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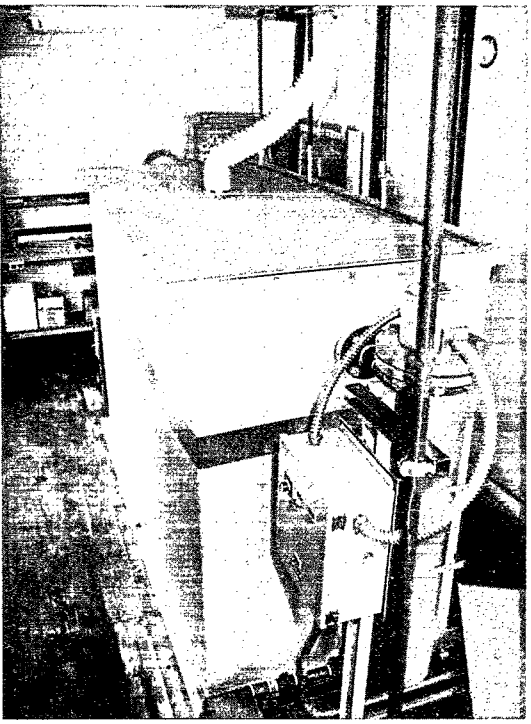
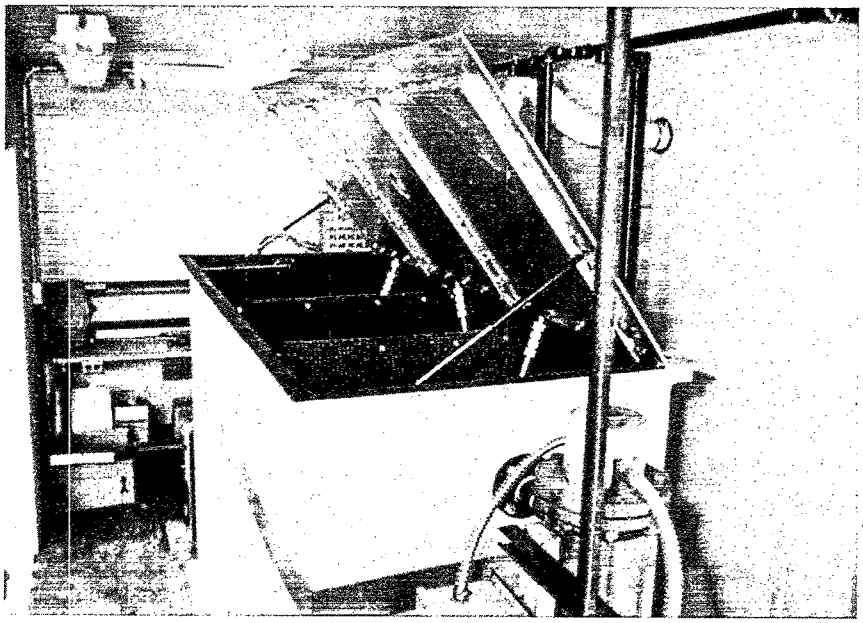
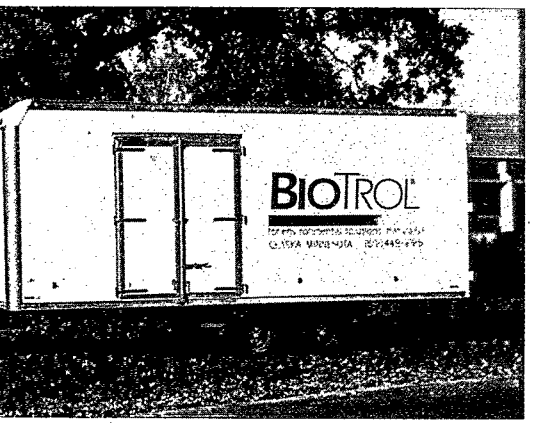
EPA

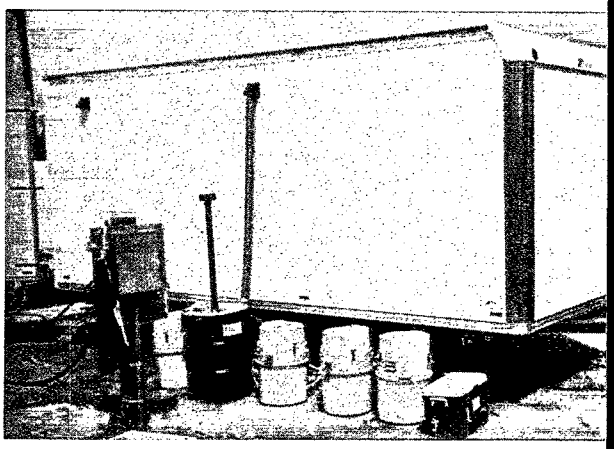
Biological Treatment of Wood Preserving Site Groundwater by BioTrol, Inc.

Applications Analysis Report









SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/A5-91/001
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Biological Treatment of Wood Preserving Site Groundwater by BioTrol, Inc.

Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Printed on Recycled Paper

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency under the auspices of the Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-03-3485 to Science Applications International Corporation. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized in the 1986 Superfund Amendments. The Program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstrations designed to provide engineering and cost data on selected technologies.

This project consisted of a demonstration of BioTrol, Inc.'s fixed-film, amended biological treatment process and an analysis of the effectiveness of the system. The study was carried out at the MacGillis and Gibbs Company site in New Brighton, MN, a site where wood preserving operations have been carried out over several decades using each of the traditional preserving chemical systems: first creosote, later pentachlorophenol, and most recently, chromated copper arsenate. In 1984 the site was added to the National Priorities List as one where soil and groundwater were contaminated with hazardous chemicals. The goals of the study, summarized in this Applications Analysis Report and described in more detail in the companion Technology Evaluation Report, were to evaluate the technical effectiveness and economics of a specific biological treatment process for the elimination of pentachlorophenol (and polynuclear aromatic hydrocarbons found in creosote) from groundwater and to establish the potential applicability of the process to other wastes and/or other Superfund and hazardous waste sites.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, OH 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA, 22161, 703-487-4650. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or 202-382-3000 in Washington, DC, to inquire about the availability of other reports.

E. Timothy Oppelt

E. Timothy Oppelt, Director

Risk Reduction Engineering Laboratory

Abstract

This document is an evaluation of the BioTrol, Inc., Aqueous Treatment System (BATS), a fixed-film, aerobic biological treatment process for contaminated groundwaters and other wastewaters.

This report summarizes and analyzes the results of the Superfund Innovative Technology Evaluation (SITE) Program's six week demonstration at the MacGillis and Gibbs Company wood preserving site in New Brighton, MN. Other pertinent data from BioTrol investigations are included to support the demonstration results. Conclusions were reached concerning the technological effectiveness and economics of the process and its suitability for use at other sites.

During the SITE demonstration, operations and sampling and analysis were carefully monitored to establish a database against which the vendor's claims for the technology could be evaluated reliably. These claims were that the BATS could achieve 90% removal of pentachlorophenol (PCP) and polynuclear aromatic hydrocarbons (PAHs) and that penta removal was by mineralization.

The conclusions from the pilot scale demonstration study and other available data are: (1) the fixed film aerobic process is capable of degrading pentachlorophenol (PCP) and other organic pollutants to more than 95% removal; (2) effluent concentrations of PCP well below 1 mg/L are attainable, if necessary by increasing the retention time, i.e., decreasing the throughput rate; (3) removal of PCP is largely by mineralization to carbon dioxide, water and salt based on chloride yields; (4) acute toxicity of the PCP-contaminated groundwater, at least to minnows and water fleas, is eliminated; (5) operating cost for labor, chemicals, and energy range from $3.45/1000 gal at 5 gpm to $2.43/1000 gal at 30 gpm and total capital and operating cost can be as low as $2.94/1000 gallons, and (6) other factors, including ambient temperature and the presence of other contaminants in the feedwater, may affect total cost and operating efficiency.

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Abbreviations and Symbols

BATS	BioTrol Aqueous Waste Treatment System
BOD	biochemical oxygen demand (mg oxygen/liter)
BTEX	benzene, toluene, ethyl benzene, and xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cfm	cubic feet per minute
COD	chemical oxygen demand (mg oxygen/liter)
EMSL	Environmental Monitoring Systems Laboratory
GC/MS	gas chromatograph/mass spectrometer
gpd	gallons per day
gpm	gallons per minute
HPLC	high pressure liquid chromatograph
HSWA	Hazardous and Solid Waste Amendments to RCRA - 1984
kwh	kilowatt-hour
LC(50)	lethal concentration to 50% of a test species population
Mgd	million gallons per day
mg/L	milligrams per liter
ng/kg	nanograms per kilogram
ng/L	nanograms per liter
NPL	National Priorities List
O/G	oil and grease
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration or Act
OSWER	Office of Solid Waste and Emergency Response
PAHs	polynuclear aromatic hydrocarbons
PCP	pentachlorophenol
PEL	Permissible Exposure Limit
POTW	publicly owned treatment works
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act of 1976
RI/FS	Remedial Investigation/Feasibility Study
RREL	Risk Reduction Engineering Laboratory
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act of 1986
SITE	Superfund Innovative Technology Evaluation
TCPs	tetrachlorophenols
TOC	total organic carbon (mg carbon/liter)
TSS	total suspended solids (mg solids/liter)

Conversion Factors

	English (US)	*x*	*Factor*	*= Metric*
Area:	1 ft^2	x	9.2903×10^{-2}	= m^2
	1 in^2	x	6.4516	= cm^2
Flow Rate:	1 gal/min	x	6.3090×10^{-5}	= m^3/s
	1 gal/min	x	6.3090×10^{-2}	= L/s
	1 Mgal/d	x	43.8126	= L/s
	1 Mgal/d	x	3.7854×10^{3}	= m^3/d
	1 Mgal/d	x	4.3813×10^{-2}	= m^3/s
Length:	1 ft	x	0.3048	= m
	1 in.	x	2.54	= cm
	1 yd	x	0.9144	= m
Mass:	1 lb	x	4.5359×10^{2}	= g
	1 lb	x	0.4536	= kg
Volume:	1 ft^3	x	28.3168	= L
	1 ft^3	x	2.8317×10^{-2}	= m^3
	1 gal	x	3.7854	= L
	1 gal	x	3.7854×10^{-3}	= m^3

ft = foot, ft^2 = square foot, ft^3 = cubic foot

in. = inch, in^2 = square inch

yd = yard

lb = pound

gal = gallon

gal/min (or gpm) = gallons per minute

Mgal/d (or MGD) = million gallons per day

m = meter, m^2 = square meter, m^3 = cubic meter

cm = centimeter, cm^2 = square centimeter

L = liter

g = gram

kg = kilogram

m^3/s = cubic meters per second

L/s = liters/sec

m^3/d = cubic meters per day

Acknowledgments

This report was directed and coordinated by Mary K. Stinson, EPA SITE Project Manager in the Risk Reduction Engineering Laboratory—Cincinnati, Ohio. It was prepared for EPA's Superfund Innovative Technology Evaluation (SITE) Program by Herbert S. Skovronek and William Hahn of Science Applications International Corporation for the U.S. Environmental Protection Agency under Contract No. 68-03-3255.

The cooperation and participation of Thomas J. Chresand and supporting staff of BioTrol, Inc. throughout the course of the project and in review of this report are gratefully acknowledged, as is the assistance of A.J. Bamby of MacGillis and Gibbs. Mark Lahtinen of the Minnesota Pollution Control Agency (MPCA) and Rhonda McBride, Linda Kern, and Darryl Owens, the Remedial Project Managers of USEPA's Region V provided invaluable assistance and guidance in initiating the project and in interpreting and responding to regulatory needs of the project. Ronald Lewis and Gordon Evans of USEPA's Risk Reduction Engineering Laboratory and Linda D. Fiedler of the Technology Innovation Office of OSWER provided invaluable reviews of the draft report. Finally, the project could not have been carried out without the tireless efforts of the many SAIC and Radian field and laboratory personnel.

Section 1
Executive Summary

Introduction

BioTrol, Inc.'s Aqueous Treatment System (BATS) has been used to treat a pentachlorophenol-contaminated groundwater stream at a site on the Superfund National Priorities List. Operational and cost data were collected for that investigation and serve as a basis for an evaluation of the utility of this biological process for remediation of other sites across the Nation. Supporting data from other studies and evaluation of the process at other sites are discussed in Appendix D.

Conclusions

Based on the results of the SITE demonstration project at the MacGillis and Gibbs site in New Brighton, MN and information concerning other studies provided by the vendor, BioTrol, Inc., for different wastes at other sites, several conclusions can be drawn.

- The fixed-film biological treatment system is capable of destroying substantially all pentachlorophenol (95%+) and the major portion (>80%) of other phenolics in wastewater from wood preserving sites.

- Destruction of >95% can be achieved for a range of other pollutants, including other halogenated hydrocarbons, benzene, toluene, ethyl benzene, and xylenes (BTEX) from gasoline, and oxygenated solvents, with final concentrations of specific pollutants well below 1 mg/L achievable in some cases.

- Specifically, with input levels of <50 mg/L pentachlorophenol, destruction of 99% and final pentachlorophenol concentrations well below 1 mg/L are achievable at low throughput rates and removals of 95+% are achievable at a flow rate of 5 gpm, equivalent to a residence time of 1.8 hours.

- Biodegradation is the predominant mechanism for elimination of pentachlorophenol. Losses by air stripping and adsorption on solids are very minor contributors to pentachlorophenol removal.

- Removal of other pollutants commonly found in contaminated waters at wood treatment facilities (e.g., polynuclear aromatic hydrocarbons) does occur based on results of other BioTrol studies but could not be confirmed in the SITE demonstration due to the relatively low concentrations in the influent groundwater. The removal mechanism for polynuclear aromatic hydrocarbons is probably a combination of biodegradation and adsorption on solids.

- Other constituents commonly encountered at such sites, including oils, suspended solids, and heavy metals, do not appear to have an adverse effect on bioreactivity. Excessive levels of these contaminants can be removed by conventional pretreatment if necessary.

- Biological treatment and removal of pentachlorophenol markedly reduces acute biotoxicity of the wastewater, making it suitable for direct discharge, introduction to a POTW, or reuse.

- The operating cost for the fixed-film biological treatment is in the range of $2.43 to $3.45/1000 gallons, depending on system size. Major contributors to cost are labor and heat requirements, with the labor contribution decreasing significantly as the scale increases.

- One advantage of the BioTrol process over other biological treatment processes is that it does not generate residues or emissions that would hamper its use, significantly increase operating cost, or require capital investment for solids separation.

- Auxiliary equipment that could be needed to support this process are comparable to that which would be needed for other above ground treatment systems, such as oil/water separators and clarifiers for pretreatment and filters, carbon adsorbers, etc. for effluent polishing to meet discharge requirements.

- With proper acclimation and appropriate bacterial inoculation, the system should be well suited to the treatment of wastewaters (groundwater, process wastes, lagoon leakage, etc.) containing a wide range of pollutants.

Discussion of Conclusions

A mobile (trailer-mounted) system with 5 gpm capacity was tested at the MacGillis and Gibbs Company site under the Superfund Innovative Technology Evaluation (SITE) program. Extensive data were collected over a six week period to assess the ability of the system to remove pentachlorophenol

and polynuclear aromatic hydrocarbons from groundwater drawn from an aquifer at the site; the operational requirements of the system; and the cost of operation. The data from this study serve as the primary basis for the foregoing conclusions. Additional supporting evidence was provided for other field studies by BioTrol.

An extensive Quality Assurance (QA) program was conducted by SAIC in conjunction with EPA's QA program, including audits and data review along with corrective action procedures and special studies to resolve specific data quality problems. This program is the basis for the quality of the data derived from the SITE project. Discussion of the QA program and the results of audits, data reviews, and special studies can be found in the Technology Evaluation Report.

With the input water essentially fixed in its pollutant composition, the primary variable that was studied was flow rate through the system. Three flow rates were selected and the system was evaluated for about two weeks at each "steady state" to provide a sound data base. Extensive data were collected on primary pollutants (penta and PAHs) and on secondary pollutants (oil, suspended solids, metals, COD, dioxins, etc.)

The results of the SITE project demonstrated the ability of the fixed-film, aerobic bioreactor to remove pentachlorophenol. At the flow selected as optimum for the system, 5 gpm, removal of 95+% was achieved and an effluent with about 1 mg/L of pentachlorophenol was attainable. At lower flow rates, 1 gpm and 3 gpm, pentachlorophenol removal increased to 99% and final concentrations down to 0.1 mg/L were achievable.

Polynuclear aromatic hydrocarbons (PAHs) probably were also removed, either by biodegradation or by adsorption on/in the biomass but, unfortunately, the groundwater source itself contained only low levels of these materials, making it impossible to estimate removal based on differences in analytical results. Other data from a creosote-contaminated site confirmed that PAHs and other phenolics are efficiently removed. Other studies reported by the vendor (see Appendix D) confirm that PAHs are removed, probably by a combination of biodegradation and adsorption on biosolids.

Secondary pollutants, such as oil, suspended solids, and even heavy metals, did not appear to interfere with the reaction, at least at the concentrations present in the wastewater studied during the demonstration. Decreases in Total Organic Carbon (TOC) and oil and grease indicated that the system removes other organic species as well. This is supported by data for other studies in which benzene, toluene, ethyl benzene, and xylene (BTEX) and various chlorinated and oxygenated solvents were removed.

