

The Trickle-Down Theory of Cleaner Air

Relentlessly single-minded, microbes have tirelessly gone about the business of life since the earth first cooled, pretty much unremarked by humanity unless it is to be labeled for their sometimes negative effects on health. But as living organisms that display many of the same life processes as the larger, more visible denizens of the planet, microbes are increasingly being recognized for their value.

Because they live, microbes must eat, and a growing body of knowledge indicates that they have a tremendous appetite for almost anything. It is this appetite that people have employed in a variety of beneficial ways: to help decompose farm and garden waste (the ubiquitous compost heap), as an invaluable link in the process of treating human sewage, and even, recently, in a combination of two strains—*Deinococcus radiodurans* and *Escherichia coli*—to create a “superbug” that can transform the toxic mercury compounds found in and around nuclear weapons waste sites into less-hazardous materials. “We’ve been using bacteria to treat a wide range of

waste for years,” says Linda Chrisey, manager of the basic research program in environmental and marine biology for the U.S. Navy’s Office of Naval Research. “By far the most common use has been to treat solid or liquid waste, but until fairly recently, there hasn’t been an effective way to use them to treat gases.”

That’s about to change. A new technology developed in a collaborative effort between Envirogen (a Lawrenceville, New Jersey–based company that specializes in remediation of hazardous waste), the Office of Naval Research, the Public Works Center of Naval Air Station–North Island, and the Navy’s Small Business Innovation Research Program adapts traditional biofiltration technology to the more difficult problem of airborne waste stream cleanup.

In its simplest terms, biofiltration involves nothing more than feeding a specialized bacterium a hazardous waste product and relying on the bacterium to metabolize the pollutant into something more benign. “What you want,” says Paul Togna, director of systems research and

development at Envirogen, “is to minimize the production and transfer of toxic waste, thus minimizing the chance of public [exposure] or environmental contamination. The great thing about biological processes is that they’re green technologies; generally, the worst you get is water and a little carbon dioxide, and you avoid many of the problems associated with traditional air treatments.”

Traditional cleanup efforts for gaseous waste involve technologies such as thermal incineration and adsorption to activated carbon. None of the traditional processes are ideal. Some produce hazardous by-products such as nitrogen and sulfur oxides or excesses of carbon dioxide, all of which must still be disposed of. Others merely change the state of the waste from gas to liquid or solid. And materials such as activated carbon are not only expensive but also have a limited number of sites to which the pollutants may bind, making them an incomplete solution.

The passage of the Clean Air Act Amendments of 1990 prompted an increased urgency to find new ways of

treating airstreams containing volatile organic compounds (VOCs) such as toluene and methyl ethyl ketone (MEK). VOCs affect the nitrogen photolytic cycle and help produce ground-level ozone and hazardous air pollutants, as well as odorous air emissions such as hydrogen sulfide and methyl mercaptan (typically produced by wastewater treatment plants and garbage piles). Bacteria have been considered as a possible solution, but as Chrisey points out, microbes can't readily degrade compounds without the moisture that may be lacking in airstreams.

The RenovAir Process

Most commercially available biofiltration technologies, Togna explains, are systems that rely on the growth of a biofilm layer on some organic support such as compost, peat, or wood chips. The problem with these technologies, he says, is that biomass growth is difficult to control on organic supports, and uncontrolled growth can clog the void spaces where air and water would flow, rendering the filter useless. Also, because the support is organic, it eventually breaks down and requires replacement, which is a difficult and time-consuming process.

The Envirogen system, called the RenovAir Biotrickling Filter, uses a proprietary synthetic packing material to support biofilm growth, and the support is continually bathed in a solution that provides the necessary moisture and nutrients to support a controlled rate of bacterial growth. The system relies on common, commercially available bacteria cultures. "It's a general inoculum, typically used in the wastewater treatment industry," Togna says. "We don't even analyze what's in the culture, but instead put our focus on optimizing the reactor design."

In the RenovAir system, untreated air enters the biofilter—which resembles the smokestack of a steamship—from the top and flows downward along with recirculated water through the packing material. How long the process takes depends on the con-

tinuant stream—the greater the percentage of less-soluble contaminants, the longer the stream must be exposed to the bacteria. The modular nature of the filter allows for the addition of different bacterial cultures in response to different pollutants. According to Togna, Envirogen's research indicates that biotrickling filters are superior in most situations to conventional biofilters for compounds of low solubility, possibly due to higher levels of the biomass and more surface area for contact with the contaminant stream within the biotrickling filter.

