Biostabilization of Multicomponent Dense Non-Aqueous Phase Liquids (DNAPLs)

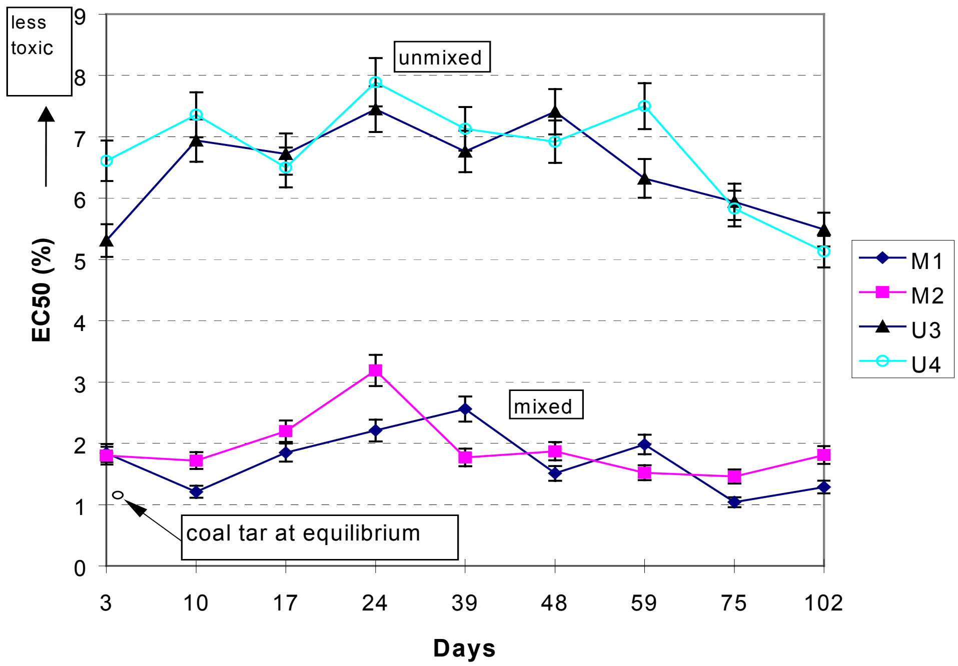
Anu Ramaswami
Department of Civil Engineering, University of Colorado, Denver
Tissa Illangasekare
Environmental Science and Engineering Division, Colorado School of Mines
Angela Bielefeldt
Dept. of Civil, Environmental & Architectural Engineering, University of Colorado, Boulder

The objective of this project is to understand key factors that control the bioavailability and biostabilization of high molecular weight organic contaminants (PAHs and PCBs) sequestered within multi-component DNAPLs entrapped in heterogeneous soil systems. The main hypothesis of this project is that slow dissolution of contaminants released from DNAPL pools entrapped in the subsurface, when combined with low-level microbial activity in the vicinity of the DNAPL source region, can result in stabilization of contamination with diminished plume formation and associated risk reduction.

The project is focussed on the following three tasks: 1) Develop rapid screening techniques to define the end-point of DNAPL biostabilization based upon four criteria: microbial biomass, aqueous phase contaminant concentrations, aggregate toxicity of the aqueous phase, and nature of the DNAPL residue; 2) Quantitatively evaluate key physicochemical and biological phenomena pertaining to DNAPL dissolution, mass transfer, bioavailability and biodegradation rates that control DNAPL stabilization in bench-scale and pilot-scale systems; and, 3) Develop engineering protocols for scale-up of integrated mass transfer-bioavailability-biostabilization models from small scale to large scale systems.

Batch Biostabilization Screening Tests: Rapid screening, batch biostabilization tests were developed and evaluated for two DNAPLs - coal tar and a PCB (polychlorinated biphenyl) mixture (Aroclor 1242). The coal tar was obtained from a field site in Maryland. Aroclor 1242 standard (from Accustandard) was used in the PCB studies. The biostabilization potential was evaluated by assessing microbial biomass, aqueous phase contaminant concentrations, aggregate toxicity of the aqueous phase, and nature of the DNAPL residue upon biotreatment if well-mixed and unmixed systems - the latter being representative of the quiescent subsurface. The results obtained from the two DNAPLs yielded results that consistently indicated favorable potential for biostabilization of coal tar (Ramaswami et al., 2001), while inconsistent results were obtained for biostabilization of Aroclor (Bielefeldt et al., 2001). Biotreatment of coal tar DNAPL in quiescent systems was found to result in a stable DNAPL residue and reduced overall toxicity of the aqueous phase (Figure 1). Based on the screening test results, DNAPL coal tar was chosen for further study to examine biochemical and physical processes that would control coal tar biostabilization in the subsurface.

