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Project Summary

A Handbook on Treatment of Hazardous Waste Leachate

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Twenty unit processes were reviewed for their applicability to the treatment of hazardous waste leachate. These processes are classified into four categories as follows: pretreatment operations, including equalization, sedimentation, granular-media filtration, and oil/water separation; physical/chemical treatment operations, including neutralization, precipitation/flocculation/sedimentation, oxidation/reduction, carbon adsorption, air stripping, steam stripping, reverse osmosis, ultrafiltration, ion exchange, and wet-air oxidation; biological treatment operations, including activated sludge, sequencing batch reactor, powdered activated carbon treatment (PACT), rotating biological contactor, and trickling filter; and post-treatment operations, including chlorination. Typical treatment process trains (i.e., combinations of the above unit processes) are presented for leachate containing organic and/or inorganic contaminants. Management of treatment process residuals (chemical/biological sludges, air emissions of volatile organic compounds, concentrated liquid waste streams, spent carbon) is also addressed.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. Environmental Protection Agency (EPA) hazardous waste site cleanup program, referred to as Superfund, was authorized and established in 1980 by the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Public Law (PL) 96-510. This legislation allows the Federal government (and cooperating State governments) to respond directly to releases and the threat of releases of hazardous substances and pollutants or contaminants that could endanger public health or welfare or the environment. Prior to the passage of PL 96-510, Federal authority with regard to hazardous substances was mostly regulatory in nature through the Resource Conservation and Recovery Act (RCRA) and the Clean Water Act and its predecessors.

Public Law 96-510 and the regulations based on it not only govern accidental releases that may occur from time to time, but also releases that already have taken place and continue to take place from uncontrolled waste-disposal sites. Leachate is one type of release covered by this law. It is formed when water percolates through a waste-disposal site, and if not properly contained and collected, it can threaten the local hydrogeologic environment. The objective of this handbook is to provide guidance in the treatment of hazardous waste leachate.

Leachate Generation

Leachate is generated by the movement of water through a waste disposal site. Precipitation falling on the land surface will either infiltrate the cover soil or leave the site as surface runoff, depending on surface conditions. Infiltrated water that is not subsequently lost by evapotranspiration or retained as soil moisture will percolate down through the waste deposit. Initially, this liquid will be absorbed by the waste material.

When the field capacity (moisture-retention capacity) of the waste is exceeded (which may take from several months to several years), leachate will be produced. At waste-disposal sites with no provisions for collection, this leachate can contaminate underlying ground-water aquifers or nearby surface streams.

Leachate generation (flow) varies greatly from site to site and over time at the same site. Among the many factors contributing to this variability are the local climate and meteorology, site topography, cover soil and vegetation, and site hydrogeology.

On the average, leachate is generated in low to moderate flows (less than 100,000 gal/day); however, seasonal and day-to-day fluctuations in leachate volume can have a significant impact on the design of a leachate treatment plant. With continuous treatment operations, some form of flow equalization is normally required to handle peak flows and to optimize plant performance. Processes that can be operated intermittently have the advantage of being able to meet increased or decreased treatment demands over the life of the plant.

Leachate Characteristics

As water percolates through a waste deposit, it solubilizes (leaches) various components of the waste and becomes polluted. This leachate typically exhibits high concentrations of dissolved organics (BOD_5, COD, TOC), toxics (TOX), and metals; high color, odor, and turbidity; and low pH.

The characteristics of leachate vary widely from site to site as well as from one site over a long period of time. The factors having the greatest effect on leachate composition are those that influence the degradation of the waste and those that affect the mobilization of waste components and degradation products.

The chemical and physical characteristics of leachate are the primary considerations in the design of a treatment system. The technologies applicable to hazardous waste leachate treatment are essentially the same as those applied to municipal wastewater and contaminated ground-water treatment; however, hazardous waste leachate is typically more concentrated and contains a wider range of organic and inorganic contaminants than municipal wastewater or ground water, and multistage treatment is often required. The proper combination of pretreatment, physical/chemical treatment, biological treatment, and post-treatment operations must be determined during the design phase to optimize the cost-effectiveness of treatment.

Treatability of Leachate Constituents

Leachate characterization studies are designed to ascertain the type and concentration of constituents in the waste stream as well as the magnitude of variations in leachate flow rate and strength. Data from leachate characterization studies are useful in the screening of potentially applicable treatment technologies and as a baseline for evaluating the effectiveness of selected technologies.

