United States Environmental Protection Agency
Office of Research and Development Cincinnati OH 45268
EPA/540/R-96/507a
April 1998

EPA

Site Technology Capsule

Rochem Separation Systems, Inc., Disc Tube™ Module Technology

Abstract

The Rochem Separation Systems, Inc. (Rochem) Disc Tube™ Module (DTM) technology is an innovative membrane separation process. It is designed to treat liquid waste that is higher in dissolved solids content, turbidity, and contaminant levels than waste treated by conventional membrane separation processes. According to the technology developer, Rochem, the innovative DTM design reduces the potential for membrane fouling and scaling, which allows it to be the primary treatment for liquid wastes such as landfill leachate.

The DTM technology was evaluated by Science Applications International Corporation (SAIC) under the Superfund Innovative Technology Evaluation (SITE) Program at the Central Landfill Superfund Site in Johnston, Rhode Island. 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; toluene at 1.8 mg/L; xylenes at 1.3 mg/L; and ethylbenzene 0.79 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 this SITE Demonstration was to assess the DTM technology's effectiveness in removing organic and inorganic contaminants from the landfill leachate and in resisting scaling and fouling of the membranes.

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 claims of 92% for TOC and 99% for TDS. The overall mean rejection for total metals was greater than 99.2%, exceeding the developer's claim of 99%. The overall mean rejection for target VOCs was greater than 92.3% which exceeded the developer's claim of 90% for VOCs. In addition, the DTM process achieved a treated water recovery rate of approximately 75%. The developer's claim was 75%. DTM operational parameters, such as permeate (treated water) flow rate and module pressure drop, and system permeate quality, indicate that there was a decrease in technology performance over the course of the Demonstration.

The Rochem DTM technology was evaluated based on seven criteria used for decision-making in the Superfund Feasibility Study (FS) process. Results of the evaluation are summarized in Table 1.

Introduction

This report provides information on the Rochem DTM technology, an innovative membrane separation process for removal of contaminants from liquid hazardous waste streams. The Rochem DTM technology was evaluated under the U.S. Environmental Protection Agency's (EPA) SITE Program during August and September 1994 at the Central Landfill Superfund Site in Johnston, Rhode Island. Contamination in an area of the Central Landfill designated as the "hot spot" resulted from the disposal of chemical wastes in the mid-1970s. Leachate from this

SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Table 1. Criteria Evaluation for the Rochem Disc Tube™ Module Technology

Overall Protection of Human Health & the Environment	Compliance with Federal ARARs	Long-Term Effectiveness	Short-Term Effectiveness	Reduction of Toxicity, Mobility, or Volume through Treatment	Implementability	Cost
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. Without additional treatment, the final permeate produced during the Demonstration met discharge permit requirements for heavy metals. The discharge requirement 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 air quality standards, depending on local ARARs. Requires compliance with OSHA regulations to protect the health and safety of workers at hazardous waste sites.	Permanently reduces the volume of contaminated leachate or other liquid waste. Involves a demonstrated technique for removal of organic and inorganic contaminants. Permeate may require treatment prior to disposal, depending on 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 application 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 (PPE) may be required for workers during system operation.	Significantly reduces toxicity of treated water and volume of contaminated water through treatment. Permeate water quality is dependent on waste characteristics. During the Demonstration, contaminant levels were reduced 90% or greater on average (99.4% for TDS, 99.2% for target metals, 96.7% for TOC, and 92.3% for VOCs). Waste volume reduction is dependent on waste characteristics and the required system water recovery rate. Waste volume reduction for the Demonstration was approximately 75%.	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, and tanks 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 fouling and scaling, thereby limiting the use of the DTM technology.	The estimated costs for treating leachate at 3 and 21 gpm at a fixed facility and with a treated water recovery rate of 75% are $0.16/ permeate-gal and $0.06/permeate-gal, 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 from 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 a higher on-line factor and treated water recovery rate (both dependent on system design and leachate characteristics) will result in a lower overall cost.

hot spot was pumped from an existing well for treatment by a Rochem Model 9122 DTM system operating at a feed flow rate of about 4 gallons per minute. Approximately 33,000 gallons of leachate were treated during the Demonstration at the Central Landfill. The leachate contained VOCs, metals, and high dissolved solids.

Information in this Capsule details the specific site characteristics and results of the SITE technology Demonstration at the Central Landfill. This Capsule presents the following information:

- Technology Description
- Technology Applicability
- Technology Limitations
- Process Residuals
- Site Requirements
- Performance Data
- Economic Analysis
- Technology Status
- SITE Program Description
- Sources of Further Information

Technology Description

The DTM technology can utilize reverse osmosis (RO), ultrafiltration (UF), or microfiltration (MF) membrane materials, depending on the application. The membranes are generally more permeable to water than to contaminants or impurities. RO membranes are most commonly used with this technology. They can reject dissolved and suspended solids, dissolved salts and ions, and many low and most high molecular weight organic compounds (1). In RO, water in the feed is forced through a membrane by applied pressure which 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 (TFC) RO membranes 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 membrane 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 as needed from modules for replacement.