Biomonitoring demonstrated that acute toxicity present in the raw groundwater at the demonstration facility was essentially totally removed. Coupled with the measured removal of specific chemical species, this suggests that any form of discharge or reuse would be safe for this wastewater.

Based on the demonstration of the BioTrol fixed-film aerobic reactor at the MacGillis and Gibbs site, there are several factors that could be critical to successful, cost effective operation at other remediation sites. Possibly first among these is the temperature, both of the feed stream and of the ambient air. Since it is recognized that biological reactivity is dependent on temperature, it is beneficial to maintain a reactor temperature of about 70°F. If groundwater or air temperatures are significantly lower, this would require the input of more heat and, consequently, would increase the electrical cost for heating. The alternative to heating the wastewater would be enlarging the system to allow for longer retention time. Thus, the operating temperature of the system becomes a compromise between operating cost (heat required) and capital cost (system size) with the final decision dependent on costs and cleanup deadlines. In the same vein, while the capital cost for the system ($30,000 for 5 gpm and $80,000 for 30 gpm) does not include the cost for a building enclosure, one might be necessary, at least for convenient winter operation in certain parts of the country.

A second critical factor is the concentration of key pollutants that can be tolerated in the feed water and the level required in the effluent to meet regulatory requirements. In other laboratory and field studies it had been demonstrated that the bioreactor is capable of destroying influent PCP concentrations in the range of 100-200 mg/L in a single pass with no evidence of toxicity to the system. In addition, partial recycle could be used to protect the system against toxicity (by dilution with the treated effluent) and to achieve high levels of removal or low effluent concentrations—as long as capacity is available in a specifically sized system. While successful operation may still be achievable under such conditions, capital cost would increase significantly. Once-through operation in a properly scaled unit would be more cost-effective under most circumstances.

A third, perhaps less critical, factor is the extent of the anticipated remediation. A given volume of feedwater, containing a given concentration of pentachlorophenol or other contaminants, can be equally well decontaminated, i.e., to the same final effluent concentration, in a 5 gpm or a 30 gpm reactor, but time constraints and availability of feedwater may dictate which system is the more cost-effective or the more desirable.

Other factors that could affect the utility of the system for removal of PCP or other contaminants include the presence of other biodegradable organics and oil, suspended solids, and heavy metals in the feedwater. While the levels of such contamination encountered in the demonstration project had no apparent adverse effect, the character of aerobic biological treatment is such that nutrient requirements may be affected and interference may be anticipated at some levels (e.g., metals). Clearly such problems are surmountable, as by the incorporation of an oil/water separator, but overall treatment cost would increase accordingly. However, it must be recognized that such pretreatment would probably be needed for almost any aboveground treatment system at some level of contamination. The acidity or alkalinity of the water would also play a part, at least by affecting the amount of pH adjustment needed.

Section 2
Introduction

The SITE Program

The EPA's Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) Program in 1986 to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its fourth year, the SITE Program is helping to provide the treatment technologies necessary to implement new federal and state cleanup standards aimed at permanent remedies, rather than quick fixes. The SITE Program is composed of two major elements: the Demonstration Program and the Emerging Technologies Program. In addition, the Program includes research on analytical methods.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. To date, the demonstration projects have not involved funding for technology developers. EPA and the developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. To qualify for the program, a new technology must have a pilot or full scale unit and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA Regional offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to evaluate thoroughly the technology and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the type of process and the quantity of waste needed to assess the technology. While it may be possible to obtain meaningful results in a demonstration lasting one week using an incineration process, where contaminants are destroyed in a matter of seconds, this is not the case for a biological treatment process such as the BioTrol process where contaminant variability, system acclimation, and system stability must be examined over an extended period of time. In order to evaluate such parameters, it was determined that a minimum of six weeks of operation, at three different flow rates, was necessary. After the completion of a technology demonstration, EPA prepares two reports which are explained in more detail below. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of systems ready for field demonstration. A third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies to better characterize Superfund sites. In this case, EPA had the good fortune to be able to evaluate such a methodology in conjunction with a demonstration project, as will be described briefly later in this report.

SITE Program Reports

The results of the SITE Demonstration Program are incorporated in two basic documents, the Technology Evaluation Report and the Applications Analysis Report. The former provides a comprehensive description of the demonstration and its results. The anticipated audience will be engineers responsible for detailed evaluation of the technology relative to other specific sites and waste situations. These technical evaluators will want to understand thoroughly the performance of the technology during the demonstration, and the advantages, risks, and costs of the technology for the given application.

The Applications Analysis Report is directed to decision-makers responsible for selecting and implementing specific remedial actions. This report provides sufficient information to determine if the technology merits further consideration as an option in cleaning up specific sites. If the candidate technology described in the Applications Analysis appears to meet the needs of the site engineers, more thorough analysis of the technology based on the Technology Evaluation Report and information from remedial investigations for the specific site will be made. In summary, the Applications Analysis will

assist in determining whether the specific technology should be considered further as an option for a particular cleanup situation.

Purpose of the Applications Analysis Report

Each SITE demonstration will evaluate the performance of a technology while treating the particular waste found at the demonstration site. Additional data from other projects also will be presented where available.

Usually the waste at other sites being considered for remediation will differ in some way from the waste tested. Waste characteristic differences could affect waste treatability and use of the demonstration technology at other sites. Thus, successful demonstration of a technology at one site does not assure that a technology will work equally well at other sites. The operating range over which the technology performs satisfactorily can only be made by examining a broad range of wastes and sites. To a limited extent, this report provides an indication of the applicability of the BATS by examining not only the demonstration test data but also data available from other field applications of the technology.

To enable and encourage the general use of demonstrated technologies, EPA will evaluate the probable applicability of each technology to sites and wastes in addition to those tested, and will study the technology's likely costs in these applications. The results of these analyses will be summarized and distributed to potentially interested parties through the Applications Analysis Report.

Key Contacts

For more information on the demonstration of the BioTrol Aqueous Treatment System for contaminated groundwater, please contact:

1. Vendor concerning the process:

   BioTrol, Inc.
   11 Peavey Road
   Chaska, MN 55318
   612-448-2515
   Dennis D. Chilcote, Vice-president, Engineering
   Thomas Chresand, Development Engineer

2. EPA Project Manager concerning the SITE Demonstration:

   Mary K. Stinson
   U.S. EPA - ORD
   Technical Support Branch (MS-104)
   2890 Woodbridge Avenue
   Edison, NJ 08837-3679
   908-321-6683

3. State contact concerning the MacGillis and Gibbs site:

   Mark Lahtinen
   Minnesota Pollution Control Agency
   Site Response Section
   Groundwater and Soil Waste Division
   520 Lafayette Road
   St. Paul, MN 55155
   612-296-7775

4. EPA Regional contact concerning the MacGillis and Gibbs site:

   Darryl Owens
   U.S. EPA, Region V
   230 South Dearborn Street
   Chicago, IL 60604
   312-886-7089

Section 3
Technology Applications Analysis

Introduction

This section of the report addresses the potential applicability of the BioTrol Aqueous Treatment System (BATS) to various other wastewaters and Superfund site situations where pentachlorophenol is the pollutant of primary interest. Supporting information provided by the vendor, BioTrol, Inc., also is referred to as a basis for considering the BATS for other biodegradable wastes. The demonstration at the MacGillis and Gibbs site provides the most extensive data base available to-date and serves as a foundation for conclusions on the effectiveness and the applicability to other cleanups. The data base is expanded somewhat by information concerning other tests that has been provided by the vendor.

The following subsections summarize observations and conclusions drawn from the current study and supporting information. Included are factors such as other applicable wastewaters, site characteristics and constraints, applicability of state and federal environmental regulations, unique handling requirements, and personnel factors. Additional information on the BioTrol technology, including a process description, vendor claims, a summary of the Demonstration Test Results and Case Studies of other investigations are provided in the Appendices.

Conclusions

Based on the results of the demonstration test program at the MacGillis and Gibbs site and other information, the vendor's key claims are substantiated. The process can extensively degrade pentachlorophenol. Pentachlorophenol levels of well under 1 mg/L are achievable, at least at reduced throughput rates, while percent removals of at least 95% are achievable even at the highest flow rate tested, 5 gpm. It appears that conversion to inorganics (mineralization), carbon dioxide, water, and chloride ion, rather than to other, intermediate organics occurs, but the data on chloride production and TOC removal are not sufficiently precise to verify this point.

A second claim, that polynuclear aromatic hydrocarbons are removed, could not be confirmed due to low levels of PAHs in the incoming groundwater studied in the SITE test program and relatively high detection limits in the GC/MS procedure used to measure the PCP. The concentrations of the individual PAHs in the effluent were, with one exception, below detection limits (10-100 µg/L). Other investigations of PAH-contaminated waters using the BATS have demonstrated successful removal of PAHs, as noted in Appendix D.

On the basis of acute biomonitoring tests, the BATS process is capable of converting wastewaters that are toxic (to certain species, at least) to a non-toxic effluent that should be suitable for discharge, reuse, or further treatment at a POTW.

The operating costs for the process are estimated on the basis of the 5 gpm mobile pilot plant and other data available from BioTrol at between $3.45 and $2.43/1000 gallons for 5 gpm and 30 gpm systems, respectively. Depending on how a system is used, total operating plus capital cost could be as low as $2.94/1000 gallons.

The process provides a rapid, compact means of detoxifying and decontaminating wood preserving wastewaters, even when significant quantities (~50 mg/L) of dispersed oil are present. The BATS has also proven to be effective on other wastewaters containing a wide range of contaminants including the benzene, toluene, ethyl benzene, xylene (BTEX) mixture resulting from gasoline contamination, where >99% removal of benzene was achieved; a solvent mixture containing methyl ethyl ketone, cyclohexanone, and tetrahydrofuran where >99% removal was also achieved even at an influent COD concentration of 3100 mg/L; and total phenolics from a creosote waste with a high COD (~1500 mg/L) loading where phenolics removal was >99%.

The system is simple to operate and requires a minimum of operator attention or maintenance once the bacterial population has been established.

Discussion of Conclusions

The SITE Program demonstration at the MacGillis and Gibbs Company facility in New Brighton, MN clearly indicated that at the maximum tested flow rate of 5 gpm the mobile unit was capable of destroying 95+% of the PCP. Operation during the demonstration at lower flow rates, i.e., at longer retention times, demonstrated that even higher PCP removal levels could be achieved along with final PCP concentrations much below 1 mg/L. Thus, depending on the nature of the contaminated water and the effluent quality limits imposed, a BATS could be operated successfully.

Pentachlorophenol Removal

The concentration in the available groundwater (<45 mg/L) precluded evaluation of the system's capability at higher PCP concentrations. However, other work by BioTrol using wastewater containing in the range of 100 mg/L PCP

demonstrated that the technology was effective (>90% removal, effluent PCP concentration of ~<1 mg/L) at higher influent concentrations. Based on other studies, BioTrol has reason to believe that PCP concentrations even higher than 100 mg/L can be tolerated and degraded without adversely affecting the viability of the bioreaction. It is recognized that some level of PCP may be reached where a wastewater would be toxic to the biological growth. At such levels dilution (with fresh water or with recycled effluent) could be used to decrease the "apparent" concentration and still allow use of the BioTrol technology, albeit at a decreased flow rate.

Mineralization of Pentachlorophenol

Analyses of influent and effluent for chloride and TOC were carried out in an effort to confirm that the removal of PCP occurred by total degradation to water, carbon dioxide, and chloride ions rather than to intermediate, partially chlorinated products that simply were not detected by the analytical protocol. While the changes in both chloride and in TOC were consistent with total degradation (mineralization) of the PCP, the changes in both parameters exceeded the expected values. In the case of the chloride, it is suggested that other chlorinated species may account for the high value. Similarly, degradation of other organics, including oil and grease and other organic species not detected by the GC/MS methodology, may explain the TOC results.

Polynuclear Aromatic Hydrocarbon Removal

While the vendor, BioTrol, claimed that polynuclear aromatic hydrocarbons (PAHs) such as those expected from creosote contamination of the soil and groundwater were also destroyed by the bacteria, constraints in the analytical procedures make it impossible to validate this claim and it can only be concluded that only low concentrations (< detection limits) of any polynuclear aromatic hydrocarbons are present in the effluent.

In a pilot scale study at another wood preserving site, >80% removal of PAHs was demonstrated. These results also indicated that both biodegradation and adsorption on biosolids contributed to PAH removal from the aqueous waste stream.

Operational Reliability/Stability

The system proved to be quite stable and required a minimum of attention over the course of the six weeks of study. Other than some attention to a leaking pump, routine checking of pH, and preparation of nutrient solutions, there was little need for an operator. Certainly, with a large reservoir of relatively constant feed water, such as a contaminated aquifer, the attention required would be minimal. In such instances it would be desirable to incorporate some means of on-line monitoring to assure that out-of-compliance effluent is recycled rather than discharged when no operator is present. At least some portion of the observed variability in results probably is attributable to sampling and analytical variations.

Costs

Cost data was developed for the 5 gpm pilot plant unit on the basis of the experience at the MacGillis and Gibbs site and other studies by BioTrol with the larger, 30 gpm unit. Other than some savings achievable by buying nutrients in bulk, the major factors in operating cost are utilities to provide heat and the labor to oversee the operation; it is expected that the labor cost for other biological systems such as activated sludge would be even higher.

Applicable Wastes

While this study of the BioTrol Aqueous Treatment System was limited to a single wastewater, the groundwater available at the MacGillis and Gibbs site, the results of the study along with other results provided by the vendor suggest that the technology would have wide applicability to other contaminated groundwaters and process waters. The design of the system is such that elevated concentrations of contaminants in the incoming stream do not affect operation, although they can be a factor in determining the throughput rate achievable at a particular installation and the nutrient cost contribution to operation. In other words, if a source of PCP-contaminated water contains significantly higher levels of PCP, the safe approach may be to dilute the stream, either with clean water or with effluent, at least until acclimation can be demonstrated. Based on other results provided by BioTrol, the system is well able to withstand and degrade wastewaters containing as much as 100 mg/L of PCP and probably more on a once-through basis. COD concentrations of up to 3000 mg/L (from BTEX and oxygenated solvents) have been successfully treated in a single pass by the BATS using only indigenous microorganisms.

Temperature, dissolved oxygen, and pH of an incoming wastewater could affect the biological reaction, except that the system incorporates means for bringing these parameters into line with specifications. The experience at MacGillis and Gibbs did not indicate nor suggest a particular sensitivity to any of these factors. While reduced temperature would be expected to decrease the degradation rate in any biological treatment system, the BATS is equipped with a heater and a heat exchanger to maximize the utilization of energy introduced to heat a cold influent. Based on engineering calculations by BioTrol, the heat losses in the system are equivalent to only a few degrees.

One other factor that was given careful consideration at the outset of the demonstration was the question of oil in the influent. During the demonstration, the system was operated with a water source containing approximately 50 mg/L of oil with no apparent adverse effect; in fact, the oil was significantly reduced in the effluent, either by adsorption or by degradation. If necessary, an oil/water separator could be incorporated in the process train, which should reduce the oil and grease (O/G) level to well below that tested in this demonstration.

Other pollutants in the incoming water, such as metals, do not appear to adversely affect the reaction efficiency, at least at the levels encountered at the MacGillis and Gibbs site. There is little reason to suspect that the BioTrol process would be more (or less) sensitive to metals than any other biological system.

The proven track record of biological treatment for many wastewaters contaminated with organics suggests the applicability of this technology to other wastes. The BioTrol process, requiring minimal reactor volume and providing high removal rates at relatively high influent concentrations of specific contaminants by virtue of the plug flow design, should be well-suited to other wastes. The system's use of an inoculum of a waste-specific bacterium for particularly recalcitrant pollutants such as PCP suggests that the process could be "customized" to other constituents where indigenous microorganisms are not present.

Site Characteristics

In the demonstration program a mobile pilot plant system was used that required only a level base (ideally a concrete pad); potable water and power were supplied by the site operator. If necessary, the small amount of potable water needed could be trucked in and power could be provided by an on-site generator. In any case where groundwater was being brought up by pump from a well for treatment, power for that pump would have to be provided. If the water being treated were surface water (e.g., a storage lagoon), this might not be necessary. In either case, placement of the system close to the water source would reduce pumping requirements.

Geography could play a small role in the effectiveness of the BioTrol system, as it would with any biological treatment. Significantly colder ambient temperatures can reduce biological reaction rates. As noted earlier, the BioTrol system is equipped with a heat exchanger and heater and low ambient temperatures can be traded-off for a [small] increase in heat input, since most heat can be reclaimed.

With the demonstrated ability of the vendor's system to reduce pentachlorophenol levels to well below 1 mg/L, acceptance of the effluent by POTWs should not be a problem in most communities. Even direct discharge to receiving waters may be defensible in light of the analytical and biomonitoring results obtained at the MacGillis and Gibbs site. Reuse of the treated wastewater should also be attractive since the only additions to the water would be small amounts of nutrients and salt. These conclusions are based on the MacGillis and Gibbs groundwater and would have to be reconfirmed for any other wastewater.

