FACTORS AFFECTING TRANSPORT OF BACTERIAL CELLS IN POROUS MEDIA

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INTRODUCTION

During the first 2 years of funding by the Subsurface Science Program of DOE, our group focused on identification of factors associated with the biology, chemistry, and hydrology of the subsurface environment that control bacterial transport through that habitat. We determined that control is a complex interaction of biological factors such as cell size and hydrophobicity, geochemical factors such as ionic strength of the ground water, and hydrological factors including the presence of preferred flow paths in the porous medium.

Our progress during the past several months has resulted in a number of findings which have been published in the refereed literature or presented at national meetings. Some of our findings are summarized in the following paragraphs.

Breakthrough curves of bacteria passing through sand columns containing a constructed, preferred flow path consisting of a vein of more transmissive (larger grain-size) sand have two peaks instead of the single peak noted in columns packed with sand of a single grain-size. Conservative dissolved (Cl^-) and particulate (colloidal Si) tracers displayed similar behavior. The second peak is not due to transport through the column in the finer-textured matrix because the mass recovery of cells from that flow domain was greater than that when the columns were completely packed with the fine-grained sand. Furthermore, when the communication between the flow domains was eliminated by a physical barrier, the large second peak was replaced by a smaller peak that represented a mass of cells roughly equivalent to that expected on the basis of the homogeneously packed columns. Simple advection-dispersion models containing a term that allows transfer of mass from one domain to the other provided reasonable fits to the data obtained for the tracers but not for the bacteria. A possible mechanism for the movement of cells between the domains involves lateral dispersion. Exercising an advection-dispersion model that included a radial dispersion term worked well for the conservative tracers but could not

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explain the second peak given estimates of the parameter values based on the homogeneously packed columns. Non-conservative interactions of the bacteria with the porous media must be accounted for in multi-domain models of bacterial transport.

In order to quantitatively assess factors influencing the fate and transport of particles in heterogeneous media, colloidal silica migration through columns containing a structured, heterogeneity was investigated. The structured heterogeneity which consisted of a tubule of coarse-grained quartz sand was embedded in a matrix of fine-grained quartz sand. The relative importance of advection, dispersion, deposition (removal of particles from suspension), entrainment (dislodgement of deposited particles), and mass transfer between the two mobile water regions was evaluated by comparing experimental data to calculations of a two-dimensional model. Independent estimates of model parameters were obtained by fitting solutions of an advection-dispersion equation, modified for kinetic deposition and entrainment, to breakthrough data produced from silica transport through either the fine or coarse media. In the experiments with the structured heterogeneity, advective-dispersive movement of silica was important in the fine-grained matrix as well as the coarse-grained preferred flow path. This transport could be characterized by small interaction between the two mobile-water regions and slow rates of colloidal deposition and entrainment. This particular study provides us with a basis for comparison of biological colloids with conservative and non-conservative **particulate** tracers.

In addition to the published work mentioned above, we are making good progress on defining the quantitative effect of bacterial cell-surface hydrophobicity and size on bacterial transport. We have characterized those cultures contained in our ground water microbiology culture collection (U.Va. Laboratory of Microbial Ecology) as to cell surface hydrophobicity by contact angle measures and by the BATH assay (bacterial adhesion to hydrocarbons). It is clear that there is only a loose relationship between these two commonly-used methods of expressing hydrophobicity (See Fig. 1).

Fig. 1. Relationship between measurements of contact angle and bacterial attachment to hydrocarbon (hexadecane) for the cultures in the U.Va. Laboratory of Microbial Ecology ground water microbiology culture collection. It is of interest to note that organisms originally derived from the sediment fraction (designated by S) of the subsurface as opposed to the water (and therefore presumed to be associated with the mineral-grain surfaces), the hydrophobicity was generally lower by both measures than that of the water-associated organisms (designated by W).

We have also begun to examine the effect of coatings of iron and organic matter on the attachment of bacteria to mineral grains. Sand coated with iron displays a complete removal of cells from suspension until the cell concentration reaches nearly 10^9 cells mL^{-1} , even though the solid surface to solution ratio is quite low (certainly far lower than would be encountered in an aquifer). Current experiments involve mixing of small amounts of

iron-coated sand (< 1% total sand weight) with uncoated sand to determine the effect of chemical heterogeneity in removing microbes from suspensions.

Experiments with organic matter are not as far along, but we have determined that for many organisms, the presence of humic acid in the ground water promotes aggregation of cells into clumps of various sizes (Fig. 2). Enhancement of the clumping phenomenon would slow the transport of cells through porous media by simple filtration processes, even in the absence of specific surface-surface interactions between the bacterial cells and the mineral grains.

Fig. 2. Shifts in the abundance of clumps of cells in the absence or presence of humic acid. The zero-line represents the relative number of clumps in artificial ground water without added humic acid, and the bars represent the degree of change in number of clumps when humic acid is added. (Note that single cells, i.e. no clumps, are denoted as clumps with one cell).

Publications and Presentations

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