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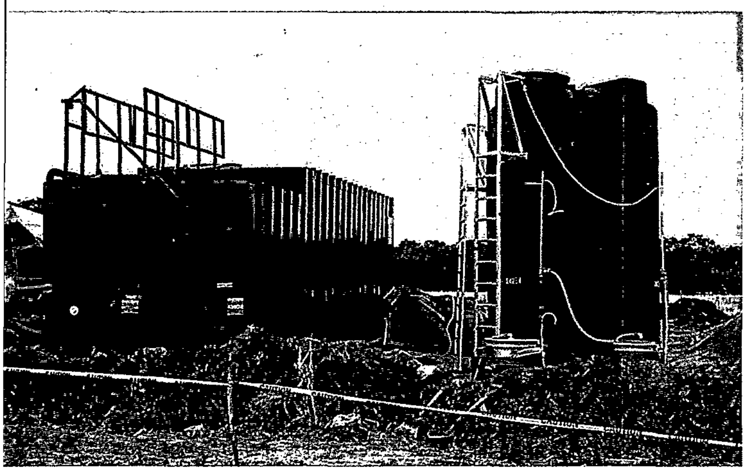
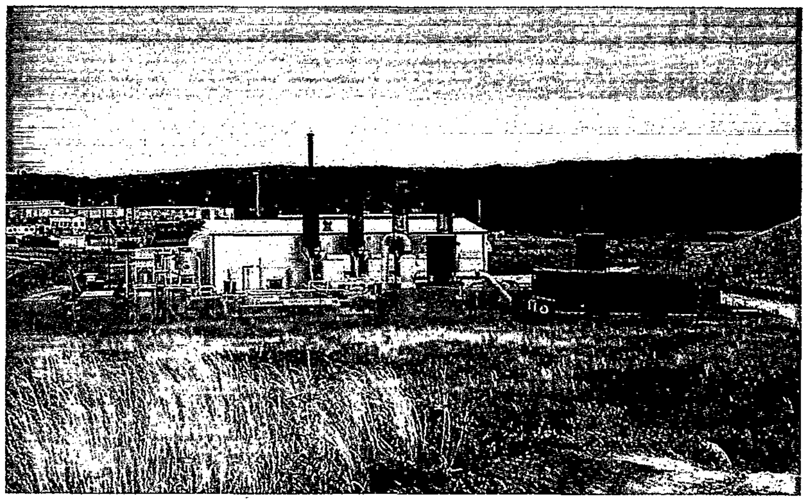
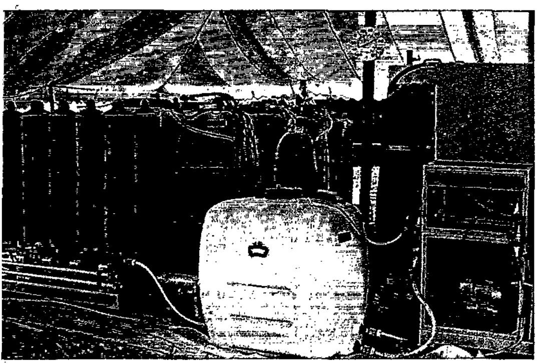
EPA

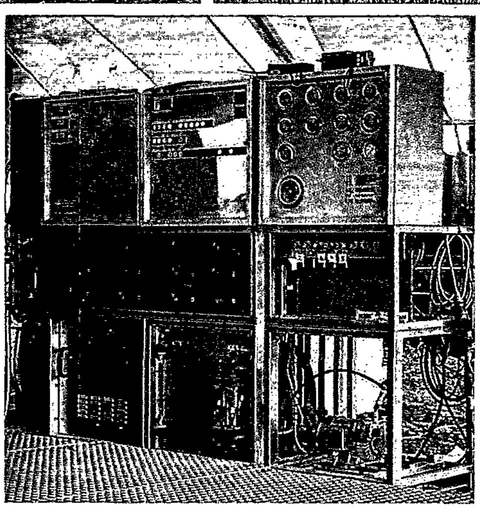
Rochem Separation Systems, Inc. Disc Tube™ Module Technology

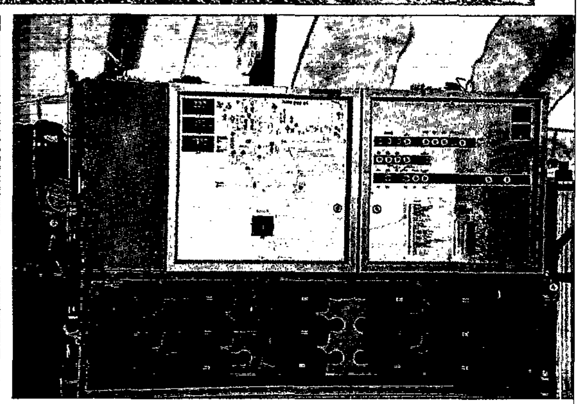
Innovative Technology Evaluation Report











SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-96/507
January 1998

Rochem Separation Systems, Inc.
Disc Tube™ Module Technology

Innovative Technology
Evaluation Report

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

Notice

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-CO-0048. This document has been subjected to the EPA's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names of commercial products does not constitute an endorsement or recommendation for use.

Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The Program is administered by the EPA Office of Research and Development (ORD). The purpose of the SITE Program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

This project consisted of a demonstration conducted under the SITE Program to evaluate the Disc Tube™ Module technology developed by Rochem Separation Systems, Inc. The technology is an innovative membrane separation process which utilizes commercially available membrane materials to treat difficult fluids ranging from seawater to organic solvents. This Demonstration was conducted on hazardous landfill leachate at the Central Landfill in Johnston, Rhode Island. This Innovative Technology Evaluation Report presents an interpretation of the performance and cost data gathered during the Demonstration and discusses the potential applicability of the technology.

A limited number of copies of this report will be available at no charge from the EPA's Center for Environmental Research Information (CERI), 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268. Requests should include the EPA document number found on the report's cover. When the limited supply is exhausted, additional copies can be purchased from the National Technical Information Service (NTIS), Ravensworth Building, Springfield, Virginia, 22161, (703) 487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection. The SITE Clearinghouse Hotline at (800) 424-9346 or (202) 382-3000 in Washington, D.C. also handles inquiries about the availability of other reports.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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List of Acronyms and Abbreviations

AEA	Atomic Energy Act
AQCR	Air Quality Control Regions
ARAR	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
ATTIC	Alternative Treatment Technology Information Center
BOD	biochemical oxygen demand
CAA	Clean Air Act
$CaCO_3$	calcium carbonate
$CaSO_4$	calcium sulfate
CERCLA	Comprehensive Environmental Response, Conservation, and Liability Act of 1980
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
CLU-IN	Cleanup Information
CO_2	carbon dioxide
COD	chemical oxygen demand
CWA	Clean Water Act
DOE	Department of Energy
DTM	Disc Tube™ Module
EPA	Environmental Protection Agency
GC/MS	gas chromatograph/mass spectrometer
gpd	gallons per day
gpm	gallons per minute
HCl	hydrochloric acid
hpd	hours per day
HPU	high-pressure unit
hr	hour
HSWA	Hazardous and Solid Waste Amendments
ITER	Innovative Technology Evaluation Report
kW	kilowatt
L	liter
LCS	laboratory control sample

Acronyms and Abbreviations (continued)

lpd	liters per day
lpm	liters per minute
MBAS	methylene blue active substances
MCL	maximum contaminant levels
MF	microfiltration
mg	milligram
mL	milliliter
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NRC	Nuclear Regulatory Commission
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
NTIS	National Technical Information Services
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
pH	parts Hydrogen
POTW	publicly-owned treatment works
PPE	personal protective equipment
psig	pounds per square inch gauge
PVC	polyvinyl chloride
Q	flow rate
$Q_{standard}$	standardized flow rate
QA	quality assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RISWMC	Rhode Island Solid Waste Management Corporation
RO	reverse osmosis
Rochem	Rochem Separation Systems, Inc.
SAIC	Science Applications International Corporation
SARA	Superfund Amendment and Reauthorization Act
SDI	silt density index
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
SWDA	Solid Waste Disposal Act
TDS	total dissolved solids
TER	Technology Evaluation Report
TFC	thin film composite
TOC	total organic carbon

Acronyms and Abbreviations (continued)

TS	total solids
TSD	treatment, storage, and disposal
TTO	total toxic organics
UF	ultrafiltration
U.S.	United States
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	volatile organic compound

Conversions

Mass

1 pound (lb) = 0.4536 kg

1 ton = 2,000 lb = 907.18 kg

1 kilogram (kg) = 2.20 lb

Volume

1 cubic inch (in^3) = 5.78E-04 ft^3 = 2.14E-05 yd^3 = 0.0164 L = 1.64E-05 m^3 = 4.33E-03 gal

1 cubic foot (ft^3) = 1,728 in^3 = 0.0370 yd^3 = 28.32 L = 0.0283 m^3 = 7.48 gal

1 cubic yard (yd^3) = 46,656 in^3 = 27 ft^3 = 764.55 L = 0.7646 m^3 = 201.97 gal

1 cubic meter (m^3) = 61,023 in^3 = 35.31 ft^3 = 1.31 yd^3 = 1,000 L = 264.17 gal

1 liter (L) = 61.02 in^3 = 0.0353 ft^3 = 1.30E-03 yd^3 = 1.00E-03 m^3 = 0.2642 gal

1 gallon (gal) = 231 in^3 = 0.1337 ft^3 = 4.95E-03 yd^3 = 3.7854 L = 3.79E-03 m^3

Length

1 inch (in) = 0.0833 ft = 0.0278 yd = 0.0254 m

1 foot (ft) = 12 in = 0.3333 yd = 0.3048 m

1 yard (yd) = 36 in = 3 ft = 0.9144 m

1 meter (m) = 39.37 in = 3.28 ft = 1.09 yd

Temperature

1 degree Fahrenheit (°F) = 0.5556°C [x°C=0.5556*(y°F-32)]

1 degree Celsius (°C) = 1.8°F [x_F=1.8*(y°C)+32]

Pressure

1 pound per square inch (psi) = 27.71 in H_2O = 6894.76 Pa

1 inch of water (in H_2O) = 0.0361 psi = 248.80 Pa

1 Pascal (Pa) = 1.45E-04 psi = 4.02E-03 in H_2O

Viscosity

1 poise = 0.1 kg/m-sec = 2.09E-03 lb/ft-sec

1 kg/m-sec = 10.00 poise = 2.09E-03 lb/ft-sec

1 lb/ft-sec = 478.70 kg/m-sec

Conversions (continued)

Rate

1 lb/hr = 2.20 kg/hr

1 kg/hr = 0.4536 lb/hr

1 gallon per minute (gpm) = 3.784 Lpm

1 liter per minute (lpm) = 0.264 gpm

1 gallon per day (gpd) = 3.784 Lpd

1 liter per day (lpd) = 0.264 gpd

Acknowledgments

This report was prepared under the direction of Mr. Douglas Grosse, the EPA Technical Project Manager for this SITE Demonstration at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. It was prepared by the Process Technology Division of Science Applications International Corporation (SAIC) under the direction of Mr. Kyle R. Cook, the SAIC Work Assignment Manager.

Contributors to the report were: Ms. Dora A. Anson, engineering, data evaluation, and technical writing; Mr. Robert Dvorin, technical consulting; Mr. Scott C. James, data evaluation and technical writing; Ms. Linda L. Hunter, economics evaluation; Mr. Raymond J. Martrano, Quality Assurance evaluation and technical writing; Mr. Brandon J. Phillips, engineering and technical writing; and Ms. Jamie Sue Winkelman, engineering and technical writing. Reviewers for this report were Dr. Victor S. Engleman and Mr. Joseph D. Evans.

The cooperation and participation of Rochem Separation Systems, Inc. throughout the course of this project and in review of this report are appreciated. Special thanks is also due to Mr. Dennis Russo at the Central Landfill for his support of the technology Demonstration.

Executive Summary

This report summarizes the findings of an evaluation of the Rochem Separation Systems, Inc. (Rochem) Disc Tube™ Module (DTM) technology. This technology is a membrane separation process for treatment of landfill leachate and other liquid wastes. The evaluation of this technology was conducted under the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program.

The Rochem DTM technology was demonstrated at the Central Landfill in Johnston, Rhode Island during August and September 1994. Approximately 33,000 gallons (125,000 liters) of landfill leachate were treated by a Rochem Model 9122 system operating at a feed flow rate of about four gallons per minute (gpm) [15 liters per minute (lpm)]. The 9122 system consisted of three stages: a leachate unit, a permeate unit, and a high-pressure unit (HPU). The first stage leachate unit received raw feed before sending the effluent onto a second stage permeate unit. The HPU was used to further reduce the liquid waste volume and increase the treated water recovery rate. Based on measurements made during the Demonstration, the landfill leachate was contaminated with chlorobenzene and 1,2-dichlorobenzene at average concentrations of 21 and 16 milligrams per liter (mg/L), respectively, and lower levels of 1,4-dichlorobenzene at 0.7 mg/L; ethylbenzene at 0.79 mg/L; toluene at 1.8 mg/L; and xylenes at 1.3 mg/L. Total organic carbon (TOC) was present in the leachate at an average concentration of 460 mg/L, and total dissolved solids (TDS) were present at an average concentration of 4,900 mg/L. Metals were also present at average concentrations such as 1.4 mg/L for barium, 130 mg/L for calcium, 48 mg/L for iron, and 21 mg/L for manganese.

The purpose of the Demonstration was to assess the DTM technology's effectiveness in removing organic and inorganic contaminants from the landfill leachate and in resisting fouling and scaling of the membranes. The technology developer, Rochem, claims that the innovative DTM design reduces the potential for membrane fouling and scaling, thereby allowing it to treat liquid waste that is higher in TDS, turbidity, and contaminant levels than liquid waste treated by conventional membrane separation processes.

To evaluate these performance features, the following critical objectives were developed for the SITE Demonstration:

- determine if the technology could meet the developer's claims for contaminant rejection of greater than 90% for volatile organic compounds (VOCs), greater than 92% for TOC, and greater than 99% for TDS and metals;

- determine if the technology could achieve and maintain a system treated water recovery rate of 75% or greater; and

- evaluate the DTM technology's resistance to membrane fouling and scaling by determining the change in flux as a result of liquid waste (leachate) treatment over the course of the Demonstration.

Measurements directly related to the critical objectives noted above undergo strict adherence to EPA quality assurance protocol including review and auditing prior to, during, and following the Demonstration. Sampling, analysis, and monitoring of the input and output streams were conducted during treatment to evaluate contaminant rejection and system water recovery rate. Baseline testing was performed before and after leachate treatment to compare the system's pre- and post-demonstration flux (flow rate per unit membrane area) and thereby evaluate resistance to scaling and fouling of membranes.

The critical (target) analytes for the Demonstration included TDS; TOC; VOCs (chlorobenzene; 1,2- and 1,4-dichlorobenzene; ethylbenzene; toluene; and xylenes); and metals (barium, calcium, iron, magnesium, manganese, potassium, sodium, and strontium). These target analytes were selected based on the developer's claims and based on their concentrations as determined from pre-demonstration leachate characterization data. Critical process measurements included DTM pressure, flow rate, and totalized flow. These measurements were necessary for the baseline testing and to determine the water recovery rate.

Based on this SITE Demonstration, the following conclusions can be drawn regarding the DTM technology's performance with respect to critical objectives:

- Overall, the DTM technology was very effective in removing contaminants from the landfill leachate. Mean contaminant rejections were greater than

96.7% for TOC and 99.4% for TDS, both exceeding the developer's claim. The overall mean rejection for total metals was at least 99.2%, exceeding the developer's claim of 99%. The calculated mean rejections of 1,2-dichlorobenzene; ethylbenzene; toluene; and xylenes were greater than the developer's claim of 90% for VOCs. The overall mean rejection for total VOCs was greater than 92.3%. However, the calculated mean rejection for chlorobenzene was 86.8% with a 95% confidence interval of 83.1 to 90.5%; the calculated mean rejection for 1,4-dichlorobenzene was 87.6% with a 95% confidence interval of 83.5 to 91.7%. These rejections were less than the specified criteria of 90%, but the 90% rejection criteria fell within the 95% confidence intervals for both compounds.

- Treated water recovery is defined as the volume of final permeate divided by the volume of feed, times 100%. The average system treated water recovery rate for the Demonstration was 73.3% with a 95% confidence interval of 70.7 to 75.9%. The developer's claim of 75% water recovery falls within this confidence interval. The treated water recovery rate was reduced by the use of first-stage and final permeate for rinsing of the second-stage unit modules and the HPU modules between batch treatment cycles each day to displace residual leachate from membrane surfaces. For other DTM system designs that are better integrated and typically require less module rinsing than the system demonstrated at the Central Landfill, achievable recovery rates may be higher (75 to 80%) when treating a similar liquid waste.

- The DTM technology's performance in resisting membrane fouling and scaling and maintaining system flux was evaluated before and after leachate treatment by measuring flux for the leachate (first-stage) unit and the HPU while treating a standard salt solution. These units received the bulk of waste loading during treatment. Baseline testing results show that the flux decreased in the first-stage unit during the Demonstration by approximately 30_12.6% at 95% confidence. However, because pH control and system operation varied during the Demonstration, it is difficult to determine the precise decrease in flux and its cause. The HPU had a flux decrease of approximately 83_2.2% at 95% confidence based on baseline testing results. The developer maintains, and performance data indicate, that the HPU membranes were probably damaged by an acid excursion during acid addition performed to remove scalants or during acid dosing for pH control. Membrane fouling and scaling may have also contributed to the decrease in flux for both units.

System operating data during leachate treatment were also evaluated to determine the performance of membranes during the Demonstration. These data indicate a decrease in flux for the first-stage unit and the HPU similar to the baseline testing results. However, these data also indicate that the lack of feed pH adjustment at the beginning of raw leachate treatment coupled with the increased treated water recovery during the HPU cycle contributed to membrane fouling and scaling, with the resultant decrease in flux measured by the baseline testing. The developer felt that better performance may have been achieved if a more thorough process shakedown had been performed and more sophisticated pretreatment for pH control had been used.

Secondary (non-critical) objectives that are of interest to future applications of the DTM technology but not directly related to developer's claims were also evaluated during this Demonstration. These included process reliability, maintenance, potential emissions, and operating costs. Secondary objectives are supported by non-critical data that may be less definitive than critical data and are not subject to the same quality assurance requirements as primary (critical) objectives.

With respect to secondary objectives, the following conclusions can be drawn:

- Membrane cleaning was easily implemented for each process unit on an as-needed basis. Cleaning was helpful in removing accumulated deposits from the membranes and restoring performance. More frequent membrane cleaning may be required for liquid waste with high scaling or fouling potential.

- The DTM technology has intermediate holding tanks for process streams. Measurements of vent emissions from the concentrate feed tank indicate that VOC losses occurred from this tank when the HPU was between treatment cycles and the first-stage unit was filling the tank with concentrate. These losses did not significantly affect the calculated removals (percent rejections) of VOC contaminants. However, depending on local air quality requirements, engineering controls may be necessary to reduce emissions from this process tank vent.

- The DTM technology was effective in removing a variety of contaminants from the landfill leachate. The final permeate from the Demonstration complied with permit limits for discharge to the local Publicly-Owned Treatment Works (POTW) with respect to metals. However, the total toxic organics (TTO) average daily concentration of the final permeate was 3.4 mg/L, which was greater than the TTO discharge permit limit of 2.13 mg/L. Discharge limits for TTO, cyanide, and oil and grease were met after activated carbon polishing. Limits for biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) were not applicable to the Central Landfill's Industrial Waste Discharge Permit. The TDS and low turbidity of the permeate lend it to treatment with many suitable polishing technologies. Based on the technology performance during this Demonstration, only minimal polishing treatment was required to meet discharge limits. If acid is used during treatment to lower the system feed pH (like during the Demonstration), permeate pH adjustment may be required to meet discharge limitations. This could be accomplished using aeration to remove CO_2 and thereby increase pH. In some applications, the final permeate may meet the discharge limitations without the need for further treatment.

- Costs estimates were prepared for leachate treatment using a 9122 system slightly smaller than the system used during the Demonstration [three gpm (11 lpm) rather than four gpm (15 lpm)] and a 9142 system sized for a larger design flow rate; both at a fixed facility. The estimated costs for treating leachate similar to the Demonstration leachate (hazardous landfill leachate), with an on-line efficiency factor of 90% and a treated water recovery rate of 75%, are $0.16/permeate-gallon ($0.04/permeate-liter) for the Rochem 9122 system [operating at three gpm (15 lpm)] and $0.06/permeate-gallon ($0.01/permeate-liter) for the 9142 system [operating at 21 gpm (79 lpm)]. These costs include all factors except for permitting and waste disposal costs for the concentrate stream. The waste disposal cost is leachate- and concentrate-specific. If only the annualized equipment costs and consumables costs are considered and other costs are assumed to be the responsibility of the fixed facility, then the cost would decrease to $0.07/permeate-gallon and $0.03/permeate-gallon for the 9122 and the 9142 systems, respectively. Labor costs per permeate-gallon decrease with system scale-up. Based on information from Rochem, systems larger than the 9122 and 9142 would have a lower cost per permeate-gallon.

- The DTM technology can effectively treat landfill leachate to significantly reduce the volume of leachate requiring further treatment and disposal. The treated water recovery rate achievable with the DTM technology is a function of the scaling potential of the liquid waste. The HPU can be used to increase treated water recovery but may be limited by scaling constituents in the liquid waste.

- On-site pilot-scale treatability testing of the liquid waste stream is necessary to evaluate technology performance and determine operational procedures and settings prior to full-scale application. For complex liquid waste streams, bench-scale treatability testing is also recommended. After process installation, a shakedown period is necessary to check technology performance and to optimize liquid waste pre-treatment and operational procedures. Rochem did not perform treatability testing with the Central Landfill leachate prior to the Demonstration, and process shakedown was very abbreviated.

The Rochem DTM technology was evaluated based on the nine criteria used for decision-making in the Superfund Feasibility Study (FS) process. Table ES-1 presents the results of this evaluation.

The following sections of this report contain the detailed information that supports the items summarized in this Executive Summary. Appendix A, “Vendor’s Claims,” presents information and data from the technology vendor concerning other applications of the DTM technology.

Table ES-1. Evaluation Criteria for the Rochem DTM Technology

Overall Protection of Human Health and the Environment	Compliance with Federal ARARs	Long-Term Effectiveness	Short-Term Effectiveness	**Reduction of Toxicity,** Mobility, or Volume through Treatment
Provides both short- and long-term protection by reducing exposure to organic and inorganic contaminants in landfill leachate (or liquid waste). Prevents harmful effects of liquid waste migration to public water supplies. Reduces the volume of contaminated material. Concentrated contaminants can be incinerated or treated by other methods. Technology is able to treat a variety of contaminants.	Requires compliance with RCRA treatment, storage and land disposal regulations (for a hazardous waste). On-site treatment may require-compliance with location-specific ARARs. Permeate discharge to POTW or surface bodies requires compliance with the Clean Water Act regulations. Withou;additional treatment, the final permeate produced during the Demonstration met discharge requirements for metals. The discharge requirements for total toxic organics (TTO) was met after activated carbon polishing. Limits for biochemical oxygen demand, chemical oxygen demand, and total suspended solids were not applicable to Central Landfill's Industrial Waste Discharge Permit. If volatile compounds are present in the liquid waste, emission controls may be needed to ensure compliance with aire quality standards, depending on local ARARs. Requires compliance with OSHA regulations to protect the health and safety of works at hazardous waste sites.	Permanently reduces the volume of contaminated leachate or other liquid waste. Involves a demonstrated technique for removol of organic and inorganic contaminants. Permeate may require polishing prior to disposal, depending on the site-specific discharge limitations. Removed (concentrated) contaminants may require treatment by other methods such as incineration or solidification/ stabilization prior to disposal. Recirculation by surface appli cation to the landfill may be appropriate for municipal landfill leachate. Membrane cleaning is required to maintain system performance and to extend membrane life. Membranes are cleaned at the discretion of the operator, typically based on a change in module pressure, flow rate or temperature readings.	Depending on the application, additional modules may be added to the DTM system to reduce remediation time. Treatment may cause noise and minor air emissions, posing short-term risks to workers and possibly to the nearby community. Process noise levels are not high. Air emissions can be mitigated. Some personal protective equipment may be required for workers during system operation.	Significantly reduces toxicity of treated water and reduces volume of contaminated water through treatment. Permeate water quality is dependent on waste charactieristics. During the Demonstration, contaminant levels were reduced 90% or greater on average (99.4% for total dissolved solids, 99.2% for target metals, 96.7% for total organic carbon and 92.3% for volatile organic compounds on average). Waste volume reduction is dependent on waste characteristics and the required system water recovery rate. Waste volume reduction for the Demonstration was approximately 75%.

(continued)

Table ES-1. continued

Implementability	Cost	Community Acceptance	State Acceptance
Utility requirements are minimal and include water and electricity. Equipment is skid-mounted or containerized and easily transportable by a tractor trailer. Support equipment includes a heavy-duty forklift or crane for loading/unloading and arranging the units. Tanks are required for process stream storage. Treatability testing with the selected waste is recommended prior to field installation. If the necessary facilities and utilities are available, the system can be set up and operational in three to five days. Initial testing (shakedown) of the equipment prior to going on-line normally takes two to five days. After treatment, the entire system can be demobilized within two to three days. The concentrations and types of scaling ions can limit the treated water recovery rate or cause membrane scaling, thereby limiting the use of the DTM technology.	The estimated costs for treating leachate at 3 and 21 gpm (11 and 79 lpm) at a fixed facility and with a treated water recovery rate of 75% are \$0.16/permeate-gallon (\$0.04/permeate-liter) and \$0.06/permeate-gallon (\$0.01/permeate-liter), respectively. These costs do not include a waste disposal fee for the concentrate since this cost is site- and concentrate-specific. Costs are based on data gathered during the Demonstration and on treating a leachate with characteristics similar to the Central Landfill leachate. Estimated costs are highly leachate-specific. Treatment costs are higher for liquid wastes that have a high potential for membrane scaling and thus require increased use of chemical cleaners and pH adjustment chemicals. Operating the technology at continuous full-scale with a higher recovery rate (both dependent on system design and liquid system design and liquid waste characteristics) will result in a lower overall cost.	Protects the community by treating liquid waste which could potentially migrate to public water supplies. Noise levels are not expected to be high, however, noise from the equipment driving the system will be constant, so noise levels should be monitored. The levels of the noise anticipated are not expected to adversely affect the community. Air emissions (potentially odorous) may present a short-term risk to the nearby community, however, these emissions are minor and can be easily mitigated as necessary.	State ARARs may be more stringent than federal regulations. These ARARs can be met using appropriate controls. An air emission permit or other appropriate control may be required, depending on local requirements. Wastewater discharge permits are required.

Section 1
Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes the Rochem Separation Systems, Inc. Disc Tube™ Module (DTM) technology. For additional information about the SITE Program, this technology, and the Demonstration site, key contacts are listed at the end of this section.

1.1 Background

Rochem Separation Systems, Inc. (Rochem) in Torrance, California is the United States (U.S.) subsidiary of the Rochem Group based in Geneva, Switzerland. Rochem is licensed to supply the DTM technology in the U.S. The DTM technology was developed based on experience gained in desalinating sea water and brackish water using reverse osmosis technology. Rochem has been building reverse osmosis units since 1981 and DTM units since 1988. The Rochem DTM units and systems are currently designed and fabricated in Germany. The technology has been used to treat leachate at over 50 landfills in Europe, according to Rochem. The DTM technology is a membrane separation process designed to treat difficult fluids ranging from seawater to organic solvents. It is a hybrid between spiral-wound and plate-and-frame membrane separation systems *(1)*. A one-stage system consisting of a leachate unit and a permeate unit is a common application of the DTM technology. Recently, however, Rochem has made available a high-pressure DTM unit that can be combined with the leachate and permeate units to make a two-stage system that provides additional waste concentration and volume reduction.

The goal of the SITE Program Demonstration of the Rochem technology was to evaluate its ability to treat landfill leachate contaminated with measurable levels of hazardous constituents. A Demonstration was originally planned at a hazardous waste landfill in the western U.S. Bench-scale treatability testing was conducted on leachate from this landfill using the DTM technology to prepare for a pilot-scale field Demonstration. The results of this test are presented in Appendix B of this report. Due to ongoing site litigation, the Demonstration was not conducted at the hazardous waste landfill in the western U.S. Subsequently, other sites and their characteristics were reviewed for their potential as Demonstration sites for the DTM technology. Finally, the Central Landfill in Johnston, Rhode Island was identified as a probable Demonstration site. Based on liquid waste characterization data collected by the EPA evaluation contractor, Science Applications International Corporation (SAIC), the levels of constituents in the leachate were high enough to evaluate the technology and also within an acceptable range for treatment. Therefore, the leachate was determined to be suitable by EPA and Rochem for a Demonstration of the DTM technology. A Demonstration was conducted at the Central Landfill during the summer of 1994. However, no treatability testing was done at this site.

1.2 Brief Description of Program and Reports

The SITE Program is a formal program established by the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements:

- the Emerging Technology Program,
- the Demonstration Program,
- the Monitoring and Measurement Technologies Program, and
- the Technology Transfer Program.

The Emerging Technology Program focuses on conceptually proven bench-scale technologies that are in an early stage of development involving pilot or laboratory testing. Successful technologies are encouraged to advance to the Demonstration Program.

The Demonstration Program develops reliable performance and cost data on innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE Demonstrations are conducted on hazardous waste sites under full-scale remediation conditions or under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of information collected. Data collected are used to assess: (1) the performance of the technology, (2) the potential need for pre- and post-treatment processing of wastes, (3) potential operating problems, and (4) the approximate costs. The Demonstrations also allow for evaluation of long-term risks and operating and maintenance costs.

Existing technologies that improve field monitoring and site characterizations are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstration methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Emerging Technology Program, the Demonstration Program, and the Monitoring and Measurements Technologies Program through various activities. These activities increase public awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 The SITE Demonstration Program

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff reviews the proposals to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile and in situ technologies are of particular interest.

Once the EPA has accepted a proposal, cooperative agreements between the EPA and the developer establish responsibilities for conducting the Demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is responsible for any costs for transport, operations, and removal of the equipment. The EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of this evaluation of the Rochem DTM technology are published in two basic documents: the SITE Technology Capsule and this Innovative Technology Evaluation Report. The SITE Technology Capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field Demonstration, while the ITER provides an in-depth evaluation of the overall performance and applicability of the technology.

1.4 Purpose of the Innovative Technology Evaluation Report

This ITER provides information on the Rochem DTM technology for treatment of contaminated liquids and includes a comprehensive description of this Demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in further evaluating specific technologies for further consideration as applicable options in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, the EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and performance, particularly as evaluated during the Demonstration. It also discusses advantages, disadvantages, and limitations of the technology. All data and supporting documentation for the Demonstration are contained in a companion Technology Evaluation Report (TER). This report is not published with the ITER but is available from EPA upon request.

