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SITE Technology Capsule

ZenoGem™ Wastewater Treatment Process

Abstract

The ZenoGem technology is a wastewater treatment process designed to treat groundwater, landfill leachate, industrial effluent, and soil washing effluent contaminated with high concentrations of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) that cause elevated levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The technology uses an innovative combination of aerobic biological treatment to remove biodegradable organic compounds and ultrafiltration to separate residual suspended solids from the treated effluent.

The ZenoGem technology was evaluated under EPA's Superfund Innovative Technology Evaluation (SITE) Program on about 30,000 gallons of contaminated groundwater at the Nascolite Superfund Site in Millville, New Jersey. The demonstration focused on the system's ability to degrade methyl methacrylate (MMA) and reduce COD from contaminated groundwater. Results for the 3-month demonstration indicate that MMA removal efficiency averaged greater than 99.9 percent, and COD removal efficiency averaged 97.9 percent. The treated effluent was clear and odorless, and accepted for discharge by the local publicly owned treatment works (POW).

The ZenoGem technology exhibited smooth and unattended operation over the course of the demonstration. The system is trailer-mounted, easily transportable, and can be operational within 1 week, if the necessary utilities are available. The ZenoGem technology fulfills the nine criteria used for decision-making in the Superfund Feasibility Study (FS) process, as summarized in Table 1.

Introduction

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, committed to protecting human health and the environment from uncontrolled hazardous waste sites. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986. These amendments emphasize the long-term effectiveness and permanence of remedies at Superfund sites. SARA mandates implementing permanent solutions and using alternative treatment technologies or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and federal agencies, as well as private parties, are now exploring a growing number of innovative technologies for treating hazardous wastes. The sites on the National Priorities List total more than 1,700 and comprise a broad spectrum of physical, chemical, and

Table 1: Feasibility Study Evaluation Criteria for the ZenoGemTM Technology

CRITERION	**ZENOGEM™** TECHNOLOGY PERFORMANCE
1 Overall Protection of Human Health and the Environment	• Effectively degrades VOCs in groundwater into innocuous products, eliminating contaminant exposure • Minimizes the mobility of contaminants in groundwater • Minimizes exposure to workers and the community from VOC emissions
2 Compliance with Federal ARARs	· Operation of the system may require compliance with location-specific ARARs • Emission controls may be required to ensure compliance with air quality standards depending on chemical-, location-, and action-specific ARARs • Compliance with RCRA treatment, storage, and land disposal regulations for a hazardous waste
3 Long-Term Effectiveness and Permanence	• Effectively degrades VOCs in groundwater • Residuals consisting of spent carbon, sludge, and treated effluent require disposal
4 Reduction of Toxicity, Mobility, or Volume Through Treatment	The process is not a volume reduction technology, but completely degrades the contaminants and reduces toxicity • Reduces long-term contaminant mobility by minimizing or eliminating contaminants from the source
5 Short-Term Effectiveness	• Presents minimal short-term risks to workers and community from air releases during treatment
6 Implementability	• System components are contained inside an easily transportable trailer • About 1,000 square feet of space is needed for trailer setup; additional space may be needed for future expansion • Requires installing utilities, production wells, and influent feed lines to the system
7 Cost	Capital costs for purchasing the **ZenoGem™** equipment is estimated to range from $90,000 to $160,000, and annual operation and maintenance costs are estimated at $40,000 for a unit similar to the system demonstrated
8 Community Acceptance	• Public acceptance is likely due to (1) the lower risk presented to the community, and (2) permanent contaminant removal
9 State Acceptance	• State acceptance is likely due to well-documented and widely accepted processes used to remove contaminants from groundwater • State regulatory agencies may require permits for system operation, air emissions, and waste storage longer than 90 days.

