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DATA REQUIREMENTS FOR SELECTING REMEDIAL ACTION TECHNOLOGIES

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DISCLAIMER

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INTRODUCTION

The National Contingency Plan (NCP) and subsequent guidance documents for remedial investigations, feasibility studies, and remedial designs set forth the procedural framework for selecting and implementing remedial responses. These documents do not specifically address the data requirements for screening, evaluating, designing, and constructing remedial action technologies at uncontrolled hazardous waste sites. The purpose of this task is to define the data requirements for screening remedial action technologies. This report presents data requirements for screening remedial action technologies applicable to: air pollution controls, surface water controls, leachate and ground water controls, gas migration controls, excavation and removal of waste and soils, removal and containment of contaminated sediments, in situ treatment, aqueous waste treatment, solids handling, other direct treatment, land disposal, sewer cleaning and rehabilitation, and alternative water supplies.

Data requirements for screening remedial action technologies for control of other site problems should fit into the five step NCP remedial response process which is presented in Figure 1 and outlined below:

1. Site Discovery or Notification--A release of hazardous substances, pollutants, or contaminants identified by Federal, State, local government agencies, or private parties is reported to the National Response Center (NRC). Upon discovery, such potential sites are screened to identify release situations warranting further remedial response consideration. These sites are entered into the Comprehensive Emergency Response, Compensation and Liability Information System (CERCLIS); this computerized system serves as a data base of site information and tracks the change in status of a site through the remedial response process.

2. Preliminary Assessment and Site Inspection (PA/SI)--The preliminary assessment involves the collection and review of all available information and may include offsite reconnaissance to evaluate the source and nature of hazardous substances present and to identify the responsible party(s). Depending on the results of the PA, a site may be referred for further action. Site inspections routinely include the collection of samples and are conducted to determine the extent of the problem and to obtain information needed to determine whether a removal action is needed at the site or whether the site should be included on the National Priorities List (NPL).

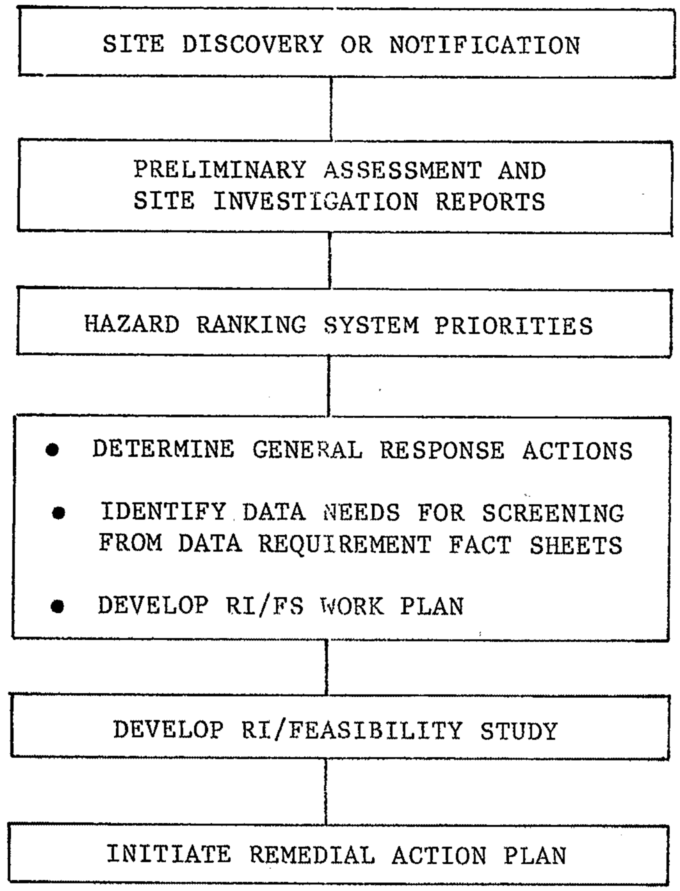


Figure 1. National contingency plan procedure.

3. Establishing Priorities for Remedial Action--Sites are scored using the Hazard Ranking System (HRS) and the data from the PA/SI. This scoring process is the primary mechanism for identifying sites to be included on the National Priorities List (NPL), which in turn is the guide for allocating Superfund monies for cleanups. Sites that receive a score of 28.5 or greater, will be proposed as candidates for the NPL. After public comment, these sites may be included on the NPL.