Figure 1 details a cutaway diagram of the Disc Tube™ Module. Membrane material for the DTM is formed into a cushion surrounding a porous spacer material. The membrane cushions are alternately stacked with hydraulic discs on a tension rod. The hydraulic discs support the membranes and provide the 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.

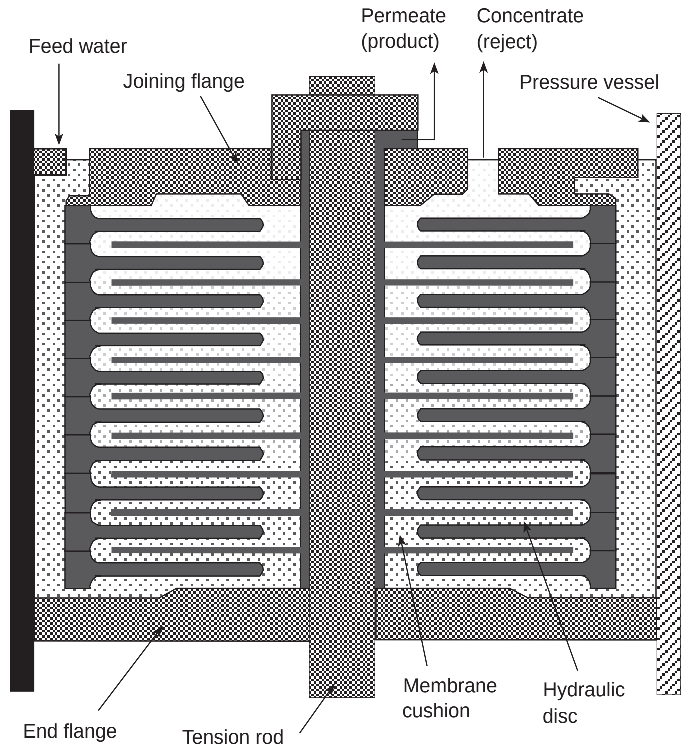

Figure 1. Cutaway diagram of the Disc Tube™ module.

Modules are typically combined in a treatment unit. The DTM system design includes built-in multimedia and cartridge filters to remove suspended particulates from the input feed and to protect pumps and membranes from physical damage. The multimedia filters are cleaned by backwashing; cartridge filters are manually replaced as needed. To monitor the operation of the modules, the system is equipped with 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 high-pressure unit (HPU) which further treated the concentrate from the first-stage to increase system water recovery. A schematic of the multistage DTM process utilized during the Demonstration is presented in Figure 2. The system operated up to eight hours a day for 19 days at a feed flow rate of 3 to 4.5 gallons per minute (gpm).

