Vibration-Accelerated Transport of Microbes in Subsurface Media

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The low transport rates of microorganisms through porous subsurface media pose severe limitations on the impact and applicability of biological processes for in-situ remediation of subsurface contaminants. We are investigating the use of vibrational energies as a tool for accelerating the transport of microorganisms and nutrients in subsurface media. This basic research focuses on evaluating the applicability of vibration-induced transport through detailed hypothesis testing in laboratory experiments to be complemented by field-scale verification. We hypothesize that vibrational energies will increase microbial transport as a result of changes in subsurface porosity, increased dispersion and increased desorption.

Our results indicate that vibrational energies do indeed increase dispersion and transport in sediments. Comparisons between vibrated and non-vibrated control columns revealed stark differences in the flow, distribution and dispersion of tracers and microspheres. Current results suggest frequencies between 40-200 Hz with power levels of several Kilowatts per cubic meter may be best suited for microbial transport. Modeling by colleague C. Santamarina of Georgia Tech revealed that vibrations of these frequencies and powers should transmit more than 10 meters in radius within shallow sandy sediments. Our column experiments revealed that vibrations of 40-200 hertz typically increased aqueous flow in sediments by 60-100%. In addition to the increased flow, we observed faster breakthrough of iodide conservative tracers, although the fraction of the tracer recovered at the height of the peak (C/Co) was ~30% of that observed in non-vibrated controls.

These results, when combined with the dramatically increased tailing observed in vibrated columns, are indicative of increased dispersion with vibration. Although the flow dramatically increases with the onset of vibration, there is a drop in the velocity of water flow over time. In experiments using Abbott's Pit intact columns, the water velocity decreased ~5% per hour of vibration, and after long periods of vibration water flow through the columns dropped below levels in non-vibrated controls as a result of plugging within the column. These observations are consistent with the ~10% reduction column volume after vibration, resulting from the repacking of grains. As expected, upon cessation of excessive (>10 hr) vibration, water flow is always much less than in non-vibrated controls.

Transport of fluorescent microspheres as determined by flow cytometry is orders of magnitude greater than in non-vibrated columns (typically below detection limits after 0.5 m). Although the fraction of transported microspheres remains low, microsphere breakthrough appeared faster than the conservative iodide tracer. The faster breakthroughs are followed by long tails indicative of dispersion followed by secondary peaks corresponding to the iodide breakthrough. Analyzing slices of columns by confocal microscopy or UV light reveals greater transport and lateral dispersion of all sizes and colors of fluorescent microspheres in the vibrated columns. Current experiments are expanding to microbial transport, dissecting mechanisms of increased transport facilitated by vibration as well as field-testing procedures (e.g., multilevel samplers, sampling protocols and drive-point well installations) for a field-scale verification of vibration-facilitated microbial transport.