4. Remedial Investigation/Feasibility Study (RI/FS)--Site investigations are conducted to obtain information needed to identify, select, and evaluate remedial action alternatives in the feasibility study based on technological, public health, institutional, cost, and environmental factors. The final result of this step is selection of the most appropriate, cost-effective solution. In some cases, the FS may show that no further action is needed.

5. Remedial Action Design and Construction--The actual design of the selected remedial action is developed, then implemented through construction.

The approach to screening remedial action technologies discussed in this report is designed to be used after the site has been listed on the NPL (step 3), and during the initial stages of the remedial investigation/feasibility study (step 4). At this point, sufficient information should be available to determine the appropriate general response actions that must be considered. Determination of the appropriate general response action and remedial technology can provide an opportunity to focus the data needs for screening remedial action technologies. Therefore, our approach was to develop data needs for each type of remedial technology catalogued by general response action. If a site has more than one problem, a common situation, the user can combine the data needs for the appropriate general response actions.

Screening of remedial action technologies involves technological, public health, institutional, cost, and environmental factors. The data requirements discussed in this report address technological issues and acceptable engineering practices. Given the information in this report, the remedial action engineer should be able to determine which technologies can be applied at the site, whether or not they are likely to effectively address the problem, and an order of magnitude estimate of costs. The screening data will also help the engineer in the final selection and evaluation process although additional data, such as pilot scale tests, may be needed after the screening process has been completed.

USE OF THIS DOCUMENT

Each potentially applicable remedial technology is described in a two-page summary, or "Fact Sheet." Once the general response actions have been identified, the engineer can use the Fact Sheet Technology Matrix presented in Table 1 to locate appropriate technologies and identify

TABLE 1. MASTER LIST OF REMEDIAL TECHNOLOGIES SPECIFIED IN THE NATIONAL CONTINGENCY PLAN.

TECHNOLOGY	APPLICATION/RESPONSE ACTION											
	Air Pollution Controls	Surface Water Controls	Leachate & Ground Water Controls	Gas Migration Controls	Excavation & Removal of Waste & Soil	Removal & Containment of Contaminated Sediments	In-Situ Treatment	Direct Waste Treatment: Aqueous Treatment	Direct Waste Treatment: Solids Handling	Direct Waste Treatment: Other Direct Treatment	Land Disposal Storage	Contaminated Water Supplies and Sewer Lines
1 Capping/Surface Sealing	X	X	X	X	X							
2 Dust Control	X				X							
3 Grading		X			X							
4 Revegetation		X			X							
5 Diversion/Collection		X										
5.1 Dikes and Berms		X										
5.2 Channels and Waterways		X										
5.3 Terraces and Benches		X										
5.4 Chutes and Downpipes		X										
5.5 Seepage Basins & Ditches		X										
5.6 Sedimentation Basins/Ponds		X										
5.7 Levees and Floodwalls		X										
6 Subsurface Containment Barriers			X									
6.1 Slurry Walls			X									
6.2 Grout Curtains			X									
6.3 Sheet Piling			X									
6.4 Bottom Sealing			X									
7 Ground Water Pumping			X									
8 Subsurface Drains			X									
9 Surface Water/Sediment Containment Barriers		X				X						
9.1 Cofferdams		X				X						
9.2 Floating Covers		X										
9.3 Silt Curtains		X				X						
10 Streambank Stabilization		X										

(continued)

TABLE 1 (continued)

TECHNOLOGY	Air Pollution Controls	Surface Water Controls	Leachate & Ground Water Controls	Gas Migration Controls	Excavation & Removal of Waste & Soil	Removal & Containment of Contaminated Sediments	In-Situ Treatment	Direct Waste Treatment: Aqueous Treatment	Direct Waste Treatment: Solids Handling	Direct Waste Treatment: Other Direct Treatment	Land Disposal Storage	Contaminated Water Supplies and Sewer Lines
11 Gas Collection/Recovery				X								
11.1 Passive Subsurface Gas Control				X								
11.2 Active Subsurface Gas Control				X								
12 Excavation/Removal					X							
13 Dredging						X						
14 Biological Treatment								X				
14.1 Activated Sludge								X				
14.2 Trickling Filter								X				
14.3 Aerated Lagooning								X				
14.4 Waste Stabilization Ponds								X				
14.5 Rotating Biological Discs								X				
14.6 Land Application							X					
14.7 Bioreclamation							X					
14.8 Permeable Treatment Beds							X					
15 Chemical Treatment								X				
15.1 Neutralization								X				
15.2 Precipitation								X				
15.3 Oxidation (Chlorination)							X	X				
15.4 Hydrolysis							X	X				
15.5 Reduction							X	X				
15.6 Chemical Dechlorination							X	X		X		
15.7 Ultraviolet/Ozonation								X				
15.8 Solution Mining (Extraction)								X				

