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Biofiltration of Volatile Pollutants: Engineering Mechanisms for Improved Design, Long-term Operation, Prediction and Implementation

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Research Objective

Biofiltration systems can be used for treatment of volatile organic compounds (VOCs); however, the systems are poorly understood and are currently operated as "black boxes". Common operational problems associated with biofilters include fouling, deactivation, and overgrowth, all of which make them ineffective for continuous, long-term use. The objective of this investigation is to develop generic methods for long-term stable operation, in particular by using selective limitation of supplemental nutrients while maintaining high activity. As part of this effort, we will provide deeper fundamental understanding of the important biological and transport mechanisms in biodestruction of sparingly soluble VOCs and extend this approach and mathematical models to additional systems of high priority EM relevance - direct degradation and cometabolic degradation of priority pollutants such as BTEX and chlorinated organics.

Research Progress and Implications

This report summarizes work after 2 years of a 3-year project. Major results are enumerated and discussed below.

1. Control of biofilm overgrowth, while sustaining high degradation rates, in operating trickle-bed bioreactors was accomplished by limiting selected nutrients. Optimal results were achieved by limiting either ammonium, sulfate, or calcium in the liquid recycle stream. Each of these allowed for decoupling of growth and degradation such that long-term operation was possible. Other nutrients examined, including chlorine, magnesium, phosphate, and nitrate, were not effective and resulted in either continued growth or minimal degradation rates.
2. A comprehensive two-dimensional predictive model was developed to elucidate mass transfer and kinetic limitations in these systems. This model can be extended to a variety of columnar biofiltration systems by changing appropriate parameters. This user-friendly model/program can be installed and run independently on any IBM-compatible personal computer using Microsoft Windows 95/98.
3. Fundamental measurements of Henry's law coefficients for a variety of sparingly soluble alkanes in biomass were made; results indicated that these compounds have substantially higher solubilities in aqueous biomass than in pure water. Since predictive calculations for bioprocesses are strongly affected by the magnitude of the Henry's law parameters, new correlations/measurements are needed to compensate for this effect.
4. Isolation of the VOC-degrading microorganism present in the trickle bed consortium was accomplished. Identification is pending.
5. Non-cometabolic degradation of a model chlorinated organic (1-chloropentane) was demonstrated in an operating trickle-bed system. This work is unusual because most dechlorination processes require the presence of an additional substrate before degradation of the target contaminant can be removed.
6. Three biofiltration units were assembled, inoculated with the VOC-degrading microbial consortium selected for use in this project, and have been operating continuously using selective

nutrient limitation for 1.5 years. The units are approximately one meter long with 2-inch internal diameters and constructed of glass, teflon, and stainless steel. Each unit is temperature-controlled and can be operated under a variety of continuous or recycling modes. This work represents a substantial breakthrough in filter operation by eliminating overgrowth of biomass in the column. Non-growth associated degradation kinetics have been measured and do not incur a substantial decrease in removal capacity as compared with growth-associated removal. Prolonged starvation via elimination of supplemental nutrient(s) will eventually result in decreased capacity but requires at least six months before changes are noticeable.

7. Measurements of mass transfer and kinetics were made for trickle-bed columns and indicated that kinetic limitations dominated all three systems under normal operating conditions (room temperature, moderate flow rates).
8. Quantification of biomass regeneration after prolonged starvation has been accomplished. Biofiltration units operated under nutrient-limited conditions began losing removal capacity after approximately six months. Upon reintroduction of supplemental nitrogen, in the form of ammonium, rates rose rapidly as the biomass underwent regeneration. This procedure was found to be complete in less than 14 days, after which the columns operated at 100% of their previous removal efficiency. This is the first example of quantification/qualification of biomass regeneration after prolonged starvation in a trickle-bed system.
9. Removal competence for C_2- to C_6-alkanes has been demonstrated using the microbial consortium. In addition, the consortium was able to non-cometabolically degrade 1-chloropentane. The kinetic pathway or pathways are currently unknown.

Planned Activities

Work during the following year will focus on:

1. Measurement of Henry's law coefficients measurements for sparingly soluble gases in biomass and development of correlations for the observed enhanced solubility effect
2. Extension of the mathematical model to other biofiltration systems
3. Publication of the model/Windows 95 program code on the World Wide Web
4. Measurement of fundamental kinetics and mass transfer parameters for trickle bed bioreactors for removal of BTEX and chloro-organic contaminant treatment
5. 16s-rRNA gene sequencing of the microbial isolate responsible for alkane consumption; subsequent development will allow for examination of consortial population dynamics within column reactors

Other Access To Information

A number of peer-reviewed publications have been submitted and/or accepted based on some of the results from this work. Several presentations at national scientific conferences have been given or are currently scheduled to be delivered during this calendar year. A complete list of submitted papers and presentations may be found below. Plans are underway for making these web accessible at **http://www.ornl.gov/divisions/ctd/Chem_Dev/Biochemical/biochem.htm**

Francisco, A.F., J.W. Barton, K.T. Klasson, and B.H. Davison, "Nutrient Limitation Effects on a Microbial Consortium in Trickle-Bed Bioreactors," submitted for publication.

Barton, J.W., B.H. Davison, K.T. Klasson and C.C. Gable III, "Estimation of Mass Transfer and Kinetics in Operating Trickle-bed Bioreactors for Removal of VOCs," accepted for publication in Environmental Progress.

Klasson, K.T., B.H. Davison, J.W. Barton and J.E. Jacobs, "Removal of Chlorinated and Non-chlorinated Alkanes in a Trickle-bed Reactor," accepted for publication in the proceeding of Air & Waste Management Association's 91st Annual Meeting & Exhibition.

Barton, J.W., X.S. Zhang, K.T. Klasson and B.H. Davison. Predictive Mathematical Modeling of Trickling Bed Biofilters For Elucidating Mass Transfer and Kinetic Effects," accepted for publication in the proceeding of Air & Waste Management Association's 91st Annual Meeting & Exhibition.

Barton, J.W., S.M. Hartz, K.T. Klasson and B.H. Davison, "Microbial Removal of Alkanes From Dilute Gaseous Waste Streams: Mathematical Modeling of Advanced Bioreactor Systems," accepted for publication in Journal of Chemical Technology and Biotechnology.

Barton, J.W., K.T. Klasson and B.H. Davison, “Extended Operation and Control of Biomass Overgrowth in Biofilters Designed for VOC Removal,” Proceedings of the 90th Annual Meeting & Exhibition of Air and Waste Management Association, Toronto, Ontario, Canada, (1997).

Barton, J.W., K.T. Klasson, L.J. Koran Jr. and B.H. Davison, “Microbial Removal of Alkanes From Dilute Gaseous Waste Streams: Kinetics and Mass Transfer Considerations,” *Biotechnology Progress*, 13, 814-821 (1997).