Environmental Regulation Requirements

Anticipating that the BioTrol system would be used on groundwater at a contaminated site, a first concern would be local well-drilling requirements. Depending on the size of these wells, their capacity, and the capacity of the treatment system being installed, storage tanks may be desirable as a reservoir and to provide needed equalization. Such tanks may need regulatory attention (permits, materials, etc.), depending on their size and whether they are placed above or below ground.

It is probable that the treated effluent from any similar site would be suitable for direct discharge or discharge to a POTW as "pretreated". At most, a NPDES permit (or state equivalent) should be required. However, under the Resource Conservation and Recovery Act of 1976 (RCRA) and the Hazardous and Solid Waste Amendments of 1984 (HSWA), there is some question as to whether the effluent, as a residual from treatment of a hazardous waste, would itself be considered hazardous, in spite of its apparent nonhazardous character.

Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA), EPA is responsible for determining the methods and criteria for the extent of removal. The utility and cost effectiveness of the BioTrol system would, to an extent, be dependent on the final level deemed appropriate and necessary at a particular site by EPA. However, since the use of remedial actions by treatment that "...permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances" is strongly recommended (Section 121 of SARA), the BioTrol system would appear to be an attractive remedy for a site contaminated with wood preserving chemicals.

SARA also added a new criterion for assessing cleanups that includes consideration of potential contamination of the ambient air. This is in addition to general criteria requiring that remedies be protective of human health and the environment. This demonstration has established that pentachlorophenol is not emitted to the ambient air. However, from a worker and environment safety point of view, it still may be desirable to incorporate an air treatment system (e.g., carbon) to assure that the escape of the more volatile PAHs such as naphthalene and 2-methyl naphthalene is minimized, even though the observed level of naphthalene at the MacGillis and Gibbs site (=<1 mg/L) is well below the OSHA Permissible Exposure Limit of 10 mg/L. And, if such a control system is installed to collect the emissions from the reactor, a state or local permit to construct and operate an air emissions control unit may be required.

Finally, the very limited data on dioxins/furans and their frequent occurrence in conjunction with chlorocarbon products suggest that it would be prudent to evaluate whether the small volume of sludge produced from the BioTrol system has to be considered to be dioxin-contaminated and managed in accordance with RCRA, thereby increasing total cost somewhat. Concurrently, any carbon used in an air treatment system or for effluent polishing at a particular site would also have to be tested to determine whether it is contaminated with dioxins, in which case special handling would also be necessary.

Materials Handling Requirements

If the BioTrol system is to be used to treat groundwater, the first need is a well drilling rig to provide the well(s) from which the feedwater is to be obtained. Once the wells are

drilled and developed, each must be equipped with a pump to draw up the necessary feed water. Local well drilling requirements would have to be taken into consideration.

If the vendor's system is provided with relatively clean ground- or process water, little special handling is needed other than pH and temperature adjustment and these needs are incorporated in the system. The demonstration has also shown that a reasonably high level of oil (~50 mg/L) has no effect. The vendor indicates that significantly higher levels of oil can be tolerated. However, in the event that even higher levels are present in a source water, a simple oil/water separator should suffice to reduce the level to an acceptable level (see Appendix D-1). Similarly, a clarifier could be added to remove high levels of suspended solids.

Operationally, the only problem encountered was the apparent backmixing through the underflow weirs separating each chamber. This seemed to have no effect on the effluent quality, and may only influence decisions as to sampling points in future installations.

While groundwater tends to be reasonably consistent over time, such may not be the case with other wastewaters. In certain cases it may be desirable to install a storage tank or even a lagoon for equalization and to avoid shock loading that could, conceivably, adversely affect biological activity. Depending on their design, the regulatory impacts of such tanks or basins could need to be considered.

If a large source of contamination were being treated, it would be cost-effective to purchase nutrients and caustic in bulk. In that event storage facilities would be required.

Personnel Issues

Even during acclimation, the system requires little attention. Nutrient addition and pH adjustment are carried out automatically. Consequently, there is little labor requirement other than to assure that all pumps are operating, nutrient and caustic reservoirs are filled, and that the final effluent is meeting discharge requirements. Some additional time would be required if oil/water separation, suspended solids removal, or effluent polishing is required at a particular installation. Consideration should be given to equipping operators working on or near the system with skin and respirator protection if exposure could occur by contact with liquid or mist when opening the bioreactor, or to air emissions stripped from the system.

Testing Issues

At this time, the only approved method for pentachlorophenol analysis during monitoring is the GC/MS method for semivolatiles. This is a costly and time-consuming procedure not well suited to on-line use for process control or effluent monitoring. BioTrol has developed a high pressure liquid chromatographic (HPLC) procedure which is much faster and may be acceptable to site management and regulatory personnel for routine use. A comparison of the BioTrol HPLC procedure and the EPA method conducted as part of the QA program for the demonstration indicated that the BioTrol method is accurate for samples containing PCP concentrations of 1 mg/L or higher.

EPA's Environmental Monitoring Systems Laboratory (EMSL) also is evaluating an alternate immunoassay technique that would be well suited to field use and would be very economical. At this time, whether the field test provides comparable results has not been validated and widescale application is certainly several years away. As with any analytical procedure, it also would be necessary to establish that the waste matrix at a particular site does not interfere with the quality of results.

Section 4
Economic Analysis

Introduction

The primary purpose of this economic analysis is to estimate costs (not including profit) for commercial-scale remediation using the BioTrol Aqueous Treatment System (BATS). With realistic costs and a knowledge of the bases for their determination, it should be possible to estimate the economics for operating similar-sized systems at other sites utilizing various scale-up cost formulas available in the literature such as the "six-tenths rule".

This economic analysis is based on assumptions and costs provided by BioTrol and on results and experiences from this SITE demonstration developed over two weeks of operation at 5 gpm. It is assumed that the performance of commercial-scale equipment will be the same as that demonstrated here for a pilot-scale 5 gpm mobile unit with an influent containing approximately 45 ppm of penta and achieving 95% removal. Certain actual or potential costs were omitted because site-specific engineering aspects beyond the scope of this SITE project would be required. Certain other functions were assumed to be the obligation of the responsible parties or site owner and also were not included in the estimates. Cost figures provided here are "order-of-magnitude" estimates, generally +50%/-30%, and are representative of charges typically assessed to the client by the vendor exclusive of profit.

The reader is also urged to obtain and review the Applications Analysis Report for the companion study, in which the BATS is used to treat process water from a soil washer.

Conclusions

- The cost to treat groundwater using the BATS in three different configurations is given below:

Configuration	*$/1000 gal.*
5 gpm leased mobile unit	14.56
5 gpm purchased fixed unit	4.61
30 gpm purchased fixed unit	2.94

- For the 5 gpm leased mobile unit, the largest cost component is the equipment lease rate (76%), followed by utilities (11%), and labor (10%). For the 5 gpm purchased fixed unit, the largest cost component is utilities (37%) followed by labor (32%), and capital equipment (25%). On a $/1000 gal basis, capital equipment costs for the fixed unit appear to be an order of magnitude less than for the mobile unit. It should be remembered, however, that an initial investment of $30,000 is required to purchase the fixed unit.

- Buying a 5 gpm treatment system would be economical if it is to be used for at least 12 months.

- For fixed units there are economic advantages due to scale, especially for labor. On a $/1000 gal basis, utilities are the largest cost component followed by labor and equipment costs. However, there is a point of diminishing returns. A six-fold increase in size resulted in a 35% reduction in costs.

- In all instances, influent heating accounted for a disproportionate share of operating costs (10-50%). Influent heating may not always be necessary. And even when it is necessary, it will be used only during the colder months.

- In no instance did consumables and supplies account for any more than 10% of total cleanup costs.

Issues and Assumptions

This section summarizes the major issues and assumptions used to evaluate the cost of BioTrol's Aqueous Treatment System. In general, assumptions are based on information provided by BioTrol. Certain assumptions were made to account for variable site and waste parameters and will, undoubtedly, have to be refined to reflect site specific conditions.

Waste Volumes and Site Size

The volume of groundwater to be treated at the MacGillis and Gibbs Superfund site has not yet been determined. Because cleanup objectives have not yet been established, it is not clear as to exactly how BioTrol will propose to remediate the site. Pumping and treating the groundwater already there may be sufficient to stop the plume from spreading, but insufficient to reduce the contaminant concentration in new groundwater that will seep in. To accomplish this goal, a larger volume of groundwater will have to be treated for a much longer period of time. To bypass this question, costs are given per 1000 gal of groundwater treated.

System Design and Performance Factors

Figure C-3 in Appendix C shows a simplified flowsheet of BioTrol's pilot-scale Aqueous Treatment System. It was

assumed that a commercial-scale unit would be similar in design and performance to that demonstrated under the SITE program.

For the purposes of this analysis, it was not necessary to assume a particular contaminant concentration. It was assumed that the performance of a commercial-scale unit would be the same as that demonstrated here and that this level of reduction would be sufficient so as not to require any further treatment.

The cost estimates do not include provisions for oil/water separation, suspended solids removal, exhaust air collection and/or treatment, or effluent polishing since these items are completely site and waste specific.

System Operating Requirements

Although the volume of the reactor is designed to give a certain level of reduction for a certain residence time at its design flow rate, it is entirely possible to operate the unit at a lower flowrate and increase the residence time to increase contaminant reduction. Examination of such flowrate variation was attempted in this study but, unfortunately, influent contaminant concentrations varied too much to draw any definitive conclusions. Decreased flowrate would increase the cleanup time and the associated costs. For this analysis, all units were assumed to be operated at their design flowrates and that this was sufficient to achieve the desired reduction.

It was assumed that the BATS would operate 24 hours per day, 7 days per week. One lead operator would be required approximately 10 hr/week to attend to the unit.

Utilization Rates and Maintenance Schedules

Costs per 1000 gal have not assumed any downtime. Since this is a continuously operating, steady-state system with very few moving parts, utilization rates should be quite high. Two weeks for mobilization and training and one week for demobilization were assumed.

Financial Assumptions

For the purpose of this analysis, capital equipment costs were amortized over a 10 year period with no salvage value. Interest rates, time-value of money, etc. were not taken into account.

Basis for Economic Analysis

In order to compare the cost-effectiveness of technologies in the SITE program, EPA breaks down costs into 12 categories shown in Table 1 using the assumptions already described. The assumptions used for each cost factor are described in more detail below.

Site Preparation Costs

The amount of preliminary preparation will depend on the site and is assumed to be performed by the responsible party (or site owner). Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, and preparations for support facilities, decontamination facilities, utility connections, and auxiliary buildings. Since these costs are site-specific, they are not included.

Additionally, well drilling and preparation are assumed to be performed by the responsible party (or site owner) and are also highly site-specific. Hence, these costs are also not included.

Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner). These costs may include actual permit costs, system health/safety monitoring, and analytical protocols. Permitting and regulatory costs can vary greatly because they are very site- and waste-specific. No permitting costs are included in this analysis; however, depending on the treatment site, this may be a significant factor since permitting can be a very expensive and time-consuming activity.

Equipment Costs

Capital equipment costs were provided by BioTrol, Inc., for three configurations:

a. A 5 gpm mobile unit that would be leased for $2400/month. This would be suitable for short term cleanups.

b. A 5 gpm skid mounted unit which could be purchased for $30,000. This could be used for long term treatment of a relatively low flow stream such as leachate from a pond.

c. A 30 gpm skid mounted unit which could be purchased for $80,000. This could be used to treat a larger aquifer.

The 5 gpm and 30 gpm purchased units were amortized over a 10 year period with no salvage value assumed at the end. This works out to $250/mo for the 5 gpm installation and $667/mo for the 30 gpm installation.

To determine costs per 1000 gal of water treated, these monthly amortized costs were divided by the respective flowrates expressed in gal/mo. (assuming 24 hr/day and 30 days/mo). The reader is cautioned to use these numbers with great care due to the amortization assumptions just made. Capital costs per 1000 gal may appear to be the lowest for the 30 gpm unit but an $80,000 investment is required up front. For short cleanup times this is clearly uneconomical. Likewise, for the 5 gpm skid mounted unit, a cleanup time of more than 12 months would make this purchase option more economically attractive than leasing a unit.

Startup

As the name implies, the 5 gpm mobile unit is designed to be moved from site to site. Transportation costs are only charged to the client for one direction of travel and are usually included with mobilization rather than demobilization. Trans-

Table 1. ***Estimated Costs for MacGillis and Gibbs Site***

Cost Category	5 gpm Mobile		5 gpm Fixed		30 gpm Fixed	
	$/1000 gal	%	$/1000 gal	%	$/1000 gal	%
1. Site Preparation	N/A	N/A	N/A	N/A	N/A	N/A
2. Permitting and Regulatory Requirements	N/A	N/A	N/A	N/A	N/A	N/A
3. Capital Equipment (amortized over 10 years)	11.11	76	1.16	25	0.51	17
4. Startup	N/A	N/A	N/A	N/A	N/A	N/A
5. Labor	1.49	10	1.49	32	0.50	17
Salary						
6. Consumables & Supplies						
Nutrient	0.042		0.042	1	0.017	1
Caustic	0.24	2	0.24	5	0.24	8
7. Utilities						
Electricity	0.216	1	0.216	5	0.216	7
Heat	1.46	10	1.46	32	1.46	50
8. Effluent Treatment & Disposal	N/A	N/A	N/A	N/A	N/A	N/A
9. Residuals/Waste Shipping & Handling	N/A	N/A	N/A	N/A	N/A	N/A
10. Analytical Services	N/A	N/A	N/A	N/A	N/A	N/A
11. Facility Repair, Replacement & Modification	N/A	N/A	N/A	N/A	N/A	N/A
12. Demobilization	N/A	N/A	N/A	N/A	N/A	N/A
Total	**14.56**	**99**	**4.61**	**100**	**2.94**	**100**

portation costs are variable and dependent on site location as well as on applicable size/weight load permits, which vary from state to state. The total cost will depend on how many state lines are crossed. For purchased units, transportation costs are borne by the buyer.

The amount of assembly required for the mobile unit is minimal. For the purchased units, assembly is a labor intensive operation consisting of unloading equipment from trucks and trailers used for transportation, as well as actual assembly. Mobilization, training, and acclimation are estimated to take 1 person working a 40 hr week about 2 weeks and this time should be included in the total time on site.

Depending on the site, local authorities may impose specific guidelines for health and safety monitoring programs. The stringency and frequency of monitoring required may have a significant impact on project costs.

Labor

Once the system is acclimated and operating at steady state, very little additional labor is involved. It is estimated that a Project Engineer at $35/hr would spend 1 hr/week and a Lead Operator at $25/hr would spend 10 hr/week on the 30 gpm unit and 5 hr/week on the 5 gpm unit for maintenance and operation. These numbers include salary, benefits, and administration/overhead costs but exclude profit. BioTrol calculates the labor to be $1.49/1000 gal for the 5 gpm units and $0.50/1000 gal for the 30 gpm unit. No provisions for per diem or car rental have been included in these figures.

Consumables and Supplies

Caustic usage would be determined by the pH and alkalinity of the incoming water to be treated. For purposes of this cost estimate, usage was assumed to be the same as that demonstrated under this SITE project (.09 gal of 50% solution per 1000 gal of water treated). More or less caustic may be required at another site; however, caustic use should remain essentially constant throughout the treatment of a specific waste. For a commercial scale cleanup, a cost of $2.60/gal of 50% solution was assumed. Thus, the cost would be $0.24/1000 gal of water.

Nutrients in the form of urea and trisodium phosphate dissolved in water in a 2:1 weight ratio are usually added regardless of system size. At the MacGillis and Gibbs demonstration site, a nutrient mixture consisting of 5 lb urea plus 2.5 lb of trisodium phosphate dissolved in 50 gallons of water was added at a rate of 2.5 ml/gallon of wastewater. For the 5 gpm units, the prices given reflect purchase of the ingredients at a local fertilizer supplier; for the larger system some economy of scale has been factored in on the assumption that the two materials would be purchased in bulk. The cost for storage facilities should be included in site preparation.

Two other items that should be considered but were not included are health and safety gear, and maintenance supplies (spare parts, oils, grease and other lubricants, etc.). Since the manpower requirements for both systems are the same, the cost for health and safety gear will be minimal (about $500). The cost of maintenance supplies can be assumed not to exceed 2% of the capital costs on a yearly basis.

Utilities

The total electrical demand for both units is estimated to be about 10 HP. This includes the pump used to deliver the groundwater to the BATS, a second pump to discharge the water against an assumed head of 50 ft of water within the BATS, and an air sparger blower. Electricity required for the air sparger blower motor will decrease somewhat for the 30 gpm unit since the reactor chambers would be 8 ft deep rather than the nominal 4 ft used in the 5 gpm unit, providing more efficient "capture" of the dispersed air. However, there would also be a somewhat higher head pressure. The vendor's calculations indicate the benefit will be minimal and the same value has been used for both size units. It does not include electricity that may be required to heat the influent. Electricity was assumed to cost $0.06/kw-hr.

The amount of heat required at a particular site would be dependent on the incoming water temperature, the ambient temperature and resulting heat loss, as well as the exothermicity of the reactions for a particular wastewater. Practically, the heat exchanger can transfer or return enough heat from the effluent so that the difference is only about 3°F. Coupled with an assumed 2°F loss to the atmosphere, the actual difference between influent and effluent will only be about 5°F and is essentially independent of the temperature of the water source except during the startup. At the MacGillis and Gibbs site during July to September, the average groundwater temperature was 55°F. (13°C) and *the heater was not used.* A difference of 5°F between influent and effluent temperatures and electricity at $0.06/kw-hr were assumed.