(continued)

TABLE 1 (continued)

TECHNOLOGY	APPLICATION/RESPONSE ACTION											
								Direct Waste Treatment				
	Air Pollution Controls	Surface Water Controls	Leachate & Ground Water Controls	Gas Migration Controls	Excavation & Removal of Waste & Soil	Removal & Containment of Contaminated Sediments	In-Situ Treatment	Aqueous Treatment	Solids Handling	Other Direct Treatment	Land Disposal Storage	Contaminated Water Supplies and Sewer Lines
16 Physical Treatment								X				
16.1 Flocculation								X				
16.2 Sedimentation								X				
16.3 Carbon Adsorption/Activated Carbon								X				
16.4 Ion Exchange								X				
16.5 Reverse Osmosis								X				
16.6 Liquid/Liquid								X		X		
16.7 Oil/Water Separator								X				
16.8 Air Stripping								X				
16.9 Steam Stripping								X				
16.10 Filtration								X				
16.11 Dissolved Air Floatation								X				
17 Solids Handling/Treatment									X			
17.1 Solids Separation									X			
17.2 Dewatering									X			
17.3 Solidification/Stabilization									X			
18 Gaseous Waste Treatment	X									X		
18.1 Flaring	X									X		
18.2 Adsorption	X									X		
18.3 Afterburners	X									X		

(continued)

TABLE 1 (continued)

TECHNOLOGY	Air Pollution Controls	Surface Water Controls	Leachate & Ground Water Controls	Gas Migration Controls	Excavation & Removal of Waste & Soil	Removal & Containment of Contaminated Sediments	In-Situ Treatment	Direct Waste Treatment: Aqueous Treatment	Direct Waste Treatment: Solids Handling	Direct Waste Treatment: Other Direct Treatment	Land Disposal Storage	Contaminated Water Supplies and Sewer Lines
19 Thermal Destruction (Incineration)									X	X		
19.1 Rotary Kiln Incineration									X	X		
19.2 Fluidized Bed Incineration									X	X		
19.3 Multiple Hearth Incineration									X	X		
19.4 Liquid Injection Incineration								X		X		
19.5 Molten Salt Combustion									X	X		
19.6 HTFW/AER										X		
19.7 Plasma Arc Pyrolysis										X		
19.8 Cement Kiln Incineration										X		
19.9 Pyrolysis									X	X		
19.10 Wet Air Oxidation									X	X		
19.11 Industrial Boiler										X		
20 Land Disposal											X	
20.1 Landfill											X	
20.2 Surface Impoundment/Gravity Separation											X	
20.3 Deep Well Injection											X	
20.4 Secure Chemical Vaults											X	
21 Sewer Cleaning												X
22 Sewer Removal and Replacement												X
23 Alternate Drinking Water Supplies												X
24 Home Water Treatment												X

appropriate data needs. For example, if a site requires: (1) excavation and removal of waste and onsite soils; and (2) surface water controls, the matrix identifies the following Fact Sheets for consideration.

1. Excavation and Removal of Waste and Soil

   1.0 Capping/Surface Sealing

   2.0 Dust Control

   3.0 Grading

   4.0 Revegetation

   12.0 Excavation/Removal

2. Surface Water Controls (additional technologies)

   5.1 Dikes and Berms

   5.2 Channels and Waterways

   5.3 Terraces and Benches

   5.4 Chutes and Downpipes

   5.5 Seepage Basins and Ditches

   5.6 Sedimentation Basins/Ponds

   5.7 Levees and Flood Wells

   9.0 Surface Water/Sediment Containment Barriers

   9.1 Cofferdams

   9.2 Floating Covers

   9.3 Silt Curtains

The user can review the information contained on the Data Requirement Fact Sheets to: 1) identify the data needs necessary to screen the remedial technologies; 2) determine why the data is necessary; and 3) obtain information on approximate costs for data acquisition.