When the characteristics of a particular leachate stream have been ascertained, potentially applicable processes for conversion or removal of target contaminants can be identified from the matrix in Figure 1. Each block of the matrix contains a "+", an "o", or a "−". Reading down a column for a contaminant of interest indicates which processes are effective in removing that contaminant (+). Reading across the row for a technology indicates the constituents that must be removed by pretreatment (−) to assure satisfactory performance of that technology. For example, volatile organics can be removed from leachate by air stripping; however, suspended solids and oil and grease (which cause plugging of the packed bed) should be removed by pretreatment. Constituents that are neither removed by the technology nor require removal by pretreatment prior to application of the technology are indicated by an "o".

The process applicability matrix can be used to screen potential treatment technologies for their applicability to leachates whose compositions are known. Treatability studies should then be performed to guide in the selection of the most cost-effective treatment alternative from among the potentially applicable technologies for a combination of leachate constituents. These studies examine the actual effectiveness of alternative methods as well as define design and operating standards.

Treatability studies can be divided into two groups—bench-scale and pilot-scale—which differ in purpose, scale, cost, time, and leachate volume required. Although the distinction is not always clear, bench-scale studies are generally used for the preliminary evaluation and selection or rejection of the most promising treatment technologies, whereas pilot-scale studies are generally used to develop and optimize design and operating parameters of the selected process(es).

Leachate Treatment Process Train Selection

Treatment of hazardous waste leachate is complicated by the diversity of organic and inorganic constituents that it contains. To effect a high degree of treatment efficiency requires several unit operations with specific applications and limitations. Because the characteristics of hazardous waste leachate vary considerably from one site to the next, selection and integration of unit treatment processes are highly site-specific. Among the factors that influence selection are effluent discharge alternatives/limitations, treatment process residuals, permit requirements, and cost-effectiveness of treatment.

Leachate containing primarily inorganic contaminants can be treated by a combination of physical/chemical processes. A typical process train might include equalization, oxidation/reduction, precipitation/flocculation/sedimentation, neutralization, and granular-media filtration. This process train is effective for removing most metals, including hexavalent chromium and soluble metal-cyanide complexes.

Leachate containing primarily organic contaminants can be treated effectively by stripping, adsorption, and/or biological treatment processes. Biological treatment processes are typically preceded by equalization and neutralization for protection of the microorganisms from toxic or inhibitory conditions and followed by sedimentation and/o filtration for separation of biologica solids. For high-strength leachate, two biological units can be used in sequence (e.g., a trickling filter followed by an activated-sludge system), with the firs serving as a roughing unit for partia degradation of the organics. Stripping and adsorption processes, on the othe hand, are typically preceded by sedimentation and/or filtration for prevention of plugging of the packing materia or granular activated carbon. The mos cost-effective treatment of leachate containing biodegradable and refractory organics includes a combination of biological and adsorption processes Normally, biological treatment precedes carbon adsorption in the process train. With this arrangement, the biolog

Technology	*Suspended Solids*	*Oil, Grease, Immiscible Liquids*	*pH (acidic, basic)*	*Total Dissolved Solids*	*Metals*	*Cyanides*	*Volatile Organics*	*Semivolatile Organics*	*Pesticides, PCB's*	*Pathogens*
Sedimentation	+	+	o	o	o	o	o	o	o	o
Granular-media filtration	+	-	o	o	o	o	o	o	o	o
Oil/water separation	o	+	o	o	o	o	o	o	o	o
Neutralization	o	o	+	o	o	o	o	o	o	o
Precipitation/flocculation sedimentation	+	+	o	+	+	o	o	o	o	o
Oxidation/reduction	-	-	o	o	+	+	o	+	+	+
Carbon adsorption	-	-	o	o	+	+	+	+	+	+
Air Stripping	-	-	o	o	o	o	+	o	o	o
Steam stripping	-	-	-	o	o	o	+	o	o	o
Reverse osmosis	-	-	-	+	+	+	o	o	+	+
Ultrafiltration	-	-	-	+	+	o	o	+	+	+
Ion exchange	-	-	o	+	+	+	o	o	-	o
Wet-air oxidation	o	o	o	o	+	+	+	+	o	o
Activated sludge	-	-	-	o	-	o	+	+	o	o
Sequencing batch reactor	-	-	-	o	-	o	+	+	o	o
Powdered activated carbon treatment (PACT)	+	-	-	o	-	o	+	+	+	o
Rotating biological contactor	o	-	-	o	-	o	+	+	o	o
Trickling filter	-	-	-	o	-	o	+	+	o	o
Chlorination	o	-	-	o	o	+	o	o	o	+

Key: (+) process is applicable for removal of the contaminant; (o) process is not applicable for removal of the contaminant; (-) process is not applicable unless the leachate is pretreated for removal of the contaminant.

Figure 1. *Process applicability matrix.*

ical operation substantially reduces the downstream organic loading on the carbon adsorbers. Biological degradation and carbon adsorption can also be performed in a single operation, as in the patented PACT process.