Effluent Treatment and Disposal

The effluent from the BATS can be handled several ways. It can be injected back into the ground to effectively "flush out" contaminant from the soil. In this case, the effluent contaminant concentration is not a critical parameter. If the effluent is clean enough to meet regulatory standards, it may be discharged to a POTW. If the effluent is not clean enough to meet regulatory standards, it may be recycled and mixed with the influent for further treatment. This will obviously extend the required cleanup time and the associated costs.

There obviously are too many variations for each one of these scenarios to be considered here. For simplicity, it will be assumed that the effluent is clean enough to meet regulatory standards and hence can be directly discharged to a POTW without further treatment.

Residuals/Waste Shipping, Handling and Transport Costs

Waste disposal costs, including storage, transportation, and treatment costs, are assumed to be the obligation of the responsible party (or site owner). It is assumed that residual or solid wastes generated from this process would consist only of contaminated health and safety gear, used filters, spent activated carbon, etc. Landfilling is the anticipated disposal method for this material at an estimated cost of $100/drum.

Analytical Costs

No analytical costs during operations are included in this cost estimate. Standard operating procedures for BioTrol do not require planned sampling and analytical activities. Periodic spot checks may be executed at BioTrol's discretion to verify that equipment is performing properly and that cleanup criteria are being met, but costs incurred from these actions are not assessed to the client. The client may elect, or may be required by local authorities, to initiate a sampling and analytical program at their own expense.

Facility Modification, Repair and Replacement Costs

As stated earlier, site preparation costs are assumed to be borne by the responsible party (or site owner). Likewise, any modification, repair, or replacement to the site was assumed to be done by the responsible party (or site owner).

Demobilization Costs

It is estimated that demobilization would take about 1 week. Site cleanup and restoration is limited to the removal of all equipment and facilities from the site. Grading or recompaction requirements of the soil will vary depending on the future use of the site and is assumed to be the obligation of the responsible party or site owner.

Results

Table 1 shows several interesting trends regarding mobile and fixed units as well as the size of fixed units.

For the 5 gpm mobile unit, the largest cost component is the equipment lease rate (76%) followed by utilities (11%), and labor (10%). Comparing this with the 5 gpm fixed unit, the largest cost component is utilities (37%), followed by labor (32%), and capital equipment (25%). The reader is cautioned to view these relative percentages carefully.

Although capital equipment costs appear to be an order of magnitude less on a $/1000 gal basis, an initial investment of $30,000 must be made for the 5 gpm fixed unit. Such a capital outlay can only be justified for long duration or large cleanups. The breakeven decision point between a fixed and mobile unit is 12 months ($30,000 for fixed unit ÷ $2,400/mo for mobile unit). Therefore, even if a 5 gpm fixed unit is not used for the full 10 year period assumed here, it might be economical to purchase the equipment if it is to be used for at least 12 months. The decision will be influenced by other financial considerations, i.e., interest rates, time value of money, cash flow, etc.

Secondly, influent heating accounts for a disproportionate amount of operating costs. As noted earlier, influent heating may not be necessary in the majority of cases. Even when it is required, it will only be used during the coldest months of the year. Additionally, influent heating was assumed to be done relatively expensively using electricity. A gas, oil-fired, or solar heat exchanger could accomplish this

much more efficiently. These points should be kept in mind when comparing total cleanup costs on a $/1000 gal basis.

Differences between the 5 gpm and 30 gpm fixed units are less dramatic. Utilities are still the largest cost component (37% for the 5 gpm unit, 57% for the 30 gpm unit), but capital equipment and labor costs have a more equal share for the 30 gpm unit. This, in part, is no doubt due to economy of scale, especially the labor cost component, which is half the amount of the 5 gpm unit. Again, heating accounts for a disproportionate share of operating costs. In no instance did consumables and supplies account for any more than 10% of total cleanup costs.

Comparison of total cleanup costs on a $/1000 gal basis indicates that there is a point of diminishing returns, as expected. A six-fold increase in size amounts to about a 35% reduction in costs.

In all of the above analysis, it should be remembered that costs for only 4 out of the 12 cost components were considered. If the additional factors are taken into account, costs could increase significantly.

Section 5
Bibliography

1. Bishop, J., GAINING ACCEPTANCE, Hazmat World, June 1989, p. 37 ffd.

2. Brown, E.J., et al, PENTACHLOROPHENOL DEGRADATION: A PURE BACTERIAL CULTURE AND AN EPILITHIC MICROBIAL CONSORTIUM, Applied and Environmental Microbiology, July 1986, p. 92-97.

3. Bourquin, A.W., BIOREMEDIATION OF HAZARDOUS WASTE, HMC, Sept./Oct. 1989, p. 16 ffd.

4. Dworkin, D. and R.M. Shapot, INNOVATIVE REMEDIAL TECHNOLOGIES AT A CREOSOTE-BASED WOOD TREATMENT PLANT, presented at HAZMAT '88, Nov. 8-11, 1988.

5. EPA, BIOLOGICAL TREATMENT OF CHLOROPHENOLIC WASTES, Final Report, Project No. 12130 EGK, June 1971.

6. EPA, METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, OH., EPA-600/4-79-020. Revised March 1983.

7. EPA, SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION (SITE) STRATEGY AND PROGRAM PLAN, EPA/540/G-86/001, Dec. 1986.

8. EPA, TEST METHODS FOR EVALUATING SOLID WASTE, SW-846, U.S. Environmental Protection Agency, US Government Printing Office, Washington, DC, Third Edition, Nov. 1986.

9. Finlayson, G., MICROBIAL CLEANUP OF TOXIC WASTES MAY PROVIDE ALTERNATIVE SOLUTION, Occupational Health and Safety, Jan. 1990, p. 36,38,40,57.

10. Kennedy, M.S., J. Grammas and W.B. Arbuckle, PARACHLOROPHENOL DEGRADATION USING BIOAUGMENTATION, Research J. Water Pollution Control Federation, *62 #3*, 227-233 May/June 1990.

11. Lee, L.S., et al, INFLUENCE OF SOLVENT AND SORBENT CHARACTERISTICS ON DISTRIBUTION OF PENTACHLOROPHENOL IN OCTANOL-WATER AND SOIL-WATER SYSTEMS, Environmental Science and Technology, *24,#5*, 654-661 (1990).

12. Lee, K.M. and H.D. Stensel, AERATION AND SUBSTRATE UTILIZATION IN A SPARGED PACKED-BED BIOFILM REACTOR, J. Water Pollution Control Federation, *58 #11*, 1066-1072 (1986).

13. Loper, J.C., THE FUTURE OF BIOREMEDIATION: PROSPECTS FOR GENETICALLY ENGINEERED MICROORGANISMS, HMC, Sept./Oct. 1989, p. 24 ffd.

14. Mathewson, J.R. and R.B. Jones, COMMERCIAL MICROORGANISMS, Hazmat World, June 1989 p. 48-51.

15. Mueller, J.G., P.J. Chapman and P.H. Pritchard, CREOSOTE-CONTAMINATED SITES—THEIR POTENTIAL FOR BIOREMEDIATION, Environmental Science and Technology, *23, #10*, 1197-1201 (1989).

16. Nicholas, R.B. and D.E. Giamporcaro, NATURE'S PRESCRIPTION, Hazmat World, June 1989, p. 30 ffd.

17. PEI Associates, Inc., REMEDIAL ALTERNATIVES REPORT FOR THE MACGILLIS AND GIBBS CO. HAZARDOUS WASTE SITE IN NEW BRIGHTON, MINNESOTA, for Twin City Testing and Engineering Laboratory Inc., State PMN Contract No. 13726, Subcontract No. 1-35086, PN 3686, April 1987.

18. Piotrowski, M.R., BIOREMEDIATION: TESTING THE WATERS, Civil Engineering, Aug., 1989, p. 51-53.

19. Rusten, B., WASTEWATER TREATMENT WITH AERATED SUBMERGED BIOLOGICAL FILTERS, J. Water Pollution Control Federation, *56 #5*, 424-431 (1984).

20. Saber, D.L. and R.L. Crawford, ISOLATION AND CHARACTERIZATION OF FLAVOBACTERIUM STRAINS THAT DEGRADE PENTACHLOROPHENOL, Applied and Environmental Microbiology, Dec. 1985, p. 1512-1518.

21. Skladany, G.J. and K.M. Sullivan, "DECAY THEORY" BIOLOGICAL TREATMENT FOR LOW-LEVEL ORGANIC CONTAMINATED GROUNDWATER AND INDUSTRIAL WASTE, Superfund '87 Conference (HMCRI), Nov. 17, 1987, Washington, D.C.

22. Steiert, J.G. and R.L. Crawford, MICROBIAL DEGRADATION OF CHLORINATED PHENOLS, Trends in Biotechnology, *3, #12*, 1985, p. 300-305.

23. Stinson, M.K., W. Hahn and H.S. Skovronek, SITE DEMONSTRATION OF BIOLOGICAL TREATMENT OF GROUNDWATER BY BIOTROL, INC. AT A WOOD PRESERVING SITE IN NEW BRIGHTON, MN, Presented at 16th Annual EPA Research Symposium, Cincinnati, OH, April 3-5, 1990.

24. Topp, E., R.L. Crawford, and R.S. Hanson, INFLUENCE OF READILY METABOLIZABLE CARBON ON PENTACHLOROPHENOL METABOLISM BY A PENTACHLOROPHENOL-DEGRADING FLAVOBACTERIUM SPECIES, Applied and Environmental Microbiology, Oct. 1988, p. 2452-2459.

25. Torpy, M.F., H.F. Stroo, and G. Brubaker, BIOLOGICAL TREATMENT OF HAZARDOUS WASTE, Pollution Engineering, May 1989, p. 80 ffd.

26. Twin City Testing Corp., REMEDIAL INVESTIGATION REPORT: MACGILLIS AND GIBBS COMPANY SITE, NEW BRIGHTON, MINNESOTA, Document #120-86-414 for Minnesota Pollution Control Agency, June 25, 1986.

27. Valine, S.B., T.J. Chresand and D.D. Chilcote, SOIL WASHING SYSTEM FOR USE AT WOOD PRESERVING SITES, Proceedings of the 1989 Air and Waste Management Association/USEPA International Symposium, p. 257-268, Feb. 20-23, 1989, Air and Waste Management Association, 1989, Pittsburgh, PA.

28. Wilson, S., THE IMPORTANCE OF BIOREMEDIATION, Pollution Equipment News, Dec. 1989, p. 67 ffd.

Appendix A
Process Description

Introduction

This section of the report presents a concise description of the process as it was carried out at the MacGillis and Gibbs site. Predemonstration factors involved in site selection are presented to assist engineers and scientists in evaluating the suitability of the process for their own needs at Superfund and other hazardous waste sites. Results of the demonstration, including a summary of analytical test results, are presented in Appendix C.

Brief reference is also made in this Appendix to two parallel studies that were also carried out in conjunction with the evaluation of the biological treatment process. These were the BioTrol soil washing study and the Westinghouse field immunoassay methodology for pentachlorophenol monitoring. Both of these subjects will be presented fully in independent SITE Program reports.

Process Description

Biological treatment has been widely used for many years in the treatment of industrial and municipal wastewaters, with aerobic treatment being the most widely used technology. However, as industrial products have been developed to provide resistance to degradation by the environment, it has often been assumed that these chemicals also would be resistant to conventional biodegradation. Of specific concern has been the resistance of chlorinated organics to biodegradation. It has now been confirmed that using proper procedures and with development of suitable biological populations, efficient biodegradation of many organic chemicals, including chlorinated aromatics such as pentachlorophenol, can be achieved.

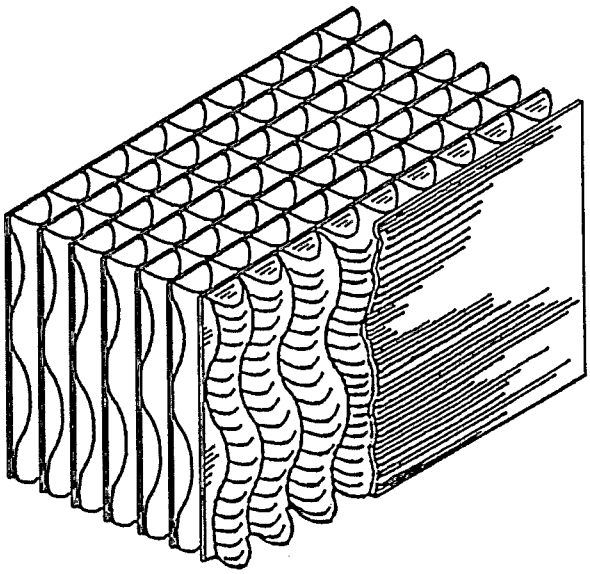
To provide the most efficient and cost effective treatment of wastewaters containing such contaminants, BioTrol, Inc. has developed and applied for a patent for a process called amended fixed-film aerobic treatment. In this technique an initial biogrowth is developed on an inert support matrix such as corrugated polyvinyl chloride sheets (Figure A-1) using an indigenous bacterial source. The initial bacterial population, having come from the local soil, has developed some resistance to the toxicity of the local contaminants and has developed a population distribution which favors the destruction of such chemicals. After this bacterial source has been allowed to grow and establish itself on the matrix in the presence of nutrients and a less toxic wastewater, an inoculum of a bacterium specific to the target chemical, pentachlorophenol in this case, may be added and further acclimation is allowed to occur using the subject wastewater in a total recycle mode. The system is then ready for once-through treatment of the groundwater.

The design of the BioTrol system allows the development of the largest concentration or population of bacteria capable of degrading pentachlorophenol in the first chamber, where the concentration is highest. As the wastewater flows through the reactor and the pentachlorophenol concentration diminishes, other bacteria more suitable to degradation of other contaminants, but perhaps more sensitive to deactivation by pentachlorophenol, have the opportunity to grow and consume those contaminants.

The BioTrol system used in this demonstration consists of a single mobile trailer (20 ft) on which all the vessels, pumps, etc. for the entire process are installed (Figure A-2). A level area (ideally a concrete apron) about 50 x 50 ft is needed to support the trailer and auxiliary facilities. The hydraulic capacity is about 10 gpm. Contaminated water from any source is brought to a mixing or conditioning tank where the pH is automatically adjusted as necessary to just above 7.0 by metering in a 50% caustic solution. A solution of nitrogen and phosphorus nutrients (urea plus trisodium phosphate) is also metered in at a predetermined rate. The mixed water is passed through a heat exchanger and then through a heater to elevate the temperature to about 70°F (21°C) before it is introduced into a 3-cell biological reactor (Figure A-3). As shown in Figure A-4, influent is introduced into the base of each chamber by means of an underflow weir. Air is simultaneously pumped to the base of each chamber and distributed by a network of sparger tubes to maintain sufficient dissolved oxygen (about 5 ppm). The combination of the flow, the air sparging, and the design of the plastic media are such that upward and lateral distribution of the water and the air occur in each chamber. After moving through the three chambers, the effluent exits at an overflow weir from the third chamber.

While the process is claimed to be relatively insensitive to suspended solids and dispersed oil and does not incorporate means of removing these contaminants, the vendor recognizes and is ready to incorporate oil/water separation or solids removal as necessary, depending on the wastewater being treated. In the case of the MacGillis and Gibbs site, no such pretreatment was deemed necessary.

Similarly, while BioTrol's experience has been that post-treatments such as suspended solids removal or carbon polish-



Blocks Cross-stacked

Figure A-1. Corrugated polyvinyl chloride media.

ing are not always necessary, EPA made the decision that a small bag filter and a carbon adsorber would be added to the effluent line to assure the safety of the discharge to the Minneapolis Metropolitan POTW. EPA also chose to install a carbon adsorber on the air exhaust line exiting from the bioreactor to assure that no hazardous volatile chemicals were discharged. Analyses were carried out before and after both carbon adsorbers as part of the demonstration program to assess the need for such protective devices at future sites.

BioTrol Soil Washing Process

In addition to the Aqueous Treatment System, Biotrol also has developed a soil washing process that separates large, relatively uncontaminated sand from more heavily contaminated fine material such as clay. PCP contamination of the fines is then reduced by biological treatment in a slurry bioreactor. The relatively clean sand and even the slurry-reactor treated clay may then be returned to the site. The BATS is employed in this sequence to treat the washwater used to separate the sand and fine materials. The Soil Washing process is the subject of a separate SITE demonstration program at the MacGillis and Gibbs site and is being reported separately.

Field Immunoassay for Pentachlorophenol

While the background for this project was being developed, EPA's Environmental Monitoring Systems Laboratory (EMSL) in Las Vegas was searching for a facility where a new field method for monitoring pentachlorophenol in wastewaters could be studied under real-world conditions. The BioTrol demonstration project at the MacGillis and Gibbs site was an ideal environment to evaluate this technique in parallel with the extensive analyses being done as part of the demonstration. Consequently, arrangements were made to have EPA's contractor personnel carry out field tests of this method as part of their assignment.