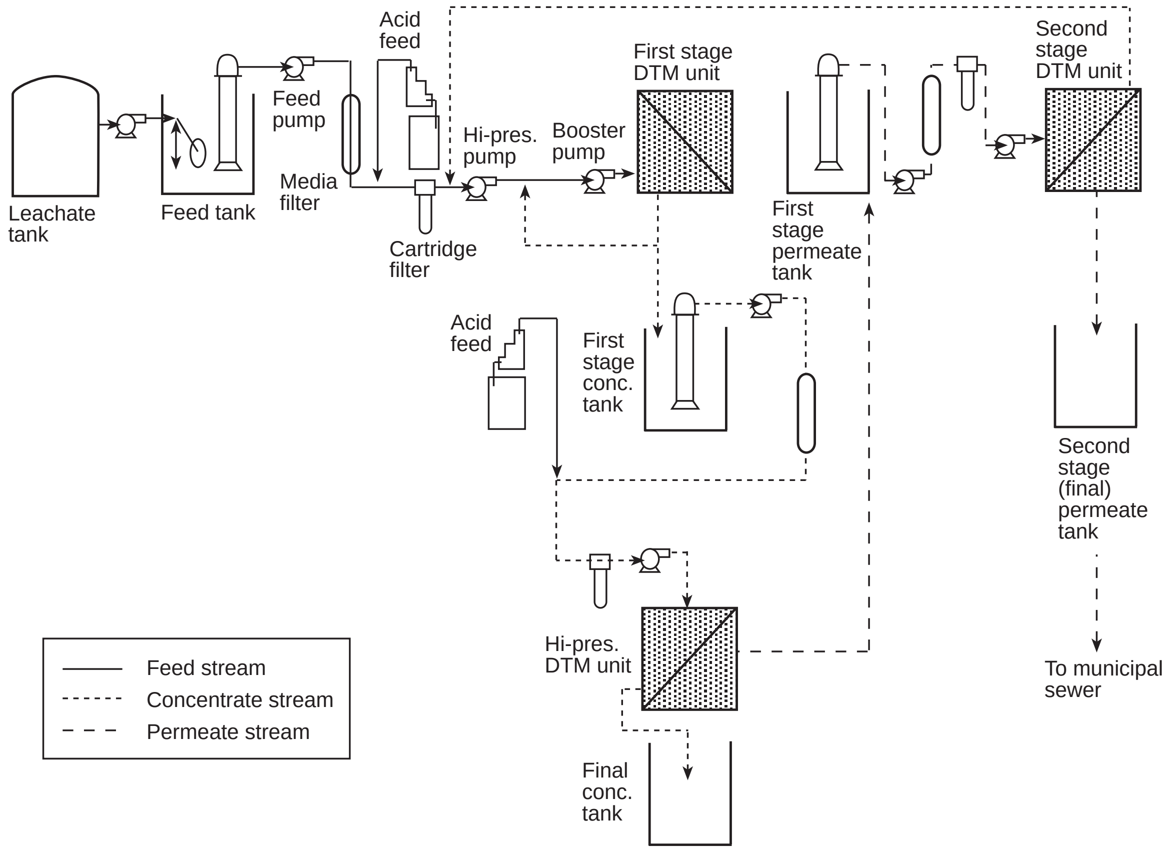

Figure 2. Schematic of the DTM process.

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 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). The first-stage unit had eight modules which utilized standard 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 to the second-stage unit for further treatment.

The second-stage unit, which had 2 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 prefabricated 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 into the HPU at 1 to 3.5 gpm and 900 to 1,800 psig. Use of the HPU was initiated later than the first two stages after accumulation of first-stage concentrate; the HPU operated in a batch mode. The HPU had two stainless steel modules which 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 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 test. 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 HPU and second-stage unit in between batch treatment cycles each day to displace any leachate from membrane surfaces. In addition, all stages were rinsed at the end of the day to flush the system prior to shutdown overnight. Cleaning was accomplished by adding cleaning agents—either alkaline for fouling, acidic for membrane scale, or detergent for both—to the rinse tank for each unit. The cleaning solution was then cycled through the unit. 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 (HCl) acid was added to the first-stage feed and the HPU feed at dosing rates of 1.6 to 2.8 liters per hour (L/hr) and 0.53 to 1.6 L/hr, respectively. The addition of HCl, which facilitated pH adjustment, was not started until the third day of leachate treatment. Rochem's target system feed pH for the Demonstration was between 5 to 6.

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

Technology Applicability

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 coolants, oil/water mixtures, and solvent/water mixtures (2). The DTM technology was used in the United States to treat lagoon water contaminated by petrochemical wastes (volatile organics, phenols, heavy metals, and polychlorinated biphenyls). In addition, the technology is treating municipal landfill leachate in the U.S. and municipal and hazardous landfill leachate in Europe. (See "Technology Status" for further details).

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. A high-pressure unit can be used to increase the treated water recovery rate for liquid wastes that have a higher level of TDS or scaling ions. Results from the Demonstration show that the DTM technology achieved excellent removals of metals, TDS, and TOC. VOC removals were also very good (approximately 90% or greater). The VOC removals are notable because membrane separation technologies typically do not effectively separate lower molecular weight organic compounds, particularly VOCs; these compounds tend to pass through the membranes (3).

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 (4). The user of the technology will be responsible for arranging for treatment and disposal of the final concentrate and disposal of the final permeate.

The Rochem DTM technology is transportable on tractor trailers and can be installed by Rochem personnel within three to five days, if power and auxiliary tankage and piping are available. Multiple DTM systems can be used to increase treatment capacity.

Technology Limitations

The composition of the feed waste may limit the applicability of the DTM technology. In RO, inorganic salt percent 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 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 also contribute to scaling and fouling as will biological activity. This, in turn, may limit membrane life and treatment effectiveness (5).

The maximum treated water recovery rate is dependent on the TDS concentration 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 offset by cost savings for treatment and disposal of a smaller volume of concentrate.

Process Residuals

The DTM process separates contaminants from liquid waste generating two process streams: permeate (treated water) and concentrate (waste). If appropriate discharge limitations are met and the proper permits are obtained, the permeate can be discharged to the local publicly owned treatment works (POTW), into surface waters, or reinjected through underground injection wells. 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 municipal sewer. 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. 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 (4).