REPORT FORMAT

Each remedial technology is described in appropriate sections of this report. The individual Fact Sheets are designed to stand alone if necessary. Each Fact Sheet is structured to display: the technology, its function, a technical description with an appropriate figure, design criteria, process limitations, current technology status, associated technologies, and data needs for screening with approximate costs.

The Type of Control and Function sections provide quick definition of the application of the selected process to a remedial problem. A general overview of the process, types of uses, related equipment, and an illustrative figure are provided in the Description section. This section may also describe similar applications of the process in other remedial situations.

The Design Criteria and Limitations sections provide information which should be considered when making decisions on the most applicable technology. Such considerations involve the efficiency of the process in certain situations, effects of outside factors such as weather, and recommended scope of use.

The applicability of a technology to the treatment of hazardous constituents is provided in the Technology Status section. Included is the status of the equipment and techniques required. Some processes are conventional and well demonstrated in application, while others have yet to be fully proven for remedial actions.

Most technologies are used in concert with other processes to accomplish treatment. Technologies also listed in this report are listed in the Associated Technology section. When collecting data to evaluate one process, it may also be necessary to refer to other Fact Sheets identified in this section for other related requirements.

Data required for process evaluation is listed in Data Needs for Screening. This section lists various process data needs, why this data is required, how it can be collected, and approximate costs. Costs listed in this section are intended for estimation of total costs only, and have been rounded to the nearest $50. Costs may also vary with the number of samples, site-specific requirements, difficulty of sampling, and other factors.

The data needs presented on the Fact Sheets will provide the engineer with an organized list of information to be collected in order to adequately evaluate any of the technologies listed for use in remedial programs.

1.0 SURFACE SEALS

Type of Control: Surface Water, Leachate, Ground Water

Function: Most commonly used to contain contamination by minimizing surface water infiltration and erosion; also provides a media for revegetation; less commonly used as an economical alternative to excavation when extensive subsurface contamination is present.

Description: Surface seals, also referred to as caps or covers, generally refer to low permeability barriers which are installed over waste disposal sites where infiltration needs to be eliminated. A variety of materials can be used in the construction of surface seals, including: soils, admixtures (i.e., asphaltic concrete, soil cement bentonite), synthetic geomembranes, and chemical sealants/stabilizers, though most CERCLA covers should meet the guidance for multiple layer covers under RCRA under Subtitle C (40 CFR Part 240).

As diagrammed in Figure 1.0, typical surface seals consist of several layers, including a top soil layer (for vegetation), buffer soil layer (usually a sandy soil to protect barrier layer), barrier layer (clayey soil or synthetic membrane which restricts passage of water or gas), filter layer (intermediate grain-sized sands used to prevent fine barrier layer particles from sifting through the coarser buffer layer), and a gas channeling layer (sand and gravel used to collect or disperse gases produced from the wastes).

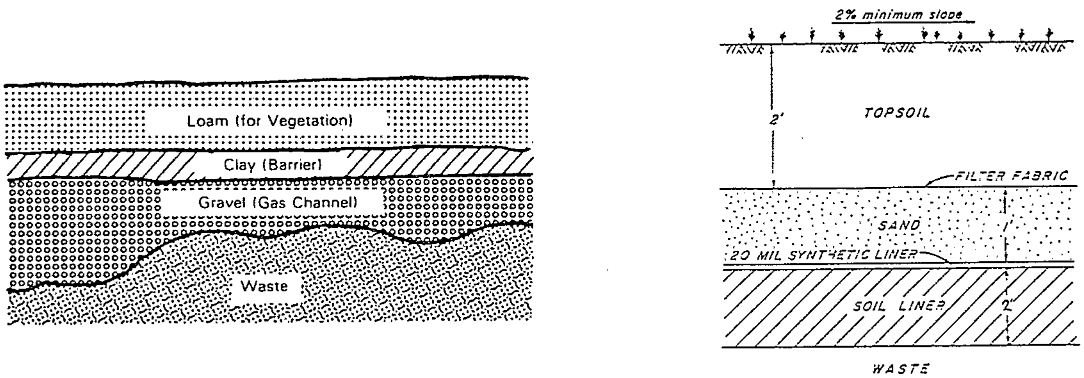


Figure 1.0. Typical surface seal designs.
Source: U.S. EPA 1985b.