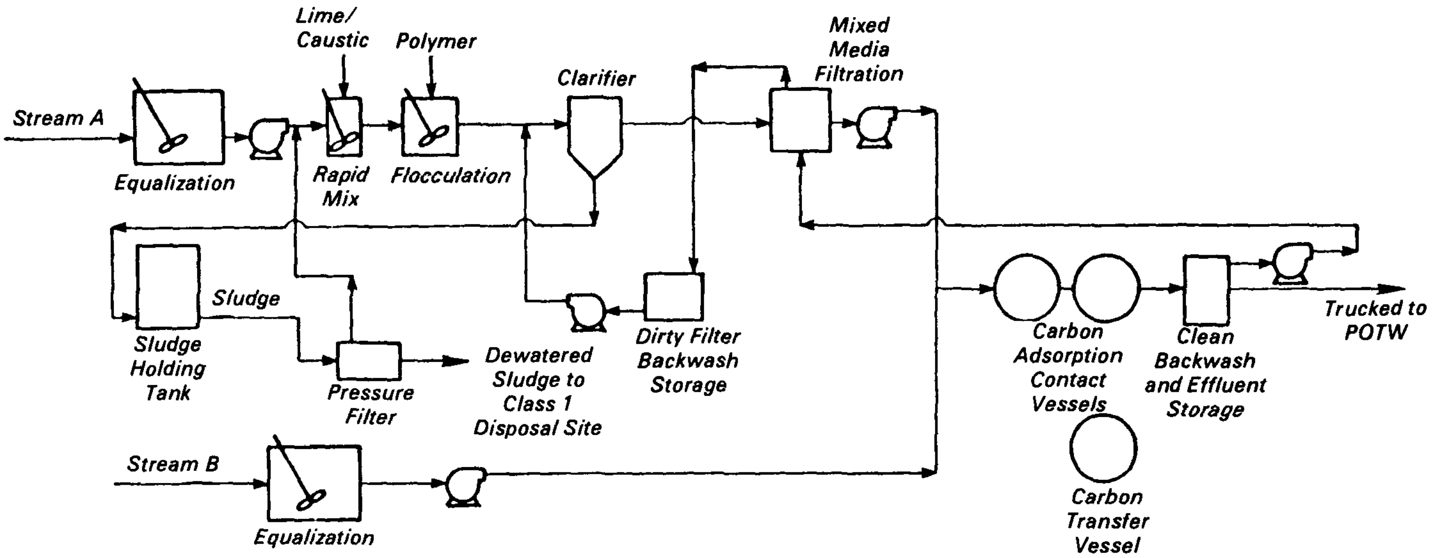
In most cases, hazardous waste leachate contains both inorganic and organic contaminants, and the treatment trains required to treat these waste streams involve combinations of the process schemes described previously. The best overall treatment efficiencies generally can be achieved by removing the inorganic constituents first and then the organic constituents. This approach protects the biological, adsorption, and stripping processes from problems caused by metals toxicity, corrosion, and scaling.

The Stringfellow leachate pretreatment plant in Glen Avon, California (Figure 2) illustrates a typical process train for leachate containing both inorganic and organic contaminants. Metals are removed from Stream A by precipitation/flocculation/sedimentation. The clarifier overflow is filtered and then mixed with Stream B. Organics are removed from the combined leachate stream by carbon adsorption, and the effluent is discharged to a POTW.

Table 1 summarizes the process trains that have been selected or proposed for treatment of hazardous waste leachate at Superfund sites. This table also contains case-study examples of process trains that incorporate innovative treatment technologies [e.g., sequencing batch reactor, powdered activated carbon treatment (PACT), and wet-air oxidation]. The information in this table was compiled from a review of approximately 130 Records of Decision available as of June 1986 and from responses to inquiries in each of the EPA Regions. A limited number of site visits were conducted to gather operating and performance data; these data are reported in the technology profiles.

Leachate Treatment Unit Processes

Twenty unit processes were reviewed for their applicability to the treatment of hazardous waste leachate. The technologies are classified as pretreatment operations, physical/chemical treatment operations, biological treatment operations, and post-treatment operations. The order in which the technologies within each category are presented reflects the reliability of the processes for leachate treatment applications (i.e., technologies that have been widely demonstrated are presented first; innovative technologies or technologies that have not been demonstrated with hazardous waste leachate are presented last).



Notes:

1. *Stream A is from wells OW-1, OW-2, OW-4, IW-1 and the French drain. Average flow is expected to be 20 gpm. Design flow is 50 gpm.*
2. *Stream B is from mid-canyon wells IW-2 and IW-3. Average flow is expected to be 40 gpm. Design flow is 80 gpm.*
3. *Currently (February 1986), influent is trucked from wells and French drain. In the near future influent will be pumped directly into the plant.*

Figure 2. *Flow diagram of the Stringfellow leachate pretreatment plant.*

The applicability of the profiled technologies to the treatment of hazardous waste leachate is based on a review of the 14 case-study sites presented in Table 1 or, where no experience exists, on the use of best engineering judgment. As the EPA and its contractors gain experience in this field, many of the existing information gaps will be filled (particularly those in the area of performance efficiency).