Each SITE Demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.5 Brief Technology Description

The Rochem DTM technology is an innovative membrane separation process which utilizes commercially available membrane materials. The patented membrane module is designed with larger feed flow channels and a higher feed flow velocity than conventional membrane separation systems. According to the developer, these features reduce the potential for membrane fouling and scaling and allow the DTM technology to be the primary treatment step for liquid wastes with high fouling potential such as landfill leachate.

The DTM system can utilize reverse osmosis (RO), ultrafiltration (UF), or microfiltration (MF) membranes, depending on the application. It is a pressure-driven process that selectively rejects and concentrates impurities present in a liquid matrix. Reverse osmosis membranes were utilized during the Rochem SITE Demonstration at the Central Landfill in Johnston, Rhode Island. Membrane material for the DTM is ultrasonically welded into a cushion around a porus spacer material. Octagonal membrane cushions with a center hole are stacked alternately with plastic hydraulic discs on a tension rod. The hydraulic discs support the membranes and form the feed flow channels. O-rings are located in the center hole of each hydraulic disk. These O-rings separate the feed channels from the inside of each membrane cushion and, when stacked, form a permeate (product water) collection channel by establishing a barrier between the feed water and the product water. Feed liquid passes over the membrane through the flow channels provided by the hydraulic discs, and clean product water exits the membrane through the center hole into the permeate collection channel. A stack of membrane cushions and hydraulic discs housed in a pressure vessel constitutes a membrane module. Flanges are used to seal the ends of each module and provide the feed water input, as well as the product and reject output, piping connections. The number of discs per module, number of modules, and the membrane materials can be custom-designed to suit the application. A detailed process description of the DTM process utilized during the Rochem SITE Demonstration is given in Section 4.3 of this report.

1.6 Key Contacts

Additional information on the Rochem DTM technology and the SITE Program can be obtained from the following sources:

The Rochem Separation Systems DTM Technology

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The SITE Program

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Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 Martin Luther King Drive in Cincinnati, Ohio, 45268 at 513/569-7562. Additional information on the SITE Program is available through the following information clearinghouses.

- The Alternative Treatment Technology Information Center (ATTIC) System (operator: 703/908-2137) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This database provides summarized information on innovative treatment technologies.
- The Vendor Information system for Innovative Treatment Technologies (VISITT) (hotline: 800/245-4505) database currently contains information on approximately 231 technologies offered by 141 developers.
- The OSWER CLU-IN electronic bulletin board contains information on the status of SITE technology demonstrations. The system operator can be reached at 301/589-8368.

Section 2
Technology Application Analysis

2.1 Key Features of the Technology

The Rochem DTM technology is designed to treat liquid waste that is higher in dissolved solids content and contaminant levels than liquid waste treated by conventional membrane separation processes. Traditionally, membrane separation processes have been used as secondary or polishing steps in liquid waste treatment schemes. According to the developer, the DTM's innovative design allows it to be the primary treatment step for liquid waste streams such as landfill leachate.

The DTM features larger feed flow channels and a higher feed flow velocity than typical membrane separation systems. The developer states that these characteristics allow the DTM greater tolerance for dissolved solids and turbidity and a greater resistance to membrane scaling and fouling. Permanent scaling or fouling of the membranes by liquid waste constituents impacts treatment effectiveness and can reduce the membrane life. Pretreatment, such as chemical addition for pH adjustment to control scaling, is relatively standard in most membrane separation treatment schemes. According to the developer, the DTM system can effectively treat liquid wastes with minimal pretreatment in many cases. However, pH control is also a standard part of the Rochem system. Acid addition for pH control was used during the Rochem DTM technology Demonstration.

The DTM system is easily cleaned and maintained. The open channel design facilitates rinsing and cleansing of particulate matter from the membranes. Chemical cleaning of the membranes can be accomplished without removing the membranes by using a built-in cleaning system, however, individual or all membranes can be easily removed as needed for replacement.

Rochem has a number of DTM systems that can accommodate feed flow rates from 3,000 to 130,000 gallons per day (gpd) [11,000 to 490,000 liters per day (lpd)]. In addition, system capacity can be increased by combining treatment units in parallel. Approximately the same amount of labor is required when operating a large DTM system as when operating a small DTM system; therefore, larger-scale treatment is more economical. The system utilized for the SITE Demonstration, a 9122 system rated for a feed capacity of 3,000 to 9,000 gpd (11,000 to 34,000 lpd), was used to treat leachate at a feed rate of approximately four gallons per minute (gpm) [15 liters per minute (lpm)] or approximately 5,800 gpd (22,000 lpd).

The DTM system is mobile. DTM units are built into containers that are readily transported on a flatbed truck. The containerized design allows the DTM units to be set in place at a site, installed, and on-line within three to five days. In addition, the modular design and construction of the equipment helps minimize and contain liquid leaks from the system during operation.

The DTM system is designed for semi-automatic operation. The units are equipped with memory-programmable microprocessor-controlled monitoring equipment and automatic shut-down logic. These features minimize the labor required to operate the DTM system. Operator attention is required to monitor and adjust the system, to initiate membrane cleaning cycles, and to perform other routine maintenance such as cartridge filter replacement.

2.2 Operability of the Technology

Membrane cleaning is required to maintain technology performance. If a liquid waste has a high scaling or fouling potential (like the Demonstration leachate did), more frequent membrane cleaning may be required to maintain technology performance. After cleaning, membrane performance levels should return to levels close to the original. Typically, membrane performance, in terms of flux, drops off gradually over time to the point where the membranes need to be replaced. If the membranes become permanently scaled or fouled, performance will be impaired. Improper membrane cleaning or chemical dosing can damage the membranes. Membranes may demonstrate an initial decrease in flux due to break-in or conditioning by the liquid waste. To account for this break-in period, Rochem designs systems for post break-in membrane conditions *(2)*.

Treatability testing is recommended before implementing the DTM process. Bench-scale testing can determine the suitability of the technology for the test waste. Pilot-scale field testing is necessary to determine operational and maintenance procedures such as chemical addition and membrane cleaning requirements before commencing full-scale treatment. Treatability testing on the liquid waste under consideration also helps to determine the number of DTM units, the type of membranes, and system configuration required for treatment of the liquid waste. It is very important to formalize these factors, especially pretreatment requirements, prior to the application of the technology. Before commencing full-scale treatment, an equipment shakedown period of two to five days is necessary in order to refine system operating parameters.

Temperature affects the DTM technology performance; colder temperatures reduce system flux and may reduce the solubility of scaling ions. As temperature increases, flux will increase, but membranes are more susceptible to chemical degradation and compaction at temperatures above about 100_F *(3)*. The temperature of the liquid waste (leachate) during the Demonstration was well below this level.

In order to minimize system down-time, a back-up inventory of critical system components should be available on-site. These components include, but are not limited to, pumps, valves, and polyvinyl chloride (PVC) piping. An adequate supply of consumable materials such as filters, pH adjustment chemicals, and membrane cleaning chemicals should also be maintained on-site.

2.3 Applicable Wastes

Like all membrane separation processes, the DTM technology reduces the volume of the liquid waste. Treatment produces permeate, which is relatively clean water, and concentrate, which is more contaminated but smaller in volume than the original liquid waste. The degree of volume reduction is dependent on the liquid waste characteristics and the DTM system design.

Rochem claims that the DTM technology can treat liquid waste streams containing volatile and semivolatile organics, metals and other inorganic ions or compounds, and radioactive wastes. The DTM technology has been used to treat landfill leachate, water soluble oil-based coolants, oil/water mixtures, and solvent/water mixtures *(1)*.

The DTM technology is capable of treating liquid waste with wider ranges and higher levels of contaminants than conventional membrane separation technologies using RO membranes. During the Demonstration at the Central Landfill, the DTM technology treated leachate contaminated with chlorobenzene and 1,2-dichlorobenzene at average concentrations of 21 and 16 milligrams per liter (mg/L), respectively, and lower levels of 1,4-dichlorobenzene at 0.7 mg/L; ethylbenzene at 0.79 mg/L; toluene at 1.8 mg/L; and xylenes at 1.3 mg/L. Total organic carbon (TOC) was present in the leachate at an average concentration of 460 mg/L, and total dissolved solids (TDS) were present at an average concentration of 4,900 mg/L. Metals were also present at average concentrations of 1.4 mg/L for barium, 130 mg/L for calcium, 48 mg/L for iron, and 21 mg/L for manganese. Results from the Demonstration show that the DTM technology achieved excellent removals of TOC, TDS, and metals. Volatile organic compound (VOC) removals were also very good (approximately 90% or greater). The VOC removals are noteworthy because membrane separation technologies typically do not effectively separate lower molecular weight organic compounds, particularly VOCs; these compounds tend to pass through the membranes (*4).* A high-pressure unit (HPU) can be used to increase the treated water recovery rate for liquid wastes that have a higher level of TDS or scaling ions.

The suitability of the DTM process is dependent on the characteristics of the feed liquid. Rochem claims that for many liquid wastes, the DTM system's hydraulic design allows it to operate with minimal or no pretreatment. However, chemical or physical pretreatment may be needed to reduce the potential for membrane scaling or fouling for liquid wastes such as the Demonstration leachate. This may add to the cost of using the technology. Pretreatment may include equalization, aeration to remove carbon dioxide generated from acid addition (for pH adjustment), and other processes *(2)*. For the Rochem Demonstration, the pH of the feed liquid was adjusted from about 6.8 to an average value of 6.1 to help control membrane scaling; pH control is a standard part of the Rochem system. Final permeate pH adjustment may be needed to comply with discharge requirements. The user of the technology will be responsible for treatment and disposal of the final concentrate and disposal of the final permeate.

The DTM technology has also been used at an industrial site in the U.S. to treat lagoon water contaminated by petrochemical wastes (volatile organics, phenols, heavy metals, and polychlorinated biphenyls). This wastewater had TOC levels of 1,700 to 1,800 mg/L *(5)*. In addition, the technology is currently treating municipal landfill leachate in the U.S. and hazardous and municipal leachate in Europe. Information regarding the DTM technology's performance while treating municipal landfill leachate and other liquid wastes is available in Section 6, "Technology Status," and Appendix A, "Vendor's Claims."

2.4 Availability and Transportability of Equipment

The Rochem DTM technology was first developed in Germany where the system components are still manufactured. Several DTM units exist in the U.S. at this time. DTM units and associated components requested by Rochem in the U.S. are built in Germany, placed in overseas carrier crates or built into cargo containers, and shipped as commercial freight to a U.S. port. From the port, the DTM units and components can be loaded into a trailer or flatbed truck and easily transported by truck to sites throughout the country. It currently takes two to four months, once an order is placed, for production and delivery of the process.

Rochem has four systems available for liquid waste treatment: Model 9122, Model 9142, Model 9152, and Model 9532. The Demonstration utilized a three-stage 9122 system, the smallest of the four models, in which the first-stage and second-stage units were connected in series to produce the final permeate. The third stage was the HPU, which treated the system concentrate to increase the system water recovery rate. Section 6, "Technology Status," provides additional information about the scale-up capabilities of the process.

Once the Rochem equipment is delivered to a site, the units can be configured as needed and can be operational within three to five days if all necessary facilities, utilities, and supplies are available. Each DTM unit is composed of a control unit and membrane modules. The control unit consists of electronic controls, pumps, filters, pressure gauges, and valves. During the Demonstration, the control units and corresponding membrane modules were separate and mounted on skids with a maximum weight of one ton each. The skid-mounted units were transported by tractor trailer and could be moved with a heavy-duty forklift. In most cases, the units are built into cargo containers for easier transportation and installation and to contain leaks and spills during operation. For loading and unloading, containerized units require a crane capable of lifting 15,000 pounds. The containerized units may be placed on wheels for indoor mobility. Additional materials necessary for system operation include auxiliary tanks for process stream storage and interconnecting piping.

After decontaminating on-site equipment (as necessary), the technology can be demobilized by disconnecting utilities, disassembling the hose connections, and loading the equipment onto a tractor trailer for transport offsite. Demobilization requires approximately two to three days for the Rochem DTM technology.

2.5 Materials Handling Requirements

A variety of equipment may be required to implement the Rochem DTM technology. This includes equipment to construct a secondary containment area, convey system liquids (via a piping system), handle water conditioning chemicals, handle process wastes, and maintain the site.

An equalization or storage tank is required to store the feed liquid prior to pumping it directly to the process. A pump is needed to convey the collected liquid waste to the first-stage treatment unit. A storage tank is also required to hold the concentrated wastewater generated from the treatment process prior to disposal. Additionally, if the treated permeate is temporarily stored prior to disposal (e.g., for testing), suitably sized storage tanks are needed. All pumps used to transport liquids from the wells and throughout the treatment system must be able to perform under harsh conditions—high solids content (both total and dissolved), corrosive pH, and variable chemical composition and concentrations. These factors should be taken into account during the selection of pumps and ancillary equipment such as hoses and fittings.

A secondary containment system for storage tanks and any auxiliary equipment, such as equipment utilized for pretreatment, may be required. Secondary containment systems can be purchased, constructed from a variety of impermeable materials, or specially designed to suit the project. Earthmoving, excavating, and specialty equipment may also be necessary for the placement and sealing of geotextile liners.

The amount of supplies and equipment needed to support the Rochem DTM treatment system depends on the magnitude of the operation. For a large operation, a forklift may be required to move the supplies delivered to the site on pallets. Tanker trucks may be used to store and transport treated liquid wastes for small projects. Other materials handling equipment may be required, depending on site conditions and the type of operation being conducted.

2.6 Site Support Requirements

Support equipment required for the DTM technology includes a heavy-duty forklift or a crane for loading/unloading and arranging the units, and tanks for process stream storage. In most cases, the DTM units are built into cargo containers and must be moved by a crane as mentioned in Section 2.4, "Availability and Transportability of Equipment."

Storage of raw feed and final concentrate is required, and storage of final permeate also may be necessary. Storage tank sizing and design are dependent on site-specific applications. The user of the technology may be responsible for providing storage tanks.

Additional support facilities include shelter to protect equipment and personnel from weather extremes. At locations with colder climates, an indoor installation with heating is preferred. During the Demonstration, the treatment units were arranged outdoors under a tent. A more permanent shelter is desirable for long-term treatment.

Utility requirements are limited to electricity and water. The DTM system used for the Demonstration (Model 9122) required a three-phase, 440/480-volt, 60-hertz electrical circuit to power the pumps and control equipment. The 9122 DTM system requires a maximum power supply of 21 kilowatts (kW). A direct on-site electric hook-up is preferred, but if this is not available, a generator may be used *(4)*. The use of a generator is not cost effective for long-term applications. DTM systems larger than the one utilized for the Demonstration have higher power requirements than Model 9122. For example, Model 9142 requires a maximum power supply of 50 kW. Additional power is needed for on-site office trailers (if present), any ancillary pumps, and outdoor lighting. Water is required to perform system leak-testing and to shake down and calibrate the equipment. Water is also needed for cleanup and decontamination.

The site must be accessible by roads suitable for occasional travel by heavy equipment and for daily travel by personnel operating and maintaining the technology. In addition, site security measures should be implemented to protect the public from potential exposures and to prevent accidental or intentional damage to the equipment.

2.7 Range of Suitable Site Characteristics

The DTM system requires level staging areas in order to control liquid levels and provide optimum operation. A 500-square-foot equipment staging area with additional storage space for auxiliary system tanks is adequate for a three-stage system. For treatment systems consisting of several treatment units for increased system capacity, a larger equipment staging area may be required. In addition, an area constructed to contain potential spills may be necessary to hold tanks for process stream storage, treatment chemicals, and process wastes.

Adverse weather including extreme temperatures and rainy conditions affect the performance and operation of the DTM system. The control panels are not water-tight, and gauges and electronic components can be damaged by rain. If a site is located in an area with extreme seasonal weather conditions, the DTM system should be staged indoors or the available containerized version of the system should be used.

2.8 Limitations of the Technology

The composition of the liquid waste may limit the applicability of the DTM technology. In RO, inorganic salt rejections are usually high (ninety to ninety-nine percent). Some constituents (barium, calcium, fluoride, iron, silica, strontium, sulfate, etc.) may cause scaling on membranes, depending on the water recovery rate. Higher water recovery rates increase the potential for scaling and fouling because of the potential for precipitation of sparingly soluble salts such as calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$). Deposits of metal oxides (formed from metals such as iron or manganese), colloids, organic compounds, or oil and grease can contribute to scaling and fouling, as will biological activity. This, in turn, may limit membrane life and treatment effectiveness *(6)*. Although typical reverse osmosis rejections of low molecular weight organic compounds may vary, the rejections of VOCs during the DTM technology Demonstration at the Central Landfill were approximately 90% or greater.

The maximum water recovery is dependent on the TDS concentration and ion balance in the liquid waste. For treatment of landfill leachate with high scaling potential, the use of acid dosing for pH control is necessary to achieve a high water recovery rate. A water recovery rate of 75 to 80% is achievable for leachate similar in composition to the Central Landfill leachate while still maintaining acceptable membrane life and permeate water quality. Higher recovery rates may be possible but may require the use of additional equipment and supplies. Any increased operating costs may be off-set by cost savings for treatment and disposal of a smaller volume of concentrate.

2.9 Technology Performance Versus ARARs

This subsection discusses specific federal and state environmental regulations pertinent to the operation of the Rochem DTM technology including the transport, treatment, storage, and disposal of wastes and treatment residuals. These regulations are reviewed with respect to the Demonstration results. State and local regulatory requirements, which may be more stringent than federal standards, must also be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Clean Water Act; (5) the Safe Drinking Water Act; (6) the Occupational Safety and Health Administration regulations; (7) radioactive waste regulations; and (8) mixed waste regulations. These eight general ARARs are discussed below and outlined in conjunction with process activities in Table 2-1.

2.9.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The CERCLA of 1980, as amended by SARA in 1986, provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment. It also provides funding to respond to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment.

As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300 and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for remedies that are highly reliable and provide long-term protection and directs the EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants;

- select remedial actions that protect human health and the environment, are cost-effective, and involve

Table 2-1. Federal and State ARARs for the Rochem DTM Technology

Process Activity	ARAR	Description	Basis	Response
Liquid waste characterization (untreated waste)	RCRA 40 CFR Part 261 or state equivalent†	Standards that apply to identification and characterization of waste to be treated	Requirement of RCRA prior to managing and handling the	Chemical and physical analyses must be performed.
Waste processing	RCRA 40 CFR Part 264 and 265 or state equivalent†	Standards that apply to the treatment of hazardous waste at permitted and interim status facilities	Treatment of hazardous waste must be conducted in a manner that meets the operating and monitoring requirements	Equipment must be maintained daily. Integrity of treatment unit and influent and effluent storage tanks, if used, must be monitored and maintained to prevent leakage or failure.
Storage after processing	RCRA 40 CFR Part 264 and 265 subpart I or state equivalent†	Standards that apply to the storage of hazardous waste in containers	Process residuals (including concentrate, contaminated materials and adsorbents) may be deemed hazardous	Process residuals must be stored in appropriate containers in good condition. Containers should be stored in designated hazardous waste storage area with proper secondary containment.
	CAA 40 CFR Part 50 or state equivalent	Regulations that govern toxic pollutants, visible emissions and particulates	Storage tank off-gases may contain volatile organic compounds or other toxic pollutants	Air emissions from storage tanks must not exceed limits set for the air district.
Waste characterization (process residuals)	RCRA 40 CFR Part 261 or state equivalent†	Standards that apply to waste characteristics	Requirements of RCRA prior to managing and handling the liquid waste; determine if treated material is RCRA hazardous waste and/or mixed waste	Chemical and physical analyses must be performed on process residual wastes prior to disposal.
On-site/off-site disposal of process	RCRA 40 CFR Part 268 or state equivalent†	Standards that apply to the disposal of hazardous waste	Nature of the liquid waste may be subject to disposal restrictions	Treated process residuals defined as hazardous must be disposed of at a permitted hazardous waste facility, or approval must be obtained from the lead regulatory agency to dispose of the liquid wastes on site.
	SARA Section 121 (d)(3)	Requirements for off-site disposal of wastes from a Superfund site	Waste is being generated from a response action authorized under SARA	Waste must be disposed of at a RCRA-permitted hazardous waste facility.
Transportation for off-site disposal	RCRA 40 Part 262 or state equivalent†	Manifest requirements and packaging and labeling requirements prior to transport	Process residuals may need to be manifested and managed as a hazardous waste	An identification (ID) number must be obtained from EPA.
	RCRA 40 CFR Part 263 or state equivalent†	Transportation standards	Treated wastes and/or oversize material may need to be transported as hazardous waste	A transporter licensed by EPA must be used to transport the hazardous waste according to EPA regulations.

(continued)

Table 2-1. Continued

Process Activity	ARAR	Description	Basis	Response
Wastewater discharge	Clean Water Act 40 CFR Parts 301, 304, 306, 307, 308, 402, and 403	Standards that apply to discharge of wastewater into POTW or surface water bodies	The wastewater may be a non-hazardous waste	Determine if wastewater could be directly discharged into POTW or surface water body. If not, the wastewater may need to be further treated by conventional processes to meet discharge requirements. An NPDES permit may be required for discharge to surface waters.
Wastewater discharge	Safe Drinking Water Act 40 CFR Parts 144 and 145	Standards that apply to the disposal of contaminated water in underground injection wells	Wastewater may require disposal in underground injection wells	If underground injection is selected as a disposal means for contaminated wastewater, permission must be obtained from EPA to use existing permitted underground injection wells or to construct and operate new wells.

† Activities may also be subject to DOE, DOT, NRC, and AEA regulations or requirements for treatment, storage and disposal and shipping of radioactive or mixed wastes, if these wastes are treated.

permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and

- avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121(b)].

In general, two types of responses are possible under CERCLA: removal and remedial action. The Rochem DTM technology is likely to be part of a CERCLA remedial action.

Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances, pollutants, or contaminants. The Rochem DTM Technology reduces the volume of contamination that would require conventional treatment. It also reduces the toxicity of the treated water (permeate). The permeate can be used to clean and rinse the DTMs and can be discharged to a publicly-owned treatment works (POTW) or into surface waters if the proper permits are obtained. In addition, pumping of leachate or groundwater and treating it with the DTM system reduces the mobility of contamination in situ and helps prevent its migration to public water supplies.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and Superfund demands for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

2.9.2 Resource Conservation and Recovery Act (RCRA)

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities and was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA.

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the Rochem DTM technology if RCRA-defined hazardous wastes are present. Potential hazardous wastes include the liquid waste to be treated, the concentrate stream, used tubing, used cleaning solutions, and other contaminated materials. If these wastes are determined to be hazardous according to RCRA (based on characteristics or listings), all RCRA requirements regarding the management and disposal of this hazardous waste must be addressed by the remedial managers. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. Hazardous wastes listed in 40 CFR Part 261 Subpart D remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that even after remediation, "clean" wastes are still classified as hazardous because the pretreatment parent material was a listed waste. For this Demonstration, the liquid waste (leachate), although not a listed hazardous waste, did contain chlorobenzene, dichlorobenzene, and other hazardous constituents. The technology concentrated these contaminants in the concentrate liquid waste stream. The concentrate was not classified as a RCRA characteristic waste and was handled as a state hazardous waste. In other applications, the concentrate liquid waste stream could be classified as a RCRA listed or characteristic waste.

For the generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (partially promulgated). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

2.9.3 Clean Air Act (CAA)

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as arsenic, asbestos, benzene, and vinyl chloride. States are responsible for enforcing the CAA through State Implementation Plans. To assist in this, Air Quality Control Regions (AQCRs) were established. Allowable emission limits are determined based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Fugitive emissions from the Rochem technology may come from intermediate process tank vents during treatment, depending on the nature of the waste being treated and how the system is operated. During this Demonstration, minor volatile gas emissions were detected from the intermediate concentrate tank when the HPU was between treatment cycles and the first-stage unit was filling the tank with concentrate. State air quality standards may require additional measures to control fugitive emissions. The handling and storage of the liquid waste to be treated and the handling and storage of the concentrated liquid waste generated in tanks outside of the Rochem process may also need emission controls to meet standards.

2.9.4 Clean Water Act (CWA)

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by establishing federal, state, and local discharge standards. If treated water is discharged to surface water bodies or POTW, CWA regulations will apply. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When a NPDES permit is issued, it includes waste discharge requirements. Discharges to a POTW must comply with general pretreatment regulations outlined in 40 CFR Part 403, as well as other applicable state and local administrative and substantive requirements.

During the SITE Demonstration, final permeate was discharged to the sanitary sewer under a modification to the Central Landfill's Industrial Wastewater Discharge Permit. Polishing treatment with activated carbon was utilized to ensure compliance with the discharge limitations. Polishing treatment may be necessary for discharge of permeate to a surface water body. Depending on the types of contaminants present in the liquid waste treated and the discharge permit limits, additional polishing treatment could include activated carbon treatment, pH adjustment, and/or air stripping of lightweight volatile organic compounds. In some applications, the DTM process may meet discharge requirements without polishing treatment.

2.9.5 Safe Drinking Water Act (SDWA)

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. Parts 144 and 145 discuss requirements associated with the underground injection of contaminated water. If underground injection of liquid waste is selected as a disposal means, approval from EPA for constructing and operating a new underground injection well is required.

2.9.6 Occupational Safety and Health Administration (OSHA) Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120 which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All technicians operating the Rochem DTM technology and all workers performing on-site construction are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum personal protective equipment (PPE) for workers will include gloves, eyewear, steel-toe boots, and Tyvek® coveralls. Depending on contaminant types and concentrations, additional PPE may be required. Noise levels are not expected to be high, however noise from the pumps driving the system will be constant, so noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, then workers will be required to wear hearing protection. The levels of noise anticipated are not expected to adversely affect the community.

2.9.7 Radioactive Waste Regulations

According to the developer, the Rochem DTM technology has the ability to treat water contaminated with radioactive materials. The primary agencies that regulate the cleanup of radioactively contaminated sites are the EPA, the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the states. In addition, non-governmental agencies may issue advisories or guidance, which should also be considered in developing protective remedies.

The SDWA has established maximum contaminant levels (MCLs) for alpha- and beta-emitting radionuclides that would be appropriate in setting cleanup standards for radioactively contaminated water. Discharge of treated effluent from the Rochem DTM technology could be subject to radionuclide concentration limits established in 40 CFR Part 440 (Effluent Guidelines for Ore Mining and Dressing). These regulations include effluent limits for facilities that extract and process uranium, radium, and vanadium ores.

NRC regulations cover the possession and use of source, by-product, and special nuclear materials by NRC licenses. These regulations apply to sites where radioactive contamination exists, and cover protection of workers and public from radiation, discharges of radionuclides in air and water, and waste treatment and disposal requirements for radioactive waste. In evaluating requirements for treating radiologically contaminated waters, consideration must not only be given to the quality of the raw water and final effluent, but also any process residuals, specifically spent filters and membranes. If the technology is effective for radionuclides, these radioactive contaminants will be concentrated on the membrane surface. This could have an impact on disposal requirements, as well as health and safety considerations.

DOE requirements are included in a series of internal DOE orders that have the same force as regulations at DOE facilities. DOE orders address exposure limits for the public, concentration or residual radioactivity in soil and water, and management of radioactive wastes.

2.9.8 Mixed Waste Regulations

Use of the Rochem DTM technology at sites with radioactive contamination may involve the treatment or generation of mixed waste. As defined by Atomic Energy Act (AEA) and RCRA, mixed waste contains both radioactive and hazardous components and is subject to both acts. When the application of both regulations results in a situation inconsistent with the AEA (for example, an increased likelihood of radioactive exposure), AEA requirements supersede RCRA requirements.

The EPA's OSWER, in conjunction with the NRC, issued several directives to assist in the identification, treatment, and disposal of low-level radioactive mixed waste. If high-level mixed waste or transuranic mixed waste is treated, DOE internal orders should be considered when developing a protective remedy.

2.9.9 State and Local Requirements

Federal, state, and local regulatory agencies may require permits prior to operation of the DTM technology. Most federal permits will be issued by the authorized state agency. If, for example, the concentrate is considered a RCRA waste, a permit issued by the state may be required to operate the system as a treatment, storage, and disposal (TSD) facility. The state may also require a TSD permit for on-site storage greater than 90 days of hazardous waste (i.e., concentrated liquid waste, spent membranes, and filters). Permits from the local planning board may be required if a permanent structure for housing the equipment will be constructed. A CAA permit issued by a state air quality control board may be required if air emissions in excess of regulatory criteria are anticipated. During treatment, appropriate waste water discharge permits will be needed to discharge the permeate to POTW, into surface waters, or through underground injection wells. If off-site disposal of contaminated waste is required, the waste must be taken to the disposal facility by a licensed transporter.

Section 3
Economic Analysis

3.1 Introduction

The primary purpose of this economic analysis is to provide a cost estimate for treating landfill leachate utilizing the Rochem DTM technology. The DTM system used during the SITE Demonstration was a 9122-type system composed of three separate units: leachate (first stage); permeate (second stage); and concentrate (high-pressure stage). This system was designed to treat the SITE Demonstration leachate at a feed rate of four gpm (15 lpm) and a permeate recovery of 75%.

This economic analysis estimates costs for a 9122 and a 9142 DTM system, each operating at a fixed facility. These are the two systems that Rochem uses most frequently. Rochem has four systems available for wastewater treatment: Model 9122 rated for 3,000 to 9,000 gpd (11,000 to 34,000 lpd); Model 9142 rated for 10,000 to 32,000 gpd (38,000 to 120,000 lpd); Model 9152 rated for 33,000 to 79,000 gpd (125,000 to 300,000 lpd); and Model 9532 rated for 9,000 to 133,000 gpd (34,000 to 500,000 lpd). The 9122 system costed is slightly smaller than the SITE Demonstration system. It is designed to treat the SITE Demonstration leachate at a feed rate of three gpm (11 lpm), rather than four gpm (15 lpm), with a permeate recovery of 75%. The 9142 system costed is designed to treat the SITE Demonstration leachate at a feed rate of 21 gpm (79 lpm) with a permeate recovery of 75%. Both the 9122 and 9142 systems costed have two stages: a combined leachate and permeate unit (first stage) and a concentrate unit (high-pressure stage).

3.2 Conclusions

Costs listed in this economic analysis are presented as dollars per permeate-gallon produced. All costs presented assume a 75% permeate recovery. To calculate the cost per gallon of leachate treated, multiply the cost per permeate-gallon by 0.75.

Estimated costs for treating leachate similar to the Demonstration leachate (hazardous landfill leachate), with an on-line efficiency factor of 90%, are $0.16/permeate-gallon ($0.04/permeate-liter) for the 9122 system and $0.06/permeate-gallon ($0.01/permeate-liter) for the 9142 system. Table 3-1 breaks down these costs into categories and lists each category's cost as a percent of the total cost. Based on information from Rochem it appears that the larger 9152 and 9532 systems would have a lower cost per permeate-gallon than the 9122 and the 9142 systems.

The total costs do not include waste disposal costs for the concentrate stream. This waste disposal cost is leachate- and concentrate-specific and thus is not included in this cost estimate. Depending on concentrate-specific characteristics and geographical location, options for treating the concentrate include: solidification/stabilization, thermal evaporation, incineration, and recirculation back to the landfill (for municipal landfills). Section 3.4.8 discusses the concentrate liquid waste disposal costs for the Demonstration.