Design Considerations: Several materials and designs are available for capping. Factors influencing the proper selection of materials and design include: desired functions of cover materials, waste characteristics, climate, hydrogeology, projected land use, and availability and costs of cover materials. For more information concerning design considerations for specific types of caps, refer to Lutton, et al., 1979 or U.S. EPA, 1985b.

Limitations: Surface seals require long-term maintenance. Periodic inspections should be made for settlement, ponding of liquids, erosion, and invasion of deep-rooted vegetation. Concrete barriers and bituminous membranes are vulnerable to cracking, but the cracks can be relatively easily repaired.

Technology Status: Conventional, demonstrated.

Associated Technologies: Grading, diversions, and revegetation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Extent of contamination	Cost-effectiveness of cap vs. excavation/removal	Sampling and analysis, site investigation	100/sample 400
Depth to ground water table	May not be effective in areas with a high ground water table	Geologic maps, observation wells, boreholes, logs, geologic survey, piezometers	Boreholes, 50/lin. ft wells, 50/vert. ft
Availability of cover materials	Implementability and cost	Site inspection, site investigation	
Soil characteristics	Suitability for use in cover		
- Gradation		- Sieve analysis	50/Test
- Atterberg limits		- Plasticity tests	50/Test
- %-Moisture		- Volume-wt analysis	50/Test
- Compaction		- Proctor compaction	50/Test
- Permeability		- Triaxial permeameter	50/Test
- Strength		- Triaxial shear, direct shear	100-400/ test
Climate (precipitation)	Expected infiltration rate; design criteria	U.S. NDAA records; local records	50
Land use	Selection of proper cap design	Site investigation, site inspection	Nominal

References: U.S. EPA, 1985b; Ehrenfeld and Bass, 1984; GCA, 1985; U.S. EPA, 1984.

2.0 DUST CONTROL

Type of Control: Air Pollution Control - Particulate Matter

Function: Prevents airborne emissions of contaminants sorbed to soil particules.

Description: Methods used to control fugitive dusts include chemical dust suppressants, physical stabilizers, wind screens, water spraying, compaction, grading, and covering. Chemical dust suppressants are applied (usually sprayed) to the soil surface and act to strengthen the bonds between soil particles such that dust formation is inhibited. Wind screens or wind fences consist of a porous polyester screen or wooden fence, typically 4 to 10 ft high, which act to deflect and/or slow wind velocity. Wind screens/fences are designed to lower the wind velocities such that soil movement by wind is inhibited. Dust emissions can also be controlled by spraying water on the exposed surfaces, a method commonly used on well-travelled areas. Covering and grading are described in Fact Sheets 1 and 3, respectively.

Design Considerations: Dust suppressants are a reliable short-term (1 to 4 weeks) control measure. However, consideration should be given to the potential impacts to soil and ground water from the use of certain chemical dust suppressants which may contain hazardous substances. Examples of commercially available dust suppressants can be found in U.S. EPA, 1985b and Rosbury and James, 1985. Some soil types may not be appropriate for use with certain chemical suppressants and physical stabilizers. Compatibility of the suppressant/stabilizer with the soil type should be determine prior to selection. Compacting the surface with rollers prior to using chemical dust suppressants or water spraying will increase the effectiveness of these dust control techniques. Water spraying is more effective for larger grain-sized particles. Wind fences/screens are easily transported and installed. Maximum wind velocity reduction can be effected for distances of one to five fence heights downstream.

Limitations: Chemical dust suppressants are only effective while the soil-chemical crust is maintained. If undisturbed by weeds and traffic, chemical dust suppressants will be 100 percent effective for a period of approximately 1 to 4 weeks, with declining control efficiencies thereafter. Wind screens are only partially effective in the control of inhalable (fine) particulates, and are not effective for particles smaller than 10 micrometers.

Technology Status: Conventional, demonstrated.

Associated Technologies: Excavation and removal, grading, and capping.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Soil type (texture)	Affects suppressant efficiency	Plasticity tests	50/test
Soil grain size distribution	Affects suppressant efficiency	Sieve analysis	50/test
Percent compaction	Affects suppressant efficiency	Proctor compaction	50/test
Climate	Affects wind transport; determines effectiveness of dust suppressant techniques	National climatic	50
Contaminant nominal characteristics	Sorption volatility; effectiveness of dust suppressant techniques	Sampling and analysis, CRC Handbook of Chemicals and Physics	50/sample
Land use	Need for traffic control	Site inspection, site investigation	Nominal

References: U.S. EPA, 1985b; Ehrenfeld and Bass, 1984; U.S. EPA, 1984; GCA, 1985, U.S. EPA, 1985d.