ARAR - Applicable or relevant and appropriate requirements
RCRA - Resource Conservation and Recovery Act

environmental conditions requiring varying types of remediation. The U.S. Environmental Protection Agency (EPA) has focused on policy, technical, and informational issues related to exploring and applying new remediation technologies applicable to Superfund sites, One such initiative is EPA's SITE Program, which was established to accelerate development, demonstration, and use of innovative technologies for site cleanups. EPA SITE Technology Capsules summarize the latest information available on selected innovative treatment and site remediation technologies and related issues. These Technology Capsules are designed to help EPA remedial project managers, EPA on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to effectively evaluate a technology's applicability for cleaning up Superfund sites. Additional details regarding the technology demonstrations are presented in Innovative Technology Evaluation Reports.

This Technology Capsule provides information on the ZenoGem technology developed by Zenon Environmental Systems, Inc. The technology is a wastewater treatment process designed to treat groundwater, landfill leachate, industrial effluent, and soil washing effluent contaminated with VOCs and SVOCs. The ZenoGem technology was evaluated under the SITE Program from September 1994 through November 1994 at the Nascolite site in Millville, New Jersey. Information in this Technology Capsule emphasizes specific site characteristics and results of the SITE field demonstration at the Nascolite site.

Technology Description

The ZenoGem technology integrates aerobic biological treatment with membrane-based ultrafiltration. This innovative system uses ultrafiltration to separate residual suspended solids from biologically treated effluent. Zenon claims that the process reduces VOCs and SVOCs in wastewater to below regulatory limits, improves effluent quality, reduces sludge production, resists contaminant shock-loading, and reduces the size of the bioreactor by maintaining a long sludge retention time.

The major components of the ZenoGem system are an influent holding-equalization tank, a biological reactor (bioreactor), an ultrafiltration module, an air blower, a pH buffer tank, a nutrient solution tank, optional off-gas carbon filters, optional permeate carbon filters, and feed, process, and metering pumps (Figure 1). The system components are computer-controlled and equipped with alarm indicators to notify the operator of mechanical and operational problems. The entire system, except for the main air blower and optional activated carbon filters, is mounted inside an 8-foot by 48-foot ZenoSite trailer. The air blower is mounted below the trailer for noise control purposes. The ZenoSite trailer is also equipped with a laboratory that enables field personnel to conduct tests to evaluate system performance.

Following equalization, treatment begins by continuously pumping wastewater into a 1,000-gallon polyethylene stirred-tank bioreactor that contains an acclimated microbial culture maintained under aerobic conditions. The aerobic, suspended-growth environment is maintained by diffused aeration, which continuously mixes the bioreactor's contents, known as mixed liquor. The mixed liquor is retained in the bioreactor for sufficient time to allow the microorganisms to metabolize the biodegradable organic contaminants into innocuous end-products and intermediate by-products.

The mixed liquor is continuously pumped from the bioreactor into a pressure-driven ultrafiltration module. The ultrafiltration module consists of eight 1 -inch diameter tubes connected in series and contained in a 12-foot by 4-inch-diameter polyvinyl chloride housing (Figure 2). The tubes support the ultrafiltration membrane, which filters some of the dissolved contaminants and all suspended solids from the mixed liquor. The cut-off threshold size above which organic compounds are retained by the membrane is called the molecular weight cut-off. This cut-off ranges between 0.003 to 0.1 microns, and depends on the membrane type.

The continuous flow of mixed liquor primarily consisting of suspended solids are drawn toward the membrane's surface, forming a gel layer. Particles from the gel layer are detached by the cross-flow water movement, maintaining a gel layer equilibrium on the membrane's non-clogging surface. The detached particles and unfiltered fraction of the mixed liquor (called concentrate) are continuously recycled to the bioreactor to maintain a desired microorganism concentration and to further degrade higher molecular weight organic compounds. The filtered effluent (called permeate) flows through activated carbon filters to remove any nonbiodegradable and trace organic compounds before final treated effluent is discharged.

The final treated effluent may be injected into the aquifer, disposed of at a POTW, reused on site, or discharged directly to surface water under an appropriate National Pollutant Discharge Elimination System (NPDES) permit.