The annualized equipment cost is based on the following life-times from Rochem: a ten-year equipment life for the units, a five-year permeate-membrane life, a three-year leachate-membrane life, and a two-year concentrate-membrane life. For comparative purposes, if the membrane life-time is actually lower, then the overall treatment costs will be higher. Treatment costs will increase to $0.17/permeate-gallon and $0.08/permeate-gallon for the 9122 and the 9142 systems, respectively, for the following membrane life-times: a one-year leachate-membrane life, a one-year permeate-membrane life, and a six-month concentrate-membrane life.

Operating labor requirements are assumed to be four hours per day (hpd) for a 24-hpd operation of either the 9122 or the 9142 DTM system. For different leachates, fewer operator-hours may be required. This would lower the overall treatment costs. If labor requirements were reduced to one hpd, then the overall treatment costs would decrease to $0.13/permeate-gallon and $0.05/permeate-gallon for the 9122 and the 9142 systems, respectively.

The on-line efficiency factor is assumed to be 90% for these cost estimates. If this were increased to 95%, then the overall treatment cost would decrease to $0.14/permeate-gallon and $0.05/permeate-gallon for the 9122 and the 9142 systems, respectively.

If only the annualized equipment costs and consumables costs were considered, then the cost would decrease to

Table 3-1. Estimated Costs for Treatment Using Rpchem DTM Technology

	9122		9142	
DTM System Model Number	9122		9142	
Permeate Recovery Percentage	75%		75%	
On-Line Efficiency Percentage	90%		90%	
Gallons of Leachate Treated per Minute	3		21	
Gallons of Permeate Produced per Minute	2.25		15.75	
	$/Permeate -Gal	% of Total Cost	$/Permeate -Gal	% of Total Cost
Site Facility Preparation Costs	0.001	0.6%	0.000*	0.2%*
Permitting & Regulatory Costs	—	—	—	—
Annualizeed Equipment Costs	0.041	26.5%	0.019	34.4%
Startup & Fixed Costs	0.030	19.4%	0.012	21.8%
Labor Costs	0.034	21.9%	0.005	9.1%
Supplies Costs	0.006	3.9%	0.002	3.6%
Consumables Costs	0.032	20.6%	0.014	25.5%
Effluent Treatment & Disposal Costs	—	—	—	—
Residuals & Waste Shipping, Handling, & Transport Costs	0.006	3.9%	0.002	3.6%
Analytical Costs	—	—	—	—
Facility Modifications, Repair, & Replacement Costs	0.005	3.2%	0.001	1.8%
Site Restoration Costs	0	0	0	0
Total Costs ($/Permeate-Gallon)	0.16		0.06	
($/Permeate-Liter)	0.04		0.01	

*Site facility preparation costs for the 9142 system are $0.0001/permeate-gallon.

$0.07/permeate-gallon and $0.03/permeate-gallon for the 9122 and the 9142 systems, respectively. This contributes approximately 50% to the overall treatment cost presented in this report for both the 9122 and 9142 systems. The remaining 50% of treatment costs include: (1) site facility preparation costs; (2) startup and fixed costs; (3) labor costs; (4) supplies costs; (5) residuals and waste shipping, handling, and transport costs; and (6) facility modifications, repair, and replacement costs.

Costs presented in this report are order-of-magnitude estimates as defined by the American Association of Cost Engineers, with an expected accuracy within +50 and -30%; however, because this is a new application of this technology, the range may actually be wider.

3.3 Issues and Assumptions

The cost for treatment using the Rochem DTM system is based on, but not limited to, the following information:

- The estimated costs presented in this analysis are representative of charges typically assessed to the client by the vendor. Costs such as preliminary site preparation, permits and regulatory requirements, initiation of monitoring and sampling programs, concentrate disposal costs, and site cleanup and restoration are considered to be the responsible party's (or site owner's) obligation and are not included in the estimate presented. These costs tend to be site-specific, and calculations are left to the reader so that relevant information may be obtained for specific cases. Whenever possible, applicable information is provided on these topics so that the reader may independently perform the calculations to acquire relevant economic data.
- Leachate treated is similar to the Demonstration leachate. Leachate characteristics directly influence the treatment cost. Different leachates may require a different cleaning frequency, on-line efficiency factor, pH adjustment requirement, membrane life, and/or cartridge filter life.
- The 9122 system costed can treat three gallons of leachate per minute (11 lpm). The 9142 system costed can treat 21 gallons of leachate per minute (79 lpm).
- An on-line efficiency factor of 90% is achieved. This factor accounts for down-time due to scheduled and unscheduled cleanings and maintenance. It is based

on observations recorded during the SITE Demonstration and other data from Rochem. The approximate on-line efficiency factor during the SITE Demonstration was 84%.

- A permeate recovery factor of 75% is achieved. This is based on data collected during the SITE Demonstration.

- Cleaning frequency and cleaning solution requirements are based on observations made during the SITE Demonstration and other data from Rochem. During the SITE Demonstration, the DTM system was off-line approximately 16% of the time. This broke down to 9.6% for cleaning and 6.4% for maintenance. Based on information from Rochem from other applications, off-line time for cleaning decreases by 50% or more from the original cleaning off-line time after the system has been on-line for several months. Based on this information and the Demonstration data, off-line time for cleaning is estimated as four percent. The cleaning solution requirement for the 9122 system is based on the volume of cleaning solution utilized per hour of cleaning during the SITE Demonstration [one-and-one-half gallons (5.7 liters) of cleaner per hour of cleaning]. This volume was scaled-up for the larger 9142 system to three gallons (11 liters) of cleaner per hour of cleaning. This corresponds to information from Rochem.

- The pH adjustment requirements are the same as those observed during the SITE Demonstration. This is approximately 6.25 gallons (23.65 liters) of hydrochloric acid for every 1,000 permeate-gallons (3,800 permeate-liters).

- The following membrane life-times are assumed: five years for the permeate-membrane, three years for the leachate-membrane, and two years for the concentrate-membrane. These life-times are based on information from other Rochem applications.

- Cartridge filters are replaced after each cleaning cycle. This is based on information from Rochem.

- System operating times are 24 hpd, seven days per week, and 50 weeks per year.

- Labor requirements are limited to one operator on-site for four hpd for both the 9122 and 9142 DTM systems.

3.4 Basis of Economic Analysis

The costs associated with treatment by the Rochem DTM technology presented in this economic analysis are defined by 12 cost categories, listed below:

- Site and facility preparation costs;
- Permitting and regulatory costs;
- Equipment costs;
- Startup and fixed costs;
- Labor costs;
- Supplies costs;
- Consumables costs;
- Effluent treatment and disposal costs;
- Residuals and waste shipping, handling, and transport costs;
- Analytical costs;
- Facility modification, repair, and replacement costs; and
- Site restoration costs.

These categories reflect typical cleanup activities encountered on Superfund sites *(7).* Each of these cleanup activities is defined and discussed, forming the basis for the detailed estimated cost analysis presented in Table 3-2. The estimated costs are shown graphically in Figures 3-1 and 3-2 for the 9122 and 9142 DTM systems, respectively.

Many actual or potential costs that exist were not included as part of this estimate. They were omitted because they would require site-specific engineering designs that are beyond the scope of this SITE project. Costs that are assumed to be the obligation of the responsible party or site owner have been omitted from this cost estimate and are indicated by a line (—) in Table 3-2. Categories with no costs associated with this technology are indicated by a zero (0) in Table 3-2.

The 12 cost factors examined and assumptions made are described in detail below. Except where specified, the same assumptions were made for the 9122 and the 9142 DTM systems.

3.4.1 Site and Facility Preparation Costs

For the purposes of these cost calculations, “site” refers to the location of the contaminated waste. For these cost estimates, it is assumed that sufficient space is available at the site to allow the DTM system to be located near the contaminated waste. Thus, costs for transportation of the contaminated waste from the site to a separate location where the DTM system is operated are not required for this cost estimate.

It is assumed that preliminary site preparation will be performed by the responsible party (or site owner). The amount of preliminary site preparation required will depend on the site. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, preparations

Table 3-2. Detailed Costs for Treatment Using the Rochem DTM Technology

DTM System Model Number	9122	9142
Permeate Recovery Percentage	75%	75%
On-Line Efficiency Percentage	90%	90%
Gallons of Leachate Treated per Minute	3	21
Gallons of Permeate Produced per Minute	2.25	15.75
Gallons of Leachate Treated per Year	1,360,800	9,525,600
Gallons of Permeate Produced per Year	1,020,600	7,144,200
	$/Permeate-Gallon	
Siteand Facility Preparation Costs		
Site design and layout	—	—
Survey and site investigations	—	—
Legal searches	—	—
Access rights and roads	—	—
Preparations for support facilities	—	—
Auxiliary buildings	—	—
Installation of major equipment & shakedown testing	0.001	0.000*
Technology-specific reqiurements	—	—
Transportation of waste feed	—	—
Total Site and Facility Preparation Costs	0.001	0.000*
Permitting and Regulatory Costs		
Permits —	—	
System monitoring requiremetns	—	—
Development of monitoring and protocols	—	—
Total Permitting and Regulatory Costs	—	—
Equipment Costs		
Annualized equipment cost		
Leachate and Permeate Unit (Ten-Year Life)	0.024	0.010
Concentrate Unit (Ten-Year Life)	0.010	0.003
Leachate-Membranes (Three-Year Life)	0.005	0.003
Permeate-Membranes (Five-Year Life)	0.001	0.002
Concentrate-Membranes (Two-Year Life)	0.001	0.001
Support equipment costs	0	0
Equipment rental	0	0
Total Equipment Costs	0.041	0.019
Startup and Fixed Costs		
Working capital	0.000**	0.000**
Insurance and taxes	0.015	0.006
Initiation of monitoring programs	—	—
Contingency	0.015	0.006
Total Startup and Fixed Costs	0.030	0.012
Labor Costs†		
Technicians	0.034	0.005
Rental Car	0	0
Travel	0	0
Total Labor Costs	0.034	0.005
Supplies Costs		
Personal protective equipment	0.002	0.000***
Spare parts	0.004	0.002
Total Supplies Costs	0.006	0.002
Consumables Costs		
Cartridge filters	0.004	0.001
Membrane cleaner	0.011	0.003
pH adjustment chemicals	0.006	0.006
Electricity	0.011	0.004
Total Consumables Costs	0.032	0.014
Effluent Treatment and Disposal Costs		
On-site facility costs	—	—
Off-site facility costs	—	—
-concentrate disposal		
-monitoring activities	0	0
Total Effluent Treatment and Disposal Costs	—	—

(continued)

Table 3-2. Continued

		9122	9142
DTM System Model Number		9122	9142
Permeate Recovery Percentage		75%	75%
On-Line Efficiency Percentage		90%	90%
Gallons of Leachate Treated per Minute		3	21
Gallons of Permeate Produced per Minute		2.25	15.75
Gallons of Leachate Treated per Year		1,360,800	9,525,600
Gallons of Permeate Produced per Year		1,020,600	7,144,200
		$/Permeate-Gallon	
Residuals & Waste Shipping, Handling & Transport Costs			
Preparation		—	—
Waste disposal		0.006	0.002
Total Residuals & Waste Shipping, Handling & Transport Costs		0.006	0.002
Analytical Costs			
Operations		0	0
Environmental monitoring		—	—
Total Analytical Costs		—	—
Facility Modification, Repair, & Replacement Costs			
Design adjustments		0	0
Facility modifications		0	0
Repair & maintenance		0.005	0.001
Equipment replacement		0	0
Total Facility Modification, Repair, & Replacement costs		0.005	0.001
Site Restoration Costs			
Site cleanup and restoration		—	—
Permanent storage		—	—
Total Site Restoration Costs		—	—
Total Operating Costs	($/Permeate-Gallon)	0.16	0.06
	($/Permeate-Liter)	0.04	0.01

† The labor costs listed are for operating labor. Additional labor, travel, and rental car costs associated with the installation of major equipment & shakedown testing are included under "Site and Facility Preparation Costs."
* The installation of major equipment & shakedown testing costs for the 9142 system are $0.0001/permeate-gallon.
** The working capital costs are $0.0003/permeate-gallon and $0.0001/permeate-gallon for the 9122 and the 9142 systems, respectively.
*** The pesonal protective equipment costs for the 9142 system are $0.0002/permeate-gallon.

for support and decontamination facilities, utility connections, and fixed auxiliary buildings. Since these costs are site-specific, they are not included as part of the site preparation costs in this cost estimate.

Installation of major equipment and shakedown testing for the DTM system consist of treatability testing, shipping the DTM system to the site, installing the equipment, and shakedown testing of the installed equipment. These costs are included under "Installation of major equipment & shakedown testing" in Table 3-2 and are described in detail below.

Rochem estimates treatability testing costs at $15,000 to $25,000. This cost is included in the purchased equipment cost, thus it is not listed in Table 3-2 under technology-specific site preparation costs. Treatability testing is a two- to six-week pilot test to determine equipment specifications (e.g., flux rate, number of modules, system size, and operation). Treatability costs include equipment rental, Rochem personnel, shipping, and travel costs.

Shipping costs for the DTM system are estimated at $6,000. This is based on shipping costs incurred during the SITE Demonstration. Rochem normally can ship either the 9122 or the 9142 system in two 20-foot shipping containers.

Installation costs are limited to labor costs. Labor costs consist of wages, per diem, and transportation. See "Labor Costs" for an explanation of these costs. It is estimated that one technician and one supervisor can install either the 9122 or the 9142 system in four days working 12 hpd. For this cost estimate, it is assumed that the site owner will provide a heavy-duty forklift or small crane to move the DTM units into place.

Shakedown testing costs are limited to labor costs. Labor costs consist of wages, per diem, and transportation. See "Labor Costs" for an explanation of these costs. It is estimated that shakedown testing will require one technician and one supervisor for 12 hpd for three days.

3.4.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner), not that of the vendor. These costs may include actual permit

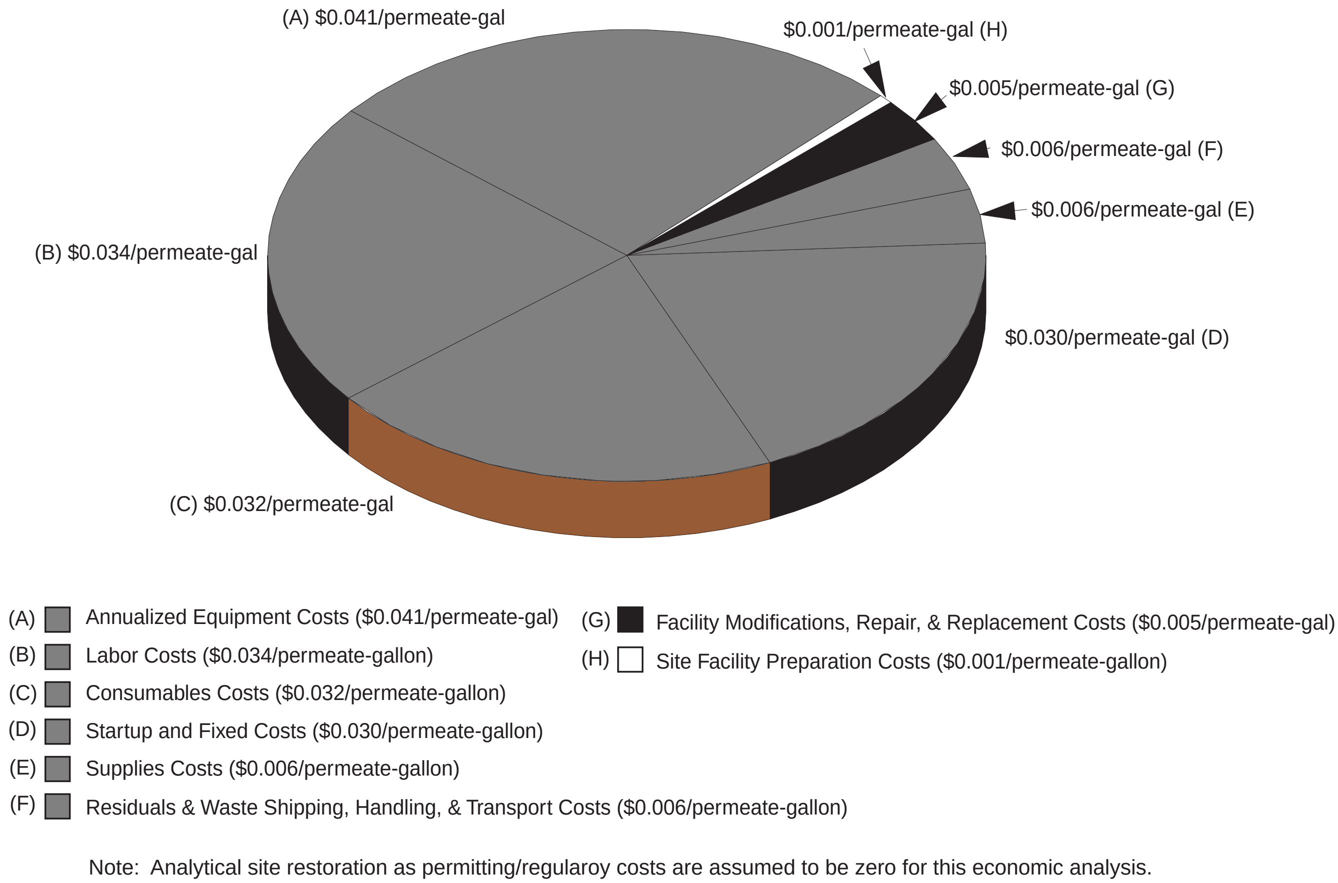
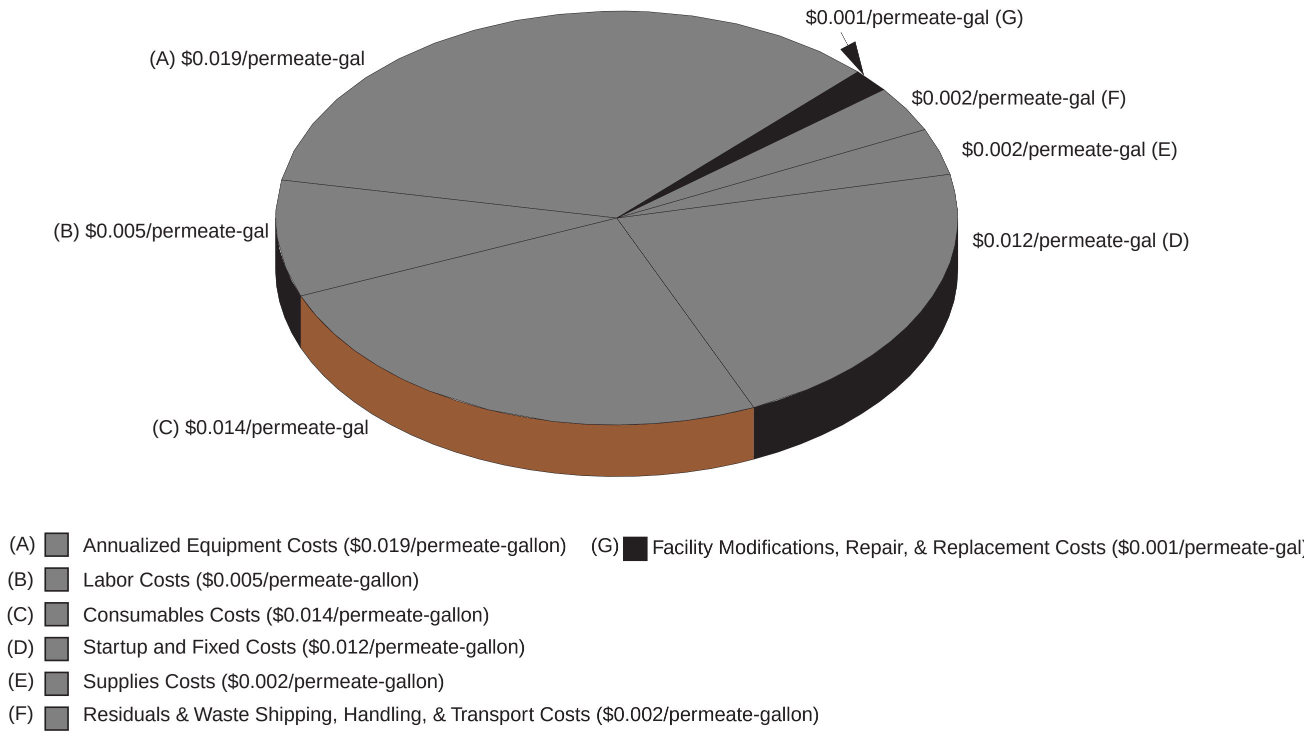


Figure 3-1. Estimated Costs for the 9122 DTM System Operating at a Fixed Facility.



Note: 1 - Site facility preparation costs are $0.0001/permeate-gallon for the 9142 system.
2 - Analytical, site restoration and permitting/regulatory costs are assumed to be zero for this economic analysis.

Figure 3-2. Estimated Costs for the 9142 DTM System Operating at a Fixed Facility.

costs, system monitoring requirements, and the development of monitoring and analytical protocols. Permitting and regulatory costs can vary greatly because they are site- and leachate-specific. No permitting costs are included in this analysis; however depending on the treatment site, this may be a significant factor since permitting activities can be expensive and time-consuming.

3.4.3 Equipment Costs

The purchased equipment costs are presented as annualized equipment costs in Table 3-2. The annualized equipment cost is calculated using a six-percent annual interest rate, a ten-year equipment life for the units, a three-year leachate-membrane life, a five-year permeate-membrane life, and a two-year concentrate-membrane life. The annualized equipment cost is based upon the writeoff of the total initial capital equipment cost, scrap value (assumed to be ten percent of the original equipment cost), and the membrane cost using the following equations *(8,9)*:

$$\text{Annualized Equipment Cost for the Units} = (V_u - V_s)\frac{i(1+i)^{n_u}}{(1+i)^{n_u}-1}$$

where

V_u is the cost of the units (either the leachate and permeate unit or the concentrate unit),

V_s is the salvage value of the unit (approximated at ten percent of the original equipment cost for either the leachate and permeate unit or the concentrate unit),

i is the annual interest rate (six percent), and

n_u is the system unit life (ten years for either the leachate and permeate unit or the concentrate unit).

$$\text{Annualized Equipment Cost for the Membranes} = (V_m)\frac{i(1+i)^{n_m}}{(1+i)^{n_m}-1}$$

where

V_m is the membrane cost (either for the leachate-, permeate-, or the concentrate-membranes),

i is the annual interest rate (six percent), and

n_m is the membrane life (three years for the leachate-membranes, five years for the permeate- membranes, and two years for the concentrate-membranes).

The 9122 system purchased equipment includes:

- a leachate and permeate (first stage) unit ($202,044) with five leachate-membrane modules ($12,675 for leachate-membranes) and two permeate-membrane modules ($5,070 for permeate-membranes); and
- one concentrate (high-pressure stage) unit ($80,300) with one membrane module ($2,535 for concentrate-membranes).

The total cost of the purchased equipment for the 9122 system is thus $302,624 ($282,344 for the system units plus $20,280 for membranes). The purchased equipment cost includes shakedown testing and on-line monitoring equipment for pH, temperature, and conductivity measurements.

The 9142 system purchased equipment includes:

- a leachate and permeate (first stage) unit ($593,878) with 40 leachate-membrane modules ($101,400 for leachate-membranes) and ten permeate-membrane modules ($25,350 for permeate-membranes); and
- one concentrate (high-pressure stage) unit ($160,644) with six membrane modules ($15,210 for concentrate-membranes).

The total cost of the purchased equipment for the 9142 system is thus $896,482 ($754,522 for the system units plus $141,960 for membranes). The purchased equipment cost includes shakedown testing and on-line monitoring equipment for pH, temperature, and conductivity measurements.

3.4.4 Startup and Fixed Costs

Working capital is based on the amount of money currently invested in supplies and consumables. The working capital cost of supplies and consumables is based on maintaining a one-month inventory of these items. (See “Supplies Costs” and “Consumables Costs” for the specific amount of supplies and consumables required for the operation of the system. These quantities were used to determine the amount of supplies and consumables required to maintain a one-month inventory of these items.)

Insurance and taxes are usually three to five percent of the total purchased equipment capital costs. Insurance and taxes are assumed to be five percent of the purchased equipment capital costs *(9)*.

The cost for the initiation of monitoring programs has not been included in this estimate. Depending on the site and the location of the system, however, local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring required may have significant impact on the project costs. Rochem does monitor pH, temperature, and conductivity with in-line monitoring equipment. The cost of this in-line monitoring equipment is included in the purchased equipment cost listed in the “Equipment Costs” section.

A contingency cost of five percent of the purchased equipment capital costs is allowed for any unforeseen or unpredictable cost conditions. These include, but are not limited to, strikes, storms, floods, and price variations *(9,10)*.

3.4.5 Labor Costs

Labor costs are limited to labor rates, per diem, daily transportation, and travel. Labor rates include overhead and administrative costs. Per diem is estimated at $70 per day per person. Daily transportation includes a rental car and fuel at $50 per day. Round-trip travel costs are assumed to be $600 per round trip per person. Only Rochem personnel on-site for equipment installation and shakedown testing require per diem, daily transportation to the site, and round-trip travel to the site. Operators are assumed to be site personnel that will be trained by Rochem personnel during shakedown testing. Thus, operators do not require per diem, daily transportation to the site, or round-trip travel to the site.

Operating labor requirements for a 24-hpd operation are one technician for four hours a day at $25 per hour for both the 9122 and the 9142 systems. This is based on treating Demonstration leachate (hazardous landfill leachate). For other leachates that require less operator monitoring, operating requirements could be as low as one to two hpd for a 24-hpd operation.

The following labor costs are listed under “Site Preparation Costs.” Equipment installation labor requirements are one supervisor at $50 per hour and one technician at $25 per hour for 12 hpd for four days. Shakedown testing labor requirements are one supervisor at $50 per hour and one technician at $25 per hour for 12 hpd for three days. Daily transportation includes one rental car during equipment installation (four days) and during shakedown equipment testing (three days). Travel includes two round trips (one trip for the supervisor and one trip for the technician to perform equipment installation and shakedown testing).

3.4.6 Supplies Costs

Supplies costs for this cost estimate are limited to PPE (personal protective equipment) and spare parts. The cost of PPE is estimated at $31 per week per technician. Based of information from Rochem, spare parts are estimated at $4,500 per year and $16,000 per year for the 9122 and the 9142 systems, respectively. Spare parts include: electrical parts, PVC pipes for repairs, membrane cushions, pulsation dampers, pump belts, pump valves, and pump seals.

3.4.7 Consumables Costs

Consumables required for the operation of the Rochem DTM technology are limited to cartridge filters, membrane cleaners, pH adjustment chemicals, and electricity. Cartridge filter replacement is based on treating SITE Demonstration leachate (hazardous landfill leachate). This requires the cartridges to be replaced after each cleaning cycle. The 9122 system has two units that each require one cartridge filter. The 9142 system has two units that each require two cartridge filters. This approximates to the 9122 and the 9142 systems expending five and ten cartridge filters per week, respectively. The volume of membrane cleaners required is based on treating SITE Demonstration leachate. This requires one-and-one-half gallons (5.7 liters) of membrane cleaner per hour of cleaning for the 9122 system and three gallons (11 liters) of membrane cleaner per hour of cleaning for the 9142 system. The cost of membrane cleaners is estimated at $21.50 per gallon ($5.68 per liter) of cleaner. The off-line time due to cleaning is estimated at four percent. The volume of pH adjustment chemicals (hydrochloric acid) is based on treating SITE Demonstration leachate. This requires 6.25 gallons (24 liters) of hydrochloric acid for every 1,000 gallons (3,800 liters) of permeate produced. The cost of pH adjustment chemicals is estimated at $0.95 per gallon ($0.25 per liter). Normal power consumption for the 9122 and the 9142 systems is estimated at 12.4 kW and 31 kW, respectively. Electricity rates are assumed to be $0.11/kW-hour.

3.4.8 Effluent Treatment and Disposal Costs

Two effluent streams are anticipated from the Rochem DTM technology: the permeate stream and the concentrate stream. For this cost estimate, it is assumed that the permeate does not require further treatment and can be discharged to a local POTW. The nominal cost of discharging the permeate to a POTW is not included in this cost estimate.

The concentrate waste disposal cost is leachate- and concentrate-specific and thus is not included in this cost estimate. Depending on concentrate-specific characteristics and geographical location, options for treating the concentrate include: solidification/stabilization, thermal evaporation, incineration, and recirculation back to the landfill (for municipal landfills). For the SITE Demonstration, a fee was paid to a waste disposal company to transport the concentrate off-site for treatment and disposal. The disposal fee paid for the Demonstration concentrate was $0.82 per gallon ($0.22 per liter) of concentrate, or at a 75% permeate recovery, $0.27/permeate-gallon ($0.07/permeate-liter).

3.4.9 Residuals and Waste Shipping, Handling, and Transport Costs

It is assumed that the only residuals or solid wastes generated from this process will be used PPE, used adsorbents, and used cartridge filters. The disposal and transportation cost for 55-gallon (208-liter) drums of these residuals and solid wastes is estimated at $435 per 55-gallon (208-liter) drum. This is based on disposal costs paid during the SITE Demonstration. For the 9122 system, it is assumed that the following residuals or solid wastes will be generated: one-half drum of used PPE per year, six drums of used adsorbents per year, and seven drums of used cartridge filters per year. For the 9142 system it is assumed that the following residuals or solid wastes will be generated: one-half drum of used PPE per year, 12 drums of used adsorbents per year, and 14 drums of used cartridge filters per year.

3.4.10 Analytical Costs

Only on-line pH, temperature, and conductivity measurements (to verify that equipment is performing properly) are included in this cost estimate. Clients may elect, or may be required by local authorities, to initiate a planned sampling and analytical program at their own expense. The cost for Rochem's on-line monitoring equipment is included in the purchased equipment cost.

The analytical costs associated with environmental monitoring have not been included in this estimate due to the fact that monitoring programs are not typically initiated by Rochem. Local authorities may, however, impose specific sampling and monitoring criteria whose analytical requirements could contribute significantly to the cost of the project.

3.4.11 Facility Modification, Repair, and Replacement Costs

Maintenance costs are assumed to consist of maintenance labor and maintenance materials. Maintenance labor and materials costs vary with the nature of the liquid waste and the performance of the equipment. Based on information from Rochem, the annual maintenance labor and materials cost is estimated at $5,000 per year and $9,000 per year for the 9122 and the 9142 systems, respectively. This is in addition to the cost for spare parts listed under "Supplies Costs." Costs for design adjustments, facility modifications, and equipment replacements are not included in this cost estimate.

3.4.12 Site Restoration Costs

Since both the 9122 and the 9142 cases are for fixed facilities, there are no site restoration costs for this cost estimate.

Section 4
Treatment Effectiveness

4.1 Background

4.1.1 Site History and Contamination

The SITE Demonstration of the Rochem DTM technology was performed at the Central Landfill Superfund Site in Johnston, Rhode Island. The Central Landfill is a solid waste disposal facility operated by the Rhode Island Solid Waste Management Corporation. It is the largest landfill in New England and is composed of two areas: a 121-acre disposal area and a 33-acre expansion area. Historically, disposal of hazardous and non-hazardous wastes took place in the 121-acre section of the landfill. Waste disposal activities in this area were discontinued in April 1993, however, 12 acres of the 33-acre expansion area are still being used for the disposal of non-hazardous municipal solid waste. Located within the 121-acre area is a half-acre (approximately) area where large volumes of liquid industrial waste were disposed of in several trenches excavated into bedrock. This area is commonly referred to as the “hot spot” and is currently undergoing cleanup.