Pretreatment Operations

Equalization entails mixing the incoming leachate, which is subject to large fluctuations in volume and strength, in a large tank or basin and discharging it to the treatment plant at a constant rate. When placed ahead of chemical operations in the treatment process train, equalization improves chemical feed control and process reliability. When placed ahead of biological operations, equalization minimizes shock loadings, dilutes inhibitory substances, stabilizes pH, and improves secondary settling. In plants that operate on an intermittent schedule, equalization tanks/basins double as influent storage tanks. Equalization is generally reliable and can improve the performance of sensitive operations such as carbon adsorption, biological treatment, chemical precipitation, and ion exchange.

Sedimentation is the gravitational settling of suspended particles that are heavier than water in a large tank or basin under quiescent conditions. Sedimentation is widely used for the removal of settleable solids and immiscible liquids, including oil and grease and some organics. Although hazardous waste leachate typically contains only small loadings of suspended solids, sedimentation may be included as a pretreatment step because of the sensitivity of many downstream processes to fouling and interference from suspended solids. Frequently, sedimentation is included in leachate treatment process trains for separation of solids generated by chemical and biological processes. Both circular and rectangular sedimentation basins (clarifiers) are used widely and are considered highl reliable if properly operated and main tained.

Granular-media filtration is a physica process whereby suspended solids ar removed from leachate by forcing th fluid through a porous medium Granular-media filtration is useful as pretreatment step for adsorption proc esses (activated carbon), membran separation processes (reverse osmosi ultrafiltration), and ion exchange pro esses, which are rapidly plugged c fouled by high loadings of suspende solids. The most common application granular-media filtration to hazardo waste leachate involves pretreatme prior to carbon adsorption. Filtratio may also be used as a polishing ste after precipitation/flocculation or bi logical processes for removal of resi ual suspended solids in the clarifier fluent. Granular-media filters ca produce an effluent with a suspend solids concentration as low as 1 to mg/liter.

Oil/water separation technology c be used to separate immiscible orga

Table 1. *Leachate Treatment Case Study Sites*

Site/location	*Contaminants*	*Unit treatment processes*	*Discharge point*	*Source*
Bofors-Nobel, Inc. Muskegon, Michigan	*Dichloroethylene Orthochloroaniline Dichlorobenzidine*	*Neutralization Powdered activated carbon treatment/wet-air oxidation*	*POTW*	*Meidl and Wilhelmi 1986*
CECOS International, Inc. Niagara Falls, New York	*Volatile organics Phenol*	*Equalization Neutralization Sequencing batch reactor Granular-media filtration Carbon adsorption*	*POTW*	*Staszak et al. undated*
**Gloucester Environmental Management Services (GEMS) Landfill Gloucester Township, New Jersey*	*Volatile organics*	*Air stripping/vapor-phase carbon adsorption*	*POTW*	*EPA 1985b*
**Helen Kramer Landfill Mantua Township, New Jersey*	*Heavy metals Volatile organics Phenols*	*Equalization Precipitation/flocculation/sedimentation Air stripping/vapor-phase carbon adsorption Activated sludge Granular-media filtration Carbon adsorption Chlorination*	*POTW or surface water*	*EPA 1985c*
**Heleva Landfill North Whitehall Township, Pennsylvania*	*Heavy metals Volatile organics Dissolved organics*	*Precipitation/flocculation/sedimentation Neutralization Activated sludge Air stripping Carbon adsorption*	*Surface water*	*EPA 1985d*
Hyde Park Landfill Niagara Falls, New York	*Phenol HET acid Benzoic acid o-, m-, p-Chlorobenzoic acid*	*Equalization Neutralization/sedimentation Sequencing batch reactor Carbon adsorption*	*POTW*	*Ying et al. 1986*
**Lipari Landfill Mantua Township, New Jersey*	*Heavy metals Volatile organics Phenols*	*Equalization Precipitation/flocculation/sedimentation Air stripping/vapor-phase carbon adsorption Granular-media filtration Carbon adsorption*	*POTW*	*EPA 1985e*
**Love Canal Niagara Falls, New York*	*Volatile organics Semivolatile organics (acid extractables, base/neutral extractables) Dioxin*	*Equalization Sedimentation Bag filtration Carbon adsorption*	*POTW*	*Shuckrow, Pajak, and Touhill 1982*
**New Lyme Landfill Ashtabula County, Ohio*	*Heavy metals Volatile organics Refractory organics*	*Neutralization/sedimentation Rotating biological contactor Precipitation/flocculation/sedimentation Carbon adsorption*	*Surface water*	*EPA 1985f*
**Pollution Abatement Services (PAS) Site Oswego, New York*	*Heavy metals Volatile organics Semivolatile organics (acid extractables, base/neutral extractables)*	*Equalization Precipitation/flocculation/sedimentation Carbon adsorption Neutralization Granular-media filtration*	*Not specified*	*EPA 1984a Rothman, Gorton, and Sanford 1984*

