2016) Hydraulic conductivity of phosphate-amended soil-bentonite backfills. In: Geo-Chicago 2016, pp 537–547

Yargicoglu E, Sadasivam BY, Reddy KR, Spokas K (2015) Physical and chemical characterization of waste wood derived biochars. Waste Manag 36(2):256–268

Yargicoglu EN, Reddy KR (2017a) Microbial abundance and activity in biochar-amended landfill cover soils: evidence from large-scale column and field experiments. J Environ Eng 143 (9):04017058

Yargicoglu EN, Reddy KR (2017b) Effects of biochar and wood pellets amendments added to landfill cover soil on microbial methane oxidation: a laboratory column study. J Environ Manag 193:19–31

Yargicoglu EN, Reddy KR (2018) Biochar-amended soil cover for microbial methane oxidation: effect of biochar amendment ratio and cover profile. J Geotech Geoenviron Eng 144 (3):04017123

Young A (1989) Mathematical modelling of landfill degradation. J Chem Technol Biotech 46 (3):189–208

Development on the Technology for Offshore Waste Final Disposal in S. Korea

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Abstract The purpose of this research is to develop technology for offshore waste final disposal. The research results include many core element parts such as establishment of master plan on infrastructure development for offshore waste disposal landfill; the establishment of legal system and code and standard or guidelines related to the offshore waste final disposal; the development of construction technologies of modular revetment structure and performance-enhancing technology for containment system; supervisory control and data acquisition (SCADA) system for offshore final disposal facility and soil/water quality improvement techniques in offshore disposal facility. Some other contributions are expected to collaborate includes: legal and institutional infrastructure construction to create the marine space projects based on the offshore final disposal facility. Additionally, in this paper, the securement of related element technology for environmental-friendly offshore waste

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disposal facility was discussed. At the same time, new marine industry and related jobs through the development of business model were created.

Keywords Offshore waste · Landfill · Soil/water quality · Waste disposal · Eco-friendly construction

1 Introduction

As waste generation is significantly increased all over the world, waste reduction and disposal become one of the global issues. The generation of waste in Korea has been increased twice for 15 years since 1998. In Korea, 139 million tons of wastes are generated in a year except for hazardous waste. It includes municipal waste by 18 million tons, construction waste 67 million tons and industrial waste 54 million tons. About 9.3% of total generated waste (13 million tons) has been landfilling every year in Korea. Currently, the disposal of marine debris such as used fishing gears and nets, floating debris from inland and deposited wastes are also an important issue in Korea. For instance, 68 thousand tons marine debris was collected in Korea in 2012. The actual generation of marine debris is estimated over 176 thousand tons a year. Most of collected marine debris has been landfilling due to high treatment cost which resulted from its leachate.

There is a need to final waste disposal method such as landfill that last as long as human lives. However, it should be considered that the capacity of existing landfill sites is limited in Korea. In more than 5 provinces among 16 provinces of Korea, estimated the available period of the existing landfill sites is less than 10 years. But, it is very difficult to find new final disposal sites on land due to the shortage of land space. One of the possible solutions is to develop offshore final disposal facilities that can provide some benefits including new land creation in the ocean space and creation of added value by developing of the landfilled site.

Research project on offshore waste landfill has been performed in Korea since 2016. Our ongoing research project consists of three main parts. The first part is the establishment of legal system and technical guidelines including technical guidelines of containment facility for offshore waste landfill and guideline for environmental impact assessment on the construction of the offshore waste landfill. The second part is the establishment of the master plan for developing the offshore waste landfill. It includes: (1) site assessment and selection of possible sites for offshore waste landfill, (2) development of the business model on the operation and future land uses of the offshore landfill, and (3) establishment of a general plan for offshore waste landfill development. The third part is the development of core technology on construction and management which includes: (1) development of barrier and liner systems such as modular revetment structure, (2) enhancement of SPSP cutoff walls with a fail-safe concept and swelled particle liner system.

In addition, the supervisory control and data acquisition (SCADA) system for offshore landfill and improvement method for contaminated water and stabilization of landfilled ground are also studied. Ongoing research on offshore waste landfill is expected that can cover cost-saving and eco-friendly construction and management of offshore waste landfill.

2 Core Technology and Experimental Results

2.1 Site Selection of Offshore Waste Final Disposal Facilities

2.1.1 The Capacity Estimation of Offshore Waste Final Disposal Facilities

Figure 1 shows the waste generation and the status of waste disposal. The capacity estimation of offshore waste final disposal facilities is increased steadily with the quantity of generated wastes during the past 16 years (2000–2015) with an average of 331,597.4 ton/day. This amount of waste consists of household wastes with 12.7% (51,247 ton/day) and industrial wastes with 87.3% (353,564 ton/day). In addition, the ratio of the average amount of waste is primarily from construction wastes 49.0%, followed by 38.3% from general industrial wastes and 12.7% from household wastes in 2015. In total, 85.2% of waste in Korea is recycled by landfill rate (8.7%) and incineration rate (5.9%) in 2015.

The amount of wastes generation is predicted from regression analysis, and the required capacity of offshore waste final disposal facilities is estimated. Figure 2 shows the estimation of future waste generation and landfill amount by major cities and provinces. The results show that there is an upward trend except for four regions (Incheon, Ulsan, Jeonnam, and Gyeonbuk), and the landfill amount is predicted to increase in Seoul and Gyeonggi and decrease in the other regions. The capacity of the offshore waste final disposal facilities is calculated by adding the estimations of the waste incineration ash and inorganic waste. As shown in Fig. 3, the capacity requirements for six regions are calculated by regional offshore waste final disposal facilities. It is predicted that the capacity requirements will be 1.5 million m^3 at the capital area and 0.5 million m^3 at the other areas.

Fig. 1 The waste generation and the status of waste disposal