Presently, several wells are being used to intercept leachate from the site to prevent off-site migration of contaminated liquids. Prior to the Demonstration, leachate from Well MW91ML7, located downgradient from the “hot spot,” was characterized during a pump test conducted on-site. Table 4-1 presents the results of the pre-demonstration characterization of the leachate. As shown in the table, analytical results indicate that the leachate contained moderate to high levels of VOCs, low to moderate levels of metals, and a high level of dissolved solids. Based on this characterization, the levels of constituents present were determined to be high enough to evaluate the technology but also within an acceptable range for treatment. Therefore, the leachate was judged suitable for treatment for a Demonstration of the DTM technology. Approximately 33,000 gallons (125,000 liters) of leachate from Well MW91ML7 were treated by the DTM technology during this SITE Demonstration.

4.1.2 Treatment Objectives

Prior to the Demonstration, bench-scale treatability tests were conducted at the Rochem facility in Torrance, California on leachate from a hazardous waste landfill in the western U.S. The leachate was contaminated with many of the same constituents as the Central Landfill leachate, including VOCs, heavy metals, and high dissolved solids. The purpose of the treatability tests was to determine how effectively the technology could treat the leachate. Data were also obtained so Rochem could establish the type of DTM system to be used, the order of system units, and the type of membranes to be used for a demonstration at that site. The treatability tests aided Rochem in developing claims for the quality and quantity of water that the DTM system could produce when treating hazardous landfill leachate. The results from the treatability tests are presented in Appendix B of this report. Rochem did not conduct treatability tests on the leachate from the Central Landfill itself prior to this Demonstration.

Based on the prior treatability tests, Central Landfill leachate waste characterization, and other information provided by the developer, critical and secondary (non-critical) objectives were developed for the Rochem DTM technology SITE Demonstration. Critical objectives are important for evaluation of the developer’s claims. Secondary objectives are of interest to future applications of the DTM technology but are not directly related to the developer’s claims. The following objectives were developed for the Rochem Demonstration:

Critical Objectives:

- determine if the technology could meet the developer’s claims for contaminant rejections of greater than 90% for VOCs, greater than 92% for TOC, and greater than 99% for TDS and metals;
- determine if the technology could achieve and maintain a system treated water recovery rate of 75% or greater; and
- evaluate the DTM technology’s resistance to membrane fouling and scaling by determining the change in flux as a result of liquid waste (leachate) treatment over the course of the Demonstration.

Secondary Objectives:

- develop capital and operating costs for the DTM system;

Table 4-1. Central Landfill Leachate Waste Stream Pre-Demonstration Characterization Results

Constituent	Average Concentration (µg/L)
Volatile Organics	
Acetone	3,000
Benzene	66
2-Butanone	3,300
Chlorobenzene	35,000
Chloroform	11
1,1-Dichloroethane	140
cis-1,2-Dichlorethene	270
Ethylbenzene	1,600
Methylene Chloride	620
Methyl isobutyl ketone (MIBK)	250
Tetrachloroethene	88
Toluene	2,800
Trichloroethene	130
Freon 11	210
Vinyl Chloride	100
Xylenes	2,300
1,2-Dichlorobenzene	29,000
1,3-Dichlorobenze	280
1,4-Dichlorobenzene	1,600
Semivolatile Organics	
Isophorone	27
Naphthalene	14
Nitrobenzene	3
1,2,4-Trichlorobenzene	28
2-Chlorophenol	50
2,4-Dichlorophenol	33
2,4-Dimethylphenol	33
2,4-Dinitrophenol	7
3- and 4-Methylphenol	160
Methylnaphthalenes	9
Metals	
Aluminum	0.30
Barium	1.4
Beryllium	0.004
Calcium	140
Cobalt	0.02
Iron	49
Magnesium	200
Manganese	22
Molybdenum	0.10
Nickel	0.23
Potassium	110
Sodium	560
Strontium	0.82
Thallium	0.06
Zinc	0.16
Anions	
Fluoride	10
Chloride	1,300
Nitrogen (as Nitrate)	2
Nitrate	7
Orthophosphate	1
Sulfate	73
Alkalinity	
Bicarbonate as $CaCO_3$	2,400
Carbonate as $CaCO_3$	ND
Hydroxide as $CaCo_3$	ND
Total as $CaCo_3$	2,400

(continued)

Table 4-1. Continued

Constituent	Average Concentration (µg/L)
Other Analytes	
Ammonia	510
Dissolved Silica	24
Total dissolved solids	4100
Total suspended solids	120
Surfactants(MBAS)	5
pH (pH units)	7
Total Organic Carbon	360
Oil and Grease	22

- determine whether the DTM system could meet applicable or relevant regulatory criteria for discharge of the permeate;
- evaluate the ease of use, reliability, and maintenance requirements of the DTM system;
- calculate a material balance for the overall process for water and primary constituents; and
- estimate the potential fugitive emissions from the system during use.

These objectives were utilized to evaluate the DTM technology's effectiveness in treating leachate from the Central Landfill.

4.1.3 Treatment Approach

The Rochem Demonstration was designed to treat leachate for up to 21 days for eight to ten hpd. A test of this duration was felt to be sufficient to evaluate the quantity and quality of permeate produced, to allow an assessment of the technology's ability to resist membrane fouling and scaling, and to allow several cycles of membrane cleaning. Cleaning of the DTM membranes was to be performed at the discretion of the operator, typically based on an increase in module pressure readings.

A brief equipment shakedown of the DTM system, utilizing potable water and then the Central Landfill leachate, was initiated immediately preceding the Demonstration to check the system and to refine operating criteria such as feed flow rate and module pressure. Leachate was treated for about eight hours during shakedown.

Rochem planned to operate the system at a relatively constant permeate (product water) production rate during the Demonstration. Also, the system was to be set to achieve a water recovery rate of 75% or greater. No chemical pretreatment of the raw feed was planned. However, because of the pH (6.8) of the untreated leachate, Rochem decided to use acid addition for pH control during the Demonstration. Hydrochloric acid was added to the first-stage and also to the high-pressure unit feed streams in an attempt to lower the pH to between 5 and 6.

Leachate was pumped continuously at two gpm (eight lpm), 24 hpd into the leachate storage tanks. This was the maximum that Well MW91ML7 could produce. Because the unit supplied by Rochem was designed for a feed flow rate of four gpm (15 lpm) or greater, the test was planned to run for eight to ten hpd in order to supply this feed flow rate. The DTM equipment is normally run 24 hpd. Operating only eight to ten hpd required Rochem to flush the modules at the end of each day and shut the system down overnight.

4.2 Testing Methodology

Sampling and data collection were performed during the Demonstration in order to evaluate project objectives. A Quality Assurance Project Plan (QAPP) *(11)*, developed specifically for the Rochem DTM technology Demonstration, set forth detailed procedures for sampling and analysis.

Samples withdrawn from sample taps located on the face of the DTM control units were collected from 11 process streams throughout the system. The raw feed was the system input, while the final permeate and final concentrate streams were the system output. These streams were considered the most important in assessing system performance. Measurements used in evaluating the critical objectives for the Demonstration were designated as critical parameters. The critical parameters consisted of VOCs; metals; TDS; TOC; system operating pressures and flow rates; and totalized flows of the raw feed, final permeate, and final concentrate streams. Parameters that were used to assess the secondary objectives were designated non-critical. Non-critical field measurements included turbidity, pH, temperature, conductivity, chemical oxygen demand (COD), calcium, hardness, silt density index (SDI), and electricity consumption. Non-critical laboratory analytical measurements were anions, ammonia, and methylene blue active substances (MBAS).

Samples for off-site laboratory analysis were collected once per day during leachate treatment. These samples were collected at different times each day in order to avoid potential bias in the results. On two selected days, samples were withdrawn from the three main process streams three times per day at two-hour intervals to evaluate short-term variations in the critical parameters. Off-site laboratory analyses included VOCs, total metals, TDS, total solids (TS), TOC, ammonia, and anions. Field analyses and process measurements of non-critical parameters were designed to supplement the laboratory data and to provide real-time information on process operation. Samples for field analyses were collected once or twice per day, depending on the analysis. Measured field parameters included turbidity, pH, temperature, conductivity, silica, alkalinity, COD, calcium, and hardness.

The critical objective for percent rejection of contaminants was evaluated utilizing the daily system feed and final permeate concentrations. The developer claimed that the DTM system could reject greater than 90% of VOCs, 99% of heavy metals and TDS, and 92% of TOC. The target VOCs (those detected at significant levels in liquid waste characterization samples and considered critical for the Demonstration) were chlorobenzene; 1,2-dichlorobenzene; 1,4-dichlorobenzene; ethylbenzene; toluene; and xylenes. The target metals included barium, calcium, iron, magnesium, manganese, potassium, sodium, and strontium.

System operational parameters were measured to assess the field performance and cost of the DTM system. Flow rates, totalized flows, pressures, and electricity usage were recorded on field log sheets hourly during system operation. The developer claimed that the DTM technology could achieve a 75% or greater system water recovery rate while treating the Central Landfill leachate. This critical objective was evaluated by utilizing the totalized flows for the raw feed and the final permeate. In addition, totalized flows and process stream flow rates aided in evaluating contaminant mass balances.

After the Demonstration, the DTM system was evaluated for flux losses to assess membrane fouling and scaling. This critical test objective was addressed with baseline testing on a saline solution of known conductivity. Pre- and post-demonstration baseline testing determined the change in flux (flow rate per unit membrane area) from before treatment of the leachate to after treatment of the leachate. Field samples and samples for off-site laboratory analysis taken during the baseline test included: conductivity, TDS, pH, and temperature measurements of the feed and permeate streams. Operating pressures, flow rates, and totalized flows were also monitored. Baseline testing was performed on only the first-stage and high-pressure units because they received most of the liquid waste loading and were the most susceptible to scaling and fouling. Membrane performance was further evaluated utilizing process data and samples that were collected during leachate treatment. In addition, samples of non-critical parameters including alkalinity, ammonia, anions, silica, and total solids were collected from various streams and analyzed. These parameters, along with SDI measurements, aided in assessing the fouling potential of the system's feed and concentrate streams.

To measure vent emissions during the Demonstration, integrated gas samples were collected in Summa™ canisters from a system intermediate concentrate holding tank vent. Gas flow measurements from a totalizing device were also obtained. Gas was discharged from the intermediate concentrate holding tank only when the HPU was between treatment cycles and the first-stage unit was filling the tank with concentrate. Gas sampling was conducted during four days of process operation for approximately thirty minutes several times per day in order to obtain representative samples. These gas measurements, in combination with VOC mass balances, were used to estimate the significance of fugitive VOC emissions and to determine if these emissions impacted calculated contaminant rejections.

Discharge samples from the DTM processes final permeate holding tank were analyzed for COD, biochemical oxygen demand (BOD), total toxic organics (TTO), heavy metals, total suspended solids, and oil and grease to determine if local discharge criteria were met. In addition, samples from the final concentrate holding tank were analyzed for liquid waste disposal purposes.

Throughout the Demonstration, leachate draw-down and flow rate measurements from Well MW91ML7 were recorded. These data, along with other draw-down data collected by Region I EPA from surrounding wells, were utilized for a long-term pump test by the EPA. This long-term pump test was separate from, but coordinated with, the Rochem SITE Demonstration; it was designed to measure the effect of leachate pumping on the water levels of the surrounding wells.

Quality Assurance (QA) measures were followed to ensure that the data collected to evaluate project objectives were acceptable and of known quality. These measures included equipment calibrations, quality control samples, field duplicate samples, and matrix spike and matrix spike duplicate samples. Also, field and laboratory technical systems reviews were conducted by an independent EPA auditor.

4.3 Detailed Process Description

The DTM technology can use MF, UF, or RO membrane materials, depending on the application. The membranes are generally more permeable to water than to contaminants or impurities. MF, which typically utilizes membranes with a pore size of 0.05 to 2 microns, retains particulates, colloids, and microorganisms. UF, which typically uses membranes with pore sizes ranging from 0.005 to 0.1 microns, is efficient in removing colloids and macromolecules *(12)*. Dissolved ionized salts will usually permeate MF and UF membranes. In contrast, RO will remove ionic species such as sodium chloride and calcium sulfate as well as many organic compounds *(13).* In RO, water in the feed is forced through a membrane by an applied pressure that exceeds the osmotic pressure of the feed. This water, called "permeate," has a lower concentration of contaminants. The impurities are selectively rejected by the membranes and are thus concentrated in the "concentrate" left behind. The percentage of water that passes through the membranes is a function of operating pressure, membrane type, and concentration and chemical characteristics of the contaminants. The DTM technology utilized thin-film composite RO membranes, for all stages, during the Demonstration at the Central Landfill.

The patented membrane module features larger feed flow channels and a higher feed flow velocity than conventional membrane separation systems. According to the technology developer, these characteristics allow the DTM greater tolerance for dissolved solids and turbidity and a greater resistance to membrane fouling and scaling. Suspended particulates are readily flushed away from the membranes during operation. The high flow velocity, short feed water path across each membrane, and the circuitous flow path create turbulent mixing to reduce boundary layer effects and minimize membrane fouling and scaling. In addition, the developer claims that the design of the DTM allows easy cleaning and maintenance of the membranes—the open channels facilitate rinsing and cleansing of particulate matter, and membranes can be removed from modules as needed for replacement.

Figure 4-1 is a cutaway diagram of the DTM. Membrane material for the DTM is formed into a cushion surrounding a porus spacing material. The membrane cushions are alternately stacked with hydraulic discs on a tension rod. The hydraulic discs support the membranes and provide flow channels for the feed liquid to pass over the membranes. After passing through the membrane material, permeate flows through collection channels out of the module to a product recovery tank. A stack of cushions and discs is housed in a pressure vessel. Flanges seal the ends of the module in the pressure vessel and provide the feed water input and the product (permeate) and reject (concentrate) output connections. The number of discs per module, number of modules, and the membrane materials can be custom-designed to suit the application.

Modules are typically combined in a treatment unit or stage. DTM units can be connected in series to improve permeate water quality or in parallel to increase system treatment capacity. The DTM system design includes built-in multi-media filters and cartridge filters for each unit to remove suspended particulates from the input feed and to protect pumps and membranes from physical damage. The multi-media filters are cleaned by backwashing; cartridge filters are manually replaced as needed. To monitor the operation of the modules, the system is equipped with micro-processor controlled pressure and flow meters.

A three-stage DTM process was used to treat the leachate at the Central Landfill site. Each stage was a separate DTM unit interconnected with piping and tankage. Two DTM stages were used in series to produce the final permeate. The third DTM stage was a HPU which further treated the concentrate from the first-stage to increase system water recovery. A schematic of the multi-stage DTM process utilized during the Demonstration is presented in Figure 4-2. The system operated up to eight hpd for 19 days at a continuous feed flow rate of 3 to 4.5 gpm (11 to 17 lpm). The second-stage and the high-pressure units were not continuously fed, but rather operated in a semi-batch mode due to the system design.

Two 5,000-gallon tanks stored leachate that was pumped continuously from Well MW91ML7. This leachate was then pumped to a 100-gallon feed tank for the first-stage

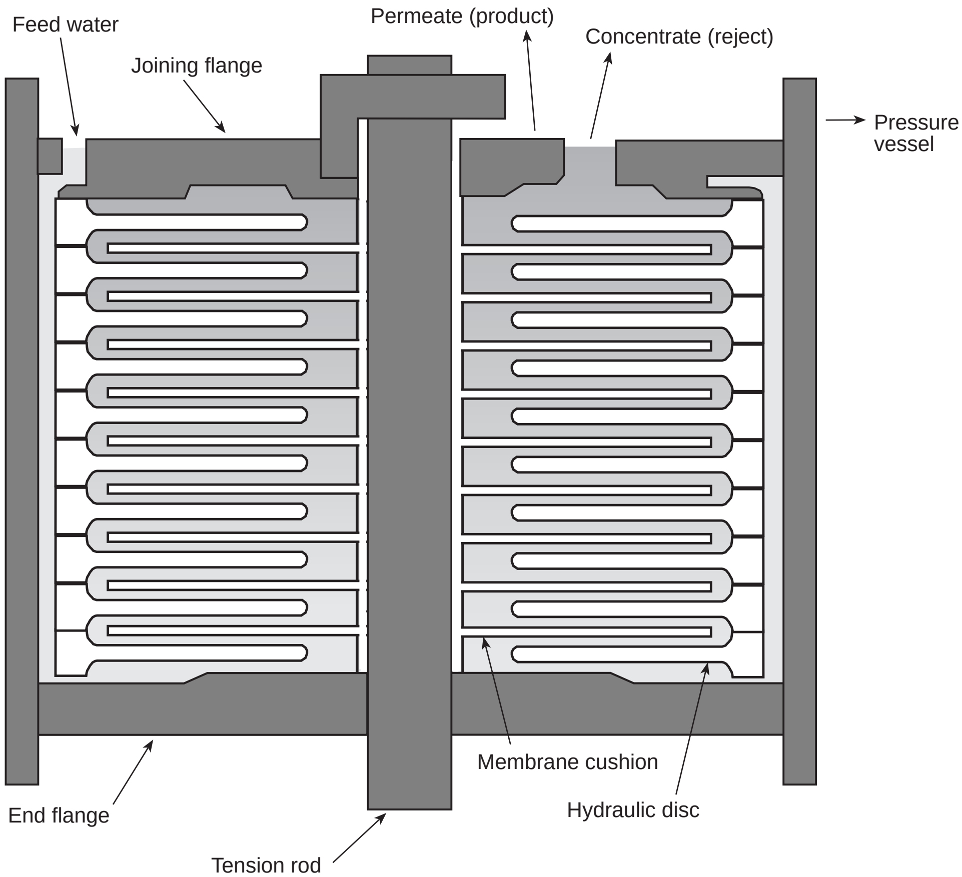


Figure 4-1. Cutaway diagram of the Rochem disc tube™ Module

unit. After filtration, contaminated leachate was pumped into the first-stage unit at pressures which ranged from 600 to 1,000 pounds per square inch gauge (psig) [4,100 to 6,900 kiloPascals (kPa)]. The first-stage unit had eight modules that utilized standard thin-film composite (TFC) membranes. The permeate produced from this unit was directed to a holding tank designated for first-stage permeate, and was then fed at 700 to 1,000 psig (4,800 to 6,900 kPa) to the second-stage unit for further treatment.

The second-stage unit, which had two modules that utilized standard TFC membranes, was not brought on-line until enough first-stage permeate accumulated in its feed holding tank. The second-stage permeate was the system's final permeate, while the second-stage concentrate was recycled into the first-stage feed line. Rochem had originally planned to use a different DTM system for the Demonstration in which the first-stage unit and the second-stage unit were combined in a single pre-fabricated container and the HPU housed in a separate container. With this type of system, the second-stage unit is not operated in a semi-batch mode, but is continuously fed permeate from the first-stage unit.

The concentrate from the first-stage unit was routed to a 300-gallon holding tank. This concentrate was fed at 1 to 3.5 gpm (4 to 13 lpm) and 900 to 1,800 psig (6,200 to 12,000 kPa) into the HPU. Use of the HPU was initiated later than the first two stages, after accumulation of first-stage concentrate; the HPU was operated in a batch mode. The HPU had two stainless steel modules that utilized TFC membranes specially modified for high pressure. The purpose of the HPU was to reduce the volume of the first-stage concentrate, thereby reducing the final liquid waste volume and increasing the system water recovery rate. High pressure was needed to overcome the osmotic pressure of the first-stage concentrate. HPU permeate was recycled into the first-stage permeate tank (feed for the second stage). The HPU produced the system's final concentrate. Initially, the HPU was operated in a recycle mode to allow the HPU concentrate to reach an optimal concentration and further increase the system's water recovery rate. This mode of operation was discontinued after the first two days of the Demonstration. It was determined by Rochem that the desired system water recovery rate could be achieved without the concentrate recycle mode; recycling the concentrate increased the chance of HPU membrane fouling and scaling.

Permeate was used to rinse and clean the DTMs. Rinsing was performed on the second-stage and high-pressure units between most batch treatment cycles each day to displace any residual leachate from the membrane surfaces. The second-stage unit was rinsed approximately four to five times each day, and the HPU was rinsed approximately two to three times each day. All stages were then rinsed at the end of the day to flush the system prior to shut-down overnight. At the end of

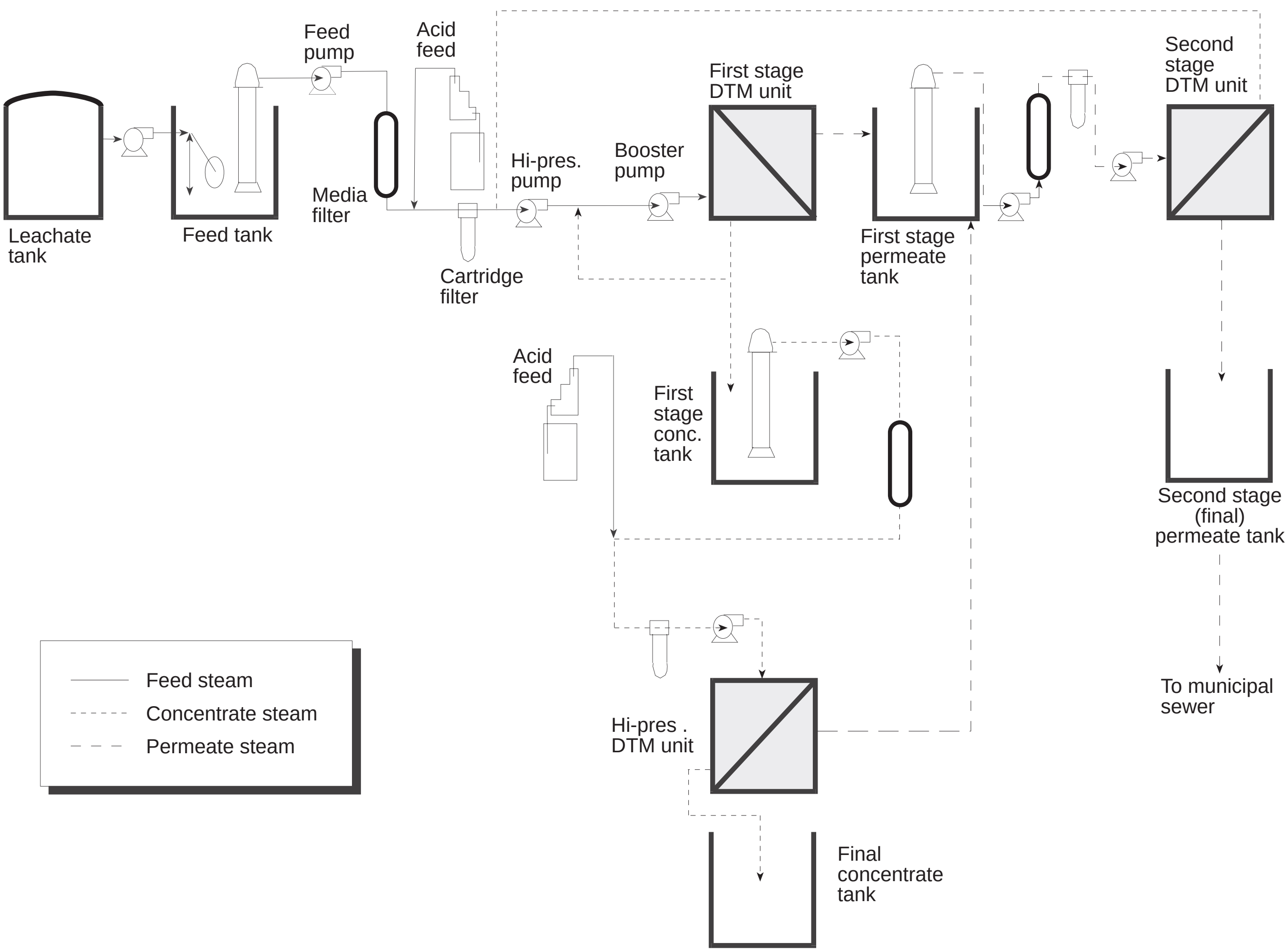


Figure 4-2. Schematic of Rochem DTM process used during SITE demonstration.

the day, the first-stage unit was rinsed with approximately 50 gallons (190 liters) of first-stage permeate; the second-stage unit was rinsed with approximately 34 gallons (130 liters) of final permeate; and the HPU was rinsed with approximately 20 gallons (76 liters) of first-stage permeate. Cleaning was accomplished by adding cleaning agents—either alkaline for fouling, acidic for membrane scale, or detergent for both—to the rinse tanks for each unit and recirculating the solution through the modules. Membranes were cleaned at the discretion of the Rochem system operator based on an increase in module pressure readings or changes in operating temperature or flow rate.

Hydrochloric acid (HCl) was added to the first-stage feed and the HPU feed at dosing rates of 1.6 to 2.8 liters per hour (lph) and 0.53 to 1.6 lph, respectively. The addition of HCl, which facilitated pH adjustment to help control membrane scaling, was not started until the third day of leachate treatment. Rochem's target system feed pH for the Demonstration was between 5 and 6.

As a precautionary measure, the final permeate was run through activated carbon canisters to ensure compliance with discharge requirements. After carbon treatment, it was stored and batch-discharged to the sanitary sewer.

4.4 Performance Data

4.4.1 General Chemistry

The leachate treated by the Rochem DTM technology at the Central Landfill was a mixture of organic and inorganic contaminants that proved to be a difficult challenge to the technology based on the Demonstration results. Table 4-2 presents the average concentrations of contaminants measured in the system feed, permeate, and concentrate process streams during the Demonstration. The average levels of chlorobenzene and 1,2-dichlorobenzene in the feed were high at 21 and 16 mg/L, respectively. Metals were present at mg/L levels; iron (at 48 mg/L) and calcium (at 130 mg/L) were significant because of their potential for membrane scaling. The presence of other metals, such as barium and strontium, and anions, such as fluoride and sulfate, also represented a potential for scaling of the membranes. Silica, another scalant of concern, was present in the leachate at 15 mg/L. The TDS in the feed averaged 4,900 mg/L. As a result of treatment, TDS in the final

Table 4-2. Average Concentrations for the System Feed, Permeate, and Concentrate Streams

Contaminant	System Feed	Final Permeate	Final Concentrate
	Average Concentration (mg/L)		
Target VOCs			
1,2-Dichlorobenzene	16	.76	23
1,4-Dichlorobenzene	0.70	<0.081	<0.80
Chlorobenzene	21	2.7	36
Ethylbenzene	0.79	<0.031	1.1
Toluene	1.8	0.083	3.4
Xylenes	1.3	<0.039	<1.7
Target Metals			
Barium	1.4	<0.014	4.3
Calcium	130	<1.1	410
Iron	48	<0.38	140
Magnesium	250	<1.6	850
Manganese	21	<0.14	70
Potassium	150	<1.8	550
Sodium	710	<5.7	2,500
Strontium	0.89	<0.0068	2.9
Anions			
Chloride	2,500	<13.	11,000
Fluoride	<2.7	<0.10	11
Nitrate	<12	<0.40	<26.
Sulfate	81	<1.8	300
Other Parameters			
Total Alkalinity (as $CaCO_3$)	1,600	<1.0*	4,100
Ammonia	650	5.3	2,300
Silica	15	<0.63*	86
Total Dissolved Solids	4,900	<32	17,000
Total Solids	5,800	<100	21,000
Total Organic Carbon	460	<15	1,600

* = Permeate concentration is based on 6 sampling days.

concentrate increased to about 17,000 mg/L, a level high enough to be of concern for solids precipitation and scaling. Ammonia was present in the feed a 650 mg/L and was removed effectively by the technology. The high level of ammonia in the feed was probably due to past disposal of septic tank waste and sewage in the landfill. The alkalinity of the leachate was primarily bicarbonate alkalinity. Alkalinity values were slightly depressed in the permeate due to pH adjustment in the feed and the resultant production of carbon dioxide (CO_2). For example, permeate alkalinity was found to be about 10 mg/L (as $CaCO_3$) after CO_2 stripping. The high alkalinity of the feed was significant because it limited Rochem's ability to adjust the leachate pH down to the desired level to help control precipitation and membrane scaling during the Demonstration.

Two silt density index (SDI) measurements were taken towards the end of leachate treatment. The SDI provides an indication of a water's fouling nature due to suspended silt or colloidal material. For the Demonstration leachate, the measured SDIs were 14 and 19 (16.5 average). For conventional RO membrane designs, a maximum SDI value of 5 is generally recommended to assure reliable operation *(14, 15)*.The measured values greatly exceeded this guideline and indicate the difficult nature of the Demonstration leachate.

4.4.2 Contaminant Removals

Contaminant removals were calculated as percent rejections from daily feed and permeate concentrations. Table 4-3 summarizes the calculated mean percent rejections achieved for the target contaminants considered critical for this Demonstration. The mean percent rejections achieved by the technology for all but three of the target contaminants met or exceeded the developer's claims based on their average values as shown in the table. The calculated mean percent rejections of 1,2-dichlorobenzene; ethylbenzene; toluene; and xylenes were greater than the specified criteria of 90%. For chlorobenzene and 1,4-dichlorobenzene, the calculated mean percent rejections were less than the Demonstration criteria of 90%, but the 90% rejection criteria fell within the 95% confidence intervals for these VOCs. Laboratory VOCs quantitations for two days of leachate treatment, August 27 and 28, 1994, are estimated because of instrument calibration problems. VOC percent rejections calculated from these data for those days are also estimated. The daily percent rejections were used to calculate the average percent rejections presented in Table 4-3. These average percent rejections were recalculated without including the estimated VOC data. The revised rejections for chlorobenzene and 1,4-dichlorobenzene were 87.7% and 89.9%, respectively. Rejections for other VOCs either did not change or increased slightly. Since the estimated VOC data agree with other analytical parameters and process measurements during the period in question, the average percent rejections using all VOC data points are thought to be valid. TOC and TDS measurements showed rejections greater than the specified criteria. All target metals except potassium showed mean rejections greater than the Demonstration criteria. The mean rejection for potassium (at least 98.7%) was within the 95% confidence interval (98.0 to 99.4%). These results indicate that the DTM system was very effective in removing all classes of contaminants in the Central Landfill leachate.