3.0 GRADING

Type of Control: Surface Water, Soil Stabilization

Function: Alters the topography and runoff characteristics of a waste site; optimizes slope and prepares area for surface sealing and/or revegetation.

Description: Grading refers to techniques used to reshape the surface of a site in order to manage surface water infiltration and runoff while controlling erosion. Grading techniques include spreading, compaction, sacrification, tracking, and contour furrowing. Figure 3.0 illustrates typical grading equipment.

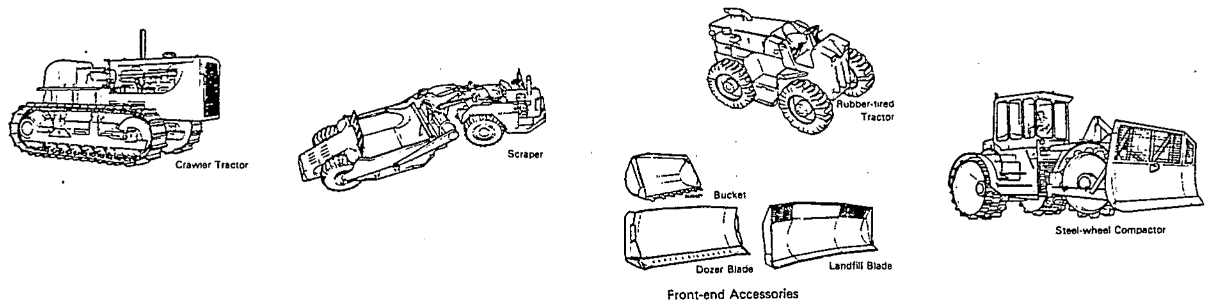


Figure 3.0. Typical grading equipment.
Source: U.S. EPA 1985b.

Spreading, and compaction are used to optimize a slope in such a way that surface runoff is increased while infiltration and ponding are decreased, without increasing erosion. These techniques are used to prevent surface water runoff from contacting waste, and/or to prepare a site for subsequent remediation activities. Sacrification, tracking, and contour furrowing are grading techniques employed to roughen soils in preparation for revegetation. These techniques slow runoff, thereby increasing infiltration and decreasing erosion potential.

Design Considerations: Generally, graded slopes should be 3 to 5 percent; sometimes greater slopes are used to promote more effective drainage, but the maximum slopes usually do not exceed 33 percent.

Limitations: Costs may be excessive if suitable soil for slope optimization can not be found within a reasonable hauling distance from the site. Also, periodic regrading and maintenance may be necessary to correct depressions formed through settlement, compaction and/or eroded slopes.

Technology Status: Conventional, demonstrated.

Associated Technologies: Excavation and removal, capping, revegetation, and diversion/collection techniques.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Climate	Average precipitation effects selection of optimum slope	National Climatic Center (NCC), local weather bureau	50
Topography	Grading operations limited for sites with steep topography; steep slopes may require drainage channels and benches to control erosion	Site inspection, site survey, topography map	Survey: 200-300/ acre (2,500 minimum)
Soil type	Affects selection of optimum slope; fill material selection	Plasticity tests	50/test

References: U.S. EPA, 1985; Ehrenfeld and Bass, 1984; U.S. EPA, 1984; GCA, 1985.

4.0 REVEGETATION

Type of Control: Surface Water, Soil Stabilization

Function: Stabilizes soil against erosion due to wind and precipitation, reduces runoff, improves aesthetic appearance, and in certain cases can treat contaminated soil and leachate through uptake of waste constituents.

Description: Revegetation refers to the establishment of a vegetative cover to stabilize the surface of a hazardous waste disposal site. It is frequently preceded by grading and capping, particularly for final cover system designs for waste disposal sites. The process of revegetating a site involves the selection of a suitable plant species, seedbed preparation, seeding/planting, mulching and/or chemical stabilization, and fertilization and maintenance.