Table 1. Continued

Site/location	*Contaminants*	*Unit treatment processes*	*Discharge point*	*Source*
**Sand, Gravel, and Stone Site Elkton, Maryland*	*Heavy metals Volatile organics Semivolatile organics (acid extractables, base/neutral extractables)*	*Equalization Reduction Precipitation/flocculation/sedimentation/sludge dewatering Neutralization Filtration Carbon adsorption*	*Ground water/surface water*	*EPA 1985g*
**Stringfellow Acid Pits Glen Avon, California*	*Heavy metals Organics*	*Equalization Precipitation/flocculation/sedimentation/sludge dewatering Granular-media filtration Carbon adsorption*	*POTW*	*EPA 1984b*
**Sylvester Site (Gilson Road Site) Nashua, New Hampshire*	*Heavy metals Volatile organics Alcohols, ketones*	*Precipitation Neutralization Filtration High-temperature air stripping/fume incineration Activated sludge (extended aeration)*	*Ground water*	*EPA 1983*
**Tyson's Dump Upper Merion Township, Pennsylvania*	*Volatile organics*	*Air stripping/vapor-phase carbon adsorption*	*Surface water*	*EPA 1984c*

**NPL Superfund site.*

ics such as chlorinated solvents and PCB oils from leachate. Gravity separators offer the most straightforward, effective means for phase separation. Coalescing separators, which use baffles in the tank to promote oil droplet agglomeration, provide more effective separation and can be used in situations where subsequent treatment processes cannot tolerate significant concentrations of immiscible organics. The use of oil/water separation technology is limited to waste streams that are composed of two immiscible phases having significantly different specific gravities. Leachate containing oil that is present as an emulsion will require the addition of an emulsion-breaking chemical for efficient treatment. The efficiency of gravimetric oil/water separators is a function of oil concentration and droplet size, retention time, density difference between the two phases, and temperature. The surface area of the baffles also affects the efficiency of coalescing separators.

Physical/Chemical Treatment Operations

Neutralization of leachate exhibiting an extreme pH involves the addition of a base or an acid to the leachate to adjust its pH upward or downward, as required, to a final acceptable level (usually between 6.0 and 9.0). In most hazardous waste leachate treatment applications, neutralization serves as a form of pretreatment for optimization of the performance of pH-sensitive processes (particularly biological treatment processes) or for minimization of corrosion in more sophisticated physical/chemical treatments (especially membrane and stripping processes). Neutralization may also be applied as a post-treatment operation downstream of certain chemical processes that yield acidic or caustic effluents (e.g., oxidation/reduction). The use of post-treatment neutralization to meet final discharge criteria is particularly applicable where treated effluent is discharged to surface or ground water. Performance of neutralization systems is highly dependent on the reliability of automated control systems.

Combined *precipitation/flocculation/sedimentation* is the most common method of removing soluble metals from leachate. Precipitation involves the addition of chemicals to the leachate to transform dissolved contaminants into insoluble precipitates. Flocculation promotes agglomeration of the precipitated particles, which facilitates their subsequent removal from the liquid phase by sedimentation (gravity settling) and/or filtration. Precipitation/flocculation/sedimentation is applicable to the removal of most metals [arsenic, cadmium, chromium (III), copper, iron lead, mercury, nickel, and zinc] as wel as suspended solids and some anionic species (phosphates, sulfates, and fluorides) from the aqueous phase o leachate. Effluent metal concentration of less than 1 mg/liter are theoreticall achievable with precipitation/flocculation/sedimentation. In practice, however, theoretical values are seldom attained because of the influence o complexing agents, fluctuations in pH slow reaction rates, and poor separation of colloidal precipitates.

Oxidation/reduction involves the addition of a chemical oxidizing or reducing agent to leachate under a controlle pH. Oxidation/reduction of certai leachate constituents may render ther nonhazardous or more amenable to removal by subsequent processes (e.g precipitation, ion exchange, or biolog cal treatment). The most common appl cations of oxidization/reduction to ha ardous waste leachate include cyanic destruction and the reduction of he avalent chromium to the less hazardo trivalent form. The effectiveness of o dation/reduction for a given constitue is directly related to the time of reaction and the degree to which interfering or competing constituents are present.