During treatment of 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 technology 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. Emissions from auxiliary storage tanks may also need to be controlled.

Site Requirements

Each DTM unit or stage is comprised 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 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 prevent 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 equipment necessary for system operation includes auxiliary tanks for process stream storage and interconnecting piping.

Utilities 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 hookup 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 shakedown and calibrate the equipment. Water is also needed for cleanup and decontamination.

Support facilities include shelter to protect equipment and personnel from weather extremes and level equipment staging areas. At locations with colder climates, an indoor installation with heating would be preferred. During the Demonstration, the treatment units were arranged under a tent. A more permanent shelter including office space is desirable for long-term treatment projects. The technology requires a flat site 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 was adequate for the three-stage Demonstration system.

Storage of raw feed and final concentrate is required, and storage of final permeate may be required. Storage tank sizing and design are dependent on site-specific applications. The user of the technology may be responsible for providing storage tanks. In addition, an area constructed to contain potential spills is required to hold containers for process stream storage, chemicals, and process wastes.

Performance Data

The DTM technology was evaluated on its effectiveness in removing organic and inorganic contaminants from leachate and the extent, if any, of membrane fouling and scaling observed when treating landfill leachate containing hazardous constituents.

Prior to the SITE Demonstration, bench-scale treatability tests were conducted on hazardous leachate from a landfill in the western U.S. This 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 hazardous 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.

Treatability testing was not conducted by Rochem on the Central Landfill leachate. Shakedown testing with the Central Landfill leachate was performed by Rochem for about one day prior to the Demonstration.

Based on prior treatability testing and other Rochem applications, the following critical objectives were developed for the Demonstration:

- 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.

Other noncritical objectives for this Demonstration were to

- develop capital and operating costs for the DTM system;
- 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 target contaminants; and
- estimate the potential fugitive emissions from the system during use.

During the Demonstration, samples were collected from sample taps on 11 process streams throughout the system. The process streams considered critical in evaluating the technology were the raw feed, the final permeate, and the final concentrate. Samples for off-site laboratory analysis were collected at a frequency of once per day (three times per day on two selected days). Samples for field analyses were collected once or twice per day, depending on the analysis. Off-site laboratory analyses included TDS, total solids (TS), TOC, VOCs, total metals, ammonia, and anions. Field parameters that were measured included turbidity, pH, temperature, conductivity, silica, alkalinity, chemical oxygen demand (COD), calcium, and hardness. Table 2 presents the average concentrations of contaminants measured in the system feed, permeate, and concentrate process streams during the Demonstration.

Percent rejections of contaminants were calculated from daily raw feed and final permeate concentrations. Table 3 summarizes the calculated mean percent rejections achieved for the target contaminants considered critical for this Demonstration. Mean contaminant rejections were greater than 96.7% for TOC and 99.4% for TDS, both exceeding the developer's claim. All target metals except potassium showed mean rejections greater than the developer's claim of 99%. The overall mean rejection for total metals was greater than 99.2%. The mean rejection for potassium was greater than 98.7% and the 95% confidence interval around this mean was 98.0 to 99.4%. The calculated mean percent 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 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. These results indicate that the DTM system was very effective in removing all classes of contaminants in the Central Landfill leachate.

Table 2. Average Concentration for the System Feed, Permeate and Concentrate Streams

	Average Concentration (Mg/L)		
Contaminant	System Feed	Final Permeate	Final Concentrate
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.

Table 3. Target Contaminants Average Percent Rejection

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	>90	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.

Vent emissions were measured during the Demonstration from an intermediate concentrate holding tank in the system. VOC losses were calculated from these measurements. Comparing these results on a mass basis to the system VOC mass shows the vent losses to be no more than 0.5% of the total mass of any given compound. Therefore, these losses did not significantly affect the calculated percent rejections of VOC contaminants.

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 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% water recovery falls within this confidence interval. The calculated daily water recovery rates ranged from 66.4 to 84.4%. The system recovery