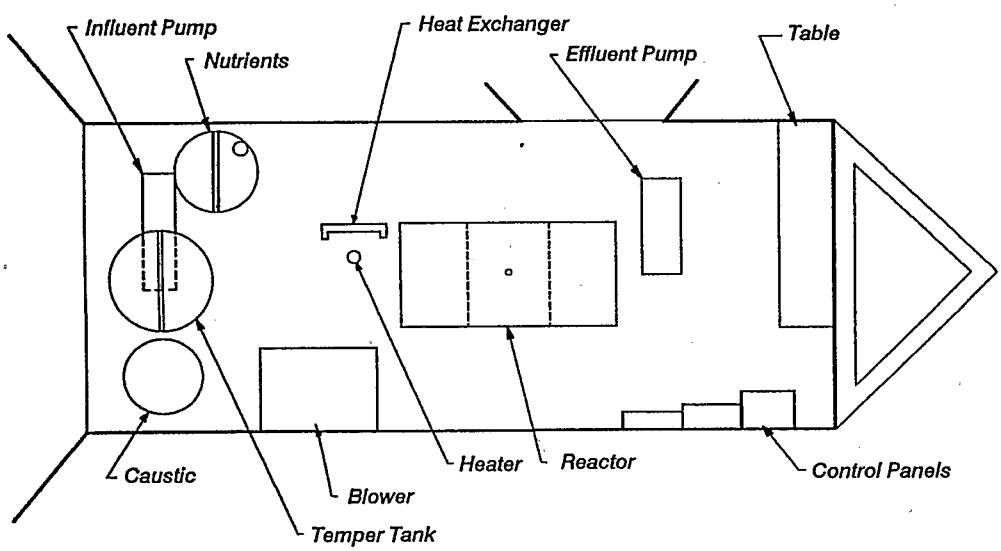


Figure A-2. BioTrol, Inc.'s mobile aqueous treatment system.

The test itself, developed by Westinghouse, takes advantage of the inhibition of bacterial enzyme activity that occurs when a target chemical, in this case pentachlorophenol, is present. The inhibition is observed by a color change in a reagent matrix and is readily quantified using standards. Only very small samples of material are needed and the results are generated within an hour. The field evaluation sought to determine the sensitivity of the test in real-world wastewater matrices, its convenience and reliability in the field when used by relatively inexperienced personnel and, most important, how well results correlated with the standard GC/MS analysis and larger scale laboratory immunoassays.

Reference is included to make the reader aware of this effort and the potential availability of the method. A report documenting the procedure, equipment, and results of this study will be available under the SITE program.

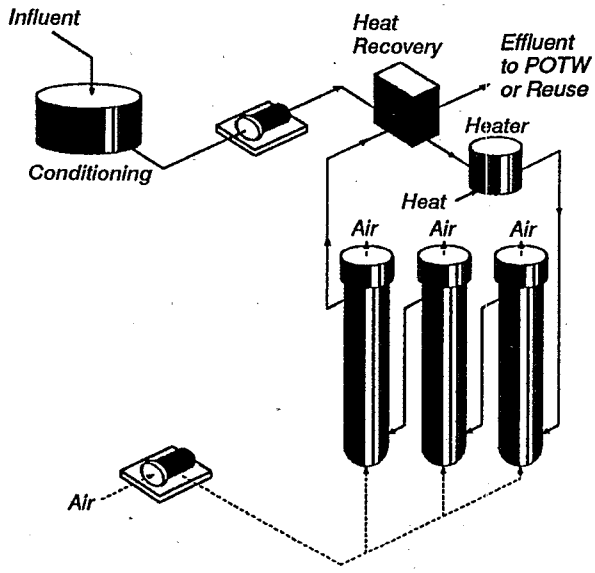


Figure A-3. Schematic of BATS system.

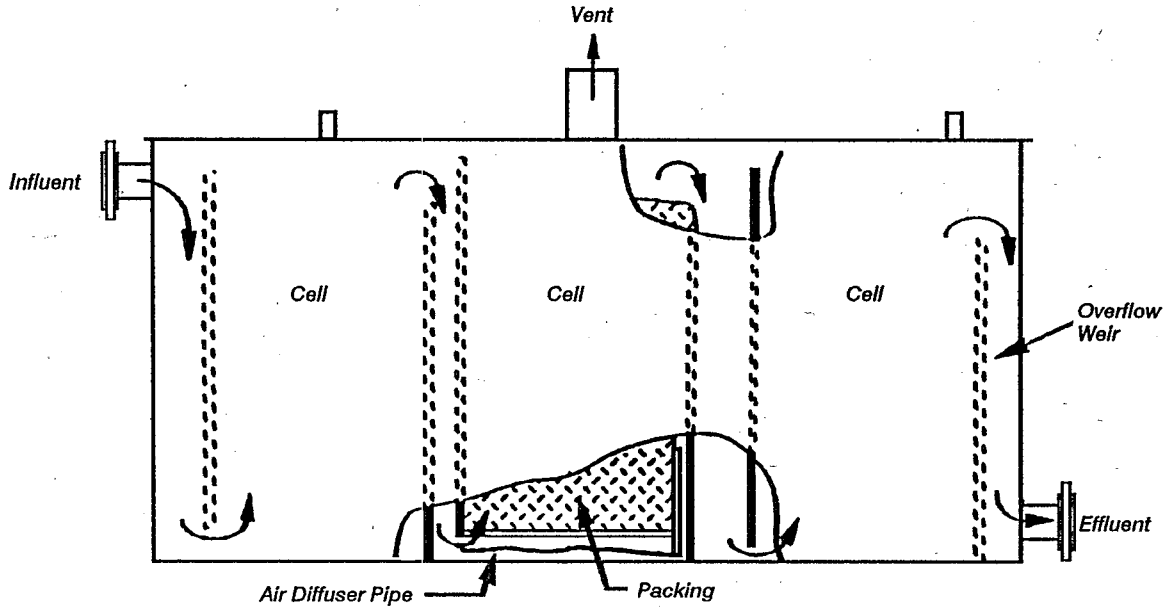


Figure A-4. Schematic of bioreactor.

Appendix B
Vendor's Claims

Introduction

The technology developed by BioTrol for treatment of wastewaters involves the use of naturally occurring microorganisms for the destruction of dissolved organic contaminants. Since the early 1900s biological treatment has been utilized for the treatment of municipal wastewaters, and has long been recognized as a low cost, highly effective technique for the destruction of organic compounds. Only recently, however, have the microbial pathways for the biodegradation of widespread priority pollutants been elucidated to the point where effective treatment systems can be applied. Using naturally occurring microbial systems, the effluent produced by this technology is substantially reduced in concentrations of many hazardous compounds, including PCP, polynuclear aromatic hydrocarbons (PAHs), gasoline components (BTEX), solvents, and substituted phenols. Removal efficiencies for these compounds in the 95 to 99 percent range have been achieved by BioTrol in on-site demonstrations and full-scale installations. Concomitant reductions in biochemical oxygen demand (BOD) in the 75 to 90 percent range have also been achieved.

While there are several treatment methods for removing organic compounds by chemical oxidation—such as UV/ozone, chlorine dioxide, or hydrogen peroxide systems—these methods often incur very high operating costs (due to quantity of oxidant required) when applied to wastewaters. Furthermore, the complete conversion of the organics to carbon dioxide and water is often not achieved. On the other hand, separation techniques, like carbon adsorption, merely transfer the contaminants to another medium (the adsorbent) which must then be regenerated, often at a very high expense.

Biodegradation offers the potential to completely mineralize the organic contaminants with little or no consequential risk to the environment, at a much lower cost than that of systems utilizing chemical oxidation or adsorption. In addition, biological treatment efficiently removes organics contributing to the BOD of the wastewater, thereby reducing sanitary sewer surcharges, or even rendering the effluent suitable for stream discharge. In cases where carbon adsorption is required as a post-treatment, the removal of BOD serves to greatly reduce the cost of carbon usage.

Technology Description

Reactor Design

Reactor design is critical to successful implementation of this technology. BioTrol employs a multi-stage, submerged, aerated, fixed-film reactor that provides a high biomass concentration and, consequently, a reduced reactor volume. This is known as the BioTrol Aqueous Treatment System or BATS. The multiple stages create a dispersed plug flow of wastewater through the reactor. The plug flow configuration is important in that contaminant concentrations typically fall in the range of first order removal kinetics. That is, the rate of removal is proportional to the concentration of contaminant. A completely mixed tank system operating at a low effluent concentration will experience low removal rates. A system with plug flow characteristics, on the other hand, will experience the same low rates in the effluent sections; however, the influent sections will operate at very high rates, thus yielding higher overall removal rates than the mixed tank system.

The use of a fixed-film system allows for a long cell retention time and, therefore, lowered production of excess sloughed biomass. Moreover, the fixed-film system eliminates the often problematic biomass separation step which is crucial to successful operation of an activated sludge system. The BATS can be skid-mounted and fully automated to allow for minimal operator attention.

Microbial Amendment

Many of the priority pollutants can be degraded by microorganisms indigenous to a given wastewater. For these compounds, treatment can be accomplished by simply adding the appropriate inorganic nutrients and allowing time for acclimation. However, in cases where a highly toxic or recalcitrant compound is to be treated, the appropriate microorganisms may be absent. In these cases, treatment can be accomplished by adding organisms with the appropriate degradative capabilities. This technique, called microbial amendment, is finding increasing use as microbiologists continue to isolate organisms with novel metabolic pathways.

As an example of microbial amendment, a *Flavobacterium* species is used by BioTrol for treatment of pentachlorophenol-contaminated wastewaters. This microorganism can perform rapid mineralization of pentachlorophenol at concentrations up to 200 mg/L.

Applicability

The following is a partial listing of organic contaminants which can be successfully biodegraded:

Pesticides

2,4-D, pentachlorophenol, dieldrin, parathion, 2,4,5-T, formaldehyde, aldrin, malathion, low-MW polynuclear aromatics

Solvents

acetone, methyl isobutyl ketone, methylene chloride, acetonitrile, methyl ethyl ketone, cyclohexanone, ethyl ether, methanol, cresols, trichloroethylene and related compounds

Petrochemicals

benzene, ethylbenzene, toluene, xylene, alkanes, styrene, tetrahydrofuran, alkenes, diethyl phthalate

Chemical Products

aniline, ethylene glycol, chlorobenzene, benzidine, substituted phenols, ethyl acetate, hexachlorobenzene, acrylamide

Case Studies

Biodegradation has wide applicability for the treatment of wastewaters contaminated with various toxic organics. In fact, treatment of PCP represents a "worst case" in that PCP is one of the most highly toxic of the common priority pollutants. BioTrol has also had success treating a variety of other wastewaters with the BATS approach. These waters range from very high strength process water with high concentrations of substituted phenols to low strength groundwater contaminated with trace concentrations of benzene.

BTEX-Contaminated Groundwater

Figure B-1 shows the performance of a full-scale BATS unit treating gasoline-contaminated groundwater (benzene, toluene, ethylbenzene, and xylenes as primary contaminants) at 15 gpm. This system has consistently performed >99 percent removal of benzene since installation, and the effluent qualifies for discharge without a polishing step. This system will ultimately be coupled with an *in situ* treatment process at the site. Effluent from the reactor will be amended with hydrogen peroxide and reinjected into the aquifer to initiate treatment of the soil.

Phenol-Contaminated Process Water

Figure B-2 shows the performance of a bench-scale BATS system for continuous treatment of a process water from a creosoting operation. The target contaminants in this case were substituted phenols. Percent removal of total recoverable phenols remained high even at very high loading rates (up to 420 lb COD/1000 ft^3 packed volume/day). The continuous flow bench-scale study, in this case, was used to generate design data for a full-scale system.

Solvent-Contaminated Process Water

Table B-1 shows the results of another continuous flow bench-scale study involving treatment of solvent-contaminated process water. The target compounds in this case were methyl ethyl ketone, toluene, and tetrahydrofuran. These removal percentages were achieved at a loading rate of 110 lb COD/1000 ft.^{3} packed volume/day and with an influent COD concentration of about 3000 mg/L. In this case, treatment was accomplished solely by microorganisms indigenous to the water.

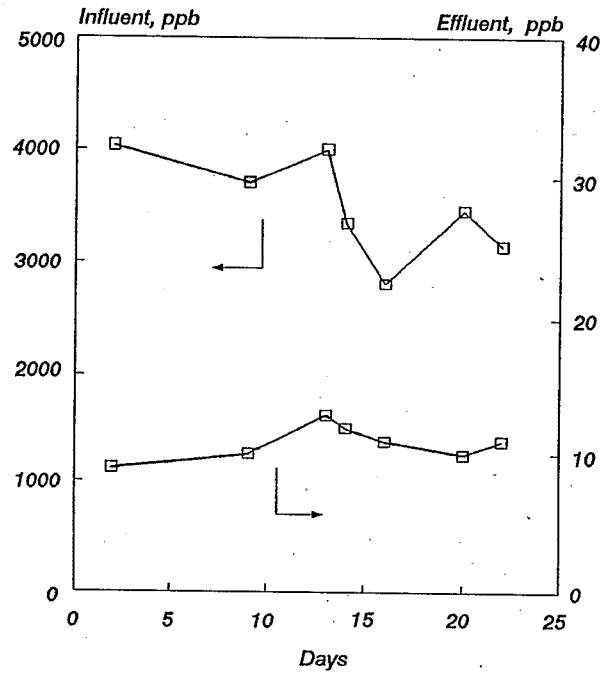


Figure B-1. Benzene treatment by BATS.

Table B-1. Treatment of Solvent-Contaminated Process Water

	Influent (mg/L)	*Effluent (mg/L)*	*% Removal*
Methyl ethyl ketone	*43.0*	*<0.005*	*>99.9*
Total BTEX	*1.3*	*<0.01*	*>99*
Tetrahydrofuran	*5.7*	*0.014*	*>99.7*
Total Unknown Peaks	*5.0*	*<0.05*	*>99*

Summary

The BATS technology demonstrated under the SITE program has wide applicability for treatment of contaminated groundwaters and process waters. Many contaminants are amenable to biodegradation by indigenous microorganisms, and in some cases, microbial amendment can be used to promote biodegradation of recalcitrant compounds. The BATS can achieve high removal efficiencies at relatively high organic loading rates. Contaminants amenable to treatment include pentachlorophenol, gasoline components (BTEX), solvents, PAHs, and substituted phenols. Table B-2 summarizes results of laboratory, pilot-scale, and commercial trials of the system.

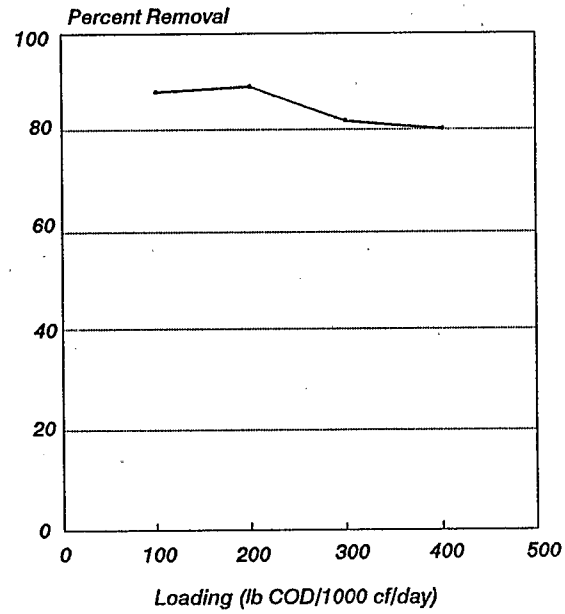


Figure B-2. Phenols removal by BATS.

Table B-2. BATS Performance Data

Description (Waste/Loc.)	Scope	Contaminants	Influent mg/L	Effluent mg/L	Removal %
Wood preserv. (GA)	lab treat	COD	1700	60	96
		Total K001	70	1.3	98
DOE Mfg site (LA)	lab treat	TCE	10	0.05	99
		vinyl chloride	3	<0.005	>99
		DCE	10	<0.005	>99
		PAH	10	2	80
Wood preserv. (GA)	lab treat	COD	100	70	30
		total phenols	2	0.6	70
		PAHs	1.2	0.02	98
Wood preserv (AL)	lab treat	COD	2000	300	85
		total phenols	6.3	0.8	87
Wood preserv. (GA)	lab treat	COD	15000	1800	88
Wood preserv. (AK)	lab treat	PCP	43	3	93
Wood preserv. (GA)	lab treat	PCP	4.5	<0.5	>89
		COD	11000	2500	77
Wood preserv. (TX)	bench cont	PCP	70-80	0.2-0.5	99
		total phenols	10-50	<0.5	>95
		COD	5500	600	89
Tape mfg. (CA)	bench cont	MEK	40-50	0.005	>99
		THF	5-10	0.02	>99
		Cyclohexanone	—	0.02	—
		COD	3100	730	76
Wood preserv. (Canada)	bench cont	PCP	9-10	0.03-0.5	>94
		total phenols	5-6	0.6	>88
		COD	800-850	300-350	>56
Gas Station (MN)	pilot	BTEX	5-10	<0.08	>98
Wood preserv. (MN)	pilot	PCP	90-100	0.5-2	>97
		Total PAHs	10-13	0.5-1	>90
		COD	250-300	150-200	—
Wood preserv. (GA)	pilot	PCP	10-15	0.2-0.5	>95
		Total phenols	50	20-30	>40
		COD	10-11000	5-6000	—
Window mfg. (WI)	pilot	PCP	2-5	0.03-0.5	>75
		BTEX	1	<0.01	>99
Wood preserv. (TX)	pilot	total phenols	20-200	1-5	>75
		COD	500-1500	200-800	—
Wood preserv (MN)	pilot	PCP	40-45	0.1-1	>98
		TOC	80	50	>38
Window mfg. (IA)	comm (.75 gpm)	PCP	90-100	<0.5	>99
		BTEX	7-8	0.1-0.2	>97
Gas Station (MN)	comm	BTEX	3-5	<0.01	>99
Wood preserv. (TX)	comm	total phenols	50-150	1-5	>90
		total PAHs	5-6	0.3	>94

Appendix C
SITE Demonstration Results

Introduction

The goal of this demonstration project was to study the effectiveness of the BioTrol ATS in removing PCP and PAHs from wood treating wastewaters. After considering another site, the MacGillis and Gibbs site in New Brighton, MN became the prime candidate on the basis of the Remedial Investigation/Feasibility Study (RI/FS) that led in its inclusion on the National Priorities List in 1984. The RI/FS study suggested that the groundwater under the site could be heavily contaminated with both target species. In addition, BioTrol, Inc. had already treated process water contaminated with pentachlorophenol in conjunction with its soil washing unit at the facility.

