United States
Environmental Protection
Agency

EPA/540/SR-93/501
August 1993

SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Technology Demonstration Summary

Peroxidation Systems, Inc. perox-pure™ Chemical Oxidation Technology*

As part of the Superfund Innovative Technology Evaluation (SITE) program, the U.S. Environmental Protection Agency (EPA) demonstrated the Peroxidation Systems, Inc. (PSI), perox-pure™ chemical oxidation treatment system. The SITE demonstration was conducted at Lawrence Livermore National Laboratory (LLNL) Site 300 in Tracy, CA. Over a 3-wk period in September 1992, about 40,000 gal of groundwater contaminated with trichloroethene (TCE), tetrachloroethene (PCE), and other volatile organic compounds (VOC) was treated in the perox-pure™ system.

The SITE demonstration results showed that the perox-pure™ system removed TCE and PCE from contaminated groundwater at the LLNL site to concentrations below detection limits. The perox-pure™ system achieved TCE and PCE removal efficiencies greater than 99.7% and 97.1%, respectively. For other VOCs, the system achieved removal efficiencies of 81.8%, 98.3%, and 93.1% for 1,1,1-trichloroethane (TCA); 1,1-dichloroethane (DCA); and chloroform; respectively. The treatment system effluent met California drinking water action levels and federal drinking water maximum contaminant levels (MCL) for TCE, PCE, TCA, DCA, and chloroform at the 95% confidence level.

Potential sites for applying this technology include Superfund and other hazardous waste sites where groundwater or other liquid wastes are contaminated with organic compounds. Economic data indicate that groundwater remediation costs could range from about $7 to $11/1,000 gal depending on contaminated groundwater characteristics. Of these costs, perox-pure™ system direct treatment costs could range from about $3 to $5/1,000 gal.

This demonstration summary was developed by EPA's Risk Reduction Engineering Laboratory in Cincinnati, OH, to announce key findings of the SITE program demonstration that is fully documented in two separate reports (see ordering information at back).

Introduction

The SITE program was established in 1986 to accelerate the development, demonstration, and use of new, innovative technologies that offer permanent cleanup solutions for hazardous wastes. One component of the SITE program is the demonstration program, which develops reliable engineering, perfor-

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Printed on Recycled Paper

mance, and cost data for innovative treatment technologies. Data developed for the SITE demonstration program enable potential users to evaluate each technology's applicability for a specific waste site.

The SITE demonstration of the perox-pure™ technology was conducted at LLNL Site 300 in Tracy, CA, over a 3-wk period in September 1992. The technology demonstration had the following primary objectives:

- Determine the ability of the perox-pure™ system to remove VOCs from groundwater at the LLNL site under different operating conditions.
- Determine whether treated groundwater could meet applicable discharge requirements at the 95% confidence level.
- Gather information necessary to estimate treatment costs, including process chemical dosages and utility requirements.

The secondary objective of the technology demonstration was to obtain information on the presence and types of byproducts formed during treatment.

Technology Description

The perox-pure™ chemical oxidation treatment technology was developed by PSI to destroy dissolved organic contaminants in water. The technology uses ultraviolet (UV) radiation and hydrogen peroxide to oxidize organic compounds present in water at parts per million (ppm) levels or less. This treatment technology produces no air emissions and generates no sludge or spent media that require further processing, handling, or disposal. Ideally, end products include water, carbon dioxide, halides (for example, chloride), and in some cases, organic acids. The technology uses medium-pressure, mercury-vapor lamps to generate UV radiation. The principal oxidants in the system, hydroxyl radicals, are produced by direct photolysis of hydrogen peroxide at UV wavelengths.

The perox-pure™ chemical oxidation treatment system (Model SSB-30) used for the SITE technology demonstration was assembled from the following portable, skid-mounted components: an oxidation unit, a hydrogen peroxide feed module, an acid feed module, a base feed module, a UV lamp drive, and a control panel. The oxidation unit has six reactors in series, with one 5-kilowatt (kW) UV lamp in each reactor, and a total volume of 15 gal. The UV lamp is mounted inside a UV-transmissive quartz tube in the center of each reactor so that water flows around the quartz tube.

A schematic flow diagram of the perox-pure™ chemical oxidation system is shown in Figure 1. Contaminated water enters the oxidation unit through a section of pipe containing a temperature gauge, a flow meter, an influent sample port, and hydrogen peroxide and acid injection points. Contaminated water is dosed with hydrogen peroxide before the water enters the first reactor; however, a splitter can be used to add hydrogen peroxide before any of the six reactors within the oxidation unit. In some applications, acid is added to lower the influent pH and shift the carbonic acid-bicarbonate-carbonate equilibrium to carbonic acid. This equilibrium is important because carbonate and bicarbonate ions will scavenge hydroxyl radicals. After chemical injections, the contaminated water flows through a static mixer and enters the oxidation unit. Water then flows through the six UV reactors. Treated water exits the oxidation unit through a pipe equipped with a temperature gauge, effluent sample ports, and a base injection point. Base may be added to the treated water to adjust the pH to meet discharge requirements.