Vent emissions were measured during the Demonstration from an intermediate concentrate holding tank in the system. Multiple VOC concentration and flow rate measurements were taken over four operating days. VOC losses on a mass basis were calculated from these measurements and are shown along with losses based on percent rejections in Table 4-4. Comparing the emission results to the system VOC percent rejections (based on mass) shows the vent losses to be no more than 0.5% of the total rejection of any given compound on any day. Therefore, these system losses did not significantly affect the calculated percent rejections of VOC contaminants. Calculated VOC rejections for the technology may actually be biased low due to potential VOC losses from feed samples that foamed during sample

Table 4-3. Target Contaminants Average Percent Rejections

Contaminant	Developer's Claims Percent Rejection	Average Percent Rejection Achieved*	95% Confidence Interval
Target VOCs			
1,2-Dichlorobenzene	>90%	94.9%	92.7-97.1%
1,4-Dichlorobenzene	>90%	>87.6%	83.5-91.7%
Chlorobenzene	>09%	86.8%	83.1-90.5%
Ethylbenzene	>90%	>95.6%	94.1-97.1%
Toluene	>90%	93.8%	90.5-97.1%
Xylenes	>90%	>95.0%	92.3-97.7%
Target Metals			
Barium	>99%	>99.0%	98.3-99.7%
Calcium	>99%	>99.2%	98.5-99.9%
Iron	>99%	>99.2%	98.6-99.8%
Magnesium	>99%	>99.3%	98.6-99.9%
Manganese	>99%	>99.4%	98.7-100.0%
Potassium	>99%	>98.7%	98.0-99.4%
Sodium	>99%	>99.2%	98.5-99.9%
Strontium	>99%	>99.2%	98.5-99.9%
Total Dissolved Solids	>99%	>99.4%	98.9-99.9%
Total Organic Carbon	>92%	>96.7%	95.6-97.8%

*Greater than symbol indicates that at least one measured value was below the method detection limit.

Table 4-4. VOC Gas Loss on a Mass Basis Compared to System Percent VOC Regjection

Date	Compound	Feed Mass (mg)	Permeate Mass (mg)	% Rejection*	Gas VOC Rate (mg/min)	Time (min)	Gas VOC loss (mg)	% Rejection with gas loss	% Change
8/17	Chlorobenzene	144141.0	8296.2	94.2%	2.050	126	258.3	94.1%	0.2%
8/17	Ethylbenzene	7520.4	181.0	97.6%	0.170	126	21.4	97.3$	0.3%
8/17	Toluene	18594.2	307.8	98.3%	0.500	126	63.0	98.0%	0.3%
8/17	Xylenes	14207.3	181.0	98.7%	0.345	126	43.5	98.4%	0.3%
8/18	Chlorobenzene	135009.0	8729.7	93.5%	2.403	143	343.6	93.3%	0.3%
8/18	Ethylbenzene	6107.6	166.3	97.3%	0.176	143	25.2	96.9%	0.4%
8/18	Toluene	16072.5	328.4	98.0%	0.546	143	78.1	97.5%	0.5%
8/18	Xylenes	11572.2	166.3	98.6%	0.362	143	51.8	98.1%	0.4%
8/19	Chlorobenzene	182493.0	10366.4	94.3%	1.335	144	192.2	94.2%	0.1%
8/19	Ethylbenzene	7434.9	188.5	97.5%	0.083	144	12.0	97.3%	0.2%
8/19	Toluene	15545.7	358.1	97.7%	0.219	144	31.5	97.5%	0.2%
8/19	Xylenes	12842.1	188.5	98.5	0.167	144	24.0	98.3%	0.2%
8/20	Chlorobenzene	120726.0	9899.4	91.8%	2.230	144	321.1	91.5%	0.3%
8/20	Ethylbenzene	4024.2	61.3	98.5%	0.135	144	19.4	98.0%	0.5%
8/20	Toluene	10060.5	240.4	97.6%	0.349	144	50.3	97.1%	0.5%
8/20	Xylenes	8048.4	61.3	99.2%	0.269	144	38.7	98.8%	0.5%

*Percent rejection = [[the mass of a compound in the feed stream minus the mass of the compound in the permeate stream (input minus output)] divided by the mass of the compound in the feed stream (input)] * 100 collection. These potential losses are discussed in more detail under Section 4.4.5, "System Mass Balance."

4.4.3 Water Recovery Rate

Flow rates, totalized flows, pressures, and electricity usage were recorded on field log sheets at hourly intervals during system operation. Totalized flows were used in the calculation of system water recovery rates. System water recovery is defined as the volume of final permeate divided by the volume of feed, times 100%. Figure 4-3 illustrates the daily percent system water recoveries. Breaks in the data represent periods when the system was off-line due to weather, maintenance, or temporary mechanical problems. The average system water recovery rate for the Demonstration was 73.3% with a 95% confidence interval of 70.7 to 75.9%. The developer's claim of 75% system water recovery falls within this confidence interval.

The calculated daily water recovery rates ranged from 66.4 to 84.4%. The system recovery rate was equal to or greater than the claim of 75% on eight days of treatment. These daily recovery rates were reduced by the use of first-stage and final permeate for module rinsing during treatment. However, an allowance was not made for permeate lost due to these rinses because they were part of the operation for the system used during the Demonstration. For full-scale continuous field operating conditions this would have little effect overall. Rinsing was performed on the second-stage unit and the HPU between batch treatment cycles each day to displace residual leachate from membrane surfaces. For typical better-integrated DTM systems in which the second-stage unit operates in a continuous mode with the first-stage unit, rinsing of the second-stage unit would not be required, and recovery rates may be higher (75 to 80%) when treating a similar waste *(2)*. Because the system was not operating 24 hpd, rinsing (or flushing) with permeate was also performed on all units at the end of each day prior to shut-down overnight. These flushes were taken into account in the evaluation of daily recovery rates, as was the start-up time required each day until the system reached steady-state operating conditions. Nevertheless, the daily system shut-down and the semi-batch mode of system operation made it more difficult to accurately determine daily recovery rates. More data on recovery rate performance for other applications of this technology can be found in Appendix A, "Vendor's Claims."

4.4.4 Membrane Performance

Baseline testing was performed to help evaluate membrane physical performance and to determine whether there was a significant decrease in flux (permeate flow rate per unit membrane surface area) over the course of the Demonstration. Testing was conducted prior to and after leachate treatment on a saline solution of known conductivity so that comparable data could be developed. Recorded permeate flow rates for the first-stage unit and the HPU, the units receiving the bulk of liquid

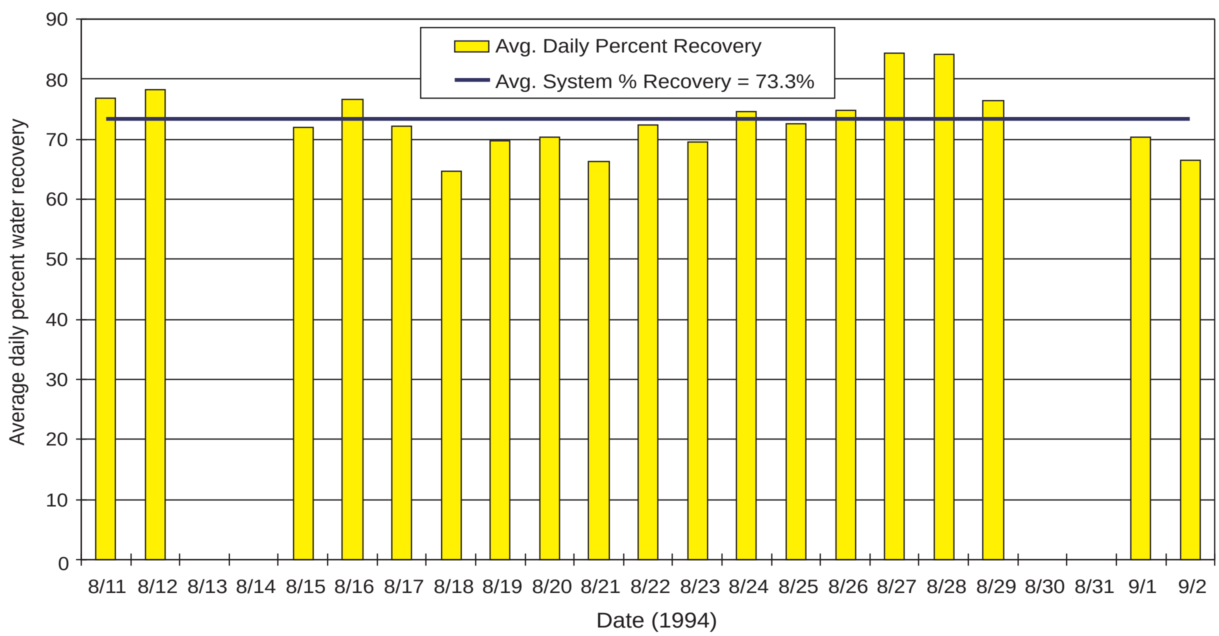


Figure 4-3. Rochem DTM System Daily Percent Water Recovery.

waste loading, were standardized so that pre- and post-demonstration data were comparable *(16)*. Table 4-5 presents the calculated results for the baseline testing. A Monte Carlo error analysis was also performed to assess the variability in these calculated results *(17, 18)*. The calculated change in flux (essentially change in flow rate since the membrane area remained constant) for the first-stage unit over the course of the Demonstration was approximately -30Å12.6% at 95% confidence. For the HPU, the calculated change in flux over the course of the Demonstration was about -83Å2.2% at 95% confidence.

These results indicate that a significant decrease in flux occurred for both units due to the action of the leachate on the membranes. However, the technology developer maintains, and other data seem to verify, that membranes in the HPU were probably damaged by an acid excursion during acid cleaning performed to remove scalants or during acid dosing for pH control. The baseline conductivity data for the HPU indicate that some condition other than scaling or fouling contributed to the flux loss. Average permeate conductivity increased for the HPU by an order of magnitude (from 300 to 2,900 micromhos per centimeter) between the initial and final baseline tests. This suggests that the membranes were damaged. The acidic solution may have caused local weaknesses in the membranes which allowed more impurities to pass through them. Visual inspection of the HPU membranes after final baseline testing showed them to have a blemished appearance compared to membranes from the other units. The HPU membranes were a new type of TFC membrane, different from those used in the other units, and may have been more sensitive to acid (low pH) *(2)*. It is possible that scaling or fouling of the HPU membranes could have been an additional factor in the large decrease in the standardized flow rate. In the first-stage unit, the quality of the permeate improved by about 25% based on conductivity readings observed during baseline testing. Therefore, damage to these first-stage membranes from acid cleaning is not indicated.

Table 4-5. Rochem DTM Technology Baseline Test Results

First-Stage Unit Baseline Results

Test	Average Standardized Flow Rate	95% Confidence Interval
Initial Baseline	2.92 gal/min	+/- 0.41 gal/min
Final Baseline	2.03 gal/min	+/- 0.24 gal/min
Δ Flux	83.6%	+/- 12.6%

High-Pressure Unit Baseline Results

Test	Average Standardized Flow Rate	95% Confidence Interval
Initial Baseline	1.61 gal/min	+/- 0.16 gal/min
Final Baseline	0.26 gal/min	+/- 0.02 gal/min
Δ Flux	83.6%	+/- 2.2%

System operating data during leachate treatment was also evaluated to determine the performance of membranes during the Demonstration. Figures 4-4 and 4-5 depict pressure and flow rate trends for the first-stage and the high-pressure units. The flow rate data were standardized for pressure, temperature, and liquid waste concentration in the same manner as the baseline data. The standardized data are also presented on the graphs. Breaks in the data represent periods when the system was off-line due to weather, maintenance, or temporary mechanical problems. Standardized flow rates were similar to the actual flow rates during the Demonstration.

In general, the data presented in these figures show an increase in operating pressures and a decrease in flow rates over time, indicating a decrease in overall performance for the units receiving the bulk of liquid waste loading during treatment. A sharp decrease in performance is seen during the first two days of treatment (pressure increasing and flow rate decreasing). After this point, the system was shut down for thorough membrane cleaning. This performance decrease is probably a result of the lack of pH adjustment to control precipitation and membrane scaling. HCl addition for pH adjustment was initiated after this time and seemed to help maintain membrane performance; membrane cleaning was not required for the next ten days of treatment. Figures 4-6 and 4-7 illustrate pH and alkalinity trends, respectively, during leachate treatment. Feed pH decreased from about 6.8 at start-up to about 6.1. The acid dosing rate was increased on August 18, 1994. Measured alkalinity (predominantly bicarbonate alkalinity) demonstrated a similar trend in response to acid addition. The decrease in alkalinity was especially noticeable in the concentrate stream. However, the high alkalinity limited Rochem's ability to reduce the feed and concentrate stream pH to help reduce precipitation and the potential for membrane scaling. The measured alkalinity of the final permeate stream was about 10 mg/L (as $CaCO_3$) after CO_2 stripping.

The feed pressure in the first-stage unit began increasing on about August 22, 1994. The system recovery rate was increased on August 24, 1994 by Rochem, and this was followed by additional pressure increases, as well as, a decrease in flux until the end of the leachate test. During this period, routine membrane cleaning was conducted for short periods of time almost every day of operation. Apparently, the first-stage membranes were beginning to foul or scale, and increasing the recovery rate compounded this problem. As a result, the system experienced a reduction in flux and a reduction in permeate quality for some contaminants. Figure 4-8 illustrates a trend in the reduction of permeate quality (most notable near the end of the Demonstration) for TDS, TOC, and total VOCs. Laboratory VOC quantitations for two days of leachate treatment, August 27 and 28, 1994, are estimated because of instrument calibration problems. Since the estimated VOC data correspond to other analytical parameters and process measurements during the period in question, which indicate a decrease in technology performance, the VOC data points are

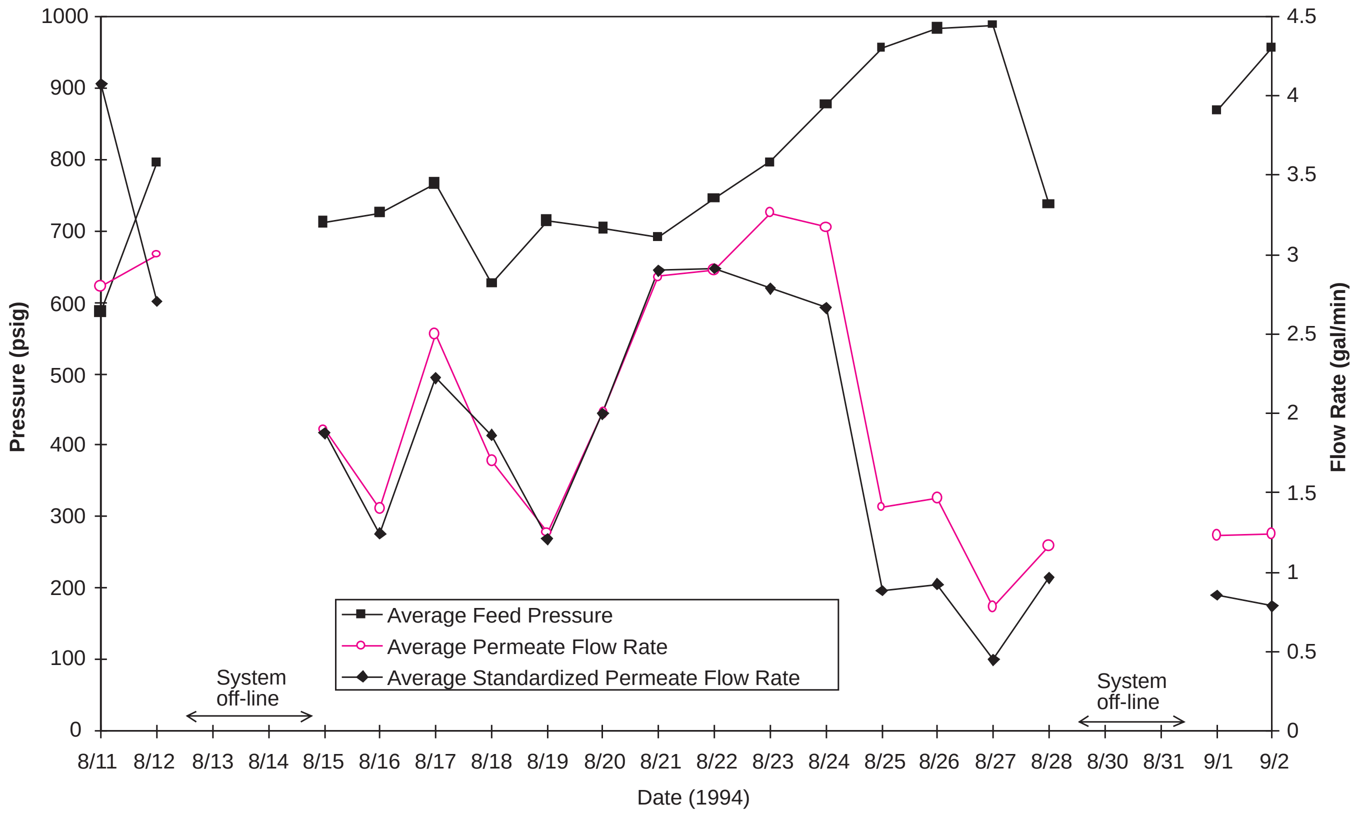


Figure 4-4. Pressure and Flow Rates vs. Time for the First-Stage Unit.

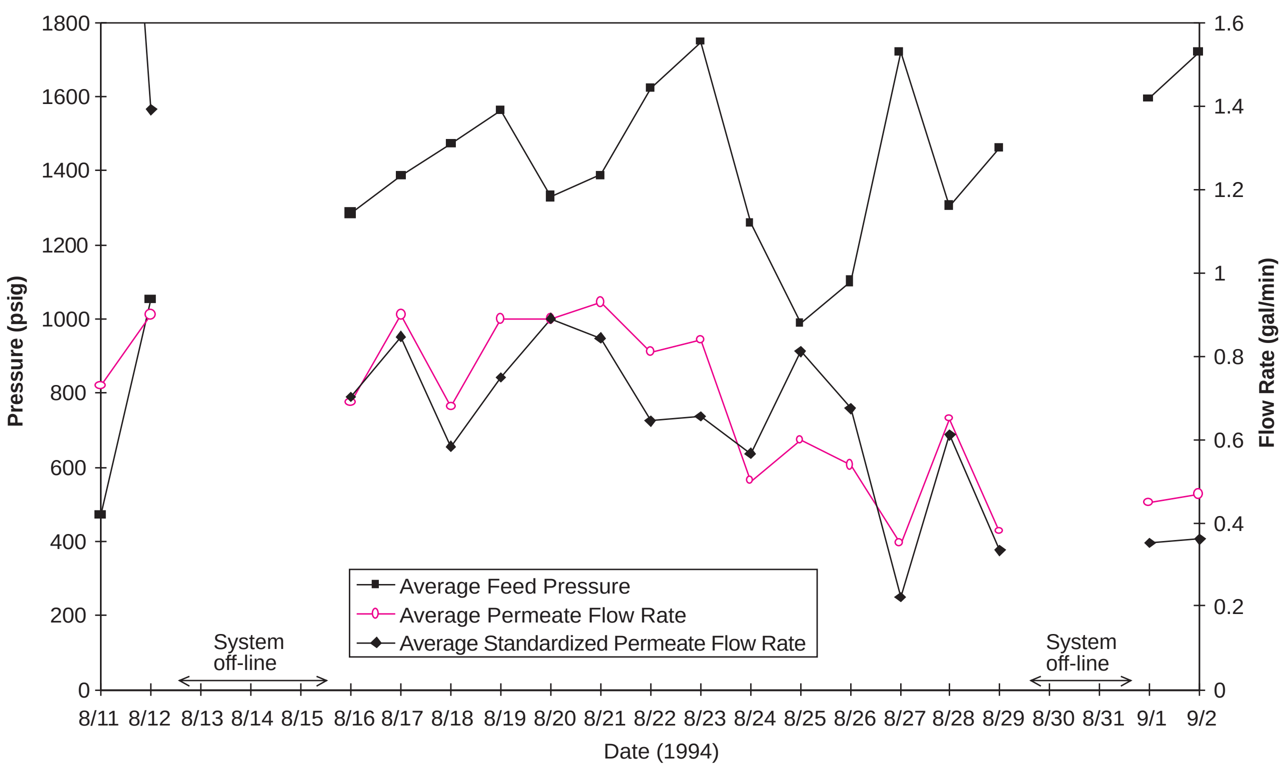


Figure 4-5. Pressure and Flow Rates vs. Time for the High-Pressure Unit.

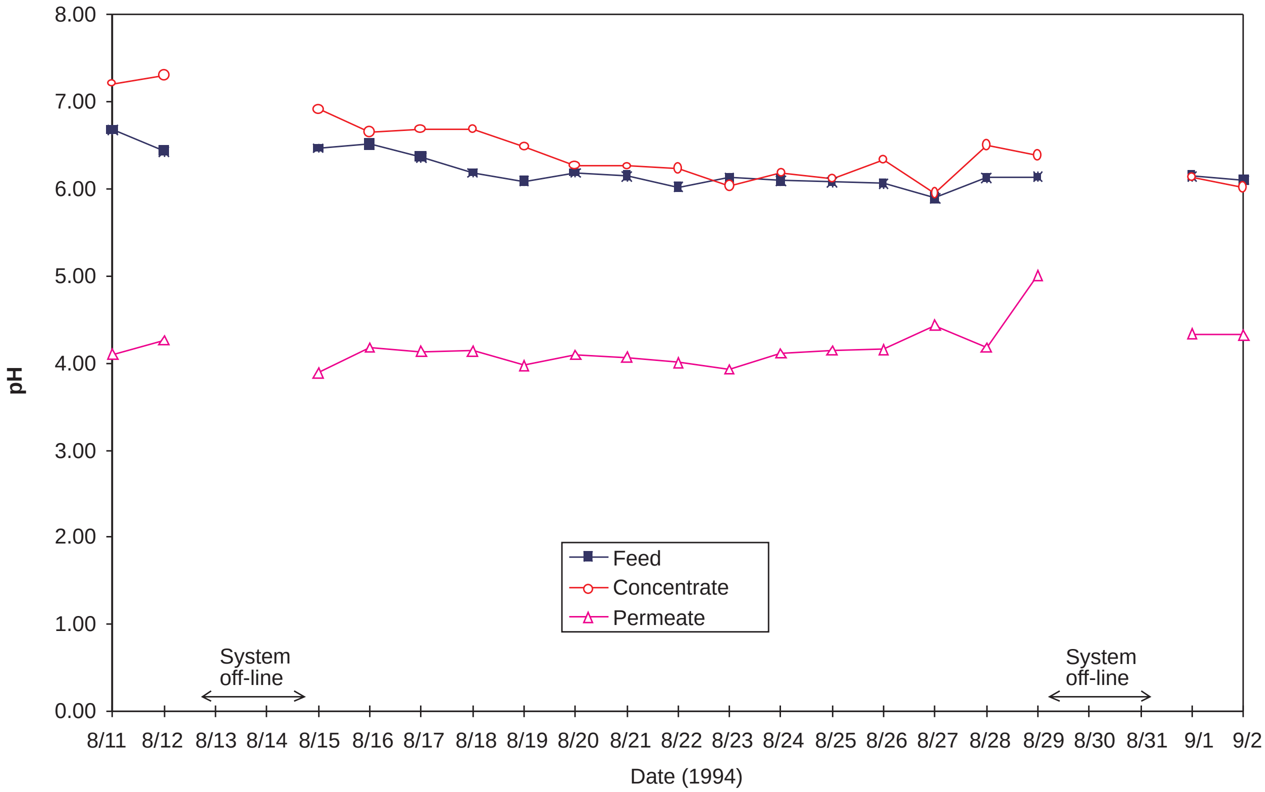


Figure 4-6. Measured pH of the System Input and Output Streams.

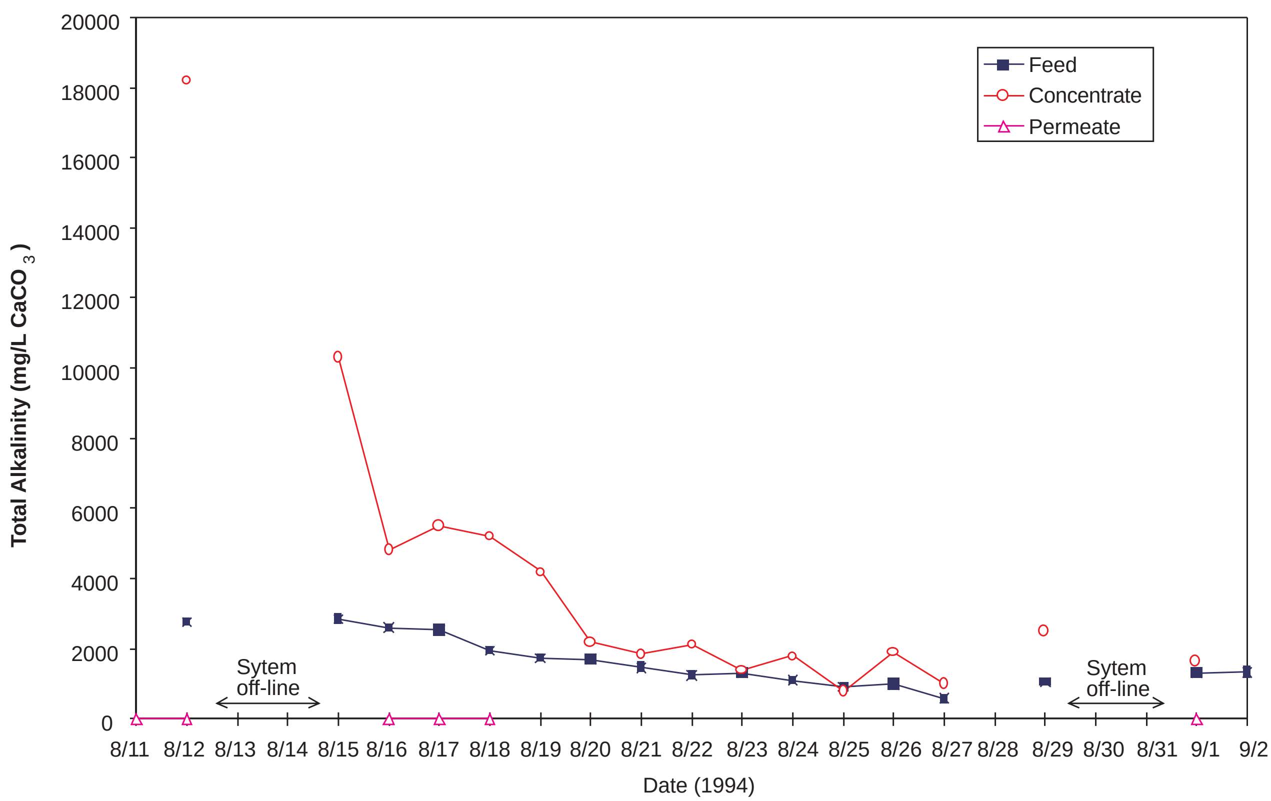


Figure 4-7. Measured Total Alkalinity (as $CaCO_3$) of the System Input and Output Streams.

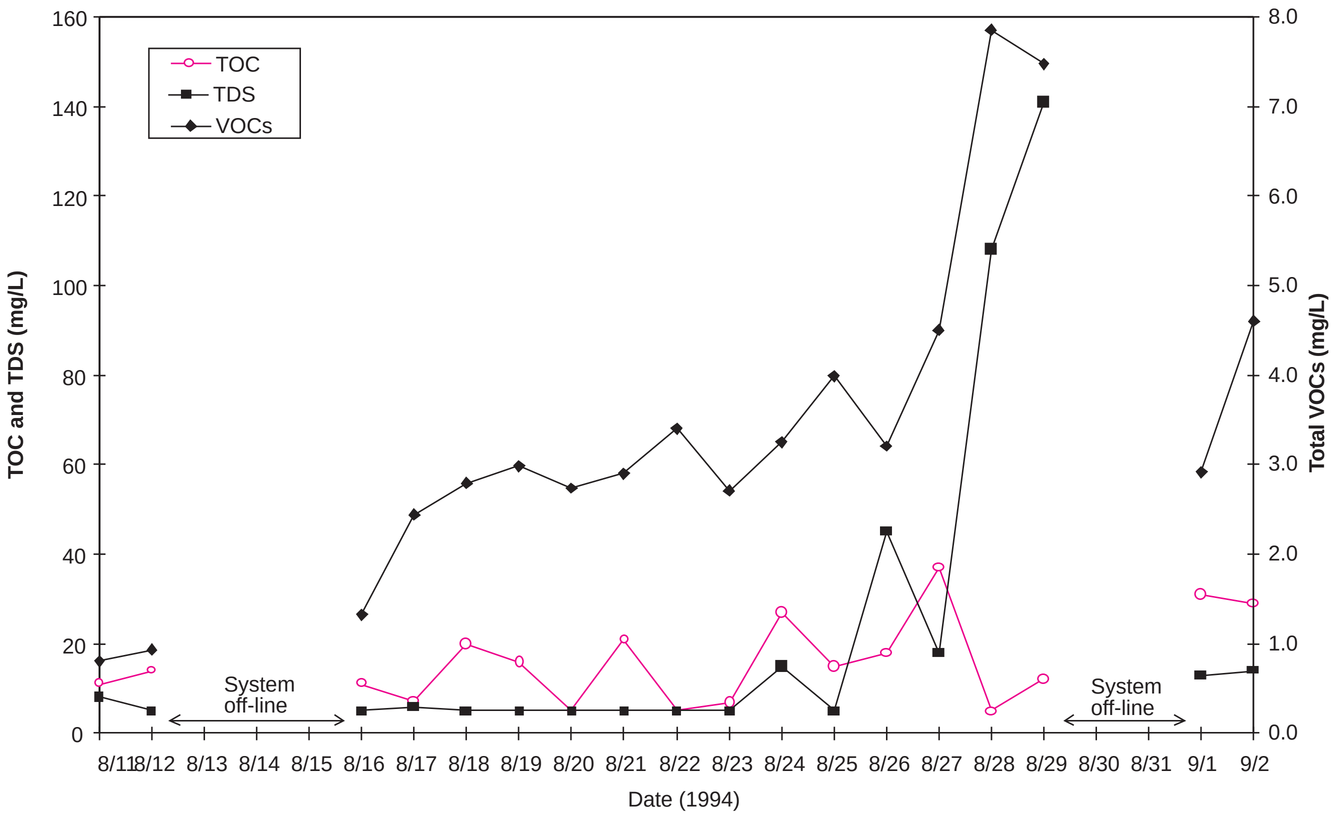


Figure 4-8. Total Organic Carbon (TOC), Total Dissolved Solids (TDS), and Total Volatile Organic Compounds (VOCs) vs. Time for the Final Permeate Stream.

thought to be valid. Membrane cleanings were helpful in maintaining system performance, but the leachate did appear to foul the membranes over the course of the Demonstration based on the leachate treatment data. However, due to the short duration of the system shake-down and of the Demonstration, it was not possible for Rochem to fully optimize the membrane cleaning procedures for this leachate *(2)*. It is possible that a better cleaning procedure could be developed to improve membrane performance.

Figure 4-9 presents the pressure and flow rate trend for the second-stage unit during leachate treatment. The flow rates shown are not standardized. Although there was a temporary decrease in permeate flow rate for this unit during the latter part of the Demonstration, overall flow rate remained fairly steady. Pressure showed a gradual increase over time. This unit did not seem to be affected by the leachate. However, the feed to this unit was first-stage permeate, which had significantly reduced contaminant levels compared to the raw feed shown in Table 4-2.