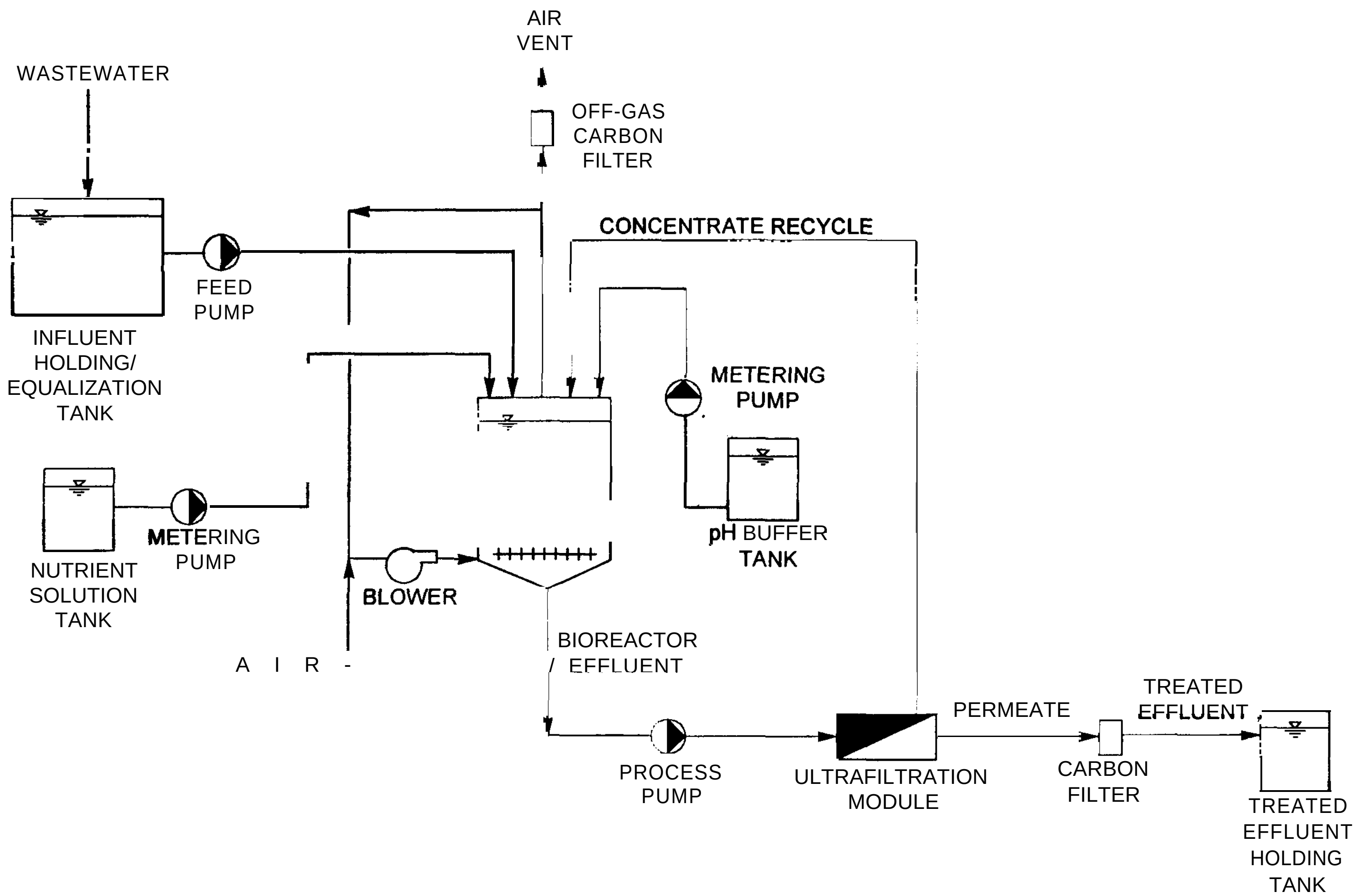

Figure 1: The ZenoGem ™ technology as demonstrated

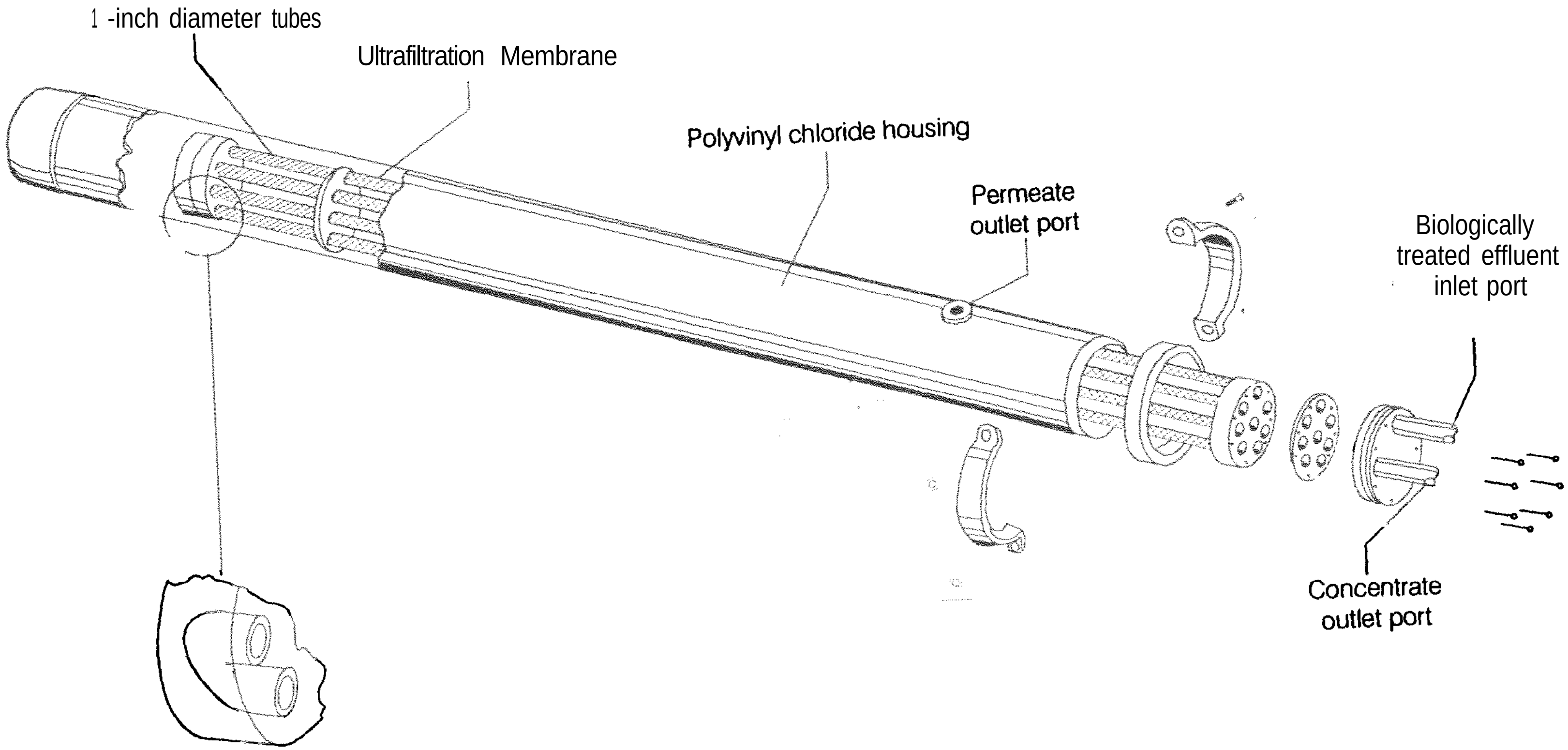

Figure 2: Cross-Section *of the* Ultrafiltration Module

Technology Applicability

In general, the ZenoGem technology is applicable for the treatment of elevated concentrations of VOCs and SVOCs that cause elevated levels of BOD and COD in contaminated groundwater. Zenon claims that the process can also be readily adapted to treat other contaminated wastewater, such as landfill leachate, industrial effluent, and soil washing effluent.

In addition to the potential different treatment applications, the ZenoGem technology provides advantages in terms of effluent quality and disposal costs. The ultrafiltration system removes suspended solids from the effluent, yielding a clear product. The ultrafiltration system also reduces the volume of waste sludge for disposal. This advantage may be important when the need to minimize residual waste is a critical disposal issue.