Circular wipers mounted on the quartz tubes housing the UV lamps are used periodically to remove any solids that may have accumulated on the tubes. Solids may accumulate as a result of metals oxidation (such as iron and manganese), water hardness, or solids precipitation. Accumulated solids could eventually coat the tubes, thus reducing treatment efficiency.

Site Preparation

About 10,000 ft^2 of relatively flat ground surface was used for the perox-pure™ chemical oxidation system, support equipment and facilities, and a parking area. A temporary enclosure covering about one-fourth of the demonstration area was erected to provide shelter for the perox-pure™ system during inclement weather. Some of the laboratory analyses were conducted onsite in a field trailer, which also served as an office for field personnel and provided shelter and storage for small equipment and supplies.

Support equipment for the perox-pure™ system demonstration included a cartridge filtration system to remove suspended solids from groundwater, storage tanks for untreated and treated groundwater, an acid feed module for untreated groundwater, a base feed module for treated groundwater, a spiking solution feed system, a static mixer, two 55-gal drums for collecting equipment washdown and decontamination rinsewater, a dumpster, a forklift, pumps, sampling equipment, health- and safety-related gear, and a van.

Technology Testing

During the 3-wk demonstration period, about 40,000 gal of groundwater contaminated with VOCs was treated. The principal groundwater contaminants were TCE and PCE, which were present at concentrations of about 1,000 and 100 micrograms per liter (µg/L), respectively. Influent groundwater was extracted from Wells W-7-O and W-875-08 at 6 gal/min (gpm) and 2 gpm, respectively. The groundwater was mixed inline using a static mixer and then pumped into a 7,500-gal bladder tank to minimize any variability in influent characteristics. The bladder tank also minimized the loss of VOCs to volatilization, and it provided a flow rate higher than the groundwater yield for several runs. Cartridge filters were used to remove suspended solids greater than 3µm from the groundwater before it entered the bladder tank. Treated groundwater was stored in two 20,000-gal steel tanks before being discharged.

During the demonstration, a total of 14 runs were performed to test the technology's ability to meet the objectives. Table 1 shows the operating conditions for each run, including the influent pH, the hydrogen peroxide dose in milligrams per liter (mg/L), and the flow rate in gpm. Operating conditions were varied during Runs 1 through 8 to determine the preferred operating conditions. The influent was spiked for Runs 9 through 14, and the results of Runs 4 and 9 were used to determine the effect of spiking. Runs 10 through 12 were reproducibility runs, and Runs 13 and 14 evaluated quartz tube cleaning.

The principal operating parameters for the perox-pure™ system, including influent pH, hydrogen peroxide dose, and flow rate, were varied during Runs 1 through 6 to observe treatment system performance under different conditions. PSI used quick turnaround analytical data from Runs 1 through 6 and its professional experience to determine the system's preferred operating conditions, — conditions under which the concentrations of effluent VOCs would be reduced below target levels during spiked groundwater runs.

Influent groundwater for Runs 9 through 14 was spiked with about 200 µg/L each of TCA, DCA, and chloroform. These compounds were chosen because they are difficult to oxidize and because they were not present in the groundwater at high concentrations.

Runs 10 through 12 involved reproducibility tests. These runs were designed to evaluate the reproducibility of treatment system performance at the operating conditions of Run 3, which were determined by PSI to be the preferred conditions from Runs 1 through 6.

During Runs 13 and 14, the effectiveness of quartz tube wipers was evaluated by performing two runs using scaled and clean quartz tubes.

During the demonstration, samples were collected at the following locations shown in Figure 1: Reactor 1 influent and Reactors 1, 2, 3, and 6 effluent, as needed. Samples were analyzed for the following parameters: VOCs, semivolatile organic compounds (SVOC), total organic halides (TOX), adsorb-