Carbon adsorption is a separation technique for removing dissolved contaminants from leachate by adsorption onto granular activated carbon. Carbon adsorption is a well-developed process recognized as standard technology for the treatment of most hazardous waste leachates. It is especially well suited for the removal of mixed organic contaminants, including volatile organics, phenols, pesticides, PCB's, and foaming agents. Carbon adsorption is economically competitive with air stripping for the removal of relatively low concentrations of volatile organics when VOC air emissions must be controlled. For higher contaminant loadings, carbon adsorption typically is used for effluent polishing of nonvolatile organics following air stripping. Carbon adsorption systems usually can be designed to effect greater than 99 percent removal of most organic contaminants. Because of the complex nature of hazardous waste leachate and the nonselectivity of carbon for specific hazardous constituents, however, effluent concentrations of target contaminants in the parts-per-billion range are difficult to achieve.

Air stripping is a mass-transfer process that uses air to remove organics that are volatile and only slightly water-soluble from leachate. As in the case of carbon adsorption, this technology has been widely demonstrated at hazardous waste sites. The applicability of air stripping for removal of a particular contaminant can be predicted by the use of vapor/liquid equilibria data, which vary with temperature and the presence of other constituents. The performance of air strippers depends on the vapor/liquid equilibrium behavior of the contaminant(s), the dimensions (height, diameter) of the tower, the efficiency of air-water contact, and the liquid temperature. In hazardous waste leachate applications, a minimum acceptable removal efficiency is usually defined, and a system is then designed to meet that level. Although generally more economical than adsorption processes, the cost advantage of air stripping may be offset by the need for air pollution control equipment to remove stripped VOC's.

Steam stripping, or steam distillation, is a separation technique in which steam is used to remove volatile organics from leachate. Although steam distillation is commonly used by industry to recover chemicals from aqueous streams or to remove contaminants from manufactured products, it is probably not practical for direct application to hazardous waste leachate treatment (except under unusual circumstances) because of its high operating costs.

Reverse osmosis is a separation technique that can be used to concentrate dissolved contaminants [inorganics and relatively high-molecular-weight (greater than 120) organics] in an aqueous waste stream. To date, reverse osmosis has not been applied to full-scale treatment of hazardous waste leachate, primarily because of the delicate nature of reverse-osmosis membranes and the strength and complexity of leachate. Steady progress is being made, however, in the development of durable membranes and self-cleaning reverse-osmosis units, and the potential exists for application of this technology to future hazardous waste leachate treatment systems. Reverse osmosis will probably be limited to use as a polishing step subsequent to other more conventional processes.

Ultrafiltration is a membrane process capable of separating solution components on the basis of molecular size, shape, and flexibility. Ultrafiltration generally removes high-molecular-weight (greater than 500) species from solution, including macromolecules (proteins, polymers), complexed metals, oil emulsions, colloidal dispersions (clay, microorganisms), and suspended solids. Ultrafiltration (like reverse osmosis) has not yet been applied to the full-scale treatment of hazardous waste leachate. As membranes exhibiting greater productivity and chemical resistance are developed, ultrafiltration will likely become a more viable treatment alternative.

Ion exchange is a process that reversibly exchanges ions in solution with ions of like charge retained on an insoluble resinous solid called an ion-exchange resin. The ion-exchange resin has the ability to exchange either positively charged ions (cation exchange) or negatively charged ions (anion exchange). Ion exchange is used primarily for the removal of dissolved ionic species when a high-quality effluent is required. The applicability of this process to the treatment of leachate is probably limited to use as a final polishing stage where effluent is discharged to sensitive surface waters. No evidence has been found that ion exchange has been applied to the full-scale treatment of hazardous waste leachate.

Wet-air oxidation is the aqueous-phase oxidation of concentrated organic and inorganic wastes in the presence of oxygen at elevated temperature and pressure. The wet-air oxidation process may be applied to any concentrated organic or inorganic waste stream with a COD between 10,000 and 100,000 mg/liter. It is particularly suitable for waste streams that are too dilute for incineration but too refractory for chemical or biological oxidation. The areas of greatest potential applicability for hazardous waste leachate appear to be treatment of concentrated liquid waste streams generated by steam stripping, ultrafiltration, or reverse osmosis; treatment of biological waste sludges; and regeneration of powdered activated carbon. No performance data are available on the wet-air oxidation of hazardous waste leachate.

