Nature's helpers: Using microorganisms to remove TCE from water

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Bruce Rittmann's Biodesign Institute research team has utilized a system, called the microbial biofilm reactor, that uses a naturally occurring group of microorganisms to remove TCE from water. Here, ASU assistant professor Rosa Krajmalnik-Brown and graduate research assistant Michal Ziv-El assemble a membrane biofilm reactor to test against TCE. Credit: Barb Backes, Biodesign Institute at Arizona State University

In 2002, Bruce Rittmann, PhD, director of the Biodesign Institute’s Center for Environmental Biotechnology, received a patent for an innovative way to use nature to lend society a hand. He invented a treatment system, called the membrane biofilm reactor (MBfR), which uses naturally occurring microorganisms to remove contaminants from water.

Now Rittmann and his research team, which includes Rosa Krajmalnik-Brown and Jinwook Chung, recently published a paper in the journal for a new application that removes a problematic contaminant that has made local headlines.

The chlorinated solvent trichloroethene (TCE) has been found to be an increasingly problematic contaminant in groundwater. The detection of TCE recently forced the shut down of the water supply for the Greater Phoenix area municipalities of Paradise Valley and Scottsdale.

TCE has been widely used as a cleaning agent and solvent for many military, commercial, and industrial applications. Its widespread use, along with its improper handling, storage, and disposal, has resulted in frequent detection of TCE in the groundwater. TCE has the potential to cause liver damage, malfunctions in the central nervous system and it is considered a likely human carcinogen.

"As with other elements, the chlorine cycle is becoming a key concern to many environmental pollution scientists," said Krajmalnik-Brown, a researcher in the Biodesign Institute's Center for Environmental Biotechnology and assistant professor in the Ira A. Fulton School of Engineering's Department of Civil and Environmental Engineering.

Transforming the chlorinated solvent to a harmless product is the best way to eliminate the harmful effects of TCE. In the case of TCE, Mother Nature is the best helper. Scientists have discovered specialized microorganisms that can replace the chlorine in the chlorinated molecules with hydrogen, a process called reductive dechlorination. While other methods are possible, they are often more costly than reductive dechlorination on a large scale, and many do not transform TCE into a harmless end product.

In the paper, the Rittmann team utilized the MBfR and a naturally occurring group of microorganisms able to remove TCE from water. Surprisingly, these microorganisms, called dehalogenerators, have an affinity for chlorinated organics and can be found all throughout nature, even in clean water supplies, the soil, and groundwater.

“These bacteria respire TCE, that is, they can use TCE like we use oxygen to breathe,” said Krajmalnik-Brown. “They take in the TCE and they start removing the chlorines, step by step. In the ideal case, the dehalogenators remove all the chlorines, converting TCE to ethene, which is harmless.”

With this knowledge in hand, the challenge for the research team was to adapt their existing MfBR system, which can remove other water contaminants, to see if it could now handle TCE. A version of the reactor that addresses perchlorate, a byproduct of rocket fuel, is already in the commercialization pipeline.

“A key challenge with using these bacteria is that, if they don’t dechlorinate all the way, the TCE can be converted to vinyl chloride, which is a known human carcinogen,” said Krajmalnik-Brown. “In other words, if you don’t have complete dechlorination, you can end up having something worse than what you started with. So, it is critical to have the right mix of microorganisms for complete dechlorination.”

Their approach was simple in execution. They took an existing MBfR that was handling perchlorate removal and then introduced TCE into the system.

Rittmann’s MBfR works by delivering hydrogen gas to the bacteria through tiny hollow tubes submerged in water. In the right environment, the tubes become coated with a biofilm containing microorganisms. The system provides the microorganisms with hydrogen gas, which must be present for the microorganisms to change the chemical composition of a contaminant and render it harmless.

Their results indicated that the MBfR could be an incredibly versatile system, quickly adapting to now handle TCE. “This was really surprising, because there wasn’t any TCE at our pilot plant experiments prior to switching,” said Krajmalnik-Brown. “So there must have been really small amounts of the critical microorganisms in the culture. When shifted to TCE, they thrived and handled the contaminants.”

By assessing the MBfR community, they found the special dehalogenating bacteria that can take the hydrogen supplied by the MBfR and reduce TCE all the way to harmless ethene. Using the latest molecular techniques, they could not only identify the bacterial population to handle TCE, but also the genes within these populations that make enzymes that detoxify TCE to ethene.

The team found one particular organism, a new type of Dehalococcoides, the bacteria known to dechlorinate TCE all the way to ethene. They were also the first group to grow these dehalogenating bacteria in a biofilm in the lab.

“The bacteria are notoriously difficult to grow into a biofilm in the lab and study because they need hydrogen as an electron donor. An advantage of our system is that the MBfR can provide hydrogen through a membrane, which allows the microbial community to grow and naturally form a biofilm surrounding the membrane,” said Krajmalnik-Brown.

Next, the team hopes to drive the TCE system toward commercialization. Other oxidized contaminants that the system has been effective in reducing in the laboratory setting include perchlorate, selenate (found in coal wastes and agricultural drainage), chromate (found in industrial wastes), and other chlorinated solvents.

Source: Arizona State University