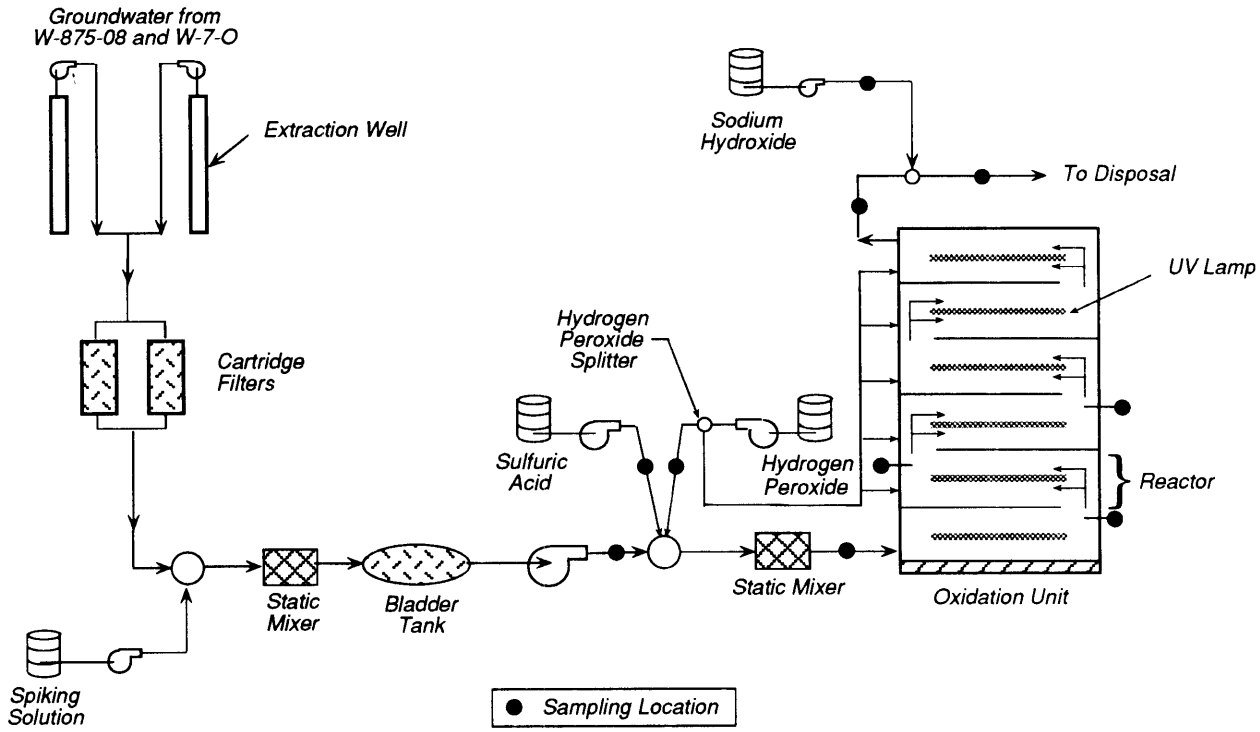

Figure 1. *perox-pure™ chemical oxidation treatment system sampling locations.*

able organic halides (AOX), total organic carbon (TOC), total carbon (TC), and purgeable organic carbon (POC). In addition, samples of Reactor 1 influent and Reactor 6 effluent were collected and analyzed for acute toxicity to freshwater organisms. The hydrogen peroxide, acid, and base solutions were also sampled and analyzed to verify concentrations.

Demonstration Results

SITE demonstration results are based on extensive laboratory analyses under rigorous quality control procedures and the observations of the SITE team during system operation.

VOC Removal Under Different Operating Conditions

Operating conditions were varied (see Table 1) to determine the ability of the perox-pure™ system to remove VOCs from groundwater at the LLNL site. Table 2 presents VOC concentrations in the influent to Reactor 1 and in the effluent from Reactors 1, 3, and 6 during Runs 1 through 9 under steady-state conditions. VOC removal efficiencies were based on VOC concentrations in the influent to Reactor 1 and effluent from the specified reactor.

VOC Removal as a Function of Influent pH

The influent pH for Runs 1, 2, and 3 was 8.0, 6.5, and 5.0, respectively, whereas the flow rate and hydrogen peroxide level were the same for all three runs. In all three runs, effluent TCE and PCE concentrations were well below the target level of 5 µg/L. Based on TCE and PCE results, the perox-pure™ system performed best in Run 1, when the influent pH was 8 (the unadjusted pH of groundwater). In Run 1, the Reactor 1 effluent had lower levels of TCE and PCE than in Runs 2 and 3, and it had the same levels of

Table 1. *Operating Conditions for perox-pure™ System*

Run Number	Influent pH	Hydrogen Peroxide at Influent to Reactor 1, mg/L	Hydrogen Peroxide at Influent to Reactors 2 to 6, mg/L	Flow Rate, gpm
Raw Groundwater Runs				
1	8.0	40	25	10
2	6.5	40	25	10
3	5.0	40	25	10
4	5.0	70	50	10
5	5.0	30	15	10
6	5.0	240	Hydrogen peroxide was added at influent to Reactor 1 only	10
7	5.0	240		40
8	5.0	60		40
Spiked Groundwater Runs				
9	5.0	70	50	10
10	5.0	40	25	10
11	5.0	40	25	10
12	5.0	40	25	10
13	5.0	40	25	10
14	5.0	40	25	10

TCE and PCE as the Reactor 6 effluent in Runs 2 and 3. The Reactor 6 effluent TCA concentration, however, was lowest in Run 3 at 1.4 µg/L. Because TCA is difficult to oxidize, PSI selected Run 3 as the preferred operating condition, with an influent pH of 5.0.

VOC Removal as a Function of Hydrogen Peroxide Level

Hydrogen peroxide levels at influent to Reactor 1 for Runs 3, 4, and 5 were 40 mg/L, 70 mg/L, and 30 mg/L, respectively. At Reactors 2 through 6, the hydrogen peroxide levels for Runs 3, 4, and 5 were 25 mg/L, 50 mg/L, and 15 mg/L, respectively. The influent pH and flow rate were the same for these three runs. Although the Reactor 6 effluent TCE and PCE concentrations were the same in all three runs, the data show that Reactor 1 effluent TCE and PCE concentrations were lowest in runs with the highest and lowest hydrogen peroxide level (Runs 4 and 5, respectively), and Reactor 1 effluent TCE and PCE concentrations were highest at the intermediate hydrogen peroxide level (Run 3). The Reactor 6 effluent TCA concentrations in Runs 3, 4, and 5 showed no correlation to hydrogen peroxide level. These data cannot be explained, and no definite trend can be identified based on TCE, PCE, and TCA data in Runs 3, 4, and 5.