Analysis of operational information indicates that membranes in the first-stage unit and HPU may have suffered some irreversible scaling during the first two days of leachate treatment, prior to the technology developer implementing pH control. During the remainder of leachate treatment, pH adjustment was used to control scaling, and this appeared to be helpful as long as the system recovery rate was not pushed too high. This initial "hit" to the membranes probably explains why flux in the first-stage unit (considered the most important by the evaluator because it treats the raw leachate) never fully recovered. However, the operational data also show a flux decrease of 30 to 35% after this initial "hit," which corresponds to the baseline results. It should be noted that the membranes were cleaned thoroughly (by performing multiple non-routine cleanings) after the initial "hit," but were not cleaned thoroughly again until after leachate treatment was completed. Although not absolutely comparable, the final baseline results for the first-stage unit indicate that after this initial cleaning the flux recovered to a level greater than that at the end of leachate treatment, after thorough post-treatment membrane cleaning. This means that cleaning was capable of removing scaling or fouling and restoring membrane performance, as the technology developer claimed. However, the first-stage unit flux did not recover to the level observed in baseline testing before leachate treatment (there was still an overall reduction in flux of approximately 30%), probably due to impacts to the membranes prior to implementing pH control.

Taking all baseline and leachate treatment data together, it appears that some degree of irreversible scaling and fouling of membranes occurred. It is difficult to specify to what degree this occurred because of the variable system operation and performance. In addition, according to Rochem, membranes have a definite break-

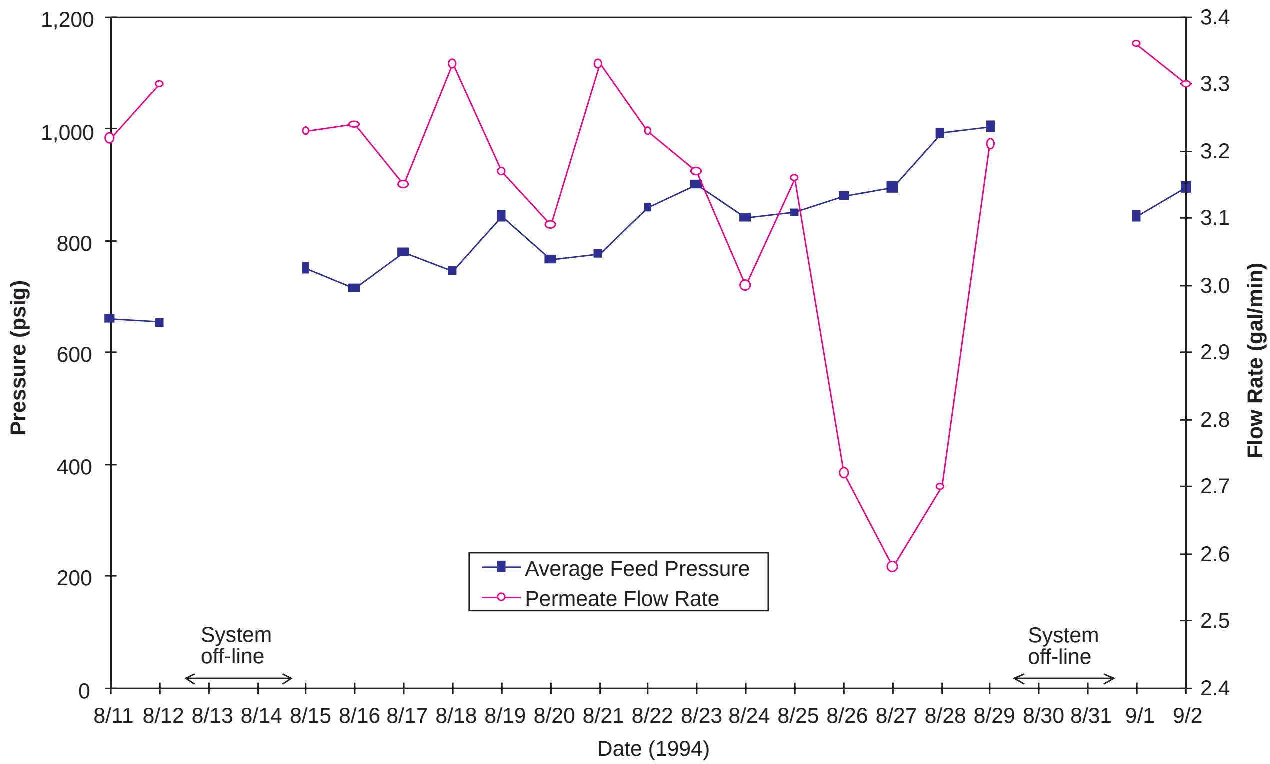


Figure 4-9. Pressure and Flow Rate vs. Time for the Second-Stage Unit.

in period during which an initial flux decline is seen (2). It is possible that part of the measured flux decline was due to this membrane break-in period. Despite the decrease in system performance based on flux, contaminant removals were still very good overall. The developer felt that better performance may have been achieved if a more thorough process shakedown had been performed and more sophisticated pre-treatment for pH control had been used. Additional information on membrane performance in other applications of the DTM technology can be found in Appendix A, "Vendor's Claims."

Figures 4-10 and 4-11 illustrate the trends for TDS and TOC during leachate treatment. Feed concentrations for both parameters remained fairly constant, with TOC decreasing slightly over the Demonstration. The graphs demonstrate the measured reduction of concentrations in the permeate and the concentrating of contaminants in the concentrate stream. Figures 4-12 and 4-13 show the trends for chlorobenzene and toluene during leachate treatment. Feed and concentrate stream concentrations varied but appear to follow each other to some extent, as would be expected. The permeate streams show a significant reduction in concentration for both compounds. An increase in permeate concentrations is shown starting around August 26, 1995. This was previously discussed and shown in Figure 4-8.

On two days of the Demonstration, August 17 and August 29, 1994, the DTM technology process streams were sampled three separate times each day to assess short-term variations in critical parameters. On August 17, the results for each analytical parameter for the different samples were very consistent; on August 29, the results showed more variability over the day. This appeared to be due to changing concentrations in the feed and variable performance of the technology. During this time period, the technology's level of performance was decreasing and daily routine membrane cleaning was being performed. These data do not clearly indicate that there was consistent variability in the critical parameters on a daily basis. Therefore, results based on critical parameters should be valid. Most results presented here are average calculated values that should tend to minimize daily variations.

4.4.5 System Mass Balance

Table 4-6 summarizes the Rochem system mass balance results for the critical contaminants. These results are based on 18 days of system operation and are expressed as percent deviations from closure. Overall mass balances were calculated by subtracting the total mass of a contaminant in the output streams (the concentrate plus the permeate) from the total mass of the contaminant in the input stream (the system feed). Closure deviations were determined by dividing a contaminant's overall mass balance by the total mass of the contaminant in the input stream (system feed). A positive deviation reflects a contaminant loss through the system indicating more input than output of that

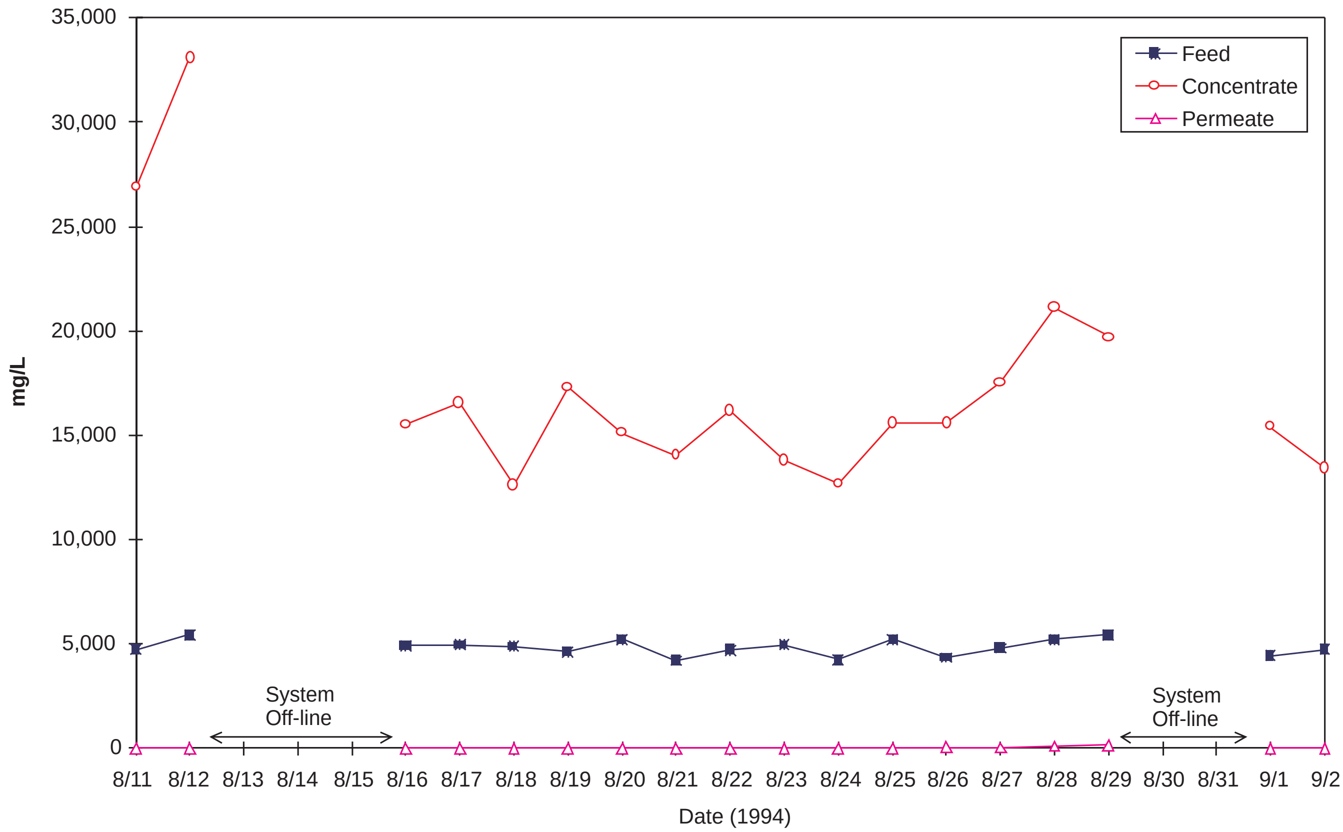


Figure 4-10. Total Dissolved Solids (TDS) Input and Output Streams vs. Time.

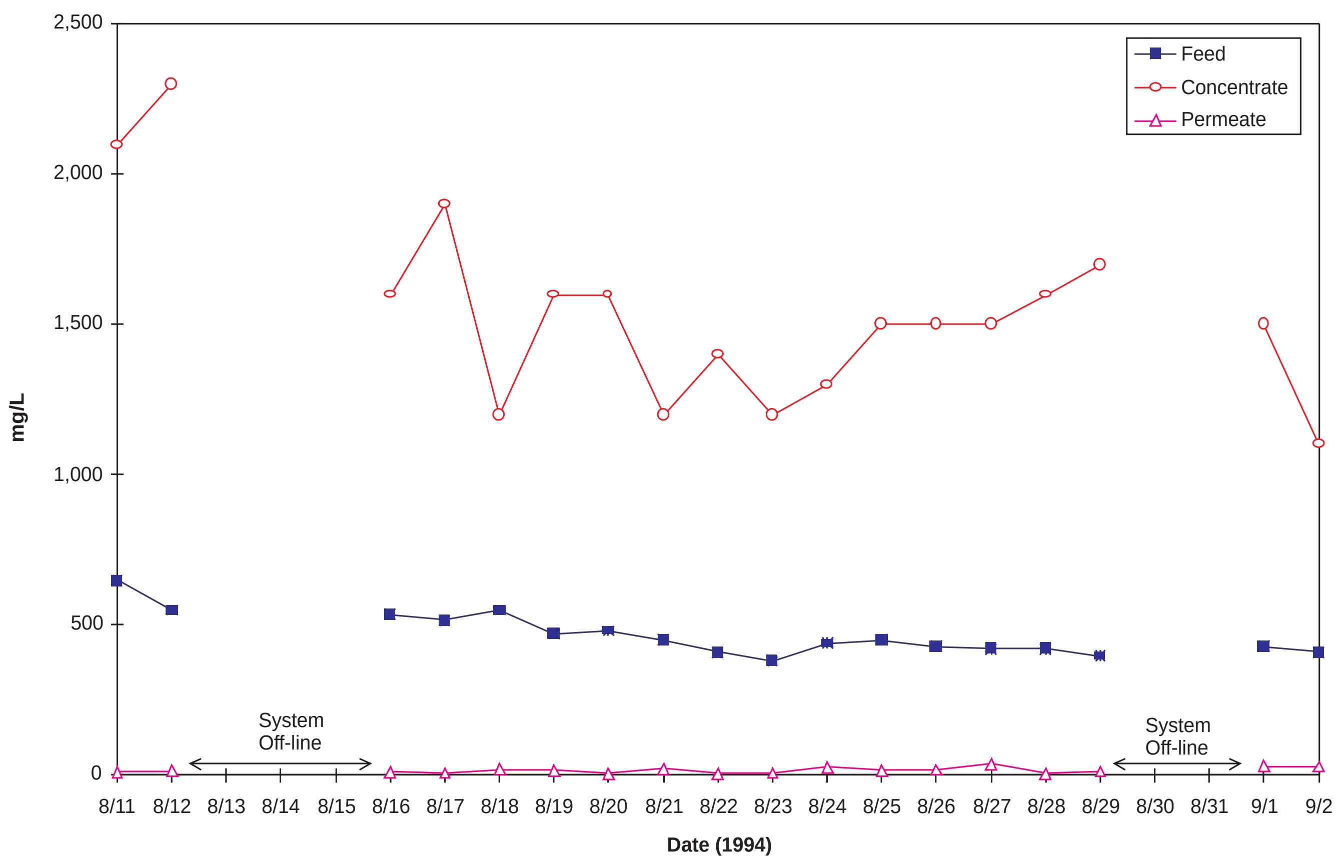


Figure 4-11. Total Organic Carbon (TOC) Input and Output Streams vs. Time.

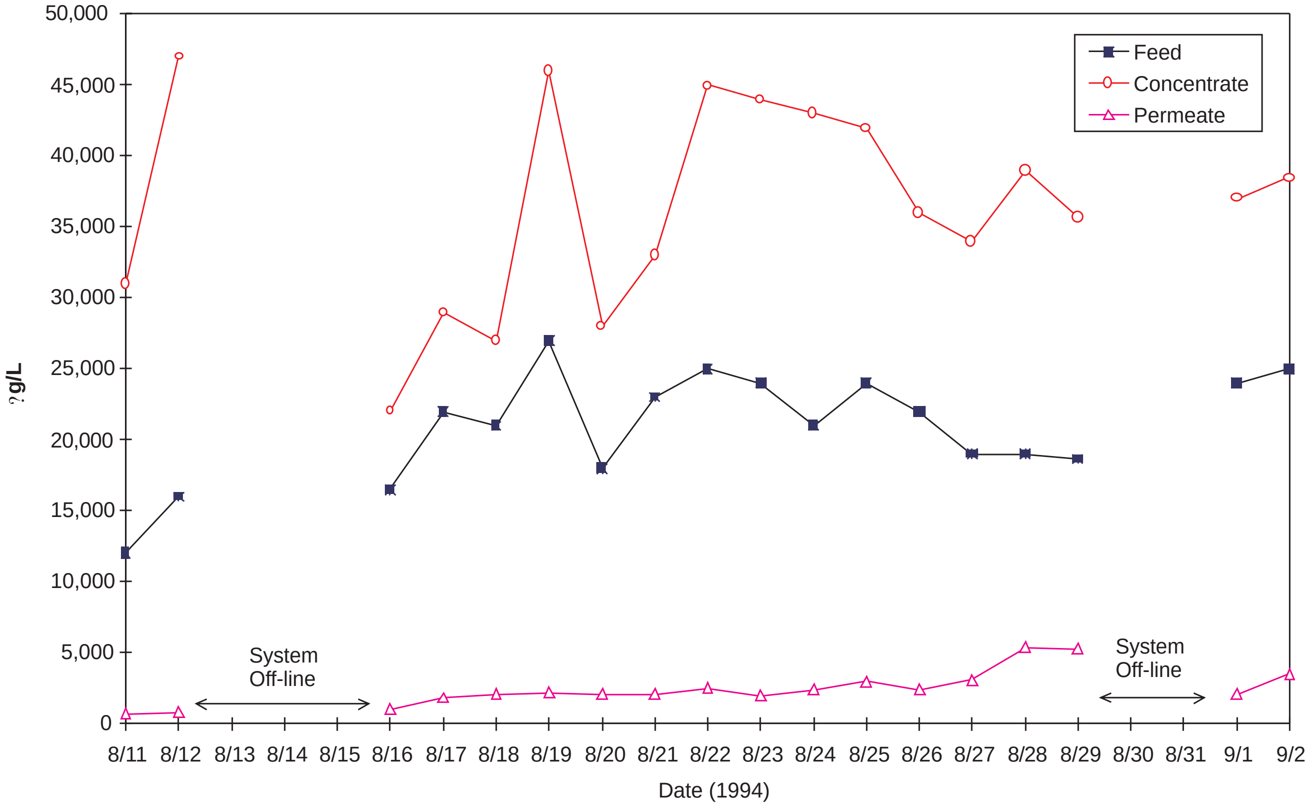


Figure 4-12. Chlorobenzene Input and Output Streams vs. Time.

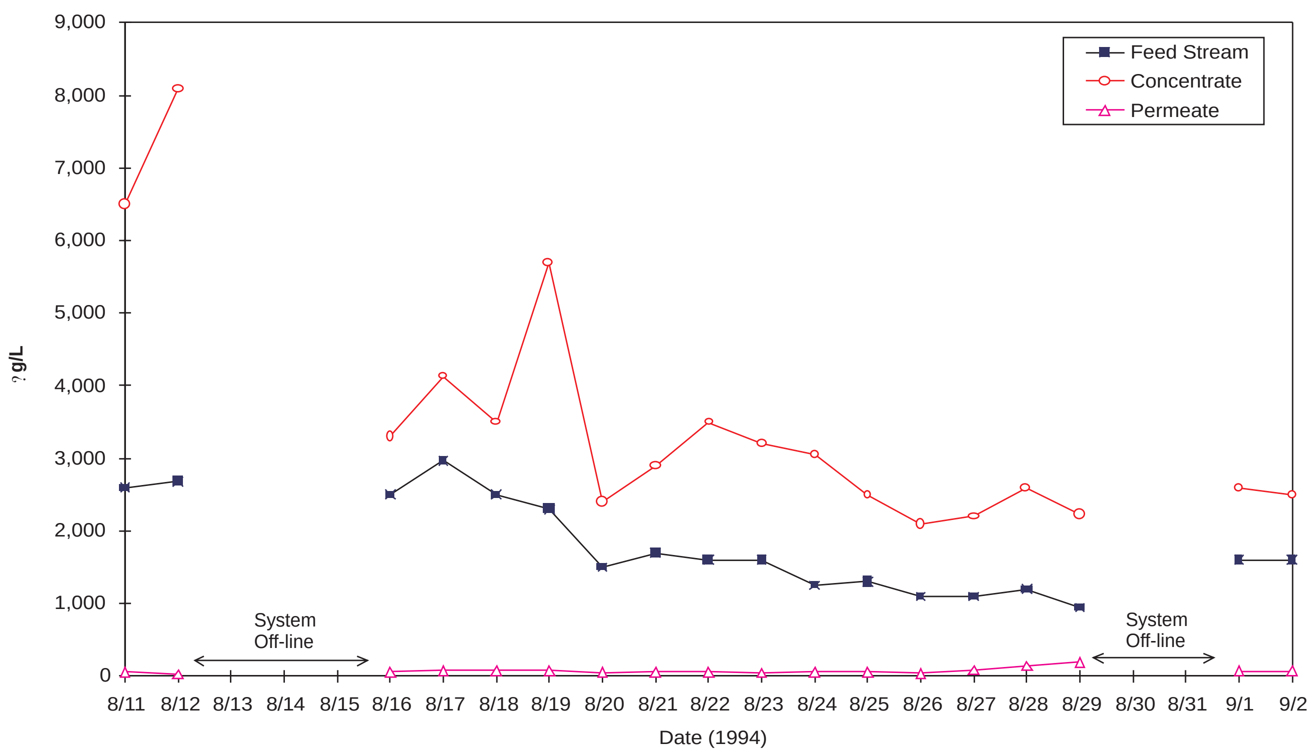


Figure 4-13. Toluene Input and Output Streams vs. Time.

Table 4-6. Rochem System Critical Contaminant Mass Balance Summary

Analyte Name	Percent Deviation from Closure %
Target Metals	
Barium	8.4
Calcium	6.2
Iron	12
Magnesium	1.7
Manganese	1.3
Potassium	-1.8
Sodium	-0.2
Strontium	3.7
Target VOCs	
1,2-Dichlorobenzene	55
1,4-Dichlorobenzene	55
Chlorobenzene	40
Ethylbenzene	56
Toluene	43
Xylenes	59
Total Dissolved Solids	1.1
Total Organic Carbon	2.7
Total Solids	-3.3

contaminant over the entire Demonstration. A negative deviation indicates excess output from the system during the Demonstration.

Totalized flow measurements were utilized in the mass balance calculations. Due to the semi-batch system configuration and operation, there was some hold-up volume in the intermediate process tanks at system shut-down each day. In order to minimize the daily effect of these hold-up volumes, 18-day flow totals were utilized for the input and output streams to calculate an overall mass balance for each contaminant. In addition to the hold-up volumes, the final permeate was used in rinse cycles during system operation. After rinsing, some of this permeate was discharged through the concentrate process line. As a result, totalized volumes for the concentrate were biased high. Therefore, adjustments were made to account for the volume of permeate used in rinse cycles that was measured (or recorded) as concentrate.

System mass balance calculations gave good results for metals, TOC, TDS, and TS. The overall mass balances for metals were within 15 percent of closure, which is considered a good balance for this type of process. The closures for TOC, TDS, and TS were within plus or minus 5 percent at 2.7%, 1.1%, and -3.3% respectively. These results indicate that analytical data and system flow measurements were of good quality and that these contaminants were accounted for.

Target VOCs showed a typical loss of 40 to 60% through the system. The levels of VOCs in the final concentrate were lower than expected based on feed levels and the system water recovery rate. These differences are probably due to VOC losses during system sampling and possibly due to VOCs adhering to membrane surfaces. As discussed under “Contaminant Removals” above, gas emissions resulted in individual VOC losses of only up to 0.5% per day or a total of 9% for 18 days. This small amount does not account for the VOC losses observed in the mass balance results. The feed and especially the final concentrate process streams were foaming during sampling due to acid addition and system pressurization, making sampling for VOCs difficult and probably resulting in VOC losses to the atmosphere. Organic fouling of the membranes was apparently occurring during leachate treatment, as evidenced by the amount of membrane cleaning required using an alkaline cleaner. Rochem used more alkaline cleaning solution (26 gallons) than acidic cleaning solution (10 gallons) over the course of the Demonstration. Alkaline cleaners are used to remove organic or biological fouling; acidic cleaners are normally used to remove inorganic scaling. Biological fouling was not a factor since, pre-Demonstration leachate characterization results were negative for coliform bacteria, indicating low biological activity. In addition, acidifying the feed leachate may have inhibited biological activity. VOCs may have been responsible for some of the fouling, possibly in combination with iron or silica, however, these organic foulants would have probably been removed from the membranes during cleaning cycles and would therefore not be accounted for in the mass balance.

4.4.6 Permeate Disposal

During the Demonstration, final permeate was collected in holding tanks and then discharged to the sanitary sewer under a modification to the Central Landfill’s Industrial Waste Discharge Permit. As a precautionary measure, before collection in the holding tanks, the final permeate was sent through activated carbon canisters to ensure compliance with discharge requirements. Table 4-7 displays the monitoring parameters and permit limits listed under the modification to the Central Landfill’s permit along with the maximum daily and average daily permeate concentration results from the Rochem system. The permeate results listed are based on samples taken prior to carbon treatment and over 18 sampling days, except for cyanide, BOD, and oil and grease. Cyanide, BOD, and oil and grease were sampled twice after carbon treatment for permeate disposal purposes. The measured quality of the permeate from the DTM technology complied with discharge permit requirements for metals. The maximum daily and average daily concentrations for TTO were 10.13 mg/L and 3.4 mg/L, respectively, indicating the average daily concentration for TTO was slightly above the TTO discharge limit of 2.13 mg/L. Discharge limits for cyanide and oil and grease were met after activated carbon polishing. Limits

Table 4-7. Permeate Discharge Comparison to Permit Limits

Monitoring Parameters	Permit Limits Maximum daily (mg/L)	Permeate Concentration Rochem Maximum daily (mg/L)	Permeate Concentration Rochem Average Daily (mg/L)
Cadmium	0.04	<.01	N/A
Chromium	0.4	<.01	N/A
Copper	1	<.02	N/A
Lead	0.3	<.05	N/A
Nickel	0.7	<.05	N/A
Silver	0.1	<.005	N/A
Zinc	1	0.1	0.06
Cyanide	0.3	<.005*	3.4
TTO	2.13	10.13	3.4
BOD	N/A	<6*	N/A
COD	N/A	60**	9.29**
TSS	N/A	902	N/A
Oil and Grease	125	10*	N/A

* Value was obtained after permeate carbon polishing.
** Value based on 16 measurements out of 18 measurements
N/A Not Applicable
< Less than the practical quantitation limit

for BOD, COD, and TSS were listed as not applicable (N/A) under the modification to Central Landfill's permit, however, the maximum daily concentrations for these parameters are also presented in Table 4-7.

The low TDS and turbidity of the permeate lend it to treatment with many suitable polishing technologies. Based on technology performance during this Demonstration, only minimal polishing treatment was required to meet discharge limits. Permeate pH adjustment may be required to meet discharge limitations, if acid is used during treatment to lower the system feed pH. This could be accomplished by aeration to remove CO_2 and thereby increase pH. In some applications, permeate from the DTM technology may meet the discharge limitations without the need for further treatment.

4.4.7 Maintenance, Cleaning, and Reliability

The primary maintenance activity for this technology is membrane cleaning. The technology is designed to facilitate membrane cleaning to maintain performance and extend membrane life. During the Demonstration, membrane cleaning was initiated at the operator's discretion, typically based on an increase in module pressure, flow rate, or temperature readings. Various chemical cleaners were added to a rinse cycle to perform membrane cleaning to remove scaling and fouling agents. Membrane cleaning cycles were helpful in maintaining technology performance. For each unit, short cleaning cycles (approximately 30 to 60 minutes in duration) were used to maintain daily treatment effectiveness. More extensive cleaning was occasionally required to remove accumulated membrane deposits. This extensive cleaning was partially effective in restoring module flow rates (flux).

The reliability of the technology during the Demonstration was good. After some initial adjustments, the system ran steadily with short breaks for routine membrane cleaning. The feed pump for the first-stage unit was defective and had to be replaced towards the end of the Demonstration. As a replacement pump was not on site, the system was down for one day while a pump was delivered. Typically, spare pumps and components would be on-site, and replacement could be completed in a few hours *(2)*.

Aside from mechanical problems and membrane cleaning, technology reliability is most dependent on proper feed liquid waste pretreatment procedures and system operational settings. For the most part, these factors are determined during system shakedown and initial operation. Due to the variability of liquid waste, system adjustments may be required later. These adjustments may be made at the front panel by simply inputting the desired operating parameters to the unit.

4.5 Process Residuals

The DTM process separates contaminants from liquid waste and generates two process waste streams: permeate (treated water) and concentrate (liquid waste). The permeate can be discharged to the local POTW, into surface waters, or reinjected through underground injection wells, if appropriate discharge limitations are met and the proper permits are obtained. When discharge requirements are not met, polishing treatment is required. Depending on its composition and classification, the concentrate may be a hazardous waste and may require further treatment and disposal.

The approximate volume ratio of permeate to concentrate (including used cleaning solutions and unused samples) produced during the Demonstration was 3:1. Permeate generated was discharged to a local POTW. Although not classified as a RCRA waste, the concentrate required off-site treatment prior to land disposal due to its elevated levels of hazardous constituents. Concentrating the liquid waste volume reduced transportation and treatment costs. Other options for concentrate treatment or disposal include solidification/stabilization, evaporation, and recirculation into the landfill by surface application in the case of municipal landfill leachate *(2)*.

Other wastes requiring disposal after the Rochem SITE Demonstration included contaminated tubing used to convey the leachate and concentrated liquid waste to and from the Rochem equipment; the tarp placed under the equipment to contain any spills; the adsorbent pillows and booms used to collect the liquids that leaked or spilled during the Demonstration; and contaminated personal protective equipment. These solid wastes were placed in drums and were incinerated prior to their ultimate disposal.

During treatment of liquid waste containing VOCs, there may be minor releases of volatile contaminants to the atmosphere from intermediate process holding tanks. Such losses were measured during the Demonstration at the Central Landfill. These losses did not significantly influence system performance results, but may require mitigation to reduce air emissions in some cases. Air emissions from auxiliary storage tanks may also need to be monitored and controlled.

Section 5
Other Technology Requirements

5.1 Personnel Requirements

The Rochem DTM system is designed for semi-automatic operation. DTM control units are equipped with memory-programmable microprocessor controls and automatic shut-down logic. Rochem has two standard systems for liquid wastewater treatment: Model 9122, with a capacity of 3,000 to 9,000 gpd (11,000 to 34,000 lpd), and Model 9142, with a capacity of 10,000 to 32,000 gpd (3,800 to 120,000 lpd). Larger systems are also available for increased treatment capacity. Due to the automatic control of the DTM systems, personnel requirements for both Model 9122 and Model 9142 are approximately the same. Once installation and shakedown are complete, a single technician usually can operate the system. However, these requirements will vary depending on the characteristics of the system feed.

For the Demonstration, two technicians working one ten-hour day installed the three-stage Model 9122 system utilized to treat the Central Landfill leachate. Installation activities included staging the equipment and making hose and electrical connections. Once the equipment was installed, two technicians performed a shakedown test to refine operating parameters. The shakedown test lasted about ten hpd for two days. Due to the hazardous nature of the Demonstration and the leachate, the remoteness of the test site, and the temporary facilities, two technicians were present during treatment. The technicians operated, monitored, and maintained the DTM system throughout the day.

For commercial operations at a fixed facility, when treating hazardous leachate, four man-hours per day are estimated to be required for a 24-hpd operation. A single system operator may perform all required duties including checking system operating parameters (i.e., flow, pressure, pH, temperature, conductivity), collecting and analyzing samples, cleaning membranes, and making process modifications. When treating non-hazardous leachates, as few as one to two man-hours per day for a 24-hpd operation are required. Equipment installation and shakedown testing are performed by Rochem personnel. Typically, system installation can be accomplished with one Rochem supervisor and one technician working 12 hpd for three to five days. Shakedown testing usually requires one Rochem supervisor and technician working 12 hpd for two to five days *(4)*.

When working with hazardous wastes, personnel operating the DTM technology must have completed the OSHA-mandated 40-hour training course and have an up-to-date refresher certification. Potential chemical splash hazards exist for workers handling the wastewater to be treated, the acid solutions used for pH control, and the solutions used for cleaning the membranes. However, when handled properly with the appropriate PPE, the potential risks are minimized. For most sites, PPE worn by system technicians will include gloves, safety goggles, steel-toed boots, and coveralls. Depending on the composition of the liquid waste treated by the DTM system, additional protection such as respirators may be required.