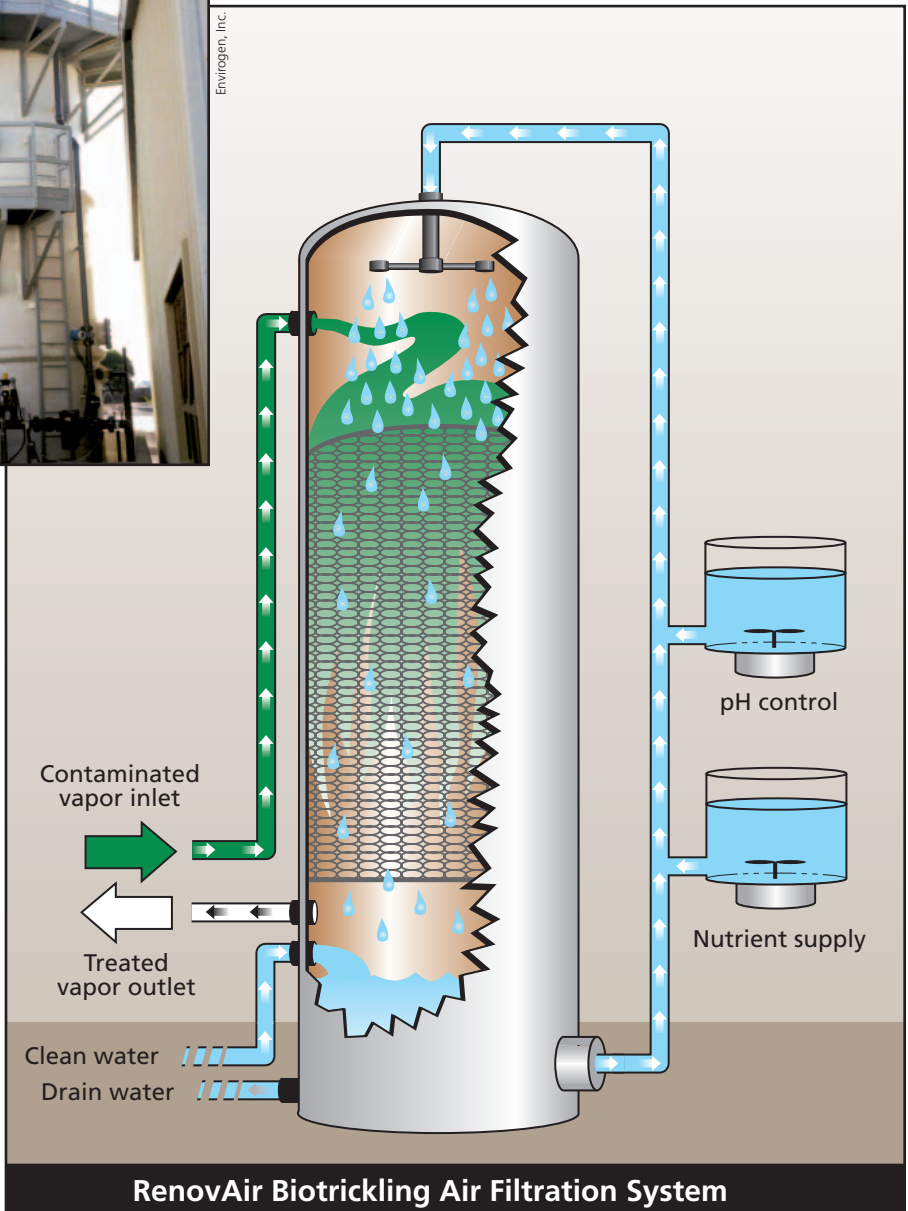
Bench-scale tests of the biotrickling filter project began in 1995 at Envirogen's lab.

The goal was to determine effective microbial cultures, target contaminants, and establish hydraulic

design parameters. The initial bench-scale testing targeted four VOCs—toluene, xylene, MEK, and *n*-butyl acetate. Test results showed a reduction in pollutants of 80–95%, depending upon the ratio of more- to less-soluble pollutants, with resulting by-products that included carbon dioxide, water, and mineral salts. According to Togna, 10–50% of the contaminant mass is used for additional biomass growth.

Field Testing

The next step was the design and implementation of a field-test demonstration project, which involved treatment of pollutants including MEK and *n*-butyl acetate in spray paint booth emissions at San Diego's Naval Air Station–North Island. Test results showed total target hazardous



From a stream to a trickle. In the RenovAir process, contaminated air trickles with recirculated water from top to bottom of a filter filled with biomass made of microbes that pull pollutants from the air, leaving mainly carbon dioxide, water, and mineral salts.

RenovAir Biotrickling Air Filtration System

air pollutant removal exceeding 88% in as little as 16 seconds of exposure (or 30–50% less than typical biofilter treatment times).

Following initial field tests, construction began of a full-scale biotrickling filter reactor to treat air emissions from the naval air station's industrial wastewater treatment plant. The facility provides treatment of the bilgewater taken off aircraft carriers of the Pacific Fleet as well as wastewater generated during aircraft maintenance. The full-scale filter is 10 feet in diameter and 30 feet high. Constructed of a fiberglass resin polymer, the vessel holds two beds of packing material through which the pollutant stream flows. Manual valve adjustment maintains an airflow rate of 3,140 cubic meters per hour. The gases being treated are contained within the vessel for approximately 30 seconds and then discharged through two vessels of activated carbon. The system was first tested without microbial cultures in December 1999 to test for any leakage or loss from the reaction vessel. Then two bacterial cultures were used to inoculate the system, and additional microbial food was added as fertilizer for an initial growth boost.