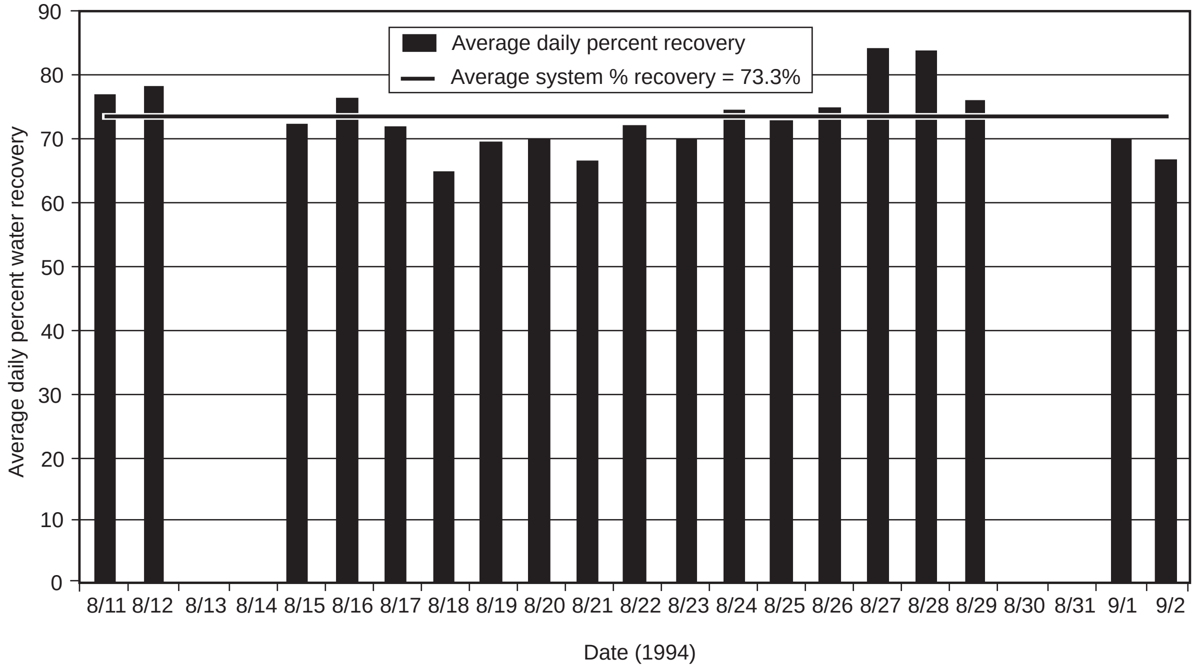

Figure 3. Rochem DTM system daily percent water recovery.

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 rinsing of the second-stage and the HPU modules between batch treatment cycles each day to displace residual leachate from the membrane surfaces. An allowance was not made for permeate lost to these rinses because they were part of normal operation for the system used for the Demonstration. According to Rochem, 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.

System operating data was evaluated to determine the performance of membranes which received the bulk of waste loading during the Demonstration. Figures 4 and 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 waste concentration using ASTM Standard D4516-85, Standard Practice for Standardizing RO Performance 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.

In general, the data presented in these figures show an increase in operating pressures and a decrease in flow rates over time, indicating a slight decrease in performance for the units receiving the bulk of 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 was probably a result of the lack of pH adjustment to control precipitation and membrane scaling. HCl acid 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. The feed pressure in the first-stage unit began increasing on about August 22, 1994. The system recovery rate setting was increased on August 24 by Rochem, and this was followed by additional pressure increases as well as a decrease in flow rate 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 flow rate and reduction in permeate quality for some contaminants. Figure 6 illustrates a trend in the reduction of permeate quality (most notable near the end of the Demonstration) for TDS, TOC, and total VOCs. Membrane cleanings were helpful in maintaining system performance, but the leachate did appear to have an impact on membrane performance over the course of the Demonstration. However, due to the short duration of system shakedown and of the Demonstration, it was not possible for Rochem to fully optimize the membrane cleaning procedures for this leachate. 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. Baseline testing also indicated a decrease in membrane performance over the course of the Demonstration. Baseline testing