5.2 Community Acceptance

Potential hazards related to the community are minimal. The Rochem DTM system generates minimal chemical and no particulate air emissions. The Rochem DTM treatment equipment is essentially a closed system except for tank vents. Therefore, even when liquid wastes containing volatile organic contaminants are treated, the potential for on-site exposure to airborne contaminants is low. Proper and secure chemical storage practices for acids and cleaning solutions minimizes the threat of community exposure. The use of a secondary containment area for the storage of the feed water and the concentrated liquid waste decreases the likelihood of a contaminant release into the environment.

The quantity of containerized liquid wastes produced depends on the quality of the wastewater treated and the type of conveyance system installed around the Rochem DTM equipment. If the concentrate is conveyed directly to a treatment works and the permeate can be discharged without treatment, the amount of containerized liquid wastes is relatively small. In this case, the movement of transport vehicles through the community is not significant. If the Rochem DTM system operates in a remote area with no access to conveyance structures, the amount of containerized liquid wastes requiring transport could be more significant.

The Rochem technology has the slight potential to cause inconveniences to the surrounding community through the generation of noise and odor. The compressor generates the greatest level of noise in the system. This noise level is not high and would only be an annoyance to neighbors nearby. Noise impacts may be mitigated by enclosing the compressor or blocking the sound waves from reaching nearby receptors. There may be minor releases of volatile contaminants to the atmosphere from intermediate process holding tanks. These releases are probably more of a concern to the process operator than the surrounding community, but emissions control equipment may be required.

The regulators and public of the region are invited to observe SITE projects firsthand during the Visitor's Day enables the public to see what is being done by the EPA to clean up the environment and gives them a chance to ask questions about the technology being demonstrated. During the Rochem SITE Demonstration, a Visitor's Day was conducted on August 16, 1994 to inform the public about the Rochem DTM system and the SITE Demonstration Program. Visitor's Day activities included a brief tour of the site and the technology. In addition, presentations were given by the developer, the EPA SITE project manager, Region I EPA, and the SITE evaluation contractor (SAIC). Participants in Visitor's Day included regulatory personnel, remediation contractors, and members of the general public.

Section 6
Technology Status

Rochem Separations Systems, Inc. based in Torrance, California is licensed to supply the DTM technology in the United States. They are a subsidiary of the Swiss-based Rochem Group which developed and patented the DTM technology. The DTM units and systems are designed and fabricated in Germany. They have been manufactured since 1981. The HPU, such as the one used during the Demonstration at the Central Landfill, represents a new design. The HPU is used to further concentrate the liquid waste and reduce the liquid waste volume. As a result, the treated water recovery rate is increased.

6.1 Previous/Other Experience

Rochem has over 800 installations of the DTM technology worldwide, mostly in Europe. During the last six years, the technology has been used to treat leachate at more than 50 landfills in Europe, according to Rochem.

Rochem has also had projects in the U.S. At the French Limited Superfund Site near Crosby, Texas, the technology treated lagoon water contaminated by petrochemical wastes (volatile organics, phenols, heavy metals, and polychlorinated biphenyls). Two DTM units with 30 modules and one with 10 modules were used to treat 3 million gallons (11.4 million liters) of lagoon water per month at this site. According to the developer, nearly 40 million gallons of water were processed at a 30 to 50 percent recovery rate. TOC levels from 1,700 to 1,800 mg/L in the lagoon water were reduced to 20 to 25 mg/L in the treated water, less than the EPA discharge requirements *(5)*. At the Superior Landfill near Savannah, Georgia the technology is currently treating municipal landfill leachate at a feed flow rate of 6,000 to 7,000 gallons per day (23,000 to 26,000 lpd). According to the developer, over 200,000 gallons (760,000 liters) of leachate have been treated to date at a 73 to 74% recovery rate *(4).*

As part of the SITE Demonstration, bench-scale treatability tests were conducted on leachate from a hazardous waste landfill in California contaminated with VOCs, heavy metals, and high total dissolved solids. Average contaminant rejections from a two-stage system utilizing thin-film composite RO membranes were 93% for total VOCs, 99% for most metals, 92.6% for TOC, and 99.3% for TDS. Design water recovery rates during the treatability studies were lower than the design water recovery rate of 75% for the Demonstration at the Central Landfill. Results from this treatability study are presented in Appendix B of this report.

6.2 Scale-Up Capabilities

Rochem has four standard systems available for liquid waste treatment: Model 9122, rated for 3,000 to 9,000 gpd (11,000 to 34,000 lpd); Model 9142, rated for 10,000 to 32,000 gpd (38,000 to 120,000 lpd); Model 9152, rated for 33,000 to 79,000 gpd (125,000 to 300,000 lpd); and Model 9532, rated for 9,000 to 133,000 gpd (34,000 to 500,000 lpd). All are one-stage systems containing a leachate DTM unit and a permeate DTM unit. A high-pressure unit can be combined with any system. The modular design and construction of the DTM units allows them to be combined in series to increase product quality or in parallel to increase treatment capacity. Labor requirements are only slightly greater for larger treatment systems, primarily for maintenance and membrane replacement activities. The use of membranes and consumables (chemicals, filters, electricity, etc.) will increase with system treatment capacity. However, the cost per permeate-gallon for treatment with the DTM technology decreases with increasing treatment capacity.

Based on the results of this Demonstration, liquid waste treatability testing is strongly recommended prior to process design and application. On-site pilot-scale treatability testing should be performed to determine operational and maintenance procedures such as chemical addition and membrane cleaning requirements. In addition, pretreatment requirements can be formalized. Rochem normally performs an on-site pilot-scale treatability test lasting two to six weeks prior to process installation *(4)*.

Treatment effectiveness is very waste-specific. Although any significant treatment concerns can probably be identified from preliminary waste characterization data, bench-scale treatability testing can be used to determine membrane compatibility with the liquid waste and expected permeate quality. This can be performed off-site by shipping samples of liquid waste to Rochem's laboratory facility or on-site by Rochem using a bench-scale system.

After installation, a few days to a week, depending on the application, are required to properly shakedown the system. Once on-line, the DTM technology can operate 24 hpd with breaks for cleaning and maintenance. This is the most cost-effective mode of operation. Operator attention requirements for system monitoring and maintenance can be as little as one to two hpd. For more difficult or hazardous wastes, greater operator attention may be required. Rochem personnel must be present during pilot-scale treatability testing to operate the technology and evaluate process operational requirements. Site personnel can be trained to operate the technology after installation.

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Appendix A
Vendor's Claims

This appendix presents the claims made by the vendor, Rochem Separations Systems, Inc., regarding Disc Tube™ Module Technology, the technology under consideration. This appendix was written solely by Rochem, and the statements presented herein represent the vendor's point of view based on independent tests, demonstrations, and commercial activities. Publication here does not indicate EPA's approval or endorsement of the statements made in this section; EPA's point of view is discussed in the body of the rept.

Rochem Separation Systems is the world leader in membrane technology for the treatment of landfill leachate. Rochem has been producing membrane filtration systems since 1981 and leachate treatment systems since 1988. Currently, the total installed capacity of Rochem leachate treatment systems is over 1 million gallons per day.

Rochem has a proven technology for leachate treatment. The patented Rochem Disc Tube™ reverse osmosis (RO) modules when combined with our systems experience results in a packaged system that can easily remove both organic and inorganic compounds. As of September 1995, Rochem has treatment systems operating on over 60 landfills worldwide. These systems range from 1500 gallons per day to over 750,000 gallons per day from a single site.

Rochem systems offer reliability, high treatment efficiency, low operating costs and low personnel requirements. The microprocessor controls on the system allow it to operate reliably with minimal operator attention. The remote monitoring and control capability of the units allow full data logging and normal operation from a remote site.

The systems are capable of removing a variety of contaminants, both organic and inorganic. Rejection rates are typically greater than 99% for inorganic compounds and for organic compounds greater than 100 molecular weight. By using Rochem's high pressure (2000 and 3000 psi) systems, recovery rates of over 95% can be achieved.

The Rochem Disc Tube™ Module Technology SITE Demonstration was a somewhat representative example of what the technology is capable of. The results show that even on a difficult stream the system will operate reliably. While we believe that in a permanent installation with additional start-up and break-in time the results would have been much better, the results obtained were very good.

There were a number of factors, most relating directly to the data collection and timing of the Demonstration, which forced Rochem to operate the equipment slightly differently than a typical leachate application. These factors included running the equipment only eight to ten hours per day, using very small interstage tanks, using three separate units instead of two integrated ones, not aerating the feed before it entered the unit, and not having a sufficient shake-down and break-in period.

The Disc Tube™ modules are a tangential flow separation system. This means that the feed flows across the surface of the membrane while a portion passes through the membrane as permeate. This tangential flushing action and the optimized hydrodynamics in the module are the primary factors in keeping the membrane clean and operating properly. When the unit stops, the flushing action stops. Even though the modules are rinsed with permeate before the pumps stop, not all the leachate and foulant are flushed from the modules. This means that foulants had an opportunity to collect on the membranes every night. Typically, membrane systems, including the Disc Tube, operate better when they operate continuously than when frequently started and stopped. Better performance in term of recovery, reduced fouling and scaling and better rejection would be expected from a continuously operating system than from the intermittent operation of eight to ten hours per day seen during the Demonstration.

The small interstage tanks contribute to the frequent starts and stops of the unit. Tanks were necessary to buffer the concentrate between the First Stage and the High Pressure Unit, and between both those units and the permeate polishing unit. The hold up volume was a concern during the demonstration due to potential loss of volatile compounds that could reduce the accuracy of the mass balance around the system. With such a small volume however, both the HPU and the Second Stage permeate polishing unit started and stopped numerous times each day as the tanks filled and emptied. It was not possible to completely balance the flow rate between the units to eliminate these starts and stops. These extra starts and stops required the use of permeate to rinse the units (this clean water was discharged as concentrate, resulting in a double decrease in measured recovery rate), as well as increasing the fouling and scaling as discussed above. In a permanent installation, the interstage tanks would be larger to decrease the number of starts and stops required. Also, the first stage and the permeate polishing unit are in one integrated unit with no interstage tanks required.

Another major difference between the Demonstration and a normal installation was the handling of the leachate before treatment. During the Demonstration, all possible actions were taken to reduce the loss of VOCs from the storage tanks. This required the full pH adjustment be completed in the first stage unit. The chemical reaction that takes place when you add acid to leachate is that the carbonate and bicarbonate compounds are converted to carbon dioxide that then is released as a gas if the maximum solubility is exceeded. In the case of the Central landfill leachate, approximately 4,800 ppm of carbon dioxide were generated during the acidification process, resulting in a release of nearly 3,500 ppm of carbon dioxide gas. This gas caused difficulties both during the operation of the unit and during sampling. The gas caused samples to foam, making it very difficult to take proper VOC samples. From an operational end, the gas made it very difficult to get a smooth flow through the flow transmitters, which resulted in the unit never running as smoothly as it could have. In a permanent installation, a large portion of this problem is removed by having preliminary pH adjustment done in a holding tank before the DTM system. This allows the gas to escape creating a much more stable operating environment. Also, any precipitates that form due to the acid addition settle out and are not removed by the prefilters on the unit. In addition, at all landfills, the leachate is aerated before being treated by the DTM system.

The largest inconsistency between the Demonstration and normal operational procedures was the lack of sufficient shake-down and break-in time. The Demonstration was driven by a number of scheduling constraints. These included the desire to finish the Demonstration within the current budget year, weather concerns, regulatory concerns, equipment availability and personnel schedule conflicts. All of these added together made for a demonstration with inadequate time to truly develop the necessary operating parameters for the best results. With less than four days of operating time before the beginning of sample collection, there was not sufficient time to develop full operational plans. Membranes show a substantial break in period. This period can range from 20 hours to over 100 hours depending on the feed water. It appears that the break-in period had not completed before the base line testing. This means that the membranes were tested at a level to which the performance could never be restored. This is not a problem as Rochem's experience allows for the complete break-in in the system design. The initial testing did not allow the full break-in to occur during the Demonstration. During the Demonstration, the flux rate (flow per area of membrane surface) of the modules never declined to below the design value for the system. The lack of experience with the fouling characteristics of this leachate required development of an appropriate cleaning procedure during the Demonstration. The conflicting requirements of maintaining the maximum operational time while developing the cleaning procedure caused a decrease in the efficiency of both. This meant that more cleanings were done for shorter periods of time while the most efficient cleaner was determined.

Due to the unique nature of the SITE program and the intended audience for the report, there are a number of costs included which would not apply to most Rochem installations. Most of the Fixed Costs, Labor Costs, Supplies Costs, and Facility Modification Costs would not be applicable to the operation of the unit at an operating landfill. These costs might be pertinent to the cost of a cleanup at an uncontrolled hazardous waste site.

There are two other points regarding the costs of the system. First, on most leachate a recovery rate of 75-80% can be achieve without the use of the High Pressure stage. This results in an immediate saving on capital costs and consumables. This is especially true for municipal solid waste leachate. Second, the cost estimate for the 9122 system is for a unit operating at the lowest possible capacity. The 9122 system can handle up to three times the volume of leachate, with very little extra equipment (an additional 6 Disc Tube™ modules). This would reduce the cost by a factor of more than two. The 9142 system could have its capacity increased by an additional 50% that would also reduce its cost per gallon. Rochem believes that the normal amortized capital and operating costs of a two stage (first stage and permeate polishing stage) operating at the mid-point of unit capability is $0.03 per permeate-gallon.

Rochem stands by the claims we made for the Demonstration. Discharge criteria are part of Rochem's normal performance guarantee. The Rochem Disc Tube™ System can effectively treat landfill leachate at a minimum of 75% recovery while maintaining a rejection rate of >90% for VOCs, 92% for TOC, and 99% for Heavy metals and TDS. Better performance has been achieved at a number of sites around the world. The attached documentation shows the performance of Rochem systems and a variety of landfill and waste water applications.

The following documents showing the performance of the Rochem Disc Tube™ system at other sites are attached. Table 1 is a summary of analyses taken by an EPA contractor of a Rochem unit operating at a Subtitle D landfill in Southern Georgia, as part of the development of categorical standards and Best Demonstrated Available Technology (BDAT) for leachate treatment.

Samples were taken 24 hours per day for five days with the samples for each day composited.

Table 2 is performance data from a Rochem Disc Tube™ system operating at a Subtitle D landfill in Northern Georgia. This landfill has purchased a Rochem system. A long term pilot test was conducted from June to December of 1994, with the permanent system installed in December of 1994. In September 1995, this landfill received a permit from the State of Georgia to directly surface apply the permeate from the Rochem system.

Table 3 is data from the landfill at Ihlenberg, Germany. This is the largest landfill in Europe, and produces a very large quantity of leachate. Rochem has been treating the leachate from this landfill since 1989. The landfill has expanded the capacity with additional Rochem systems on three different occasions.

Rochem would like to thank the United States Environmental Protection Agency, National Risk Management Research Laboratory, especially our SITE project manager Mr. Douglas Grosse. We also thank SAIC, and all of the individuals involved for their efforts on this project. Without all of their efforts, this project would never have been a success.

Table 1. MSW Landfill Leachage Treatment Data - US EPA Sampling and Analysis Subtitle D Cell, Summary Data

Compound	Units	Feed	Permeate 1	Permeate 2	Detection Limit
Ammonia as Nitrogen	mg/l	66	12.7	0.53	
BOD 5-Day (Carbonaceous)	mg/l	1340	70	5	
Chemical Oxygen Demand (COD)	mg/l	1600	65	BDL	10
Chloride	mg/l	266	53	1	
Total Dissolved Solids	mg/l	2580	133	BDL	10
Total Organic Carbon (TOC)	mg/l	690	28	BDL	10
Total Phenols	µg/l	1310	333	BDL	50
Total Sulfide (Iodometric	mg/l	16	4.8	BDL	1
Total Suspended Solids	mg/l	190	BDL	BDL	4
Arsenic	µg/l	16.8	BDL	BDL	2
Barium	µg/l	276	BDL	BDL	1
Boron	µg/l	1780	815	77.1	
Calcium	µg/l	330000	11400	379	
Iron	µg/l	92800	3010	104	
Magnesium	µg/l	94500	2570	BDL	51
Manganese	µg/l	4580	152	3.6	
Potassium	µg/l	76300	6780	BDL	1000
Silicon	µg/l	4290	514	296	
Sodium	µg/l	275000	18600	BDL	123
Strontium	µg/l	1440`	BDL	BDL	100
2-Butanone	µg/l	3597.29	2001.87	276.14	
4-Methyl-2-Pentanone	µg/l	413.06	BDL	BDL	50
Benzoic Acid	µg/l	8903.46	133.21	BDL	50
Hexanoic Acid	µg/l	6963.05	148.82	BDL	10
P-Cresol	µg/l	771.75	275.17	19.51	
Phenol	µg/l	1228.84	123.21	29.03	
Toluene	µg/l	366.68	95.63	16.05	10
Trichlorofluoromethane	µg/l	3182.72	BDL	BDL	10
Tripropyleneglycol Methyl Ether	µg/l	1328.03	BDL	BDL	99
2,4,5-TP	µg/l	40.1	BDL	BDL	0.2
2,4-D	µg/l	23.4	BDL	BDL	1
2,4-DB	µg/l	14.2	BDL	BDL	2
Dicamba	µg/l	2.3	BDL	BDL	0.2
MCPP	µg/l	933	BDL	BDL	50
Hexane Extractable Material	mg/l	6	BDL	BDL	5
Hexavalent Chromium	mg/l	0.04	BDL	BDL	0.01
Nitrate/Nitrite	mg/l	2.02	0.57	0.39	
PH	units	7.04	5.27	4.56	
Total Phosphorus	mg/l	0.03	BDL	BDL	0.01
Aluminum	µg/l	92.5	BDL	BDL	52
Cadmium	µg/l	4.1	BDL	BDL	4
Lead	µg/l	78.8	BDL	BDL	49
Nickel	µg/l	18.1	BDL	BDL	14
Sulfur	µg/l	4080	BDL	BDL	1000
Yttrium	µg/l	2.8	2	BDL	2
Zinc	µg/l	13.4	BDL	BDL	9
1,4-Dioxane	µg/l	13.448	BDL	BDL	10
Acetophenone	µg/l	10.643	BDL	BDL	10
Alpha-Terpineol	µg/l	47.203	BDL	BDL	10
Diethyl Ether	µg/l	98.142	BDL	BDL	50

(continued)

Table 1. continued

Compound	Units	Feed	Permeate 1	Permeate 2	Detection Limit
Ethylbenzene	µg/l	34.509	BDL	BDL	10
Terbuthylazine	µg/l	10.1	BDL	BDL	5
Vinyl Chloride	µg/l	15.121	13.108	10.228	
1,2 Dibromo-3-Chloropropane	µg/l	0.22	BDL	BDL	0.2
2,4,5-T	µg/l	0.8	BDL	BDL	0.2
Benefluralin	µg/l	0.33	BDL	BDL	0.2
Diallate	µg/l	2.16	BDL	BDL	2
Diazinon	µg/l	9	BDL	BDL	2
Dichlorprop	µg/l	7.3	BDL	BDL	1
Disulfoton	µg/l	14	BDL	BDL	2
Gamma-BHC	µg/l	0.25	BDL	BDL	0.05
Hexamethylphosphoramide-2	µg/l	7.14	BDL	BDL	2
MCPA	µg/l	58	BDL	BDL	50
Phosphamidon E	µg/l	5	BDL	BDL	5
Propachlor	µg/l	0.7	BDL	BDL	0.1

BDL = Below Detection Limit

Table 2. Municipal Solid Waste Leachate - Northern Georgia
Rochem Leachate Treatment System - July 1995 Analysis

Parameter		Feed	Permeate	Units
General				
pH		6.5	N/A	units
Conductivity		4940	126	mho/c
COD		510	BDL	mg/l
TSS		N/A	BDL	mg/l
TDS		1510	18	mg/l
BOD		2500*	34*	mg/l
Sulfate		BDL	BDL	mg/l
Chloride		450	13	mg/l
Alkalinity		1830	46	mg/l
Ammonia-Nitrogen		N/A	9.7	mg/l
Appendix I - Metals - Georgia				
Total Antimony	(Sb)	0.012	BDL	mg/l
Total Barium	(Ba)	1.4	BDL	mg/l
Total Nickel	(Ni)	0.03	BDL	mg/l
Total Selenium	(Se)	0.02	BDL	mg/l
Appendix IX, Georgia Modified Standard Method				
Volatile Organics (EPA 8260) (GMSM)				
Benzene		3.7	BDL	µg/l
Chloroethane		9.5	BDL	µg/l
1,1 Dichloroethane		22	BDL	µg/l
1,2 Dichloroethane		1.5	BDL	µg/l
Methylene Chloride		98	8	µg/l
Ethylbenzene		14	BDL	µg/l
MEK (2-butanone)		780	BDL	µg/l
MIBK (methyl isobutyl ketone)		170	BDL	µg/l
Styrene		7.3	BDL	µg/l
Tetrachloroethene		1.7	BDL	µg/l
Toluene		210	BDL	µg/l
1,1,1-Trichloroethane		1.2	BDL	µg/l
Trichloroethene		2.1	BDL	µg/l
Xylenes (total)		69	BDL	µg/l
Base/Neutral Extracable Organics (EPA 8270) (GMSM)				
Diethylphthalate		23	BDL	µg/l
Acid Extractable Organics (EPA 8270)(GMSM)				
Cresol (o,m,p)		280	BDL	µg/l
Phenol		28	BDL	µg/l
Herbicides, Chlorinated Acid Derivartives (EPA 8150-GC/EC)				
2,4,5-TP		0.3	BDL	µg/l

(continued)

Table 2. continued

Parameter		Feed	Permeate	Units
Toxic Metals				
Barium	(Ba)	1400	BDL	µg/l
Iron	(Fe)	70000	BDL	µg/l
Lead	(Pb)	7	BDL	µg/l
Mercury	(Hg)	0.2	BDL	µg/l
Selenium	(Se)	15	BDL	µg/l
Total Formaldehyde		580	BDL	µg/l
Volatile Organics (EPA 8260)				
Benzene		4	BDL	µg/l
Chloroethane		9	BDL	µg/l
1,1-Dichloroethane		22	BDL	µg/l
cis-1,2 Dichloroethene		6	BDL	µg/l
Ethylbenzene		14	BDL	µg/l
Methylene chloride		98	BDL	µg/l
Toluene		210	BDL	µg/l
Trichloroethene		2	BDL	µg/l
Xylenes		69	BDL	µg/l
Acid Extractable Organics (EPA 8270)				
Phenol		28	BDL	µg/l
Base/Neutral Extractable Organics (EPA 8270)				
Diethylphthalate		23	BDL	µg/l

* = Previous Result
NA = not analyzed for
BDL = Below Detection Limit

Table 3. Rochem Leachate Treatment System - Hazardous Constituent Removal Rates
Ihlenberg Lanfill, Germany

Parameter	ed Concentration (mg/l)	Permeate Concentration (mg/l)	Removal
COD	2619	1.20	99.95%
BOD	184	2.50	98.64%
Sodium	3255	2.40	99.93%
Chloride	3091	2.70	99.91%
Calcium	192	0.90	99.53%
Magnesium	97	0.30	99.69%
Ammonium	380.00	0.40	99.89%
Arsenic	0.25	<0.005	>98%
Cyanide	2.35	<0.005	>99.79%
Heavy Metals	0.25	<0.005	>98%

Appendix B
Summary of Procedures and Results for Rochem Separation Systems' DDisc Tube™ Module Treatability Tests

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I. Introduction

Treatability testing of the Rochem Separation Systems' Disc Tube Module (DTM) system took place in Rochem's facility in Torrance, California during the week of July 27, 1992. Testing was performed on samples of leachate from the Gallery Well at the Casmalia Resources site in Casmalia, California. The aqueous phase of the leachate was pumped from the Gallery Well into 15-gallon DOT approved drums and shipped via truck to the Rochem Separations Systems' facility the week previous to the testing. The week following completion of all treatability tests, all of the leachate was returned to the Casmalia Resources site via truck in the 15gallon DOT approved drums.

Testing was conducted using bench-scale DTM systems equipped with reverse osmosis and ultrafiltration membranes. Rochem Separation Systems' (Rochem) personnel assembled and operated the bench-scale systems used during the tests. SAIC personnel performed sampling and field analysis of samples from process streams during the test; samples were also sent to SAIC's subcontract laboratory for analyses.

II. Purpose and objectives of the Treatability Tests

The treatability tests were designed to accomplish several objectives in order to prepare for a full demonstration test of the Disc Tube Module (DTM) technology. The treatability tests were conducted to provide data for the developer (Rochem) to design a system for treating the waste liquid, including the number and types of DTM units to be used, the order of units in the treatment system, and the membrane types to be used. Information from the treatability tests will be used by Rochem to develop claims for the quality of water that can be produced by treatment of the waste liquid using their system.

The treatability tests also provided an opportunity for SAIC to test the field and laboratory methods to be used to analyze process stream samples during the demonstration test. This information will be used to develop the Sampling Plan and Quality Assurance Project Plan (QAPP) for the demonstration test.

III. Summary of Events

Testing of two different reverse osmosis (RO) membranes, two different micellular-enhanced ultrafiltration (MEUF) membrane units, and one regular ultrafiltration (UF) membrane unit was performed. The testing protocol outlined in Rochem's Treatability Test Plan (which may be found in Appendix A) was followed during the tests. However, due to information gathered in the initial phase of testing and due to time constraints" this protocol was modified during testing. The following text describes the testing that took place on each day of the treatability tests.

The laboratory equipment was set up on Monday, July 27. Testing of the first system, consisting of RO followed by MEUF, commenced on Tuesday afternoon. The RO unit contained approximately 4 ft2 of membrane material; a thin film composite (TFC) polyamide RO membrane was used. This is a commonly used membrane and one that is good for many general applications of RO.

The RO unit was set up to receive raw feed (leachate) directly from one of the 15-gallon storage/shipment drums via a flexible hose. Leachate in a drum was sampled for laboratory and field

analysesprior to connection to the system. The permeate produced from thesystem was collected in a stainless steel pot, which was kept covered during the tests except when samples or measurements were taken. The reject (concentrate) from the membrane module was redirected back to the feed drum so that operation occurred in a continuous recycle mode. All units were operated in a similar fashion during the treatability tests.

After approximately two hours of operation of this unit, and after several gallons of clear-looking permeate had been produced, a cloudy yellow liquid was seen in the permeate hose. The unit was stopped, and after investigation it was determined that a slipped O-ring was allowing raw feed to enter directly to the permeate side of the unit. The test was considered scrapped because the permeate was contaminated, and a repeat test was planned for the following morning. SAIC did not collect any of the permeate for laboratory analyses before the problem occurred. However, an interim sample of the permeate had been collected by Rochem, and this sample was later used for field analyses. This aborted test is referred to as RAMX1 in the data tables.

On the morning of July 29, a new drum of raw feed was used for the RO test. A modification of the RO unit was made, substituting a module with approximately 35 membrane cushions (25 ft2 of membrane area) for the previous unit with nine membrane cushions (approximately 4 ft2 of membrane area) in order to produce permeate at a faster rate. The test was halted after approximately half an hour because the permeate was not clear. A missing O-ring was determined to be the cause, the module was repaired, and the test restarted within another half an hour. Samples were collected and the system run was completed approximately 80 minutes after restart. These samples were labelled RAMX-P1 and C1 for permeate and concentrate.

After the permeate had been sampled, approximately 4.5 gallons of the liquid (half of the permeate produced) was transferred to the mixing/f eed tank on the UF unit. Two quarts (0. 5 gallons) of unscented mineral oil were added to the liquid in the tank, along with 125 mL of non-ionic surfactant (approximately 1%, by volume). The mixture was agitated to form a milky, white emulsion, and then the UF unit was started. A polytetrafluoro ethylene UF membrane was used f or this test. A suf f icient quantity of permeate f or sampling purposes was produced after 20 minutes of operation. Samples of the permeate and concentrate were collected for laboratory and field analyses (RAMX-P2 and C2).

On Thursday, July 30, a new test run was started using a new batch of raw feed. This test consisted of two-stage RO using differentmembranes in each stage. The first stage utilized a TFC polyamide RO membrane. The second stage utilized a high rejection TFCpolyamide membrane designed to reject smaller molecular weight compounds. The f irst stage of RO was run on the raw feed, requiring three hours to produce sufficient permeate for sampling and further testing (RBRB-Pl and Cl) . The second stage of RO used the same unitl and ran for almost four hours before samples of permeate and concentrate were collected (RBRB-P2 and C2).

While the second stage RO test was conducted, another test of UF occurred concurrently, a new drum of raw feed was treated with a non-micellular UF unit containing a polyetheramide UF membrane. Treatment with this unit finished and the permeate and concentrate from the UF run was sampled just after those of the second stage RO unit (UF-Pl and Cl).

IV. Sampling, Monitoring, and Field Analysis Procedures

During the treatability tests/ samples of all of the raw feed, permeate, and some concentrate process streams were collected for potential laboratory analyses. These samples were held in coolers, the volatile organic samples and the herbicide samples on ice,until theywere either sent to the laboratory or set aside to bediscarded. Further discussion of the samples sent to the laboratory may be found in section VI. of this document.

There was no attempt during this testing to evaluate process mass balances because the bench-scale equipment used did not allow process measurements accurate enough for this purpose. **A** process mass balance will be evaluated during the pilot-scale demonstration test.

Sampling Procedures

Samples of the raw feed were collected directly from the storage drums. The samples for volatile organic analyses were collected using a clean disposable glass drum thief. All of the other raw feed samples were collected using a small polyethylene siphon pump. This pump was decontaminated between uses, and was always flushed with the liquid being sampled before any samples were collected. Extra liquid was collected in beakers for field tests.

All of the permeate samples were collected from the stainless steel collection pots using glass beakers. The stainless steel pots used during the test were decontaminated according to the procedures for laboratory, glassware and tools. The beakers used for sample collecting were decontaminated on both the inside and the outside to reduce the potential for cross contamination. Clean gloves were worn while sampling permeate.

Concentrate samples were collected using the sampling method appropriate for their container. RO concentrates were sampled from the raw feed drum using the method described for feed sampling. UF concentrates were sampled from the feed vessel on the UF unit using glass beakers.

Field Analysis Procedures

Several analyses and measurements were performed on process stream samples in the field. Field measurements included:

- Temperature
- 0 pH
- Conductivity
- Turbidity
- Chemical Oxygen Demand (COD)
- Total hardness
- Calcium

The temperature of the process stream samples was measured with a glass thermometer. Conductivity and pH were measured with field meters by placing probes directly into a sample of the liquid. These meters were appropriately calibrated each morning, and the calibration of the pH meter was checked each time the meter was used. Dilutions were sometimes made to enable measurement of conductivity in samples with an undiluted conductivity higher than 19,000'gmhos/cm, the instrument range limit.

Turbidity was measured with a turbidimeter which was standardized to an appropriate standard before each sample measurement. Some samples were too turbid to be measured using the turbidimeter, which measures turbidity to 200 NTU.