Primary contaminants targeted at the naval facility included phenol, methylene chloride, MEK, benzene, toluene, ethylbenzene, and xylene, with concentrations ranging from 7 to 521 parts per million. "From the tests I've seen during the point booth testing and laboratory experiments," says Chrisey, "we've seen 90% of the solvents being removed and close to 100% of the sulfides. On the average, I believe, we saw about a 94% reduction in total hazardous air pollutants." James Sanfedele, treatment plant director at the naval air station, says the filter shows promise, but a restart of the system became necessary when contaminants in

one of the treatment tanks were pulled into the biotrickling filter. Envirogen had to wash out the system and reinoculate with the microbial culture. This has pushed back the time when Sanfedele expects to start seeing firm data.

Prior to the biotrickling filter's installation, the naval facility had relied on the activated carbon method of air treatment. "We would pull air from the holding tanks through filters of activated carbon," Sanfedele explains. "That was a somewhat expensive process, as we used 300 pounds of carbon [that] had to be removed and replaced with regenerated carbon on a monthly basis. That stuff costs \$2 a pound, not including regeneration and/or disposal costs, so the biotrickling filter could save us a lot of time and money." However, he says, "Because we haven't had enough operating time to demonstrate the 90% removal we're required to show, we're still running the air through the activated carbon. When we can demonstrate that kind of efficiency [with the biotrickling filter], we'll be able to discontinue the carbon, which will result in some significant savings across the board."

Another problem the project encountered was one of water temperature. "At night, the [recirculated] water gets cold here," says Sanfedele. "That makes it hard to get the bioactivity started, but Envirogen has added a heating element. Once biogrowth is going, it generates its own heat, so we'll just use the heater in early stages."

Limitations and Expectations

There are situations the biotrickling filter cannot handle, such as very high concentrations of pollutants (1,000 parts per million or more) where it would be more economical to burn the contaminants, or chlorinated compounds, such as

trichloroethylene or carbon tetrachloride, that are very resistant to biodegradation. However, the biotrickling filter holds promise on several fronts.

"For one thing, it's more robust and will last longer than conventional biofiltration technology," says Togna. For example, he says, the treatment of many chlorinated compounds results in the formation of hydrochloric acid (HCl) as the compound is oxidized. As HCl forms, it drives the pH of the system down. Microorganisms function best in a pH range of 6–8, so as the pH drops, microbial activity slows and ultimately ceases. "The conventional biofilter has no way to control pH effectively over long periods of time," Togna says. "You can infuse the packing material with a buffer solution, but since this is a sealed system, once it's exhausted, there's no way to control pH. With ours, we can buffer the circulating water indefinitely, keeping the pH at the optimum level."

"There are contaminants where biodegradation doesn't work," says Chrisey, "or at least, where we haven't yet found microbes that will work efficiently. I think we'll need to see more work on development of a specialized consortium of microorganisms to deal with specific waste stream components. [For example], Envirogen has been contacted by automobile manufacturers about using the biotrickling filter technology in their auto spray paint booths, so the commercial potential is there." According to Togna, the RenovAir system would also be useful for treating chemicals used in printing facilities, pharmaceutical manufacture, pulp and wood products, and furniture finishing businesses, among others.

"Now is when we have to start value-engineering the system," Togna says. "We started with a small-scale test, then got a little bigger, but it's still a prototype system. What we have to do is to look at the overall cost for the system and try to minimize it where we can." He adds, "At this time, the biotrickling filter is still more expensive [initially] than conventional biofiltering technologies, but costs less to operate and maintain, and is more reliable and longer-lived. The next step will be to engineer the initial cost downward."

Lance Frazer

Suggested Reading

Chetty AS, Dyer JA, Mulholland KL. The role of economics in selecting VOC controls. Paper #92-114.13. In: Proceedings of the Air & Waste Management Association 85th Annual Meeting and Exhibition, Kansas City, Missouri, 21–26 June 1992. Pittsburgh, PA:Air & Waste Management Association, 1992.

Driscoll JN. CAAA: EPA's game plan for fighting air toxics. *Environ Prot* 9(10):20–23 (1998).

Webster TS, Togna AP, Yang Y, Guarini WJ. From bench- to pilot-scale experimentation: the treatment of volatile organic compound emissions from spray paint booth applications using a biological trickling filtration reactor. Paper #98-MP20A.04. In: Proceedings of the Air & Waste Management Association 91st Annual Meeting and Exhibition, San Diego, California, 14–18 June 1998. Pittsburgh, PA:Air & Waste Management Association, 1998.