Runs 7 and 8 had hydrogen peroxide levels at Reactor 1 of 240 mg/L and 60 mg/L, respectively, and flow rate and influent pH were the same for both runs. A comparison of TCE and PCE levels shows that both TCE and PCE concentrations in Reactor 1 effluent were higher in Run 7 than in Run 8. Effluent TCA levels at Reactors 1, 3, and 6 were about the same in both runs. Higher Reactor 1 effluent TCE level in Run 7 may be attributed to higher influent TCE level in that run. Reactor 1 effluent TCE levels correspond to 99.5% and 99.9% TCE removal in Runs 7 and 8. Similarly, Reactor 1 effluent PCE levels correspond to 92.9% and 99.2% PCE removal in Runs 7 and 8. These data seem to indicate that higher doses of hydrogen peroxide may have scavenged hydroxyl radicals or excess hydrogen peroxide reduced UV transmittance through water, which resulted in lower removal efficiencies for Run 7 than those for Run 8.

VOC Removal as a Function of the Method Used to Add Hydrogen Peroxide

Runs 4 and 6 were performed at the same flow rate and influent pH. In these runs, the same total amount of hydrogen peroxide was added to the contaminated groundwater. In Run 4, however, hydrogen peroxide was added at multiple points in the system using the splitter, whereas in Run 6, all hydrogen peroxide was added at the influent to the system. Based on a comparison of TCE and PCE levels in Runs 4 and 6, the effect of adding hydrogen peroxide at multiple points in the perox-pure™ system cannot be evaluated, because in both runs, effluent TCE and PCE levels were below the detection limit of 1.0 µg/L. However, TCA levels in Reactors 1, 3, and 6 were less in Run 4 than in Run 6. Based on TCA data, adding hydrogen peroxide at multiple points in the perox-pure™ system appears to enhance the system's performance.

VOC Removal as a Function of Flow Rate

The flow rates for Runs 6 and 7 were 10 gpm and 40 gpm, respectively, and hydrogen peroxide level and influent pH were the same for both runs. A comparison of TCE, PCE, and TCA levels in Runs 6 and 7 shows that the effluent concentrations of these three VOCs were higher in Run 7 than in Run 6. These observations are consistent with the operating conditions, because contaminated groundwater had a much longer UV expo-

Table 2. *VOC Concentrations for Runs 1 through 9*

		Influent, µg/L	Effluent, µg/L		
Run	Contaminant	Reactor 1	Reactor 1	Reactor 3	Reactor 6
	TCE	1300	0.5*	0.5*	0.5*
1	PCE	150	0.5*	0.5*	0.5*
	TCA	17†	11.5	9.6	6.7
	TCE	1300	9.6	0.5*	0.5*
2	PCE	100	3.4	0.5*	0.5*
	TCA	13†	8.9	5.9*	3.1
	TCE	1100	1.2	0.5*	0.5*
3	PCE	130	1.6	0.5*	0.5*
	TCA	9†	6.8	3.7	1.4
	TCE	980	0.5*	0.5*	0.5*
4	PCE	110	0.5*	0.5*	0.5*
	TCA	8†	4.4	2.5	1.8
	TCE	910	0.5*	0.5*	0.5*
5	PCE	100	0.5*	0.5*	0.5*
	TCA	7†	5.3	3.7	2.1
	TCE	990	0.5*	0.5*	0.5*
6	PCE	120	0.5*	0.5*	0.5*
	TCA	8†	7.0	3.7	3.0
	TCE	1100	5.3	0.5*	0.5*
7	PCE	85	6.0	0.5*	0.5*
	TCA	6†	5.7	3.9	3.9
	TCE	890	0.5*	0.5*	0.5*
8	PCE	71	0.6*	0.5*	0.5*
	TCA	6†	5.3	4.3	4.0
	TCE	690	3.2*	2.4*	2.4*
	PCE	63	3.2*	2.4*	2.4*
9	TCA	110	84	47	7.8*
	DCA	160	23	3.0*	2.9*
	Chloroform	150	89	37	14

* *More than one of the four replicate samples had analyte concentrations at nondetectable levels. For these replicate samples, one-half the detection limit was used as the estimated concentration. If more than one replicable sample had concentrations at nondetectable levels, 0.5, 0.4, 0.6, and 0.4 times the detection limit were used as estimated concentrations for the first, second, third, and fourth replicate samples, respectively.*

† *The reported concentration is from analysis of one sample by the gas chromatography/mass spectroscopy (GC/MS) method. All other reported concentrations are the mean concentrations of four replicate samples analyzed by the GC method.*

sure time in Run 6 than in Run 7. UV exposure times were 1.5 and 0.4 minutes in Runs 6 and 7, respectively.