The MacGillis and Gibbs Company site had been used for wood treatment since the early 1940s. Creosote was the preservative until the mid-1950s when a shift was made to pentachlorophenol in a light oil. Impregnation was carried out in open troughs, resulting in significant spills and drippage. In addition, the pentachlorophenol/oil mixture occasionally was used for weed control throughout the site. In the 1970s, pentachlorophenol was replaced by the newer chromated copper arsenate process and enclosed pressure kettles were substituted for the open troughs, thereby eliminating many of the sources of contamination.

An adjacent facility, the Bell Pole and Lumber Company, also was treating wood during the same period. While it is still unconfirmed, there may be movement of contaminated groundwater from the Bell site to the MacGillis and Gibbs site. A disposal area in the western portion of the MacGillis and Gibbs site also may be a source of soil and groundwater contamination. Figure C-1 presents the general layout of the facility and the location of two wells that were drilled to assess the suitability of the site for the SITE demonstration project.

While the RI/FS sampling results suggested that there were pockets of creosote and pentachlorophenol contamination as a result of operations dating back to the 1940s, there were no groundwater test well results to assure that an appropriate wastewater (sufficient flow, suitable levels of pentachlorophenol) would be available for the demonstration. Therefore, two wells were drilled in locations based on the RI/FS reports (Figure C-2). During the drilling, rapid tests for pentachlorophenol (PCP) were carried out at increasing depths using the High Pressure Liquid Chromatography (HPLC) method devised by BioTrol. [Data in the QA comparison study conducted as part of the QA program confirmed that BioTrol's HPLC data are comparable to data from EPA's SW-846 Method 8270.] The first of the two wells contained about 45 mg/L of PCP, adequate for the demonstration (although a higher level would have been preferred) and was of adequate flow (>5 gpm) for the demonstration project. This well was fully developed by pumping for about 69 hours; further PCP analyses at about 10 hour intervals (by HPLC) confirmed the 45 mg/L range. The second well, located about 65 feet away, contained an unacceptably high level of oil (a lens of oil), significantly lower PCP levels, and inadequate flow when subjected to a pump test of flow (Table C-1).

Upon consideration of the BioTrol process and the groundwater available, it was determined that the key variable that could be tested was flow rate. At a constant concentration, this allowed the capacity of the system in terms of pentachlorophenol removal to be studied. To avoid shock loading and the need for re-acclimation, the flow rate into the system was incrementally increased, allowing it to stabilize at each flow rate so that analytical results of "steady state" operation could be obtained. Three experimental stages of two week duration, at 1, 3, and 5 gpm flow rate, were selected on the basis of the capacity of the pilot scale system.

Influent, effluent, and intermediate points in the bioreactor were sampled by 24-hour composites for PCP or full semivolatile organic scans during each regime. Other constituents were sampled and analyzed at varying frequencies and locations, including the well, during each experiment using appropriate grab or compositing techniques. Included were oil/water, total and volatile suspended solids, volatile organics, nitrogen and phosphorus nutrients, and heavy metals. Chloride and TOC analyses were given particular attention since changes in these parameters should parallel pentachlorophenol destruction and establish whether mineralization of the pentachlorophenol does occur, as claimed by the vendor.

Air leaving the bioreactor was also monitored for volatile organics and semivolatiles, before and after a carbon adsorber, to determine whether stripping was a significant contributor to removal. The Quality Assurance Project Plan also called for the sludge in the bag filter to be collected and analyzed to learn if absorption of pentachlorophenol on the biological growth was a contributor to removal; however, the nature of the filter and the small amount of sludge produced allowed only limited analyses. The effluent from the aqueous carbon adsorber was also analyzed to assure that the discharge met the 2 mg/L pentachlorophenol limit imposed by the POTW.

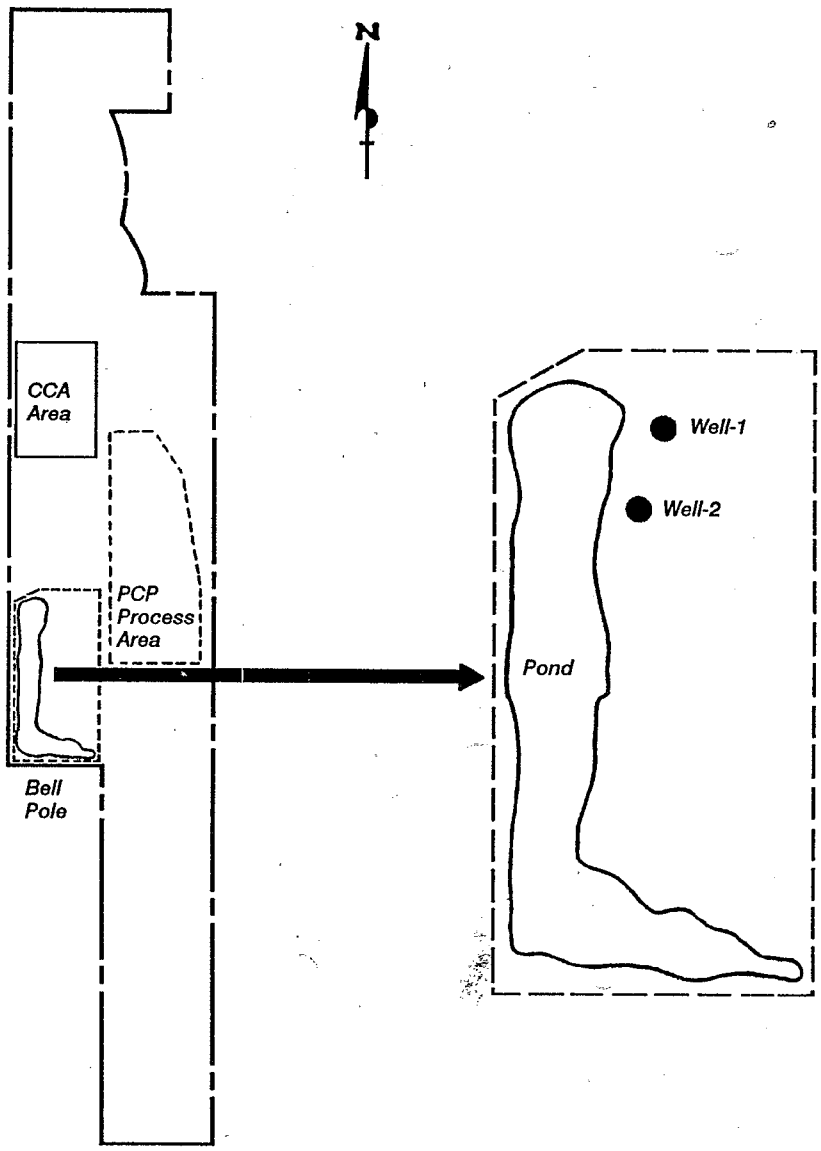


Figure C-1. MacGillis & Gibbs site.

Field Activities

BioTrol personnel were responsible for acclimating the system over about a two week period using the selected well water in a recycle mode. The system was inoculated with a PCP-specific flavobacterium after one week. EPA contractor personnel initiated sampling when BioTrol advised EPA that the system was acclimated. A separate laboratory trailer was available where contractor personnel could prepare equipment and samples, although much of the sample handling was done outside.

Test Procedures

Composite samples were collected in ice-chilled Isco samplers for 22 hours. Grab samples were taken on a predetermined schedule using transfer beakers or by direct immersion of bottles and then were processed in a manner similar to that for the composite samples. Samples were transferred to bottles, inhibited or preserved as called for by the individual methods, labelled, sealed, and shipped in ice-filled coolers to off-site laboratories by overnight express. Flow was occasionally measured manually at the well as well by monitoring readings from a flowmeter on the effluent line. The temperature, dissolved oxygen, and pH in the three chambers of the bioreactor and the groundwater were also documented to assure that no gross change in conditions affected reaction effectiveness. Sampling points are indicated on the schematic of the system, Figure C-3. The sampling schedule, analytical protocols used and results, and QA/QC protocols are described in the Technology Evaluation Report. The ongoing QA program allowed for the collection and reporting of high quality data.

Table C-1. Analyses of Wells on MacGillis and Gibbs Site

Well No.	Max. Flow (gpm)	Avg. PCP (mg/L)
1	28	45.9 [a]
2	3	11.2 [b]

[a] by HPLC during 69 hr well pump test
[b] by HPLC after development, well not "pump tested"

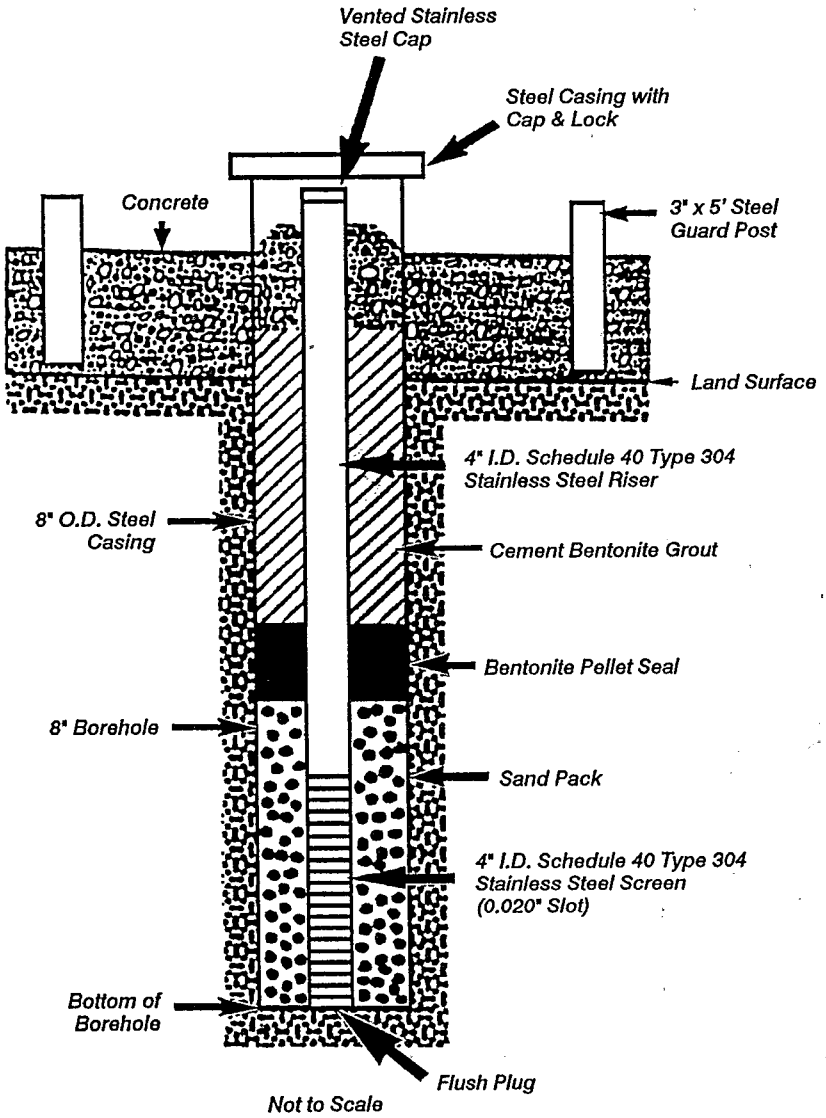


Figure C-2. Well construction.

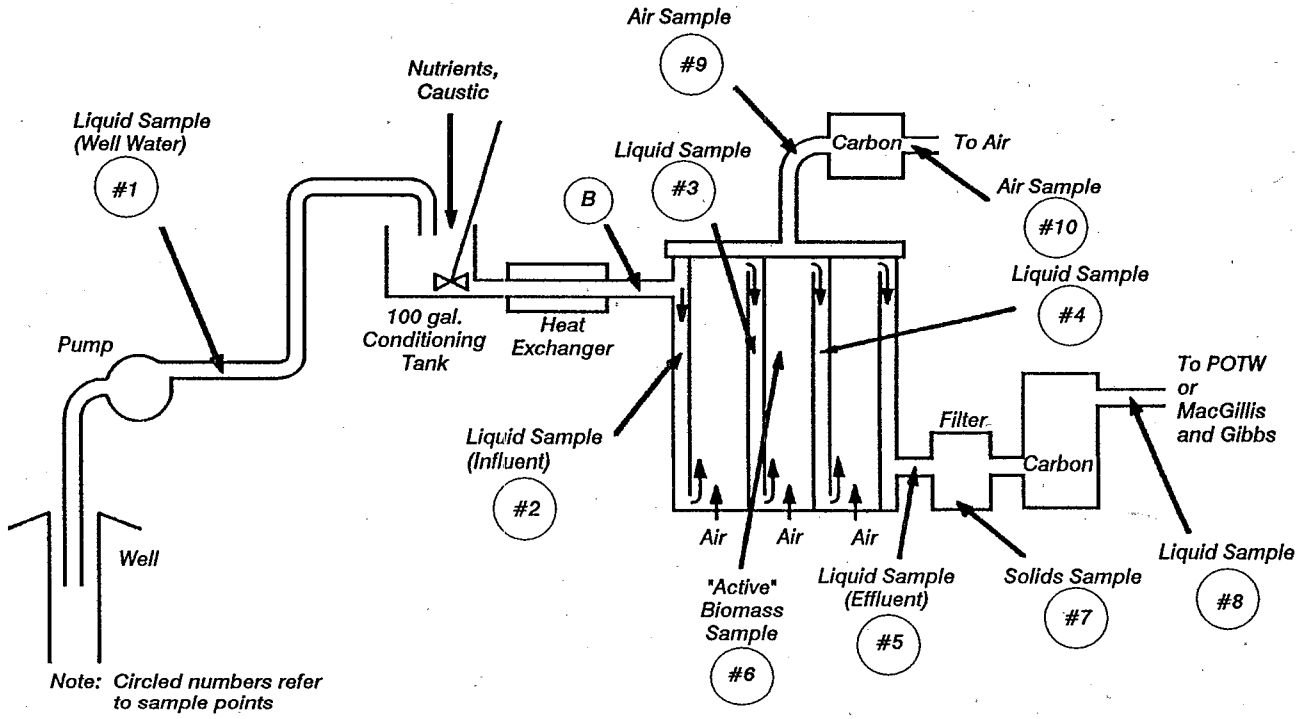


Figure C-3. BioTrol aqueous treatment system (BATS) with sampling points shown.

With the exception of an inoperative dissolved oxygen meter at the outset of the project, all process and sampling equipment functioned well. The design of the reactor and the mobile trailer is such that space was very limited and some improvisation was necessary in collecting certain samples.

Air monitoring of the exhaust stack from the bioreactor before and after the carbon adsorber used a modified MM5 stack method and XAD adsorbent resin traps. Modifications were necessary when determining air flow through the system, because of the narrow diameter of the stack (3-4 inches). These tests were carried out about once per week for three weeks.

The sludge in the bag filter could not be readily, consistently, nor completely removed from the bag. Eventually, the bag was removed at arbitrary times and cut up so that solids could be flushed from the fabric for sampling purposes.

Results

System Parameters

Nitrogen as nitrate, nitrite, and ammonia, and phosphorus as phosphate were monitored over the course of the investigation. No unusual effects were observed; the presence of residual nutrients in the effluents suggests that reaction (biodegradation) was not inhibited by insufficient nutrients.

Similarly, dissolved oxygen was measured in each chamber of the reactor twice daily over the course of the study and found to remain reasonably constant between 5 and 6 mg/L. There was a slight increase in the dissolved oxygen as the

water passed through the system and was aerated by the air sparger system. The incoming groundwater contained <1.0 mg/L dissolved oxygen.

Some variation in temperature was observed throughout the project (Table C-2). The temperature of the influent to the bioreactor was lower in the 3 gpm (14-17 C) and the 5 gpm (14-21 C) studies than in the 1 gpm study (22-25 C). This probably was partially due to a decrease in the temperature of the groundwater over the course of the program, and possibly also due to inadequate heat exchange to the incoming groundwater, which was at a lower temperature (11 - 16 C). The heater was not used. As expected, temperature increased slightly as the wastewater passed through the system, i.e., the effluent temperature was higher than the influent temperature in all three study segments.