Biological Treatment Operations

The *activated-sludge* process is a suspended-growth, biological treatment process that uses aerobic microorganisms to biodegrade organic contaminants in leachate. Variations in the conventional activated-sludge process have been developed to provide greater tolerance for shock loadings, to improve sludge settling characteristics, and to achieve higher BOD_5 removals. Process modifications include complete mixing, step aeration, modified aeration, extended aeration, contact stabilization, and the use of pure oxygen. A practical upper limit for influent BOD_5 to an activated-sludge system is 10,000 mg/liter. In general, the activated-sludge process can readily degrade simple organic species such as alkanes, alkenes, and aromatics. Halogenated hydrocarbons are degraded more slowly. The performance of an activated-sludge system is related to the degree of acclimation of the biomass. The use of indigenous bacteria from the waste-disposal site can speed reaction rates and improve total system performance.

The *sequencing batch reactor* (SBR) is a fill-and-draw activated-sludge system. Unlike conventional, continuous-flow, activated-sludge systems, the SBR performs all operations in a single tank. Each cycle of the batch operation involves five phases of treatment in timed sequence: fill, react, settle, draw, and idle. The sequencing batch reactor, like the conventional activated-sludge process, can be used to biodegrade organic contaminants (e.g., phenol) in leachate. The SBR is particularly applicable to the treatment of leachate that is not generated in sufficient volume to justify a continuous-flow process. With an SBR, the leachate can be accumulated in a holding tank for intermittent treatment. The SBR also has greater operational flexiblity to accommodate changing feed characteristics (flow and/or organic loading) and can achieve more complete treatment through adjustment of reaction parameters than the conventional activated-sludge system. Good treatment performance with leachate has been demonstrated at the laboratory scale under varying conditions of influent TOC, feed rate, aeration/mixing, HRT, MLSS concentration, organic loading, temperature, and cycle time. Satisfactory treatment performance has also been demonstrated at full scale.

The patented *powdered activated carbon treatment* (PACT^R) process (Zimpro, Inc.) involves the controlled addition of powdered activated carbon to the aeration tank of a conventional activated-sludge system. Removal of organics is achieved through a combination of biological oxidation/assimilation and physical adsorption. The PACT process is applicable to nearly all wastewaters with a COD between 50 and 50,000 mg/liter. It is particularly effective for treatment of wastes such as leachate that are variable in composition and concentration, that are highly colored, and that contain refractive materials. A number of volatile organic, acid-extractable organic, and base/neutral-extractable organic priority pollutants are amenable to treatment by the PACT process. Laboratory studies have shown that the PACT process is capable of better organic removal efficiencies than either activated sludge or carbon adsorption alone.

The *rotating biological contactor* (RBC) is an attached-growth, aerobic biological treatment process. Rotating biological contactors can be used for treatment of leachate containing readily biodegradable organics. Although not as efficient as conventional activated-sludge systems, RBC's are better able to withstand fluctuating organic loadings because of large amount of biomass they support. Rotating biological contactors provide a greater degree of flexibility for meeting the changing needs of a leachate treatment plant than do other attached-growth biological processes. The characteristic modular construction of RBC's permits their multiple staging to meet increases or decreases in treatment demands. The hydraulic retention time of the waste and the rotational speed of the disks can be controlled to effect the desired degree of system performance.

The *trickling filter* is an attached-growth, aerobic biological treatment process in which leachate is continuously distributed over a bed of rocks or a plastic medium that supports the growth of microorganisms. Trickling filters may be used to biodegrade nonhalogenated and certain halogenated organics in leachate. Although not as efficient as suspended-growth biological treatment processes, trickling filters are more resilient to variations in hydraulic and organic loadings. For this reason, trickling filters are best suited to use as "roughing" or pretreatment units that precede more sensitive processes such as activated sludge. The applicability of trickling filters to the full-scale treatment of hazardous waste leachate has not yet been demonstrated.

Post-Treatment Operations

Post-treatment processes are those operations that occur downstream of the primary waste treatment stages to "polish" the system's effluent or prepare it for discharge. Such processes include filtration to remove residual suspended solids, pH adjustment to return the effluent to a neutral condition, and chlorination to disinfect the effluent prior to its discharge to surface water.

Chlorination is a post-treatment process used primarily for disinfection to destroy microorganisms in treated leachate prior to its discharge to ground or surface waters. The effectiveness of chlorination for disinfection depends on pH, temperature, contact time, mixing, and the presence of interfering compounds. Performance of chlorination systems is tied to the reliability of automated control systems.

Residuals Management

Important considerations in the selection of a leachate treatment process are the type and volume of residuals generated by the process, as these factors affect operating and maintenance costs. Residuals generated by the technologies profiled in this document include sludge, air emissions, concentrated liquid waste streams, and spent carbon. Table 2 presents a listing of the residuals generated by each of these processes. Current residuals management practices are discussed under the appropriate headings in the remainder of this section.