VOC Removal as a Function of Influent Groundwater Spiking

A comparison of the perox-pure™ system's performance in treating spiked groundwater (Run 9) and unspiked groundwater (Run 4) shows that TCE and PCE levels in treated groundwater were higher in spiked groundwater than in unspiked groundwater. These data suggest that spiking compounds (TCA, DCA, and chloroform) affected the perox-pure™ system's performance in removing TCE and PCE, perhaps because they present an additional oxidant demand. TCE and PCE concentrations presented in Table 2, however, are estimated concentrations. The concentrations in Run 9 were estimated higher than in Run 4 for two reasons: (1) the detection limit for TCE and PCE in Run 9 was 5 µg/L and in Run 4 was 1 µg/L, and (2) TCE and PCE were present at nondetectable levels in both runs. Therefore, the estimated data are inconclusive with regard to the effect of spiking compounds on the removal of TCE and PCE.

VOC Removal as a Function of Quartz Tube Cleaning

Table 3 presents VOC concentrations in Runs 12, 13, and 14, which were conducted to evaluate quartz tube cleaning. In Run 12, quartz tubes from the previous demonstration runs were used. In Run 13, scaled quartz tubes were used. The tubes had been exposed to an environment that encouraged scaling, but they had not been maintained with cleaners or wipers. In Run 14, quartz tubes that had been maintained by cleaners or wipers were used.

A comparison of removal efficiencies for TCE after Reactors 1 and 2 shows that TCE removal efficiencies were about the same in all runs. PCE removal efficiencies were about 3% to 4% less in Run 13 than in Runs 12 or 14. In general, removal efficiencies for TCA, DCA, and chloroform were less in Run 13 than in Run 14; this indicates that periodic cleaning of quartz tubes by wipers is required to maintain the perox-pure™ system's performance. Without such cleaning, the removal efficiencies will likely decrease in an aqueous environment that would cause scaling of quartz tubes. For example, after Reactor 2, chloroform removal efficiency in Run 13 was 53.6%, compared with 61.3% removal efficiency in Run 14. Because the quartz tubes used in Run 12 had little coating, removal efficiencies in Run 12 were expected to be higher than in Run 13. The demonstration did not confirm this for all VOCs, however. For example, Run 12 TCA removal efficiencies were less than Run 13 TCA removal efficiencies; this inconsistency cannot be explained.

Reproducibility of Treatment System Performance

Based on the results from Runs 1 through 6, PSI selected Run 3 operating conditions as the preferred operating conditions for spiked groundwater. As a result, Runs 10 through 14 were performed at Run 3 conditions.

VOC removal efficiencies in reproducibility runs (Runs 10, 11, and 12) are plotted in Figure 2. Figure 2 shows that for TCE and PCE, which are relatively easy to oxidize, most of the removal occurred in Reactor 1, leaving only trace quantities of TCE and PCE to be removed in the rest of the perox-pure™ system. For TCA, DCA, and chloroform, however, which are difficult to oxidize, considerable removal occurred beyond Reactor 1. During the three reproducibility runs, average removal efficiencies for TCE, PCE, TCA, DCA, and chloroform after Reactor 1 were 99.5%, 95.9%, 17.4%, 67.0%, and 41.3%, respectively. After Reactor 6, average overall removal efficiencies for TCA, DCA, and chloroform increased to 81.8%, 98.3%, and 93.1%, respectively. In general, overall removal efficiencies of the perox-pure™ system were reproducible for all VOCs. For certain compounds, removal efficiencies after Reactor 1 were quite variable (for example, chloroform removal efficiencies ranged from 27.4% to 56.3%).

Compliance with Applicable Discharge Requirements

Figure 3 compares the 95% upper confidence limits (UCL) of effluent VOC concentrations with target levels in reproducibility runs. For this project, the target level for a given VOC was set at the most stringent limit in cases where the VOC has multiple regulatory limits. For all VOCs but chloroform, the most stringent limit is the California drinking water action level. For chloroform, the most stringent limit is the MCL specified in the Safe Drinking Water Act. Figure 3 shows that perox-pure™ system effluent met the target levels at the 95% confidence level in all three reproducibility runs; this indicates that the system performance was reproducible.

Byproducts Formed During Treatment

GC/MS analysis of influent and effluent samples for VOCs indicated that new target compounds or tentatively identified compounds (TIC) were not formed during the treatment. GC/MS analysis of influent and effluent samples for SVOCs showed that target SVOCs were not present at detectable levels. Several unknown TICs were, however, present in both the influent and effluent samples.

During Runs 10, 11, and 12, bioassay tests were performed to evaluate the acute toxicity of influent to and effluent from the perox-pure™ systems. Two freshwater test organisms, a water flea *(ceriodaphnia dubia)* and a fathead minnow *(pimephales promelas)*, were used in the bioassay tests. Toxicity was measured as the lethal concentration at which 50% of the organisms died (LC_{50}), and was expressed as the percent of effluent (or influent) in the test water. One influent and one effluent sample were tested in each run. One control sample was also tested to evaluate the toxicity associated with hydrogen peroxide residual present in the effluent. The control sample had about 10.5 mg/L of hydrogen peroxide (average effluent residual in Runs 10, 11, and 12), and had characteristics (alkalinity, hardness, and pH) similar to those of effluent in Runs 10, 11, and 12.