The COD of the process stream samples was measured using a calorimeter (filter photometer) and vials pre-filled with reagent, following the instrument-supplied procedures including use of a constant-temperature incubator set at 1500C. Three ranges of COD concentration could be measured using three different sets of vials: low range, 0-150 ppm; high range, 0-1,500 ppm; and high range plus, 1-15,000 ppm. Because the general concentrations of COD in the samples were unknown, several dilutions were prepared for each measurement on several of the concentration ranges.

The total hardness and calcium of the samples were measured using a titration technique with prepackaged reagents and a digital titrator. Some of the samples required dilution to avoid problems with interferences from other constituents or characteristics of the liquid. Some concentrate samples could not be titrated properly due to opacity or interference, even at high dilution ratios.

Total iron was measured on some of the samples using a calorimetric test kit with pre-filled ampules. None of the analyses were within the concentration range for this analysis kit (0-1 ppm) . Since this analysis was not an official part of the treatability test, no special dilutions were made to get iron results. No iron results are reported.

Vapor Monitoring

For health and safety purposes, an Hnu portable gas detector witha 10.2 eV probe,and an LEL meter, were used during thetreatability tests. The Hnu was used to monitor for volatilecompound emissionsfrom the treatment system, to analyze the headspace of concentrate and permeate collection containers, and to monitor for hazardous vapors in the breathing zone. The LEL meter was used to check for potentially explosive conditions around the process equipment. No potentially explosive conditions were encountered.

V. Results of Field Analyses

Table 1 presents a summary of the results of field analyses performed on treatability test process stream samples. This. summary was compiled from the field laboratory notebook where all data was written during testing. Organic and inorganic parameter analysis helped to evaluate process performance in the field and generally correlated well with the laboratory analytical results presented in the following section. Heat generated from the process operation contributed to elevated permeate and concentrate temperature readings.

Discussion of Methods and Method QC

Duplicate pH, temperature and conductivity measurements showed good repeatability. For pH, occasional secondary checks with pH paper were also performed and confirmed the results from the meter. The results for these measurements agreed with values which could be anticipated based on previous information on the leachate and on knowledge of the process.

The calcium and hardness determinations were sometimes limited in accuracy due to interferences by other materials in the liquids; dilutions were sometimes, but not always, helpful. More apparent problems with interferences were encountered during the determinations for hardness than those for calcium; the color change for hardness was frequently too gradual to pinpoint the correct titration point. Only one of each titration was performed on each sampled stream so no duplicate measurements were made. However., several different raw feed samples from different feed batches were measured and the results show good reproducibility.

COD was a more complex analysis to perform in the field than other measurements. The COD concentrations in each of the streams could not be accurately predicted, therefore several dilutions in several of the available test ranges were prepared for each sample. The comparability of the measurements made, using different dilutions and different reagent vials, ranged from fair to poor. Even when measuring the same sample vial twice for COD in the calorimeter, readings showed poor reproducibility (up to 10% RPD). The results reported for this measurement are often averages of multiple readings for each sample, and are therefore only approximate. The two concentrate samples analyzed were not diluted enough to allow readings within the calibration range.

Observations

Observations on the samples from each process stream, and on process operation, were made during sampling and testing activities. General observations included:

- The raw feed was yellow in color, highly turbid and had a strong odor.
- All RO permeate samples appeared clear and colorless. The odor of these samples ranged from moderate to slight.
- The RO concentrate generated from treatment of the raw feed was more turbid than the feed, and formed a yellow precipitate when allowed to sit.
- The permeate samples from the MEUF seemed to contain high levels of surfactant which formed bubbles and had a surfactant odor. The RAMY samples exhibited less surf actant behavior than the RAMX samples.
- Concentrate samples from the MEUF runs were an opaque milky-white. The samples eventually separated into a white layer and a cloudy layer.
- The permeate from the UF run was a pale yellowgreen color.
- The headspace Hnu reading inside the RO permeate container sometimes had higher readings than the raw feed.
- O-rings are vital to the proper operation of the DTM unit. Missing or unseated o-rings caused the only operational problems during the testing.
- Brown staining, most likely from iron, formed on the membranes during each first-stage test. This did not seem to affect the short-term performance of the system.

Table 1. Summary of Treatability Test Field Analysis Results

Associated Laboratory Sample Number	Date of Test	Test Type	Process Stream	Chemical O_2 Demand (mg/L)	Calcium (as $CaCO_3$) (mg/L)	Hardness (as $CaCO_3$) (mg/L)	Conductivity (µmhos/cm)	pH	Temp. (°F)	Turbidity (NTU)
RAMX'-RF*	7/28	RO,MEUF	Raw Feed	22,000	3,760	8,280	18,000	5.4	71	>200
RAMX'-P1*	7/28**	RO,MEUF	Permeate	6,000	NA	NA	424	4.3	58	1
RAMX-RF-01	7/29	RO,MEUF	Raw Feed	25,000	NA	NA	19,600	5.1	70	>200
RAMX-P1-02	7/29	RO,MEUF	1st Stg Perm	5,800	171	410	576	4.1	82	1.3
RAMX-C1-03	7/29	RO,MEUF	1st Stg Conc	NA	NA	NA	54,700	5.2	82	NA
RAMX-P2-04	7/29	RO,MEUF	2nd Stg Perm	12,000	76	290	665	4.4	72	140
RAMX-C2-05	7/29	RO,MEUF	2nd Stg Conc	>16,500	NA	NA	613	4.3	NA	NA
RAMY-P2-06	7/29	RO,MEUF	2nd Stg Perm	8,500	78	200	749	4.3	72	3.7
RAMY-C2-07	7/29	RO,MEUF	2nd Stg Conc	>49,000	NA	NA	345	4.4	74	emulsion
RBRB-RF-08	7/30	RO,RO	Raw Feed	32,000	3,840	7,800	16,600	5.2	68	>200
RBRB-P1-09	7/30	RO,RO	1st Stg Perm	4,100	64	188	574	4.8	79	1.4
RBRB-C1-10	7/30	RO,RO	1st Stg Conc	NA	NA	NA	44,800	5.3	94	high
RBRB-P2-11	7/30	RO,RO	2nd Stg Perm	1,500	14	31	123	4.9	79	0.3
RBRB-C2-12	7/30	RO,RO	2nd Stg Conc	NA	NA	NA	957	5.0	83	8.3
UF-RF-15	7/30	UF	Raw Feed	26,000	NA	NA	14,200	5.3	70	NA
UF-P1-16	7/30	UF	Permeate	29,000	3,960	NA	13,600	5.4	69	3.9
UF-C1-17	7/30	UF	Concentrate	NA	NA	NA	15,600	5.4	68	high

* RAMX' was an aborted test
** Permeate sample from RAMX' was collected by Rochem, and tested the following day after chilling on ice overnight.
NA - Not Analyzed

VI. Laboratory Analyses

Identification of Samples for Laboratory

Not all of the process stream samples collected were sent to the laboratory for analysis. Samples were sent to the laboratory for analysis based on the results of field tests and the recommendations of the developer.

Samples were sent to the laboratory for analysis on July 30 and 31. On July 30, all of the samples from the first RO run (raw feed and permeate) were sent for all analysis parameters, as were samples of the permeate from the second MEUF run (RAMY) . Samples of the concentrate from the second MEUF run were sent for volatile organics analysis, herbicide analysis, and total phenol analysis. Samples of the permeate from the first MEUF run (RAMX) were sent for volatile organics analysis only, due to apparent high surfactant levels.

Samples sent on July 31 were hand delivered to the laboratory. The samples sent included an equipment blank for volatile organic compounds, metals, cations, and total Phenols analyses, and a field blank for volatile organic compounds analysis.

All of the samples from the two-stage reverse osmosis test (RBRB) raw feed, first-stage permeate and second-stage permeate were sent for all analyses. A set of duplicate samples for all analyses of the second stage permeate from this run were also sent to the laboratory. From the straight UF run, samples of the raw f eed and permeate were sent to the laboratory f or volatile organics and total phenol analyses.

Laboratory Analysis Results

The results from the laboratory analyses are presented in Table 2 for all analytes. The results are organized by the type of system tested (run type) Table 3 presents calculations of the percent rejections of the measured parameters achieved by each treatment system tested. These percent rejections were calculated from the raw feed and permeate analyte concentration and are approximations; they are intended to show general trends for the three treatment systems tested.

Table 2. Results of Treatability test Laboratory Analysis

Test Type >>	< ---------------------------- RO,MEUF ---------------------------- >				
Process Stream	Raw Feed	1st Stg Perm	2nd Stg Perm	2nd Stg Perm	2nd Stg Conc
Laboratory Sample Number	RAMX-RF-01	RAMX-P1-02	RAMX-P2-04	RAMY-P2-06	RAMY-C2-007
(Units)	(ppb)	(ppb)	(ppb)	(ppb)	(ppb)
VOLATILE ORGANIC COMPOUNDS					
Methylene Chloride	640,000 B	490,000 B	240,000 B	160,000 B	170,000
Acetone	1,000,000 B	1,600,000 B	1,800,000	1,400,000 B	470,000 B
Carbon Disulfide	4,400	1,900	<500	<500	<500
1,1-Dichloroethene	2,600	310 J	<500	<500	<500
1,1-Dichloroethane	10,000	2,000	500 J	<500	360 J
Chloroform	30,000	9,400	2,400	1,100	1,600
1,2-Dichloroethane	11,000	6,700	2,700	1,500	1,800
2-Butanone	1,600,000	620,000	810,000	730,000	720,000
1,1,1-Trichloroethane	59,000	1,400	<500	<500	<500
Carbon Tetrachloride	2,100	<500	<500	<500	<500
1,2-Dichloropropane	340 J	<500	<500	<500	<500
Trichloroethene	11,000	1,600	<500	<500	<500
1,1,2-Trichloroethane	330 J	<500	<500	<500	<500
Benzene	2,900	370	<500	<500	<500
4-Methyl-2-pentanone	9,300 J	5,100	6,200	4,700	1,400
2-Hexanone	3,600	400 J	520 J	360 J	950 J
Tetrachloroethene	6,400	<500	<500	<500	<500
Toluene	10,000	430 J	<500	<500	<500
Ethylbenzene	1,800	<500	<500	<500	<500
Xylene	6,800	<500	<500	<500	<500
TOTAL VOCs	3,411,570	2,739,610	2,862,320	2,297,660	1,366,110
HERBICIDES					
2,4-D	<5000	<5.0	NA	<5.0	125
2,45-TP	<2500	9.57	NA	16.1	10.9
Dichloroprop	<5000	<5.0	NA	<5.0	300
Dicamba	165,000	147	NA	124	79.6
METALS/CATIONS					
Calcium	1,780,000	160,000	NA	158,000	NA
Iron	179,000	14,400	NA	15,100	NA
Potassium	59,000	10,800	NA	11,100 B	NA
Magnesium	1,120,000	88,000	NA	94,500	NA
Manganese	42,400	3,750	NA	3,940	NA
Sodium	1,550,000	182,000	NA	208,000	NA
Nickel	3,140	9,800	NA	11,200	NA
Zinc	4,310	495	NA	3,380	NA
OTHER ANALYTES					
Total Phenols	275,000	51,800	NA	121,000	270,000
TOC (ppm)	8,125	1,840	NA	2,500	NA
TDS (ppm)	18,000	846	NA	499	NA

continued

Table 2. Continued

Test Type >>	< ---------- UF ---------- >		Blanks	
Process Stream	Raw Feed	Permeate :	Equipment Blank	Field Blank
Laboratory Sample Number	UF-RF-015	UF-P1-016 :		
(Units)	(ppb)	(ppb) :	(ppb)	(ppb)
VOLATILE ORGANIC COMPOUNDS				
Methylene Chloride	650,000 B	440,000 B :	10 B	27
Acetone	1,100,000 B	950,000 B :	20 B	12
Carbon Disulfide	8,300	1,500 :	<5	<5
1,1-Dichloroethene	2,700	990 :	<5	<5
1,1-Dichloroethane	12,000	6,400 :	<5	<5
Chloroform	32,000	20,000 :	2 J	3 J
1,2-Dichloroethane	10,000	8,200 :	<5	<5
2-Butanone	2,100,000	2,100,000 :	24	14
1,1,1-Trichloroethane	63,000	21,000 :	<5	<5
Carbon Tetrachloride	2,200	<500 J :	<5	<5
1,2-Dichloropropane	390 J	220 J :	<5	<5
Trichloroethene	13,000	2,800 :	<5	<5
1,1,2-Trichloroethane	230 J	210 J :	<5	<5
Benzene	3,500	1,500 :	<5	<5
4-Methyl-2-pentanone	110,000	100,000 :	<10	<10
2-Hexanone	2,600	3,000 :	<10	<10
Tetrachloroethene	6,300	430 J :	<5	<5
Toluene	11,000	2,900 :	<5	<5
Ethylbenzene	2,000	200 J :	<5	<5
Xylene	7,000	820 :	<5	<5
TOTAL VOCs	4,136,220	3,660,170 :		
HERBICIDES		:		
2,4-D	NA	NA :	<0.50	NA
2,4,5-TP	NA	NA :	<0.25	NA
Dichloroprop	NA	NA :	<0.50	NA
Dicamba	NA	NA :	<0.50	NA
METALS/CATIONS				
Calcium	NA	NA :	<560	NA
Iron	NA	NA :	235 B	NA
Potassium	NA	NA :	<3225	NA
Magnesium	NA	NA :	<505	NA
Manganese	NA	NA :	<10	NA
Sodium	NA	NA :	<1075	NA
Nickel	NA	NA :	65 B	NA
Zinc	NA	NA :	<55	NA
OTHER ANALYTES				
Total Phenols	260,000	510,000 :	126	NA
TOC (ppm)	NA	NA :	NA	NA
TDS (ppm)	NA	NA :	NA	NA

NA - Not Analyzed
J - Estimated Quantity
B - Comound was detected in associated laboratory blank
<MDL Not Detected

Table 3. Calculated Percent Rejections of Treatability Test Analytes Based on Laboratory and Field Analysis Concentration Results

Test Type >>>	< ---------- RO,MEUF	----------	---------->	< ---------- RO,RO	----------	---------->	< --- UF --- >
Parameter	Percent Rejection (a) 1st Stage	Percent Rejection (a) 2nd Stage (b)	Percent Rejection (a) Both Stoages (b)	Percent Rejection (a) 1st Stage	Percent Rejection (a) 2nd Stage	Percent Rejection (a) Both Stages	Percent Rejection (b)
VOLATILE ORGANIC COMPOUNDS							
Methylene Chloride	23.4%	67.3%	75.0%	71.6%	68.1%	90.9%	32.3%
Acetone	-60.0%	12.5%	-40.0%	81.7%	50.0%	90.8%	13.6%
Carbon Disulfide	56.8%	>74%	>88%	69.6%	91.2%	97.3%	81.9%
1,1-Dichloroethane	80.0%	>75%	>95%	97.1%	>86%	99.6%	46.7%
Chloroform	68.7%	88.3%	96.3%	95.5%	90.0%	99.5%	37.5%
2-Butanone	61.3%	-17.7%	54.4%	86.1%	60.0%	94.4%	0.0%
1,1,1-Trichloroethane	97.6%	>64%	>99%	98.8%	93.2%	99.9%	66.7%
Trichloroethene	85.5%	>69%	<95%	98.2%	78%	>99.6	78.5%
Benzene	87.2%	NC	>82%	97.9%	>31%	>98%	57.1%
4-Methyl-2-pentanone	45.2%	7.8%	49.5%	96.3%	77.2%	99.2%	9.1%
2-Hexanone	88.9%	10.0%	90.0%	96.0%	72.6%	98.9%	-15.3%
Toluene	95.7%	NC	>95%	99.1%	>54%	>99.6%	73.6%
Xylene	>93%	NC	>92%	99.6%	NC	>99%	88.3%
TOTAL VOCs	19.1%	15.9%	32.0%	82.6%	59.6%	93.0%	11.3%
HERBICIDES							
2,4-D	NC	NC	NC	98.8%	56.1%	99.5%	NC
2,4,5-TP	NC	-68.2%	NC	NC	>81%	NC	NC
Dichloroprop	NC	NC	NC	99.0%	81.1%	99.8%	NC
Dicamba	99.9%	15.6%	99.9%	NC	NC	NC	NC
METALS/CATIONS							
Calcium	91.0%	1.3%	91.1%	98.2%	73.4%	99.5%	NC
Iron	92.0%	-4.9%	91.6%	98.5%	79.3%	99.7%	NC
Potassium	81.7%	-2.8%	81.2%	94.7%	NC	>94.5%	NC
Magnesium	92.1%	-7.4%	91.6%	98.2%	78.1%	99.6%	NC
Manganese	91.2%	-5.1%	90.7%	98.0%	78.4%	99.6%	NC
Sodium	88.3%	-14.3%	86.6%	96.8%	79.0%	99.3%	NC
Nickel	-212.1%	-14.3%	-256.7%	39.7%	79.7%	87.8%	NC
Zinc	88.5%	-582.8%	21.6%	97.7%	35.9%	98.5%	NC
OTHER ANALYTES							
Total Phenols	81.2%	-133.6%	56.0%	89.5%	85.1%	98.4%	NC
TOC (ppm)	77.4%	-35.9%	69.2%	84.5%	52.1%	92.6%	NC
TDS (ppm)	95.3%	41.0%	97.2%	97.0%	75.8%	99.3%	NC
FIELD ANALYTES							
COD	76%	-46%	66%	87%	63%	95%	-11.5%
Calcium	NC	NC	NC	98%	78%	99.6%	NC
Hardness	NC	NC	NC	97%	83%	99.6%	NC
Conductivity	97%	-30%	96%	96%	78%	99.2%	4%
Turbidity	>99%	-180%	>98%	>99%	>78%	>99.8%	>98%

NC - Not Calculated: samples were not analyzed or results were below detection limits.
(a) - Percent rejections calculated based on initial and cinal concentration for stage or stages. Permeate values below MDL were calculated as > minimum percent rejections
(b) - Percent rejections calculated based on data from second RO run (RAMY)

OA/OC of Laboratory Results

The Quality Control (QC) results of the laboratory analyses were good in general. The QC for specif ic analyses are discussed below.

In order to achieve good quantif ication of the volatile organic compounds, each sample was run using two dilutions. Because of the high levels of organic compounds in most of the samples, the detection limits were 50 to 500 ppb. Most surrogate compound recoveries were within control limits and all laboratory control samples were within control limits. In the initial data submitted from the laboratory, vinyl acetate was reported as detected in nearly all samples; however, in the final data package it was reported that these results were false positives.

The results for field duplicate samples for VOCs were very inconsistent for some analytes, especially acetone and 2-butanone, two of the more prevalent compounds. Upon review it was determined that the duplicate samples were analyzed at different dilutions, a laboratory error, which accounts for the data inconsistencies.

Small amounts of acetone, methylene chloride, and chloroform were detected in the equipment blank and field blank samples, and both acetone and methylene chloride were detected in laboratory method blanks. The levels of blank contamination were very low as compared to sample results and do not affect data quality.

The highly organic nature of the sample matrix for most samples caused some problems with the herbicide analysis. Some analytes were detected in only the undiluted samples while others were detected in only the diluted samples. However, the laboratory has confidence in the analysis results. Surrogate recoveries were good, except for Dalapon which was not a target analyte. Laboratory control samples were within limits for herbicide analysis. Field duplicate results were comparable.

All laboratory QC results for metals were within limits. Iron and nickel were detected in both the equipment blank and laboratory blanks. The levels are generally low as compared to sample values. However, it is possible that contamination from process equipment may have occurred, leading to both the equipment blank results and@ to the seeming increase in nickel concentration during the RO-MEUF test run.

Laboratory QC for total phenols, total organic carbon and total dissolved solids were within limits.

VII. Conclusions for the Treatability Test

Percent Rejections

Percent rejections of measured parameters were calculated and were presented in Table 3. Based on these approximate percentages, the two-stage reverse osmosis system produced the greatest rejections of organic and inorganic contaminants overall.

System Operation

The DTM bench-scale systems operated as expected except for operational problems caused by missing or unseated o-rings. A process unit could be returned to operation quickly after identification of a problem. Changing of membranes and unit cleaning seemed to proceed smoothly. A larger scale operation will require more setup and shakedown time to ensure that the system is operating properly before testing begins. The o-ring problems experienced during bench-scale testing were a result of having to change membranes an the same module several times for different tests. During the pilot-scale demonstration, shakedown testing should eliminate this problem.

The Gallery Well leachate formed a brown layer on the membranes during operation, most likely due to a high iron content. While this did not effect the short-term process performance, it should provide a good test of the ability of the module to self-clean and resist detrimental fouling and scaling problems.

Based in part on the results from the treatability tests, the developer has selected a two-stage system for the demonstration test. This system will consist of a first-stage unit using a thin film composite polyamide reverse osmosis membranel followed by another unit using a high rejection (“tight”) thin film composite polyamide reverse osmosis membrane like the membrane used during treatability. A post-treatment unit for polishing of the effluent water (permeate) may be used during the demonstration test to meet discharge requirements, but will not be considered part of the system for the demonstration test.

Field Analysis Protocols for the Demonstration

The methods used for field analysis are all suitable for use during the demonstration. The conductivity measurement would even be suitable for a critical analysis. The measurement of COD using a calorimetric technique provides some useful and reasonably quick information on the organic content of the process streams. More experience with the use of the instrument, and additional equipment for volumetric measurement for dilution and aliquoting would make this method even more useful and accurate. The acquisition of COD standards for testing and verification would increase the confidence of results from using this method.

Laboratory Analysis Protocols for the Demonstration

All laboratory analyses used during the treatability testing would be suitable for use during the demonstration test. More herbicides were detected than expected from previous characterization results; herbicide analysis is likely to be performed during the demonstration because herbicides in water tend to be strictly regulated. However, the accuracy of this analysis may not be as good as for other types of organic compounds. Experience with analysis of this leachate has shown that acceptable analyses of other organic parameters (volatile organic compounds, phenols and TOC) can be performed despite the highly organic nature of the samples.

Acetone, 2-butanone and methylene chloride are the most prevalent volatile organic compounds in the Gallery Well leachate. Special precautions and procedures will be followed during further analysis of 'this leachate to ensure acceptable data in generated for these compounds.

Appendix C.
Treatability Test Plan

July 20, 1992

Treatability Testing Protocol

The following protocol will be followed in the handling and processing of all samples from the Casmalia Resources facility in preparation for a SITE demonstration at that facility. The testing will be completed using bench scale system configurations using small quantities of material (less than 20 gallons). The objectives of the test are to develop data on the optimum system configuration, including the number and type of units. Additional objectives are the selection of the most appropriate membranes and the development of reduction goals for the SITE demonstration.

The treatability testing is being overseen by Science Applications International Corporation (SAIC) as a contractor to the United States Environmental Protection Agency. SAIC is responsible for the collection of samples at the Casmalia Resources site, shipment of the waste to the Rochem facility and the handling of all testing residues at the conclusion of the treatability testing. All samples will be shipped in DOT approved plastic drums and will be transported by a certified hazardous waste hauler.

The purpose of the SITE demonstration is to demonstrate the effectiveness of the Rochem. Disc Tube™ modules in the concentration of hazardous constituents in landfill leachate. To achieve this end, three main membrane processes utilizing the Disc Tube will be explored during the treatability testing. The three processes are reverse osmosis (RO), ultrafiltration (UF) and micellar-enhanced ultrafiltration (MEUF).

Reverse osmosis uses a semipermeable membrane to selectively remove dissolved materials from water based on the relative permeabilities. Water has a very high permeability and passes through the membrane very quickly, while salts, heavy metals and most organics pass through much more slowly. Due to the difference in permeation rates, very high separation rates (as high as 99%+) can be achieved for most inorganic materials and organic materials with a molecular weight of more than 100.

Ultrafiltration uses a porous membrane with a known, but very small pore size to filter contaminants from water. Typically membranes with a pore size of 5,000 to 100,000 molecular weight are used, with a standard of approximately 20,000. Because of the pore size, the materials larger than the pores are completely removed, while smaller materials pass through. A typical application of UF is the separation of oil from water.

Micellar-enhanced ultrafiltration is an extension of traditional UF technology. In MEUF, a material is added to the raw water which forms a micellar emulsion. The emulsion is formed in such a way that it preferentially binds certain materials, either metals or organic compounds and holds them in large molecules. When the emulsion is passed across a UF membrane, the emulsion containing the contaminants is removed from the water, allowing contaminants, which would be smaller than the membrane pore size if not encapsulated in the emulsion, to be removed.

Treatability Protocol

During the treatability testing we intend to explore three different system configurations and several different membranes. The first configuration will be as follows:

RO $\rightarrow$ MEUF

This configuration uses RO as the main purification process and MEUF as an additional process to remove trace organics.

The second configuration will be as follows:

MEUF $\rightarrow$ RO

In this configuration, the organics will be removed before the RO step. This will be tested to determine if higher concentrations allow better removal in MEUF, or if lower concentrations improve the efficiency of the RO process.

The final configuration will be as follows:

UF $\rightarrow$ RO

This process will use the same membranes as the MEUF step, but will not have an emulsion- forming material added. This step is necessary to demonstrate the effectiveness of the emulsion in the effectiveness of the separation.

During the treatability testing, at least two different RO membranes and two different UF membranes will be tested. Multiple membranes will be tested to identify the best membrane to treat the specific leachate at the Casmalia Resources site.

UF & MEUF Testing

Ultrafiltration and Micellar-Enhanced Ultrafiltration tests will be conducted in a bench scale UF test cell. The unit consists of a 10-gallon stainless steel holding tank, pre-filter, pressure pump and Disc Tube module. The module used can contain from one to nine membrane cushions, for a total membrane area of 0.45 to 4.0 square feet. For this test it is anticipated that nine cushions will be used. The system operates in recirculation mode. The pump draws two gallons per minute (gpm) of feed from the tank and passes it through the module. A portion of the liquid passes through the membrane and is filtered. The remaining concentrated liquid returns to the tank for further concentration. During initial startup the filtered liquid will also be returned to the tank.

For these tests, it is anticipated that approximately five to ten gallons of feed will be used. The test will probably be run in 5-gallon batches, i.e., 5 gallons of liquid put in the feed tank and re-processed until it is highly concentrated then 5 more gallons of feed will be added. This will allow the production of more filtrate for later testing.

RO Testing

The RO treatability tests will be performed using a high pressure pump and a Disc Tube module. The module used will contain approximately 4 square feet of membrane. The maximum pressure used will be 1000 psi. The high pressure pump will take suction from a container, probably a 5- gallon pail. The concentrated material will be returned to the pail, the filtered material will be collected in another container. During startup, the filtered material will be returned to the feed container.

This test will be performed on water which has been pre-filtered. If raw feed is used, it will be filtered through a 10 micron cartridge filter as it is being transferred to the feed container. If UF or MEUF filtrate is used, it has already been filtered to less than 1 micron.

Parameters to be Measured

The field parameters which will be measured are the same for UF, MEUF and RO systems. The main parameters of interest are pressure and filtrate flow rate. Both test cells are fitted with pressure gauges to measure both the inlet and outlet pressure of the module, both of which will be recorded. Feed flow through the module will be determined by the pump used. Both cells use positive displacement pumps which flow a set amount of water on each revolution. Filtrate flow will be measured using a graduated cylinder and a stopwatch. In addition, additional field analyses may be performed. These may include, but are not limited to conductivity, pH, COD, temperature, turbidity and calorimetric tests for specific water parameters.

Samples of all feed streams and filtrate streams will be taken. Based on field measurements, samples from the most promising tests will be analyzed at an approved laboratory. Sampling and analysis will be done by SAIC. SAIC is preparing a Sampling and Analysis Plan.

Health and Safety

The scope of the work to be done under this plan is bench scale treatability testing. The test to be performed will be batch mode tests using very small volumes of liquids. No more than 20 gallons of material will be used at any given time.

All appropriate precautions will be taken in handling and testing the materials. All treated and untreated materials will be stored in plastic DOT approved shipping containers (drums). The shipping containers will be stored in plastic secondary containment vessels. The volume of the secondary containment will be sufficient to contain at least 150% of the volume of waste stored therein.

During actual testing, steps will be taken to minimize any potential spills. The test equipment will be set up in secondary containment vessels, and all transferring of liquids will be done in those areas. During actual testing, containers will be kept closed. Necessary venting will be done using PVC hose to outside of the building.

The area the testing will be done in contains no floor drains. A complete spill cleanup kit including absorbent, brooms and shovels, and disposal drums will be available at all times.

Ventilation to the testing room will be positive pressure forced air. The return vent from the room will be blocked to prevent drawing vapors to other areas of the building.

The following measures will be taken to minimize hazards associated with the test. The area of the test will be monitored with both an organic vapor analyzer and an LEL monitor. The action level for the organic vapor monitor will be 5 ppm above background. The action level for the LEL monitor will be 10%. All equipment will be leak tested with fresh water before testing of contaminated materials begins.

Standard operating procedures will include the following.

A. Buddy system (no one works alone)
B. Decontamination and contamination control
   1. Defined contamination zone
   2. Defined contamination control zone. A haz waste trash receptacle and wash bucket will be available at the exit from the control zone.

3. Non-essential personnel will be exclude from the contamination zone
4. Gloves and contaminated clothing will be removed before leaving the contamination zone.
5. All non-disposable items will be washed before being removed from the contamination zone.
6. All personnel involved with the project will wash hands, face and forearms before eating, drinking, or leaving for the day.
7. Food and beverage will not be allowed in the contamination zone. Smoking will be prohibited.

A list of emergency numbers will be posted, including fire department, hospital, ambulance and other regulatory agencies. An airhorn will be used as an evacuation signal. All personnel in the building will be advised of the emergency plan, evacuation procedures and meeting location. A daily safety meeting will be held for all personnel involved with the project. The meeting will discuss the days, tasks and the physical hazards of the project and the need for all personnel to be aware of their surroundings and to seek help in the lifting of heavy objects. The safety meeting will also discuss the placement of emergency equipment (telephone, procedure to summon aid, fire extinguisher placement, etc.).

In the event of an accident, injured persons will be decontaminated unless the injury is life threatening. Any medical personnel will be notified of the nature of materials involved.

The following personnel protection equipment will be used.

A. Steel toed boots
B. Gloves (nitrile or vinyl for lab work, covered with heavy nitrile or neoprene for material handling and sampling.)
C. Goggles
D. Respirators with organic vapor cartridges
E. Aprons or tyvek will be worn for splash protection.

Decontamination

Between each different feed stream and at the conclusion of the test, all equipment will be rinsed with water until no contamination is evident. The equipment will be triple rinsed at the conclusion of testing. All rinse waters will be collected. All feed samples remaining, concentrate, filtrate, rinsate or any other liquid generated during the testing will be collected and returned to the Casmalia Resources site for treatment/disposal during the subsequent Technology Demonstration Test. Materials returned to the Casmalia site will be transported in DOT approved containers (plastic drums) by a certified waste hauler. Any solid waste (filter cartridges, rubber gloves, etc.) will be collected and disposed of by SAIC in accordance with all applicable regulations.

Reporting

A report detailing the analytical results of the treatability testing will be written. The report will include a summary of the laboratory results as well as field data. This data will be used to determine the Developers Claims for the SITE demonstration at the Casmalia Resources facility.