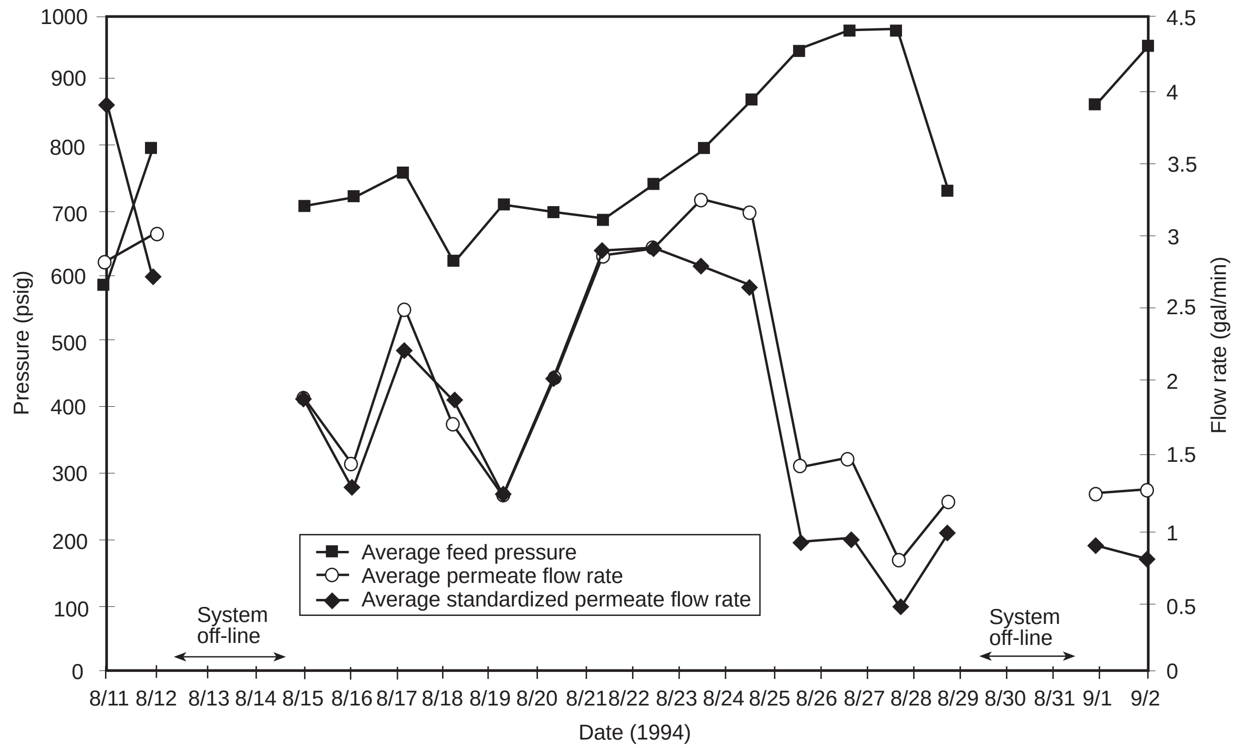

Figure 4. First-stage unit: feed pressure and permeate flow rate vs. time.

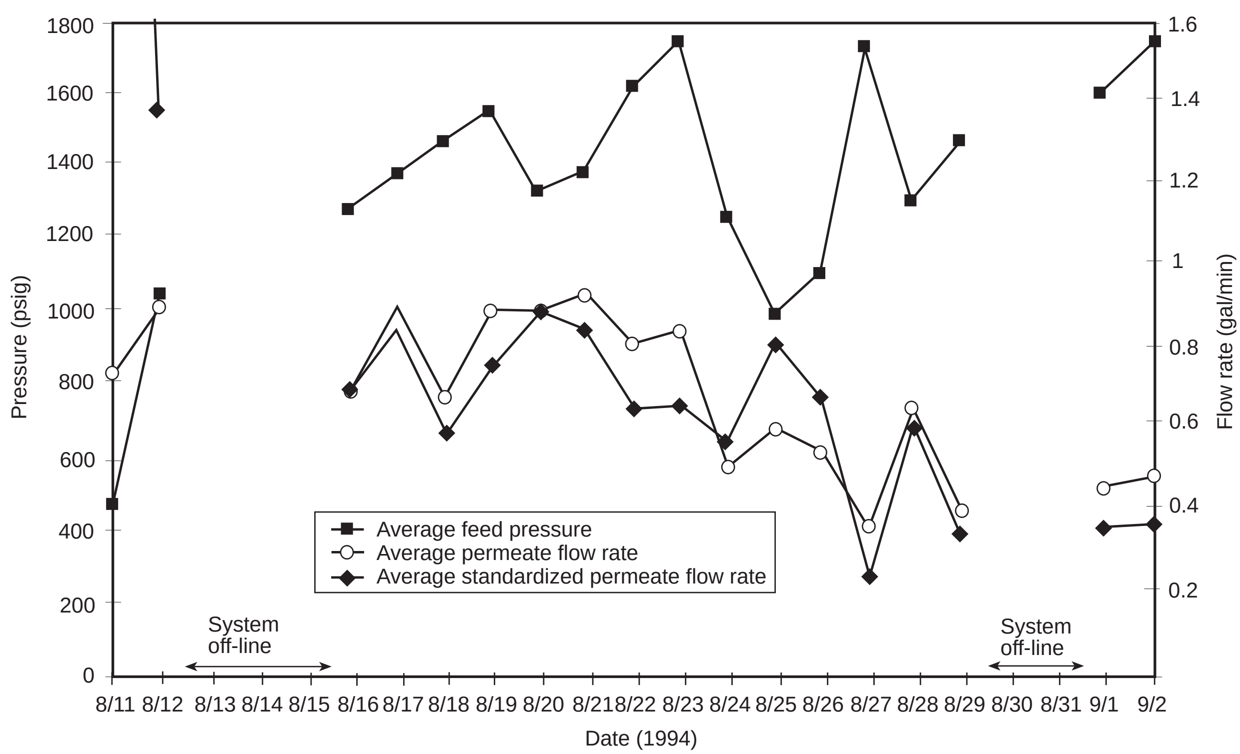

Figure 5. High pressure unit: feed pressure and permeate flow rate vs. time.