In general, the influent was not found to be acutely toxic to either test organism. The effluent was found to be acutely toxic to both test organisms. The influent LC_{50} values for both organisms indicated that in the undiluted influent sample more than 50% of the organisms survived. LC_{50} values for the water flea, however, were estimated to be 35%, 13%, and 26% of effluent in Runs 10, 11, and 12, respectively; and LC_{50} values for the fathead minnow were estimated to be 65% and 71% of effluent in Runs 10 and 11, respectively. In Run 12, more than 50% of the fathead minnows survived in the undiluted effluent. The LC_{50} value for the water flea was estimated to be 17.7% in the control sample, indicating that the sample contained hydrogen peroxide at a concentration that was acutely toxic to water fleas; however, more than 50% of the fathead minnows survived in the undiluted control sample indicating hydrogen peroxide was not acutely toxic to fathead minnows at the concentration of 10.5 mg/L. This observation however, is not entirely consistent with observations made by the Department of Environmental Protection, State of Connecticut (CDEP). The CDEP Water Toxics Section of Water Management Division reports LC_{50} value of 18.2 mg/L of hydrogen peroxide with 95% confidence limits of 10 mg/L and 25 mg/L.

Comparison of the LC_{50} value of the control sample with LC_{50} values of effluent samples for water fleas indicates the toxicity associated with the effluent samples is probably due to hydrogen peroxide residual in the effluent. No conclusion can, however, be drawn on the effluent toxicity to fathead minnows because the control sample toxicity results from the SITE demonstration data are not entirely consistent with the data collected by CDEP.