Technology Limitations

Elevated oil and grease concentrations, inorganic suspended solids, and heavy metals may reduce the ZenoGem treatment efficiency. Elevated oil and grease concentrations and oil containing biocides can inhibit or prevent microbial activity. Unemulsified oil and grease concentrations may also foul the ultrafiltration membrane surface, reducing the amount of permeate discharge from the module.

Inorganic suspended solids that are not biologically degraded will accumulate in the mixed liquor and increase the amount of sludge for disposal. Suspended solids can also limit the process pumps' efficiency to recirculate the concentrate and could foul the ultrafiltration membrane. In addition, heavy metal concentrations can be toxic to microorganisms, reducing biological growth enough to discontinue treatment.

Depending on wastewater characteristics, pretreatment can be incorporated into a treatment train to prevent these problems. Pretreatment options include sedimentation, flotation, chemical precipitation, and microfiltration. Zenon manufactures pretreatment systems for any necessary application.

Site Requirements

The ZenoSite trailer requires a 12-foot by 60-foot area to support a maximum operating weight of 45,000 pounds. The trailer also requires 14-feet of overhead clearance. About 1,000 square feet are necessary to operate and unload equipment. Once the trailer is set up, the system can be operational within 1 week, if all necessary utilities, production wells, feed lines, and supplies are available.

According to Zenon, the system can also be constructed in a 40-foot International Standard Organization (ISO) shipping container or mounted on a modular skid. The 40-foot IS0 container can be modified to provide shelter, where the skid-mounted unit needs to be housed inside a building.

Potable water must be available for personnel decontamination, performing laboratory analytical procedures, and for bioreactor cooling. For bioreactor cooling, the water supply must be capable of providing 60 pounds per square inch (psi) pressure and a flow rate of 30 gallons per minute (gpm). If potable water is unavailable, arrangements must be made to deliver, store, and pump water. In addition, about 200 gallons of potable water are required for equipment washing and decontamination. The electrical requirements of the ZenoSite trailer are a three-phase, 460-volt power supply that is located within 15 feet of the trailer. If an electrical source is unavailable on site, a trailer-mounted generator can supply electricity to the system.

Support facilities include an area for optional untreated and treated groundwater storage tanks, and a drum staging area for generated wastes. Additionally, a building or shed is useful to protect supplies. Other installation and monitoring requirements include security fencing and access roads for equipment transport.

Process Residuals

The primary residual generated by the ZenoGem technology is waste sludge, which consists of microorganisms and unfiltered wastewater from the bioreactor. Zenon can reduce the volume of waste sludge by continuously recirculating the contents through the ultrafiltration module. This procedure dewaters and concentrates the sludge, yielding a smaller volume for disposal. During the SITE demonstration, the ultrafiltration system reduced the volume of sludge in the bioreactor from 700 gallons to 400 gallons in about 4 hours. Waste sludge can be stored in 55-gallon drums for off-site transport and disposal. The waste sludge may be subject to RCRA or state regulations as a hazardous waste depending on influent metals concentrations.

Secondary waste streams generated by the ZenoGem technology include proprietary membrane cleaning solution, spent carbon filters, and decontamination water. During the SITE demonstration, Zenon generated about 100 gallons of membrane cleaning solution, which was treated in the bioreactor. Spent carbon used for VOC removal in the permeate and off-gas streams may be disposed of or regenerated. Decontamination water may be stored in 55-gallon drums for off-site disposal.