Biochemical Studies: Four polyaromatic hydrocoarbons (PAHs) were chosen as representative compounds in coal tar. Biodegradation kinetics of individual PAH compounds was measured and compared with that of the same compounds in the coal tar mixture to assess any inhibitory or synergestic effect of the PAH mixture on coal tar biotreatment. PAH mixture biokinetics was found to be fairly well-represented by the biokinetic parameters obtained for individual PAH compounds, as shown in Figure 2. As shown in Figure 2, the microbial degradation parameters determined for pure naphthalene in water were found to represent the degradation of aqueous-phase naphthalene released from coal tar, wherein the aqueous phase contained several other PAHs released from DNAPL coal tar. Preliminary results such as these suggest no significant effects created by the mixture, i.e., the biokinetic parameters determined for individual representative PAH compounds describe the degradation kinetics of the mixture quite adequately, although some evidence for competitive substrate inhibition was observed for methyl-naphthalene. Ongoing work is modeling microbial growth arising from degradation of a mixture of PAHs released from coal tar.



<u>The impact of biogrowth on transport parameters</u> was assessed in column systems. Protocols were developed for the design of column systems in which microbes were introduced into the porous medium at simulated groundwater velocities. Microbes at a concentration of $3x10^6$ per mL were introduced into the column and the effluent was monitored to determine the attachment and transport of microbes in porous media. Aquifer properties such as the changes in porosity and dispersivity were measured by means of tracer tests. Bacterial attachment and transport (in the absence of substrate) were observed to cause an increase in longitudinal dispersivity and a decrease in the porosity of the saturated porous media, as shown in Figures 3&4, at a simulated groundwater flow rate of 100 m/yr. However, trends in dispersivity were not consistent at lower flow rates.

<u>Multicomponent DNAPL dissolution-degradation modeling</u> A numerical finite element code (NPDTBio: NAPL Pool Dissolution and Transport with Biodegradation) has been developed to model 2-dimensional multi-component DNAPL pool dissolution and biodegradation, incorporating changes in dispersivity due to processes such as microbial growth. The model is currently being tested with a two-component DNAPL composed of naphthalene and hexachlorobutadiene. Modifications have also been made to ModIME, an integrated modeling environment that couples the flow simulator, MODFLOW with the contaminant transport simulator, MT3D multi-component coal tar. This model is being tested with coal tar dissolution observations in a bench-scale, 2-dimensional cell.

<u>References</u>

1. Ramaswami, A.; Johansen, P.; Isleyen, M.; Bielefeldt, A.; Illangasekare, T. *"Potential for Biostabilization of Multicomponent DNAPLs: 1. Coal Tar*". **ASCE J. of Environmental Engineering** (Accepted).
2. Bielefeldt, A.; Riffel, A.; Ramaswami, A.; Illangasekare, T. *"Potential for Biostabilization of Multicomponent DNAPLs: 2. Aroclors*". **ASCE J. of Environmental Engineering** (revised and in final review).

<u>Acknowledgements</u>: This project has been supported by a grant from the USEPA R 825961-01-0.

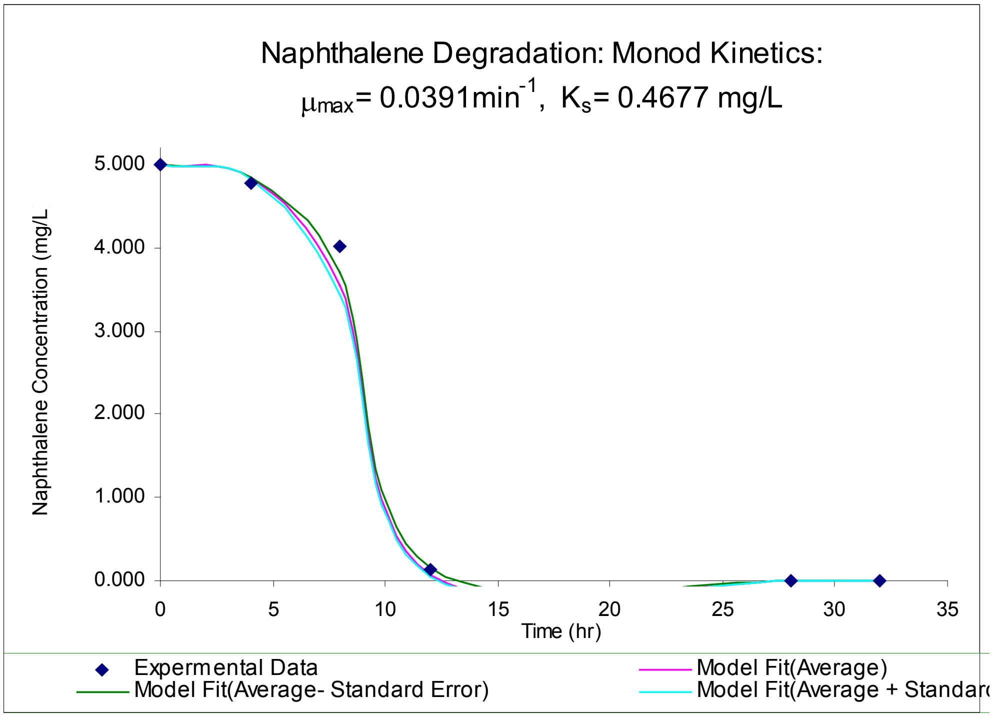


Figure2: Monod model parameters determined from single substrate experiments conducted with naphthalene were found to represent the degradation of aqueous-phase naphthalene present within a mixture of PAHs released from DNAPL coal tar.