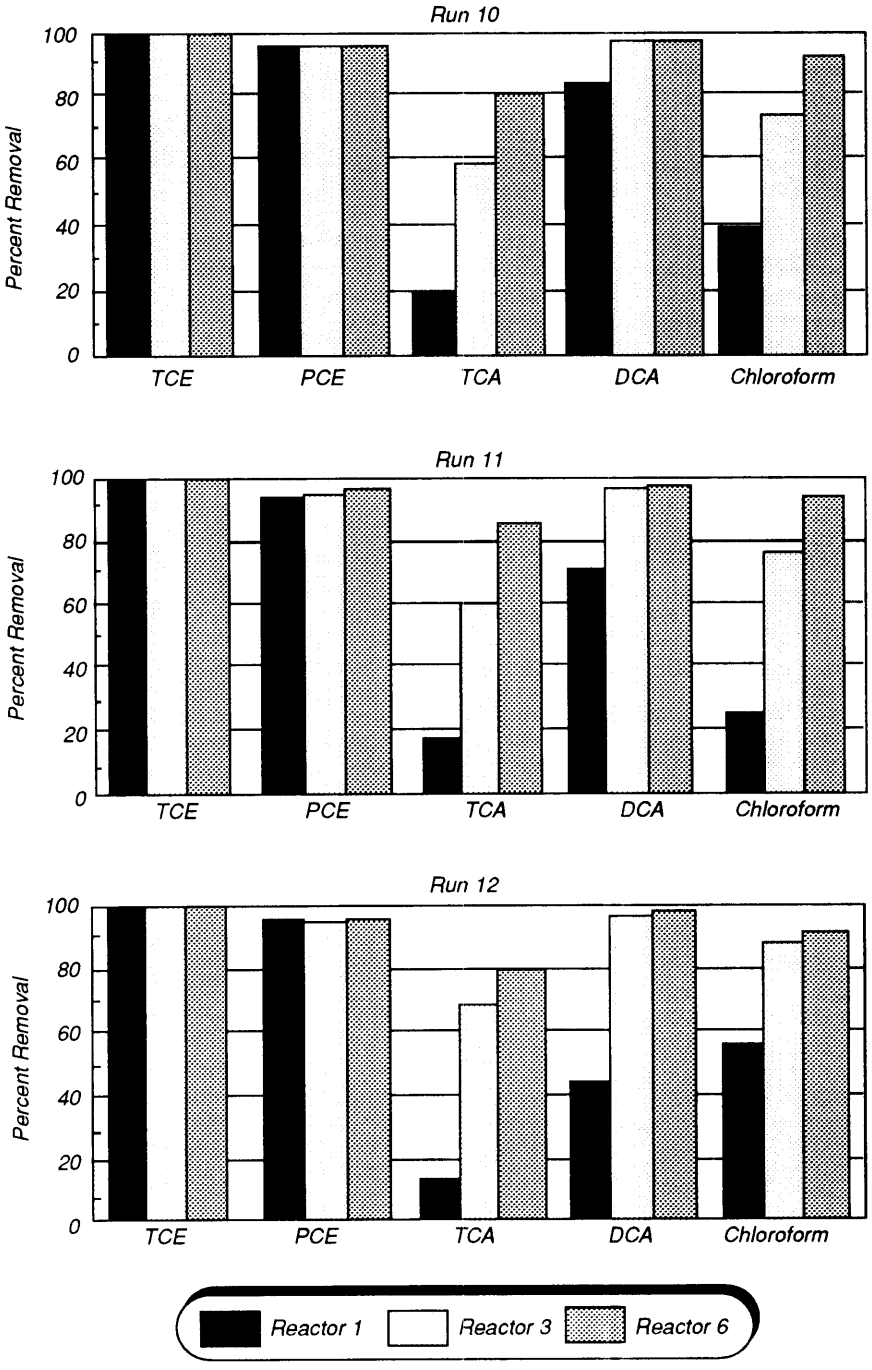

Figure 2. *VOC removal efficiencies in reproducibility runs (influent pH=5.0; hydrogen peroxide level at Reactor 1= 40 mg/L; hydrogren peroxide level at Reactors 2 through 6 = 25 mg/L; flow rate = 10 gpm.*

Miscellaneous Parameters

The technology demonstration also evaluated analytical results of several parameters other than VOCs, including TOX, AOX, TC, TOC, and POC.

TOX and AOX were analyzed upon request by the German Federal Ministry of Research and Technology, under a U.S.-German bilateral technology transfer program. Average Reactor 1 influent TOX and AOX levels were 800 µg/L and 730 µg/L, respectively. The perox-pure™ system achieved TOX removal efficiencies that ranged from 93% to 99% and AOX removal efficiencies that ranged from 95% to 99%.

Runs 10, 11, and 12 Reactor 1 influent and Reactor 6 effluent samples were analyzed for TC, TOC, and POC. Average TC concentrations in the influent and effluent were 75 mg/L and 55 mg/L, respectively. The decrease in TC concentration in the perox-pure™ system may be due to the loss of dissolved carbon dioxide that occurred as a result of the turbulent movement of contaminated groundwater in the perox-pure™ system. TOC decreased about 38% during treatment, which corresponds to the amount of organic carbon that was converted to inorganic carbon (carbon dioxide) during treatment. Organic carbon may have originated from the VOCs or from some other compounds present in groundwater. Effluent POC concentration was about 0.02 mg/L, which is below the reporting limit of 0.035 mg/L. POC concentration data show that the average POC removal efficiency was about 93%. Assuming that the majority of organic carbon associated with VOCs could be measured as POC, these data show that about 93% of the volatile organic carbon was converted to either carbon dioxide or nonpurgeable organic carbon.

Estimated Treatment Costs

With the use of information obtained from the SITE demonstration, an economic analysis examined 12 separate cost categories for perox-pure™ systems treating about 260 million gal of contaminated groundwater at a Superfund site. This analysis examined two cases based on groundwater characteristics. In Case 1, the groundwater was assumed to have five contaminants, of which two are easy to oxidize (TCE and PCE) and the remaining three are difficult to oxidize (chloroform, DCA, and TCA). In Case 2, the groundwater was assumed to have only two contaminants that are easy to oxidize (TCE and PCE). For each case, costs for three different flow rates (10, 50, and 100 gpm) were estimated. Costs for the 50-gpm flow rate scenario for each case are summarized below.

For Case 1, capital costs are estimated to be about $906,000 of which the perox-pure™ system direct capital cost is $185,000. Annual operation and maintenance (O&M) costs are estimated to be about $188,000 of which perox-pure™ system direct O&M costs are $125,000. Groundwater remediation costs to treat 1,000 gal of contaminated water are estimated to be about $11 of which perox-pure™ system direct treatment costs are $5.

For Case 2, capital costs are estimated to be about $776,000 of which the perox-pure™ system direct capital cost is $55,000. Annual O&M costs are estimated to be about