Table 2: MMA and COD Results from the ZenoGamT Demonstration*

Weeks	Number of Samples	Influent: MMA Concentration[a] (mg/L)	Influent: Average Flow Ratd (gpd)	Permeate: MMA Concentration’ (mg/L)	Permeate: Percent Reduction	Effluent: MMA Concentration[a] (mg/L)	Effluent: Percent Reduction
1-6	39	2,000	420	1 .00	**>99.9**	**NA**	NC
7-6	17	2,200	450	**<** 0.02	**>99.9**	**0.03**[b]	>99.9
Nov. 8 **1994**[c]	3	7,100	**480**[d]	< 0.02	>99.9	< 0.02	>99.9
9-10[e]	13	8,100	140	0.02	<99.9	0.02	>99.9
		COD Concentration’ (ms/L)	**Average Flow Rate[a] (gpd)**	**COD Concentration[a] (mg/L)**	**Percent Reduction**	**COD Concentration[a] (mg/L)**	**Percent Reduction**
1-6	38	***4,900***	***420***	***500***	***89.7***	***NA***	NC
7-8	15	5,500	450	900	83.6	72.0[f]	***98.7***
Nov. 8 **1994**[c]	3	18,200	**480**[d]	1,200	93.6	430	***97.6***
9-10[e]	13	19,900	140	1,100	95.0	365[f]	98.2

mg/L Milligrams per liter
NA Not analyzed
NC Not calculated

a Average values for weeks noted
b 11 samples collected
c Organic shock-loading
d Flow rate maintained for 4 hours
e Maintained volumetric loading
f 7 samples collected