Table C-2. Temperature Across BioTrol System

	Temperature (°C, avg)				
Flow (gpm)	*Gdwater #1*	*Influent #2*	*Midpt #3*	*Midpt #4*	*Effluent #5*
1	*21*	*23.4*	*24.6*	*24.5*	*24.8*
3	*11*	*15.7*	*20.4*	*20.4*	*20.9*
5	*13*	*14.6*	*20.8*	*21.0*	*20.9*

While vendor specifications called for a pH of about 7.3 in the tempering (conditioning) tank, the pH measured in the three chambers of the bioreactor usually was somewhat higher, particularly at the lower flows and, at least at the 1 gpm flow, appeared to increase across the system. The pH of the groundwater was consistently in the range of 6.7-6.9 standard units.

Initial oil and grease values of approximately 50 mg/L were reduced to <10 mg/L by passage through the system. Total suspended solids levels (TSS) in the incoming well water were quite low (<5 mg/L) and increased (to 54 mg/L at 1 gpm, 26 mg/L at 3 gpm, and 18 mg/L at 5 gpm) over the course of the study (Table C-4). At these levels, the suspended solids (sloughed biomass) probably do not represent a significant mechanism for removal of organic pollutants. Volatile suspended solids represent approximately 40% of the total suspended solids in the effluent, increasing slightly (to ~50%) at the highest flow rate.

Pentachlorophenol Removal

With the receipt of the first PCP analytical data generated by SW-846, Method 8270, it became clear that the anticipated results were not being obtained. Influent PCP values (composite samples) were significantly lower than the concentration at the well (grab samples). Analyses by BioTrol using grab samples just before the bioreactor (Point "B" in Figure C-3) and the HPLC method agreed with the higher well data. At first it was thought that the difference might have been due to foaming during the extractions for the analytical procedure (SW846 Methods 3510/8270). While that problem persisted throughout the study and did affect the recovery achievable for the samples, it became clear that it was not the cause of the drastic differences between the well or BioTrol's samples and the influent chamber samples.

Additional QA testing indicated that BioTrol's HPLC method for PCP and EPA's Standard Method (SW-846, Method 8270) are comparable when extraction efficiency is taken into account. This information aided in establishing that the well water concentrations of PCP were actually better representations of the influent concentrations than the influent data by the SW-846 method. Consequently, removal efficiency determinations (Table C-4) were based on well water and effluent data (both by Method 8270) instead of the influent samples.

Other possible explanations for the anomaly in results were then considered, including absorption on the walls of the bioreactor, separation of a PCP-in-oil layer, and backmixing under the underflow weirs separating the chambers. Backmixing appears to be the best explanation for the low values obtained for the influent and the gradual improvement in agreement between well water data, BioTrol HPLC data, and influent data as the flow rate was increased each two weeks. Well water (sampling point #1) and influent (sampling point #2) PCP values in Table C-4 are much more in agreement at the 5 gpm flow than at the 1 or 3 gpm rates, suggesting that the importance of the backmixing decreases as the flow increases.

Grab samples also were taken from a "T" just before the influent chamber (point B on Figure C-3) and analyzed by BioTrol's HPLC method. These samples, which were not subject to the backmixing, agreed with the well samples (sampling point #1). Consequently, the grab samples from the well were primarily used in determining PCP removal. Within limits discussed later, free chloride and TOC data at the several sampling points also support this conclusion.

On the assumption that the correct concentration of PCP in the influent was about 45 mg/L in the 1 gpm study but was about 7 mg/L in the first chamber of the bioreactor, it was estimated that approximately 5 gallons was "leaking" back through the system for every gallon introduced.

Nevertheless, using either the well water or sampling point #1, it is clear that the BioTrol Aqueous Treatment System does effectively remove PCP from the groundwater as it moves through the system. Concentrations of PCP after treatment (but before carbon polishing) were about 0.13 mg/L at the 1 gpm flow rate and increased to an average of 0.99±0.49 mg/L at the 5 gpm flow rate.

The BATS achieves at least 95% PCP removal at the 5 gpm flow rate and 99% at the lower flow rates. Even using the lower influent chamber analytical results (#2), percent removal is still excellent.

Based on the estimated mass of PCP introduced to the system over each two week experimental period, and assuming that all PCP is lost by biological degradation, mass removals of >95% are consistently achievable (Table C-5).

Table C-3. Average TSS and Oil Across the BioTrol System

Flow (gpm)	Groundwater TSS	Groundwater O/G	Influent TSS	Influent O/G	Effluent TSS	Effluent O/G
	mg/L		mg/L		mg/L	
1	2.5 ± 0.7	54.5 ± 2.1	29.6 ± 9.4	57.5 ± 10.7	53.6 ± 6.6	6.0 ± 0.4
3	13 ± 12.7	61.0 ± 1.4	24.2 ± 17.6	37.8 ± 14.9	26.3 ± 11.1	6.0 ± 1.3
5	1.5 ± 0.7	47.5 ± 10.6	15.7 ± 8.9	50.8 ± 10.5	22.5 ± 9.5	8.0 ± 2.4

Note: Complete data can be found in the Technology Evaluation Report.

Table C-4. Average Pentachlorophenol Removal by BioTrol System

Flow (gpm)	PCP (#1) Gdwtr	PCP (#2) Infl	PCP (#5) Effl	Removal (%) Gdwtr/Eff	Removal (%) Infl/Effl
1	42.0 ± 7.1 [a]	6.9 ± 3.4	0.13 ± .25	99.8	98.1
3	34.5 ± 7.8 [a]	19.0 ± 5.8	0.34 ± .15	98.5	98.2
5	27.5 ± 0.7 [a]	24.2 ± 6.8	0.99 ± .49	96.4	95.9

[a] *The gradual decrease in groundwater concentration may be a result of well drawdown over the 6 weeks of operation.*

Comparison of analytical results for PCP in as-is samples and in filtered samples indicated that very little if any of the PCP was absorbed on the filterable solids. While there were measurable concentrations of PCP in the sludge samples, the amount of sludge exiting the bioreactor was so small that this is not considered a significant contributor to the removal of PCP from the system. Similarly, the low concentration of oil in the effluent (<10 mg/L) strongly argues against loss of PCP by extraction into that phase. Analyses of the air exhausted from the bioreactor confirmed that no detectable quantities of pentachlorophenol were lost by this route.

Table C-5. Mass Removal of Pentachlorophenol

Week	Flow (gpm)	Total PCP In (lbs)[a] (#1)	Total PCP Out (lbs) (#5)	Removal (%)
1	0.98	3.32	.178	94.6
2	1.0	2.65	.002	99.9
3	2.92	8.39	.077	99.1
4	3.02	6.29	.075	98.8
5	5.14	9.99	.533	94.7
6	5.03	10.13	.221	97.8

[a] *Based on well water (#1) analyses*

Chloride and TOC monitoring of the groundwater and the effluent produced results that are consistent with the vendor's claim that the pentachlorophenol is mineralized, but indicate that other contributors to chloride and TOC are present. Table C-6 summarizes the actual *changes* in chloride and TOC and the changes calculated on the basis of the observed decrease in pentachlorophenol.

Removal of other organic constituents, even including oil or biomass, may explain why the observed decreases in TOC levels are greater than calculated. The concentrations of mono-, di-, and trichlorophenols (by SW846 Method 8270) all were below the detection limits in the semivolatile scans of the groundwater, influent, and effluent; however, the detection limits were often quite high since pentachlorophenol was the primary "target" of the analyses. It is also reported that commercial pentachlorophenol may contain as much as 20% by weight of tetrachlorophenols (TCPs). If, for example, the PCP were accompanied by 20% by weight as tetrachlorophenols (which were not target analytes), this would mean 8.4 mg/L of TCPs were present and could contribute 5.1 mg/L of chloride. [Review of two archived scans of groundwater indicated total TCP contents of about 4% and 10% of the PCP concentrations.] And, if all the partially chlorinated isomers (mono-, di-, and trichlorophenols) were present at just below their detection limits in the well water sample, they could contribute an additional 6.4 mg/L of chloride. Table C-7 summarizes the calculated chloride yields during the 1 gpm study.

Polynuclear Aromatic Hydrocarbon Removal

Concentrations of the various PAHs in the incoming well water were lower than anticipated and below the detection limits. The high detection limits for PAHs in the semivolatile organics GC/MS scans, often in the range of 2 mg/L when analyzing for PCP in the 10-50 mg/L range, precluded measurements at µg/L level. Two values for total PAHs obtained during the predemonstration well drilling effort, 145 and 295 mg/L, are consistent with the absence of PAHs at the indicated detection limits during the project. The lack of specific values for PAHs in the well water and/or the influent makes it impossible to assess the removal of these chemicals across the system. Specific PAHs also were not measurable in the effluents even though the detection limits were now 10-100 µg/L. In other studies by BioTrol it was demonstrated that PAHs are removed by the BATS (see Appendix D). Limited analyses on a few sludge samples for PCP or PAHs indicated detectable quantities of selected PAH compounds, as noted in Table C-8. Because of the small amount of sludge discharged, accumula-

tion of PAHs (or PCP) in the sludge is not a significant contributing mechanism for the removal of these species.

Monitoring of the reactor exhaust air, before and after the carbon adsorber, indicated that some stripping of polynuclear aromatic hydrocarbons does occur, probably due to the air bubbled through system (Table C-9). Additional air was also introduced to the stack during the monitoring, which may explain the observation that some naphthalene did pass through the carbon, possibly by an air "regeneration" phenomenon. Small amounts (=< 1 µg/L) of phenol, 2,4-dimethyl phenol, and other, higher molecular weight PAHs (dibenzofuran and fluorene) also were found occasionally in the pre-carbon samples but not in the after-carbon samples.

Polychlorinated Dibenzo-p-Dioxins/ Dibenzofurans

Selected samples were scanned for the various dioxins and furans using high resolution GC coupled with low resolution MS. A number of the chlorodioxin and furan species were found to be present in the influent and the effluent, usually at the nanogram/liter level. The 2,3,7,8-TCDD isomer was reported at above detection limit in only one sample (62 ng/L in an effluent sample). Review of the data (Table C-10) also indicates an increase in concentration for all the isomers as the wastewater moves through the reactor, possibly due to accumulation of dioxins on the biomass, which does increase across the system and is sloughed off into the effluent.

Table C-11 presents dioxin/furan data for the sludges collected in the bag filter during the study. Some dioxin/furan isomers were found in the sludge, in the ng/gm range based on wet weights. This is not considered a problem in light of the small amount of sludge generated, except that the sludge may require disposal as a dioxin-contaminated material.

Heavy Metals

While arsenic and various heavy metals were found in the groundwater at low concentrations, these constituents pass through the system with little change in concentrations (Table C-12)—with the exception of the first effluent sample, which shows anomalous results

Volatile Organics

Analyses for volatile organics indicated that few of these materials were present in the groundwater, even at low concentrations. Levels were further reduced by passage through the treatment system, probably by stripping. Volatile organics were not detected in the exhaust air collected from the reactor.

Biomonitoring

Biomonitoring with two different species, minnows and water fleas, was carried out on the groundwater, the influent, and the effluent. The results confirmed that the groundwater was toxic to these species and that treatment removed the cause of the toxicity. The results in Table C-13, presented as LC(50) values, reflect the percentage of groundwater, influent, or effluent in the water that could be tolerated in the test water before 50% of the species succumbed. When 1% or even less of either the groundwater or the influent is incorporated in the test water, 50% or more of the test species die during the test period. After treatment, the effluent has essentially no adverse effect on either species during the test period, even when 100% effluent is the test water.

Table C-6. Comparison of Chloride and TOC Changes with PCP Removal

Flow (gpm)	PCP change	Increase in Cl(fd)[a] mg/L	Cl(calc)[b]	Decrease in TOC(fd) mg/L	TOC(calc)
1	-41.9	+40.2	+27.9	-25.5	-11.3
3	-34.1	+37.2	+22.7	-31.5	-9.2
5	-26.5	+27.2	+17.6	-21.0	-7.0

[a]fd = found; (effluent - groundwater)
[b]calc = calculated from change in PCP, as 5Cl/PCP & 6C/PCP

Table C-7. Potential Chloride Contributions from Partially Chlorinated Phenols

Substance	Detection Limit mg/L	Chloride Yield mg/L (calc)
2-Monochloro	2	0.6
2,4-Dichloro	2	0.9
2,4,6-Trichloro	2	1.1
2,4,5-Trichloro	10	5.4
Tetrachloro	na, 2PCP[a]	5.1
Possible non-PCP total		**13.1**
Pentachloro	42 found	27.9
Total Calculated		**41.0**

[a]Estimated only, on the basis that PCP may contain as much as 20% tetrachloro- isomers.

Table C-8. Sludge Analysis Results

Sample	Pollutant	Conc (mg/kg dry)
B-09-07S	PCP	34
	Pyrene	15
	Chrysene	5.3
	Benzo(b)fluoranthene	10
	Benzo(a)pyrene	6.1
C-05-07S	PCP	170
	Anthracene	92
	Benzo(k)fluoranthene	74
C-10-07S	PCP	2.7
	Anthracene	3.0
	Pyrene	2.5
C-10-15S[a]	PCP	18
	Phenanthrene	1.9

[a] This sample is sludge found adhering to walls of bioreactor.

Table C-9. PAHs in Air Emissions from Bioreactor

Test #	Liquid Flow at Time of Test	Naphthalene b.c.[a]	Naphthalene a.c.[a]	2-me Naphthalene b.c.	2-me Naphthalene a.c.	Acenaphthene b.c.	Acenaphthene a.c.
		[----------(µg/L)----------					]
1	1	6.5	0.6	4.7	nd[b]	0.5	nd
2	1	3.8	1.6	3.0	nd	0.3	nd
3	1	4.6	1.7	3.7	nd	nd	nd
4	3	4.6	0.6	6.7	nd	0.7	nd
5	5	34.6	1.1	47.9	nd	2.8	nd

[a] b.c. = before carbon adsorber
a.c. = after carbon adsorber
[b] nd = not detected

Table C-10. Dioxins/Furans Found in System

Week	HpCDD	HpCDF	HxCDD	HxCDF	OCDD	OCDF	TCDD	2378-
	Influent/Effluent Concentrations (ng/L)							
1	60/180	<10/20	-[a]	-	340/1100	<17/23	-	-
2	32/180	<2.8/30	<2.2/8.8	<1.5/4.1	170/910	<7.3/40	-	-
3	<4.4/4.3	-	-	-	28/42	-	-	-
4	-	-	-	-	<8.6/28	-	-	-
5	25/62	2.1/7.0	-	-	140/390	<4.8/12	-	-
6	-	-	-	-	-	-		<3.2/62

[a] A '-' indicates the isomer was absent or below detection limit in both influent and effluent.

Table C-11. Dioxins/Furans Found in Sludge

Week	Sludge Concentrations (ng/gm)							
	HpCDD	HpCDF	HxCDD	HxCDF	OCDD	OCDF	TCDD	2378-
1	260	46	13	13	1900	41	<.054	<.054
2	no sample							
3	no sample							
4	25	3.9	1.4	1.7	190	3.0	<.088	<.088
5	<.20	<.14	<.17	<.12	0.98	<.22	<.16	<.16
6	23	4	1.5	1.7	140	3.1	<.08	<.08

Table C-12. Metals Found in System

Week	Concentration of Metals (Groundwater/Effluent) (µg/L)					
	As	Cu	Ni	Cr	Pb	Zn
1	6.4/220	25/4400	60/390	ND[a]/450	7.7/580	32/20,000
2	4.1/5.6	19/37	54/67	ND/8.0	11/ND	20/20
3	5.4/5.3	20/23	81/73	ND/ND	ND/11	ND/8.0
4	—[a]/6.0	—/19	—/60	—/ND	—/8.1	—/13
5	6.5/7.7	—/23	67/71	ND/23	3.9/6.1	23/30
6	5.9/5.7	ND/30	91/87	7.0/ND	6.9/5.9	20/17
DL[b]	1.5	12	21	6.7	2.9	5.7

[a] A '—' indicates the analysis was not carried out; an ND indicates the concentration was below detection limit.
[b] DL = Detection limit

Table C-13. Acute Biotoxicity of Groundwater and Treated Effluent

Week	Flow (gpm)	LC(50)-Daphnia[a] (% Wastewater/Test water)			LC(50)-Minnow[b] (% Wastewater/Test water)		
		Grdwtr	Infl.	Effl.	Grdwtr	Infl.	Effl.
1	1	—	0.35	100	—	0.3	100
2	1	—	0.84	100	—	1.07	100
3	3	—	0.26	100	—	0.43	100
4	3	—	0.54	100	—	0.3	35
5	5	1.0	0.61	100	0.22	0.20	100
6	5	0.27	0.66	100	0.22	0.20	100

[a] 48 hour static test at 20°C, Daphnia magna
[b] 96 hour static test at 20°C, Pimephales promelas

Appendix D-1
Full Scale Wood Preserving Site

Introduction

The subject of this study is a wood preserving facility using the Boultonizing process that generates a process water contaminated with creosote-derived phenolics, polynuclear aromatic hydrocarbons (PAHs), and aromatic compounds extracted from the wood. The BATS unit offered an opportunity to treat this wastewater biologically in a compact, efficient manner with minimal operator attention.