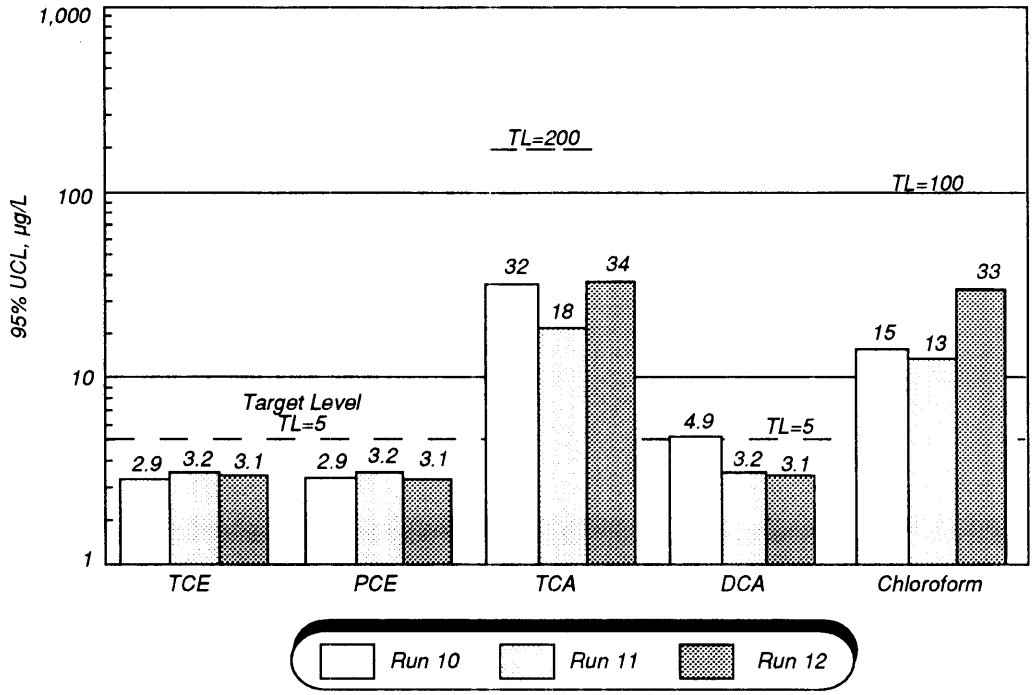

Figure 3. *Comparison of 95% UCLs for effluent VOC concentrations with target levels in reproducibility runs (influent pH = 5.0; hydrogen peroxide level at Reactor 1 = 40 mg/L; hydrogen peroxide level at Reactors 2 through 6 =25 mg/L; flow rate = 10 gpm.*

$111,000 of which perox-pure™ system direct O&M costs are $61,000. Groundwater remediation costs to treat 1,000 gal of contaminated water are estimated to be about $7 of which perox-pure™ system direct treatment costs are $3.

Conclusions

The following conclusions about the PSI perox-pure™ technology are based on the results of the SITE demonstration:

For the spiked groundwater, PSI determined the following preferred operating conditions: (1) influent hydrogen peroxide level of 40 mg/L, (2) hydrogen peroxide level of 25 mg/L in the influent to Reactors 2 through 6, (3) influent pH of 5.0, and (4) flow rate of 10 gpm. At these conditions, the effluent TCE, PCE, and DCA levels were generally below detection limit (5 µg/L) and TCA levels ranged from 15 to 30 µg/L. The average removal efficiencies for TCE, PCE, chloroform, DCA, and TCA were about 99.7%, 97.1%, 93.1%, 98.3%, and 81.8%, respectively.

For the unspiked groundwater, the effluent TCE and PCE levels were generally below the detection limit (1 µg/L), with corresponding removal efficiencies of about 99.9% and 99.7%. The effluent TCA levels ranged from 1.4 to 6.7 µg/L with removal efficiencies ranging from 35% to 84%.

The perox-pure™ system effluent met California drinking water action levels and federal drinking water MCLs for TCE, PCE, chloroform, DCA, and TCA at the 95% confidence level.

The quartz tube wipers were effective in keeping the tubes clean and appeared to reduce the adverse effect scaling has on contaminant removal efficiencies.

TOX removal efficiencies ranged from 93% to 99%. AOX removal efficiencies ranged from 95% to 99%.

For spiked groundwater, during reproducibility runs, the system achieved average removal efficiencies of 38% and greater than 93% for TOC and POC, respectively.

The temperature of groundwater increased at a rate of 12°F/min of UV exposure in the perox-pure™ system. Since the oxidation unit is exposed to the surrounding environment, the temperature increase may vary depending upon the ambient temperature or other atmospheric conditions.

Table 3. *Percent Removal Efficiencies for VOCs in Quartz Tube Cleaner Runs**

	TCE		PCE		TCA		DCA		Chloroform	
Run	Reactor 1	Reactor 2	Reactor 1	Reactor 2	Reactor 1	Reactor 2	Reactor 1	Reactor 2	Reactor 1	Reactor 2
12	99.7	99.7	96.7	96.7	13.9	46.9	44.2	96.5	56.3	76.7
13	99.4	99.4	92.1	92.1	42.0	57.5	82.4	97.0	25.4	53.6
14	99.4	99.4	95.5	95.5	48.5	63.5	84.2	96.9	37.2	61.3

* *Influent pH = 5.0 ; hydrogen peroxide level at Reactor 1 = 140 mg/L; hydrogen peroxide level at Reactors 2 through 6 = 25 mg/L; and flow rate = 10 gpm*

☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 750-071/80036

The EPA Project Manager, ***Norma Lewis,*** *is with the Risk Reduction Engineering Laboratory, Cincinnati, OH 45268 (see below)*

The complete report, entitled "Technology Evaluation Report: SITE Program Demonstration of the Peroxidation Systems, Inc., perox-pure™ Chemical Oxidation Technology," (Order No. PB93-213528AS; Cost: $27.00, subject to change) discusses the results of the SITE demonstration and will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

A related report, entitled "Applications Analysis Report: SITE Program Demonstration of the Peroxidation Systems, Inc., perox-pure™ Chemical Oxidation Technology," discusses the applications of the demonstrated technology.

The EPA Project Manager can be contacted at:

Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/540/SR-93/501

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35