Sludge

Physical/chemical treatment sludges are generated by the sedimentation of suspended solids and/or insoluble reaction byproducts. Biological treatment sludges are generated by the microbial conversion of soluble organics to cellular biomass. Because contaminants are often concentrated in these sludges, they will require further treatment and disposal in an environmentally sound manner.

Sludge dewatering is a physical (mechanical) operation used to reduce the moisture content and volume of sludges. Moisture reduction, which is normally required prior to the landfilling or incineration of sludges, facilitates handling and reduces transportation and ultimate disposal costs. *Chemical stabilization/solidification* involves the addition of absorbents and solidifying agents to the sludge. This process is designed to improve the handling anc physical characteristics of the sludge, tc decrease the surface area for transpor of hazardous constituents, to limit the solubility of pollutants in the sludge and/or to detoxify the containec pollutants. Available methods for th stabilization/solidification of sludges include sorption, lime/fly-ash/pozzola processes, pozzolan/portland cemen processes, thermoplastic microencapsulation, and macroencapsulation (jacketing). *Biological stabilization* c sludges can be achieved by aerobic c anaerobic sludge digestion. In aerobi digestion, microorganisms in the presence of oxygen consume to depletio the available food in the sludge an then continue to feed on their own pr toplasm to continue living. In anaerob sludge digestion, organic material is b ologically converted under anaerob conditions to methane and carbon dio ide. *Incineration* of sludges destro some or all of the hazardous co stituents or characteristics of th sludge. High operating and maint nance costs are associated with *incine* ation. *Land disposal* of sludge requir that the sludge meet or exceed Sta standards for solids content and tha

Table 2. *Residuals Generated by the Various Leachate Treatment Processes*

Treatment process	*Sludge*	*Air emissions*	*Concentrated liquid waste stream*	*Spent carbon*
Pretreatment operations				
Sedimentation	X			
Granular-media filtration			X	
Oil/water separation			X	
Physical/chemical treatment operations				
Neutralization	X			
Precipitation/flocculation/ sedimentation	X			
Oxidation/reduction	X			
Carbon adsorption			X	X
Air stripping		X		
Steam stripping			X	
Reverse osmosis			X	
Ultrafiltration			X	
Ion exchange			X	
Wet-air oxidation		X		
Biological treatment operations				
Activated sludge	X	X		
Sequencing batch reactor	X	X		
Powdered activated carbon treatment (PACT)	X			X
Rotating biological contactor	X	X		
Trickling filter	X			

contains no free liquids. If the sludge demonstrates hazardous characteristics or is a hazardous waste by definition, it must be disposed of at an EPA-approved hazardous waste landfill.

Air Emissions

By design, certain leachate treatment technologies (e.g., air stripping) transfer VOC's from the liquid phase to the vapor phase. Other treatment processes (e.g., activated sludge, rotating biological contactor, and sequencing batch reactor) strip some VOC's by nature of the aeration process. Unless provisions are made for treatment of air emissions, VOC's will be discharged to the atmosphere.

Vapor-phase carbon adsorption is an effective method for removing VOC's from the vapor phase. Contaminant-laden air is passed through a column of activated carbon. Organics are adsorbed from the air stream, and clean air is discharged to the atmosphere. *Fume incineration* may be useful for the control of combustible atmospheric emissions that are generated by air stripping of organic compounds from leachate.

Concentrated Liquid Waste Streams

Liquid waste streams (backwash water, concentrate, and condensate) generated by many physical/chemical treatment operations contain high concentrations of suspended solids or pollutants that the particular treatment process was designed to remove. Backwash water is usually returned to the head works of the treatment plant; however, if recycling is not practiced, the backwash water must be treated or disposed of. Options available for the treatment or disposal of concentrates and condensate include incineration or stabilization/solidification in preparation for land disposal.

Spent Carbon

Granular and powdered activated carbon are used extensively for leachate treatment and for the control of air pollutants such as VOC's. When the carbon becomes exhausted, it can either be regenerated and reused or disposed of by incineration or land disposal. In most cases, however, spent carbon is regenerated by the supplier and reused.

Carbon regeneration techniques can be categorized as either thermal regeneration or nondestructive regeneration processes. Thermal oxidation involving the use of a multiple-hearth, fluidized-bed, or rotary kiln furnace is the most prevalent means of regenerating granular activated carbon. Wet-air oxidation can be used for thermal regeneration of powdered activated carbon. Nondestructive regeneration of activated carbon is accomplished by the use of steam to remove VOC's, solvents to remove a variety of organics, and a pH shift for weak acids and bases. Other options for management of spent carbon include *incineration* and *land disposal.*

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The complete report, entitled "A Handbook on Treatment of Hazardous Waste Leachate," (Order No. PB 87-152 328/AS; Cost: $18.95, subject to change) will be available only from:
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Springfield, VA 22161
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The EPA Project Officer can be contacted at:
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