The process water to be treated contains significant oily material. It is treated in two stages for oil/water separation and then cooled in a cooling tower. Water from the cooling tower, which was previously discharged to an on-site lagoon, was treated in the pilot study and, subsequently, in the commercial unit. The character of the feedwater varied considerably, depending on the type of wood treated, rainfall, and evaporation rates (Table D-1).

Table D-1. Characteristics of Phenolic Process Water

Constituent	*Average (mg/L)*	*Range (mg/L)*
Phenols	*129*	*11-327*
SCOD	*1059*	*412-1912*
BOD	*752*	*75-1200*
TSS	*104*	*22-659*
Oil/grease	*28*	*8-270*
pH		*6-9*
Temperature (F)		*80-90*

Pilot Scale Studies

A pilot scale demonstration study using a 3-celled mobile unit with a 15 gpm flow capacity was carried out over six weeks at flow rates of 2 gpm and 1 gpm. Influent and effluent samples were collected daily as 24-hour composites while the bioreactor cells were grab-sampled. Key analyses were total recoverable phenolics (TRP) by Standard Method 510.B and chemical oxygen demand (COD) by the OI Corp. method. In addition, biochemical oxygen demand (BOD), oil and grease, and total suspended solids (TSS) were also analyzed. On three occasions during the course of the pilot demonstration, samples were analyzed by EPA Method 610 for polynuclear aromatic hydrocarbons (PAHs).

Based on analytical results from a pilot unit (Figure D-1), effluent concentrations of phenols were almost always below 1 mg/L, corresponding to an average phenolics removal of >99%. Decreases in BOD and COD, while significant, were not as great, possibly due to sloughed biomass. Variations in TSS indicate a cyclic character to the TSS values, suggests that solids accumulation occurs followed by solids release. PAH removal was in the range of 80+%, but elevated PAH levels for total samples (including sloughed solids) from the middle cells suggest that adsorption of PAHs on solids as well as biodegradation is occurring (Figure D-2).

Commercial System Evaluation

Based on the success of the pilot scale demonstration in removing phenolics from the aqueous wastewater, a commercial (30 gpm) unit was installed in August 1988. After a two week acclimation period (no specific bacterium was added), the unit has been in continuous operation with the flow rate starting at 20 gpm and then increased to the design rate of 30 gpm. The effluent is discharged to a POTW. Based on the results for the first 5 months of operation (Table D-2), the system has produced effluent with an average phenolics concentration below 1 mg/L with minimal operator attention.

Table D-2. Wood Preserving Wastewater Treatment by BATS

Month	*Phenolics in Effluent (mg/L)*
August	*0.12*
September	*0.058*
October	*0.14*
November	*0.20*
December	*1.11*
5 Month Average:	*0.33*

Cost Data

Operating cost data were developed on the basis of operation of the commercial unit. Assuming a 30 gpm flow rate and an influent with 1000 mg/L of BOD and 200 mg/L of phenols, the operating costs were as shown in Table D-3.

Conclusions

Based on the pilot scale studies and operation of the commercial unit for several months, the BATS is a cost-

effective means of removing phenolics and PAHs from this wastewater.

The nature of the BATS system is such that it requires a minimum of labor relative to conventional activated sludge systems where trained personnel may be needed to assure that optimum sludge separation and return is carried out.

Table D-3. Operating Cost for BATS Commercial Unit

Cost Item	$/1000 gallons
Electricity (@ $0.06/Kwhr)	0.15
Nutrients (@ $0.71/gallon)	0.14
Labor (10 hr/wk @ $15/hr)	0.49
Total	**0.78**

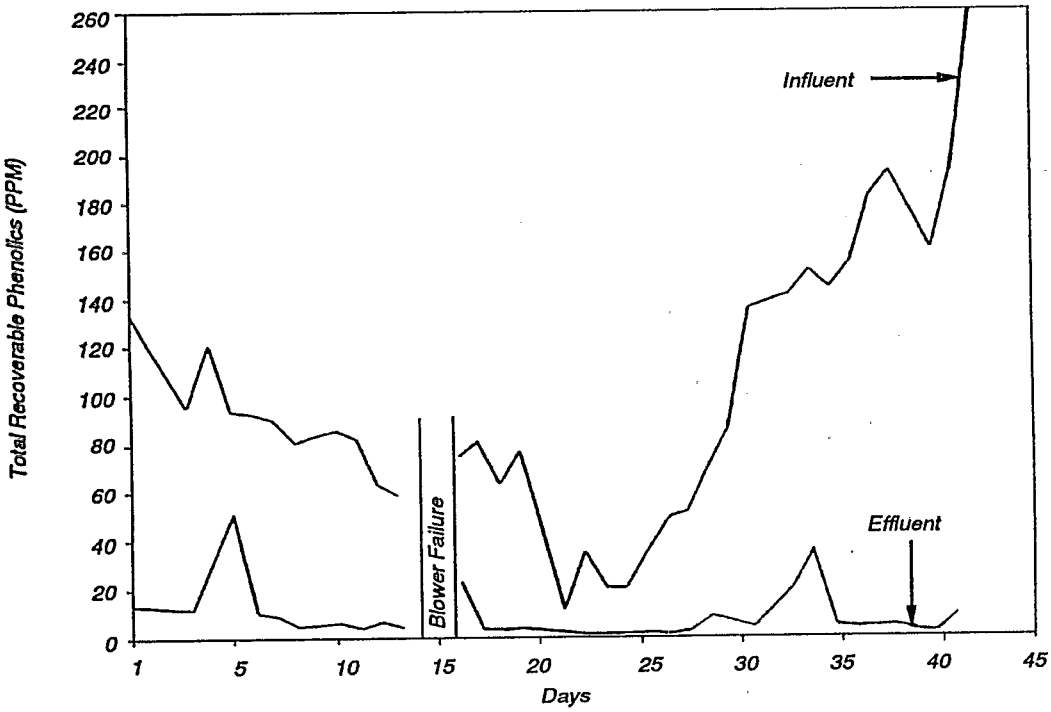


Figure D-1. Phenolics removal in commercial BATS.

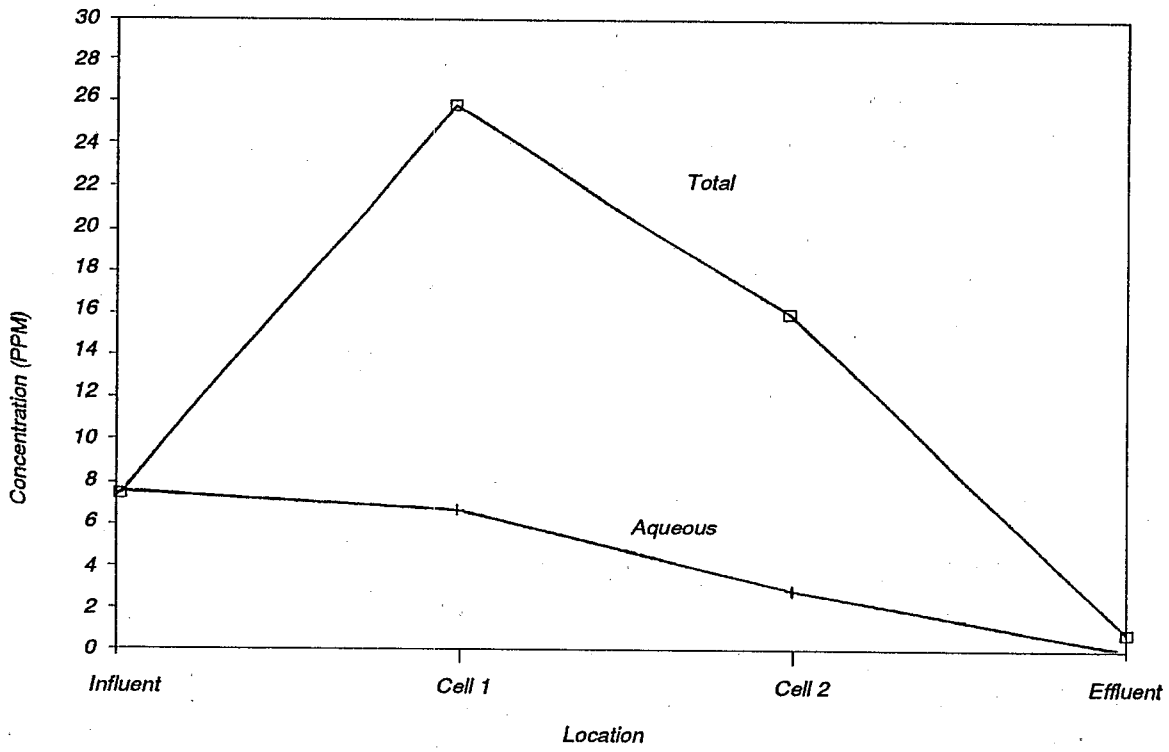


Figure D-2. PAH removal in commercial BATS.

Appendix D-2
Tape Manufacturer
California

Introduction

A tape manufacturing facility in California produces about 15,000 gpd of solvent-contaminated process water. Contributing to a high COD are toluene, xylene, methyl ethyl ketone, tetrahydrofuran, and cyclohexanone. Currently, the plant uses activated carbon pretreatment prior to discharge to the POTW. Biological treatment was considered as an alternate, less costly treatment.

A bench scale continuous flow evaluation of biological treatment using the BATS was carried out. Because of high variability in wastewater loading, the goal of the investigation was to evaluate the effectiveness of the system at various organic loadings, in addition to the removal of specific contaminants.

Bench-scale Study

The bench scale continuous flow studies were carried out using a 55 gallon drum of process water shipped to the BioTrol facility. The system consisted of a 4 in. ID translucent PVC column packed to a depth of 12 in. with 1 in. Intalox PVC saddles to simulate the structured PVC packing used in a commercial unit. Air was injected at the base. The column was inoculated with activated sludge from a POTW and acclimated over 10 days. Continuous flow operation was then maintained for 1 week at each of 3 flow rates: 2, 4, and 8 L/day, corresponding to loadings of 110, 235 and 485 lb COD/1000 ft^3 of packing/day.

Results

Samples were removed by BioTrol and measured for the parameters noted in Table D-4 using standard methods.

Biological treatment effectively removed 99% of the specific components of concern with only slight fall off in efficiency when the loading rate was increased from 110 to 235 lb/1000 ft^3/day. Final effluent with residual concentrations of 5 to 15 µg/L were achieved at the lower loading and somewhat higher at the higher loading.

The difference between removal efficiency for specific components and that for COD is consistent with the presence of other, more recalcitrant constituents. (Other tests indicate that stripping of volatile organics accounts for less than 10% of their removal.)

Cost Data

Using the removal data developed in the bench scale study, cost data were developed for a commercial system with a 10 gpm capacity. On that basis, the total anticipated operating cost would be $3.51/1000 gallons of wastewater as shown in Table D-5.

Table D-4. BATS Removal Efficiency—Tape Process Water

Parameter	Influent mg/L	Effluent mg/L	Removal %
Loading: 100 lb/1000 ft^3/day			
Toluene, xylene	1.3	<0.01	>99
MEK	43.0	<0.005	>99.9
THF	5.7	0.014	>99.7
COD	3178	758	76
Loading 235 lb/1000 ft^3/day			
Toluene, xylene	1.3	0.06	95
MEK	43.0	0.55	98.7
THF	5.7	<0.05	>99.1
COD	3178	1413	55

Table D-5. Operating Cost for 10 gpm BATS

Item	$/1000 gal
Nutrients (liquid fertilizer)	0.32
Electricity (for pumps) (2 lb oxygen/hp-hr and 10 gpm effluent pump @ 50 ft head)	0.37
Labor (10 hr/wk @ $20/hr)	1.98
Base for neutralization (NaOH)	0.84
Total	**$3.51**

Appendix D-3
BATS Treatment of BTEX
Minnesota

Introduction

A truck stop in Minnesota experienced widespread soil contamination by gasoline from leaking underground storage tanks. In addition to removing the tanks and highly contaminated soil, it was necessary to treat soil beneath buildings and groundwater to prevent spread of a contaminated plume.

BioTrol proposed that both goals could be achieved by above-ground treatment of the groundwater in a BATS, followed by reinjection of the treated water to stimulate *in situ* bioremediation of the soil. Laboratory studies demonstrated that with proper additions of nutrients and oxygen, the indigenous microflora were capable of destroying benzene, toluene, ethyl benzene, and xylenes (BTEX) in the soil to below detectable levels in 8 days. Since this remediation scheme depended on initial above-ground treatment to levels suitable for reinjection, a pilot scale evaluation of the BATS was deemed to be necessary.

Pilot-Scale BATS

A single column pilot-scale BATS was installed at a gas station in the Minneapolis area. The reactor column was 1 ft in diameter and filled to 9-ft depth with 1 in. Intalox PVC saddles to simulate the structured PVC packing used in the full scale unit. The system provided 1.6 hr of residence time.

The system was first acclimated for 2 wk with no addition of bacteria except that in the groundwater. The reactor was then sampled daily for 1 wk, using composite samples of influent and effluent taken with a zero headspace sampling device. Analyses of these samples confirmed that >99% removal of BTEX could be achieved with an influent ranging from 1900 to 15,000 µg/L, and effluent concentrations of <20 µg/L for individual components were achieved. The BTEX results are summarized in Table D-6.

Table D-6. BETX Treatment with the BATS

Day	*Influent (µg/L)*	*Effluent (µg/L)*	*Removal (%)*
1	*1962*	*<80*	*>96*
2	*4700*	*<80*	*>98*
3	*15300*	*<80*	*>99*

Full-Scale BATS

On the basis of the pilot study it was concluded that the process was very effective at removing BTEX. A two-stage reactor was installed at the contaminated site to be used in conjunction with a closed loop groundwater extraction system. Modelling of shallow groundwater flow was used to design the extraction well and infiltration gallery network.

The BATS is currently treating groundwater at a 15 gpm flowrate. With a groundwater temperature of 50°F, no heat input has been found necessary to maintain reactivity. With influent BTEX concentrations of approximately 4200 µg/L, consistent reductions to <80 µg/L have been achieved. Measurements of BTEX concentrations in the air exhaust from the reactor established that air stripping accounts for removal of only 5 - 10% of the removed BTEX.

Cost Data

The operating and maintenance cost of the combined in situ and above-ground treatment is expected to average about $9000/yr. Total cost of remediation, including capital, maintenance and operation, but excluding groundwater monitoring and project management fees, is approximately $165,000 with a 3-yr anticipated project life. More detailed information is not available at this time.

Appendix D-4
Pilot Plant BATS
Minnesota

In the fall of 1986, the feasibility of treating contaminated groundwater at a wood preserving site in Minnesota was evaluated in a 9-month pilot study using the BioTrol Aqueous Treatment System. The study was funded by a grant from the U.S. Geological Survey.

The purpose of the study was to establish the long term effectiveness of the BATS for such wastewaters, particularly for the removal of PCP and, secondarily, for PAHs. These materials are commonly found contaminating sites where wood preserving operations using PCP and creosote had been practiced over previous decades. The groundwater at the site contained 60-100 mg/L of PCP based on preliminary studies.

Pilot Plant Study

A simple 30-gallon packed bed reactor was used in the 9-month pilot study. The system was activated with indigenous microflora and later amended with inoculations of a *Flavobacterium* specific to PCP. The unit was operated essentially in a continuous mode, over the length of the study, adjusting pH and adding nutrients as necessary. Air was continuously injected to maintain aerobic conditions.

BioTrol subsequently developed a proprietary bioreactor design specifically suited to treatment of contaminated groundwater with an amended, fixed-film microbial system.

Results

The packed bed system effectively removed PCP, PAHs, and other constituents that were found to be present. The specific rate of PCP degradation was as high as 70 mg of PCP/L of reactor volume/hr, well beyond the values normally reported in the literature. In later work using the proprietary system design, PCP removal rates between 40 and 50 mg PCP/L of reactor volume/hr were consistently achieved, with rates as high as 65 mg/L/hr being achieved. All PCP analyses were carried out using a HPLC method developed by BioTrol. Extensive removal of PAHs was also confirmed. While substantial reductions in COD also occurred, the levels in the effluent indicate the presence of considerable refractory material. Typical results are summarized in Table D-7.

While the influent and effluent data over the 9-month investigation did exhibit occasional elevated levels in the effluent, these usually were attributable to mechanical failures, such as loss of aeration, loss of heat, etc. Daily tabulation of influent and effluent data indicates that the system had excellent recovery capability after such upsets.

No cost data is available for this small scale study.

Table D-7. Groundwater Treatment in 30 gal Packed Reactor

Constituent	Well water (µg/L)	Effluent (µg/L)	Removal (%)
Pentachlorophenol	93,000	nd	~100
Acenaphthalene	4,402	nd	~100
Naphthalene	1,932	81	96
Acenaphthene	2,041	140	93
Phenanthrene	264	38	86
Anthracene	252	20	92
Fluoranthene	466	153	67
Pyrene	232	15	94
Benzo(a)anthracene	292	9	96
Chrysene	171	8	95
Benzo(b)fluoranthene	448	8	98
Benzo(k)fluoranthene	178	7	96
Benzo(a)pyrene	211	5	98
Dibenzo(a,h)anthracene	296	33	89
Benzo(g,h,i)perylene	315	4	99
Fluorene	545	nd	~100
Indo(1,2,3-c,d)pyrene	203	nd	~100
COD (mg/L)	250-300	100-150	>40

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