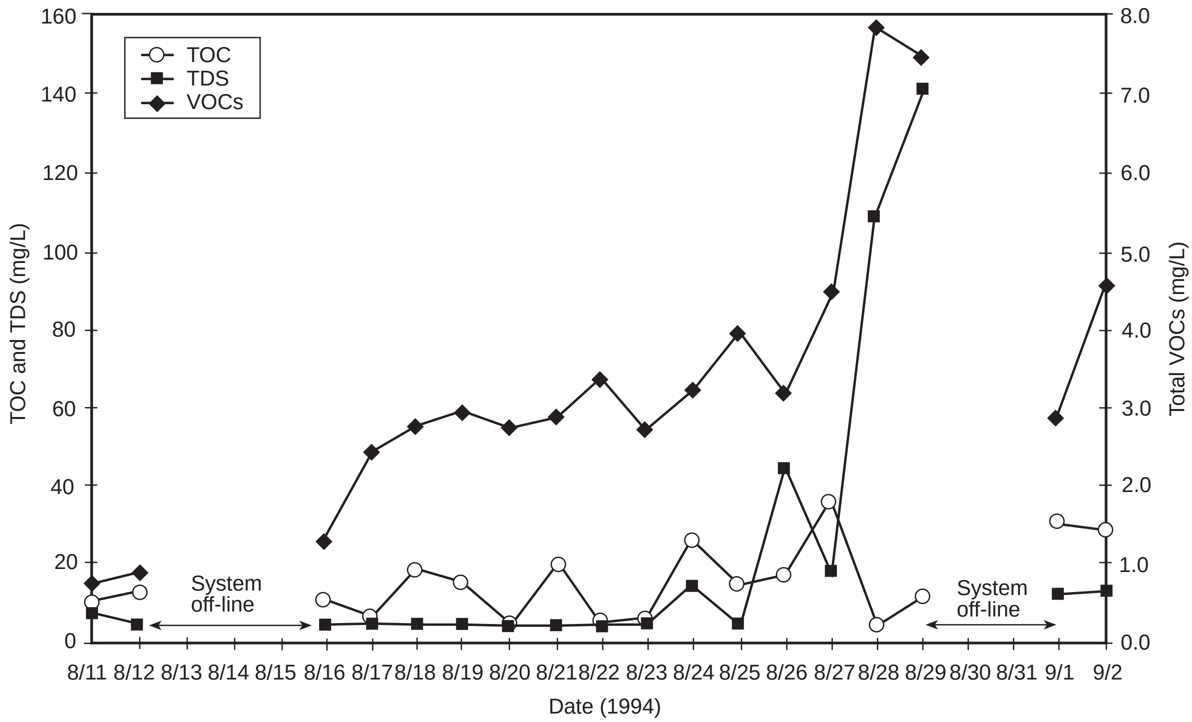

Figure 6. Final permeate stream: TDS, TOC, and total VOCs vs. time.

involves determining the change in flux (flow rate per unit membrane area) as a result of liquid waste (leachate) treatment. Baseline testing results can be found in the Innovative Technology Evaluation Report (ITER).

System mass balance calculations gave good results for metals, TOC, TDS, and TS. Totalized flow measurements were used for daily mass balance calculations. Adjustments were made to these measurements to account for rinse cycles that used permeate to perform rinses. This permeate was lost as concentrate. The overall mass balance for metals was within 15 percent of closure, which is considered good for this type of process. The closures for TOC, TDS, and TS were within plus or minus 5 percent. These results indicate that analytical data and system flow measurements were of good quality and that these contaminants were accounted for. Mass balances for VOCs showed a typical loss of 40 to 60% of these compounds through the system, and final concentrate levels for VOCs 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. The feed and especially the final concentrate process streams were foaming during sampling due to acid addition and pressurization, making sampling for VOCs difficult and probably resulting in VOC losses to the atmosphere. Organic fouling of the membranes was occurring during leachate treatment, as evidenced by the amount of membrane cleaning required using an alkaline cleaner. VOCs may have been responsible for some of the organic fouling, possibly in combination with iron or silica, however, these foulants would have probably been removed from the membranes during cleaning cycles and would therefore not be accounted for in the mass balances.

