Scientific and Engineering Considerations for Cost-Effective In Situ Bioremediation of Large, Deep Plumes

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Background/Objectives. In situ bioremediation of a large, deep plume presents a unique challenge because it is cost prohibitive to perform active treatment over the entire plume (especially when an alternation of indigenous redox conditions is needed). Plume interception is considered a more cost-effective approach for managing this type of plume. Traditional reactive barriers are also considered not economical in dealing with deep plumes, and thus a hydraulic in situ biological barrier or a pump-and-treat (P&T) system is often a remedial component for the large, deep plume management. To enhance the cost effectiveness of in situ bioremediation in comparison with the P&T approach, it is conceivable that in situ bioremediation systems that can handle higher contaminant mass flux and flow rate will likely be more economical. Such bioremediation systems can be considered as high-rate bioreactors; therefore, scientific and engineering principles known to help smooth operation of high-rate reactors can provide innovative perspectives for bioremediation of large, deep plumes. In this presentation, we provide an in-depth discussion on factors that often limit the performance of a high-rate bioreactor and solutions to address these limiting factors.

Approach/Activities. Inadequate growth substrate concentrations, chemical toxicity, bioclogging, and microbial community evolution are the most common factors that affect the performance and operations of a high-rate bioreactor. The model in situ bioremediation systems assessed in our presentation include those utilizing metabolic biological transformation reactions to treat chlorinated ethenes, as well as those using aerobic cometabolic biodegradation to treat emerging contaminants, such as 1,4-dioxane, 1,2,3-trichloropropane and ethylene dibromide. We use case studies (both laboratory and field scale studies) published in the literature or industrial guidance reports to illustrate the complicated interplay of these factors on the stability of treatment performance. For example, chemical toxicity has been well recognized to be a potential factor to plague treatment performance; meanwhile, some field demonstration studies have shown that chemical toxicity can also be used to reduce bioclogging potential and promote smooth system operations. We also review recent applied research ideas related to bioremediation that may lead to treatment enhancement for large, deep plumes.

Results/Lessons Learn. Our case study evaluation provides an historical overview of how innovation has been made to enhance the performance of high-rate bioreactors, which may serve as a platform for future innovation. We found that the ongoing innovation efforts can be classified into two groups; the first group focuses on manipulating extrinsic properties of the bioremediation system, such as (1) more efficient substrate distribution methods (e.g., angled well), (2) substrate delivery patterns (e.g., alternate substrate pulsing), (3) substrate blends, and (4) use of chemical inhibitors to create a more evenly distributed bioactive zone. Innovation success made by the first group can directly benefit bioremediation of large, deep plumes through biostimulation. The second group focuses on overcoming intrinsic limitations of microbial reaction processes for recalcitrant contaminant degradation, such as searching for appropriate microbial strains that target specific contaminants (1,1,1-trichloroehane and 1,1-dichlorehene) and can still thrive along with the indigenous microbial community. Innovation success made by the second group will directly benefit bioremediation of large, deep plumes through bioaugmentation.