Various types of grasses, legumes, shrubs, and trees may be used for revegetation. Important characteristics of these plant species can be found in Lutton, 1982 and U.S. EPA, 1985b. Generally, grasses provide a quick and lasting ground cover with dense root systems that anchor the soil and enhance infiltration. Legumes are most suited for stabilization and erosion control and enhancing soil fertility (through nitrogen fixation). Shrubs provide a dense surface cover and tend to be more tolerant of acidic soils and other disposal site stresses. Trees provide a long-term protective cover and aid in developing a stable, fertile layer of decaying leaves and branches. Gas migration controls may be required (Figure 4.0).

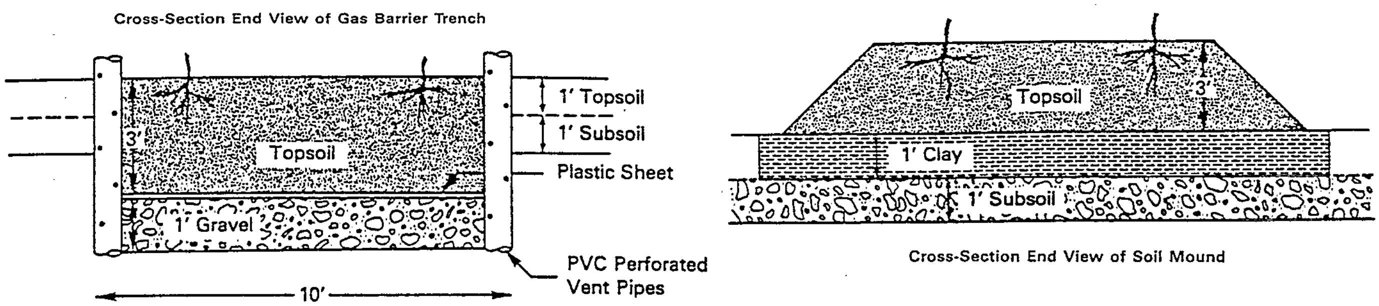


Figure 4.0 Gas migration controls for vegetation.
Source: U.S. EPA 1985b.

Design Considerations: Temporary stabilization via straw-bale check dams, mulching, or chemical methods, may be required while vegetation is being established. Also, in cases where revegetation is to be part of a final cover system, it is important to consider the expected root system when selecting the vegetative species, because the roots can interfere with the cover system (e.g., by penetrating liners, etc.).

Design Considerations: Earth fill may be available onsite. Low permeability clayey soils are best for construction, but compacted sands and gravel may also be used. Dikes are not recommended for upsloped drainage areas larger than 5 acres.

Technology Status: Conventional, demonstrated.

Associated Technologies: Capping, revegetation, excavation and removal, site clearing.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
100-yr floodplain elevation	Location of dike/berm	Topography map; USDA records; Federal Emergency Management Agency (FEMA) Flood Study	Nominal
Soil permeability	Low permeability best for fill	Triaxial permeameter	50/test
Soil type	Clayey soils best for dike/berm construction, compacted sands and gravel also effective	Sampling and sieve analysis; plasticity tests; Proctor compaction	50/test
Site accessibility	Sufficient accessible area for equipment	Site inspection; site survey; town/city/county records records	Nominal
Topography	Grading operations limited for sites with steep topography; steep slopes may require drainage channels and benches to control erosion	Site inspection, site survey, topography map	Survey: 200-300/acre (2,500 minimum)

References: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984' JRB, 1984; Phelps, 1986; Brady, 1974.

5.0 DIVERSION/COLLECTION SYSTEMS

5.2 DITCHES, CHANNELS, SWALES, DIVERSIONS, AND WATERWAYS

Type of Control: Surface Water

Functions/Uses: Used to intercept runoff and/or reduce slope length; conveys runoff from one area to another.

Description: Ditches and channels are depressions or shallow, excavated areas with V-shaped, trapezoidal, triangular, or parabolic cross-sections, which intercept runoff or reduce slope length. Earthen channels can be used to divert runoff from entering the site. Waterways are channels that have been stabilized with vegetation or stone rip-rap, and are able to collect and transfer diverted water offsite or to an onsite storage/treatment area. A diversion is a modified earthen channel that has a supporting dike or berm along the downhill edge of the channel. Swales are similar to channels except that their side slopes are not as steep, and they have a vegetative cover for erosion control. Figure 5.2 shows typical channel design features.