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 Wastewater Discharge Permit. The measured quality of the permeate from the DTM technology complied with discharge permit requirements for heavy metals without further treatment. Polishing treatment with activated carbon was utilized to ensure compliance with the total toxic organics (TTO) discharge limit of 2.13 mg/L. The TTO level of the final permeate from the DTM technology ranged from about 1 mg/L, less than the discharge limit, to 10 mg/L, with an average of about 3.4 mg/L for the Demonstration. The calculated TTO for the final permeate is based on VOC analytical results; other organic compounds were not detected in the full TTO analysis performed on the final discharge samples. Measured COD, BOD, and TSS values were generally very low mg/L or non-detectable. There were no discharge permit limits for these parameters.

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, for each unit, short cleaning cycles (approximately 30 to 60 minutes in duration) were used to maintain daily treatment effectiveness. More thorough cleaning was occasionally required to remove accumulated membrane deposits. This extensive cleaning was partially effective in restoring membrane flow rates (flux). During the Demonstration, membrane cleaning was performed more frequently than typical due to inadequate pH control.

The reliability of the technology during the Demonstration was good. After some initial adjustments, the system ran steadily with short breaks for routing 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 (4).

Economic Analysis

Estimates on capital and operating costs have been determined for treating leachate similar to the SITE Demonstration leachate (hazardous landfill leachate). Two cost estimate cases are presented for DTM systems operating 24 hours per day (hpd) at fixed facilities. The first case is for a 9122 DTM system treating three gallons of leachate per minute. This is slightly smaller than the 9122 Demonstration system. The second case is for a 9142 DTM system treating 21 gallons of leachate per minute. For both cases the DTM system includes a high pressure unit (HPU).

The estimated costs for treating leachate similar to the Demonstration leachate are $0.16/permeate-gallon ($0.04/permeate-liter) for the 9122 system case and $0.06/permeate-gallon ($0.01/permeate-liter) for the 9142 system case. These costs are for operating at a fixed facility. They include all factors except for permitting and waste disposal costs for the concentrate stream. Costs are highly site- and leachate-specific. If only annualized equipment costs and consumables costs were considered, then the cost would decrease to $0.07/permeate-gallon and $0.03/permeate-gallon for the 9122 and 9142 systems, respectively.

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

- Treating leachate similar to the leachate at the Demonstration. 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 cartridge filter life.
- An on-line efficiency factor of 90%. This factor accounts for downtime 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%. This is based on data collected during the SITE Demonstration.
- Cleaning frequencies and cleaning solutions requirements based on observations made during the SITE Demonstration and other data from Rochem.
- The same pH adjustment requirements that were observed during the SITE Demonstration.
- The following membrane lifetimes: five years for the second stage permeate-membrane, three years for the first stage leachate-membrane, and two years for the concentrate-membrane. These lifetimes are based on information from other Rochem applications.
- System operating times of 24 hpd, 7 days per week, and 50 weeks per year.
- Labor requirements of one operator on-site for four hpd. Because these cost estimates are based on the Demonstration leachate characteristics, they are higher than costs estimated for treating a non-hazardous landfill leachate. This is because the Demonstration leachate required more frequent cleanings and a larger volume of pH adjustment chemicals than other types of leachates would require. A detailed explanation of these cost estimates can be found in the ITER.

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 1988. The high-pressure unit such as used during the Demonstration at the Central Landfill is a new design implemented to increase treated water recovery rates where high recovery rates are desirable or for applications with high TDS.

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 landfill leachate at more than 50 landfills in Europe, according to Rochem. Rochem has also had projects in the United States. At the French Limited Superfund site near Crosby, Texas, the technology treated lagoon water contaminated by petrochemical wastes (volatile organics, phenols, heavy metals, and PCBs). Two units with 30 modules and one with 10 modules were used to treat three million gallons of lagoon water per month at this site. According to Rochem, 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 (6). At the Superior Landfill in Savannah, Georgia, the technology is treating municipal landfill leachate at a flow rate of 6,000 to 7,000 gallons per day. According to Rochem, over 200,000 gallons of leachate have been treated to date at a 73 to 74% recovery rate (4).

Rochem has four systems available for waste treatment: Model 9122 rated for 3,000 to 9,000 gallons per day (gpd) [11,000 to 34,000 liters per day (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 (two-stage) to increase product quality, or in parallel to increase treatment capacity. The cost per permeate-gallon for treatment with the DTM technology decreases with increasing treatment capacity.

Based on the results of this Demonstration, 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. If needed, bench-scale treatability testing is used to determine membrane compatibility with the 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. Once installed, 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 hours per day with occasional 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 hours per day. For more difficult or hazardous wastes, greater operator attention is required.

SITE Program Description

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA). The primary purpose of the SITE Program is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements: the Demonstration Program, the Emerging Technology Program, the Monitoring and Measurement Technologies Program, and the Technology Transfer Program. The Rochem DTM technology was evaluated under the Demonstration Program. This Capsule was published as part of the Technology Transfer Program.

Sources of Further Information

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