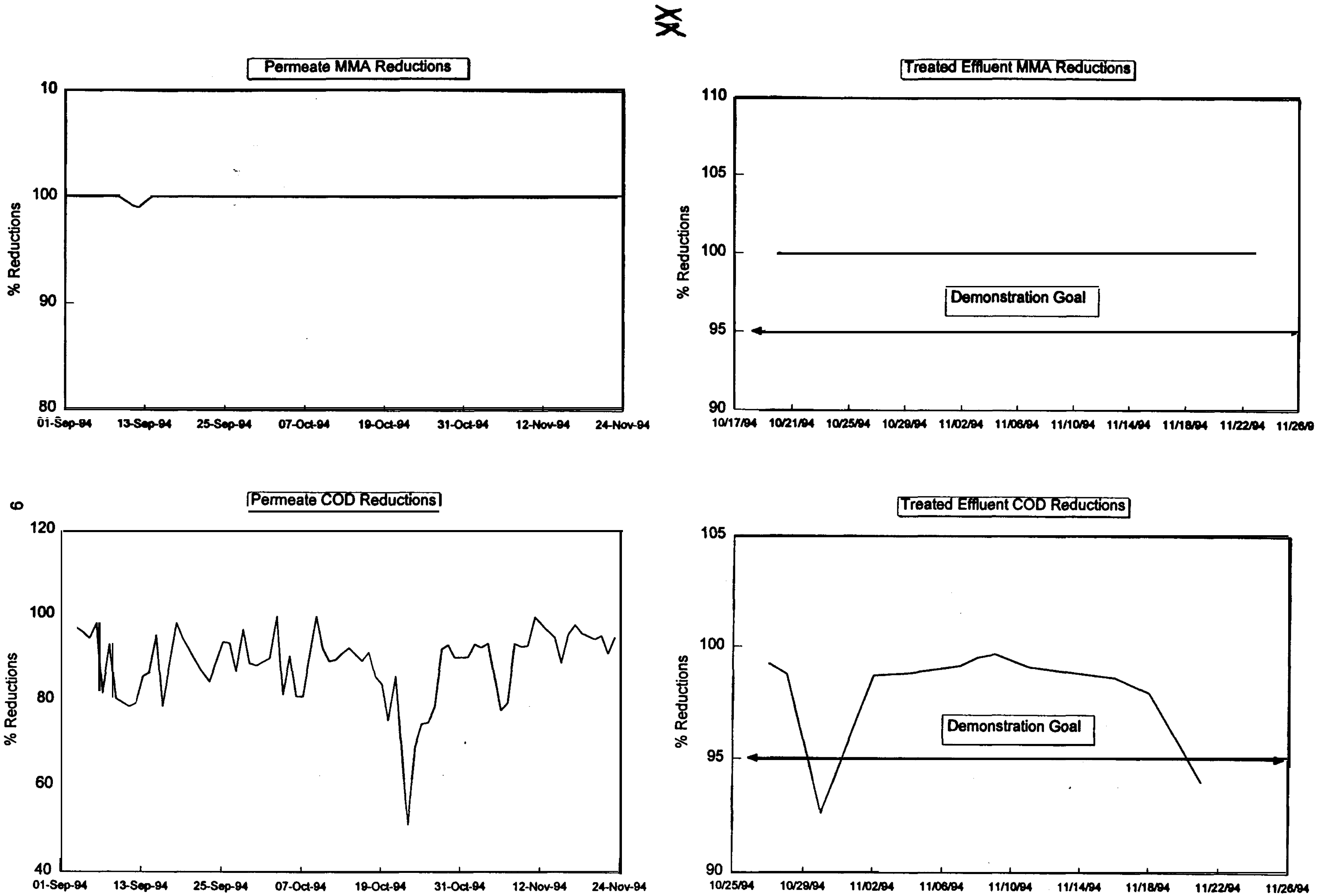

Figure 3: MMA and COD Percent Removal

Economic Analysis

A number of factors affect the estimated costs of treating groundwater with the ZenoGem treatment system. The factors affecting capital equipment costs and annual operation and maintenance costs are highly variable and depend on site-specific factors, including (1) system size, (2) influent characteristics, (3) process rate, and (4) target cleanup concentration. The cost of time-dependent factors such as labor, and consumables and supplies varies directly with treatment time.

One-time capital costs for a single pilot-scale unit were estimated to be $90,000 for the modular skid, $118,000 for the 40-foot IS0 container, and $160,000 for the ZenoSite trailer unit. Annual operation and maintenance costs for the first year were estimated to be $40,000. Based on the estimates for the 40-foot IS0 contained unit, the total operating cost for 1 year is estimated to be $158,000. Following treatment, the unit can be decontaminated, allowing the equipment to retain some residual value. These costs are based on the following:

The site is a Superfund site located in New Jersey.

Suitable site access roads are available.

Overhead utility supply lines, such as electricity and telephone lines, are available on site.

No pretreatment, such as oil separation, solids removal, or pH adjustment of the influent groundwater, is necessary.

The treatment system operates automatically without the constant attention of an operator.

Necessary consumables and supplies include treatment chemicals, activated carbon, personal protective equipment, and sampling equipment.

The total annual electrical energy consumption is estimated to be 80,000 kilowatt hours (kWh) of electricity at $0.09 per kWh.

Annual equipment costs, excluding labor, are estimated to be about 3 percent of the capital equipment costs.

One trained operator spends 3 hours per week performing routine equipment monitoring and sampling activities.

One treated and one untreated groundwater sample will be collected monthly from the system and analyzed for pH, VOC, SVOC, and COD; quality assurance samples will also be collected.

Contaminated groundwater will be treated to below maximum contaminant levels and injected into the ground.

A detailed breakdown of the costs for operating the ZenoGem system is presented in the Innovative Technology Evaluation Report (ITER). The ITER will also include a scenario for a full-scale system treating landfill leachate over a 10-year period.

Technology Status

Since the development of the ZenoGem technology in 1987, Zenon has performed pilot tests for government and private clients on several different types of wastewater, including oily wastewater, metal finishing wastes, cleaning solutions containing detergents, alcohol-based cleaning solutions, landfill leachate, aqueous paint-stripping wastes, and de-icing fluids. Information is available on two demonstrations conducted in Canada and the United States. At the Canadian Department of National Defense fire fighting school, the ZenoGem biological unit was demonstrated on wastewater containing burned and unburned fuel residue. The system successfully demonstrated the biodegradation of aqueous foam formulation compounds and simultaneous removal of oil and grease, petroleum hydrocarbons, and suspended solids. The system was also demonstrated at the Army Material Command Watervliet Arsenal, where the ultrafiltration module treated oily wastewater. Results indicated that the ultrafiltration module reduced waste disposal by 70 percent at a significant cost savings. Full-scale systems are in operation at design capacities of 150 gpm in North America and Europe.

Disclaimer

Data presented in this Technology Capsule were reviewed by the PRC SITE QA Manager. When the draft ITER and TER are submitted, the EPA National Risk Management Research Laboratory QA office will conduct a data review to verify compliance with project QA requirements.

Sources of Further Information

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