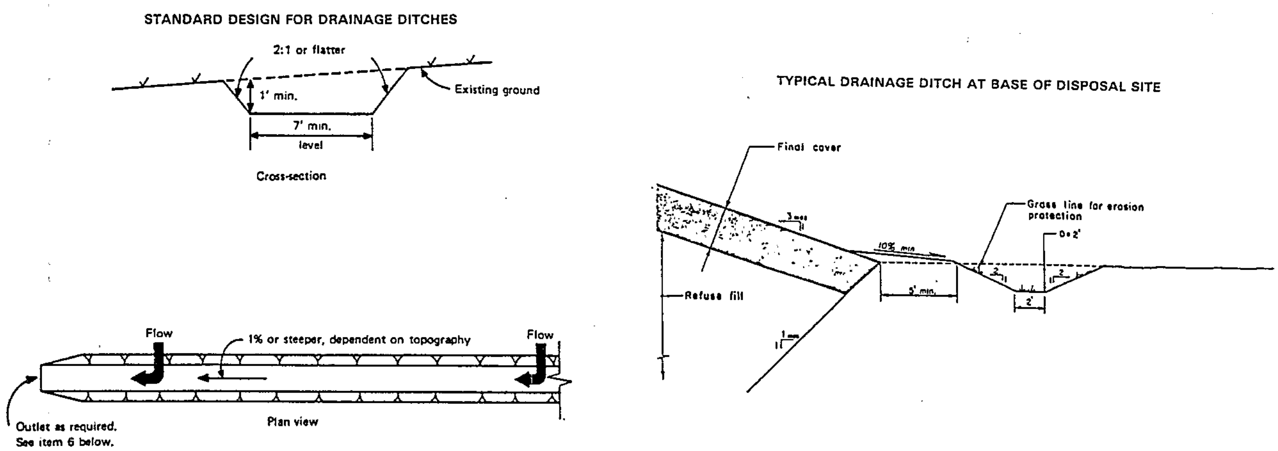


Figure 5.2. Typical channel design features.
Source: U.S. EPA 1985b.

Design Considerations: Channels and waterways are generally designed to intercept flows from 10 or 25-year storm events, in such a way as to be able to convey these flows at non-erosive velocities. Wider and shallower channel cross-sections have lower flow velocity and thus reduced potential for erosion of channel side slopes. Narrower and deeper channels require stabilization through vegetation or the use of stone rip-rap to line channel bottoms and break up flow. Half-round channels, which are constructed of cut corrugated metal pipe or pre-fabricated asphalt sections, can be placed below grade and have low maintenance and installation costs.

<u>Limitations</u>: Diversions should only be used for slopes of 15 percent or less. Ditches are designed for short-term use only. Diversions and waterways are more permanent. For channel slopes greater than 5 percent, vegetation, mulches, or stone rip-rap may be necessary for stabilization.

<u>Technology Status</u>: Conventional, demonstrated.

<u>Associated Technologies</u>: Revegetation, grading, surface sealing, excavation and removal, site clearing.

<u>Important Data Needs for Screening</u>:

Data need	Purpose	Collection method	Costs ($)
Soil permeability	Low permeability preferable	Triaxial permeameters	50/test
Area land use	Trees, bushes, stumps, need to be cleared	Site inspection, site survey	500
Climate	Channels & waterways are better suited for areas with heavy and/or frequent rains	National Climatic Center (NCC), local weather bureau	Nominal
Topography	15 percent or less slopes required for diversions; channel slopes 5 percent need to be revegetated	Site inspection, site survey, topographic map	200-300/acre (2,500 minimum)

<u>References</u>: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984a; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984; JRB, 1984; Phelps, 1986; Brady, 1974.

5.0 DIVERSION/COLLECTION SYSTEMS

5.3 TERRACES AND BENCHES

Type of Control: Surface Water

Function: Control erosion by reducing slope length (terraces); intercept and divert surface water flow (benches).

Description: Terraces and benches are embankments, or combinations of embankments, constructed across long or steep slopes. In climates where rainfall is frequent and/or heavy, benches and terraces are typically constructed in association with drainage channels so that concentrated surface flows can be intercepted and transported offsite. Drainage benches may be seeded, mulched, sodded, rip-rapped, chemically stabilized, or lined with concrete or grouted rip-rap (the latter two techniques are more costly alternatives).

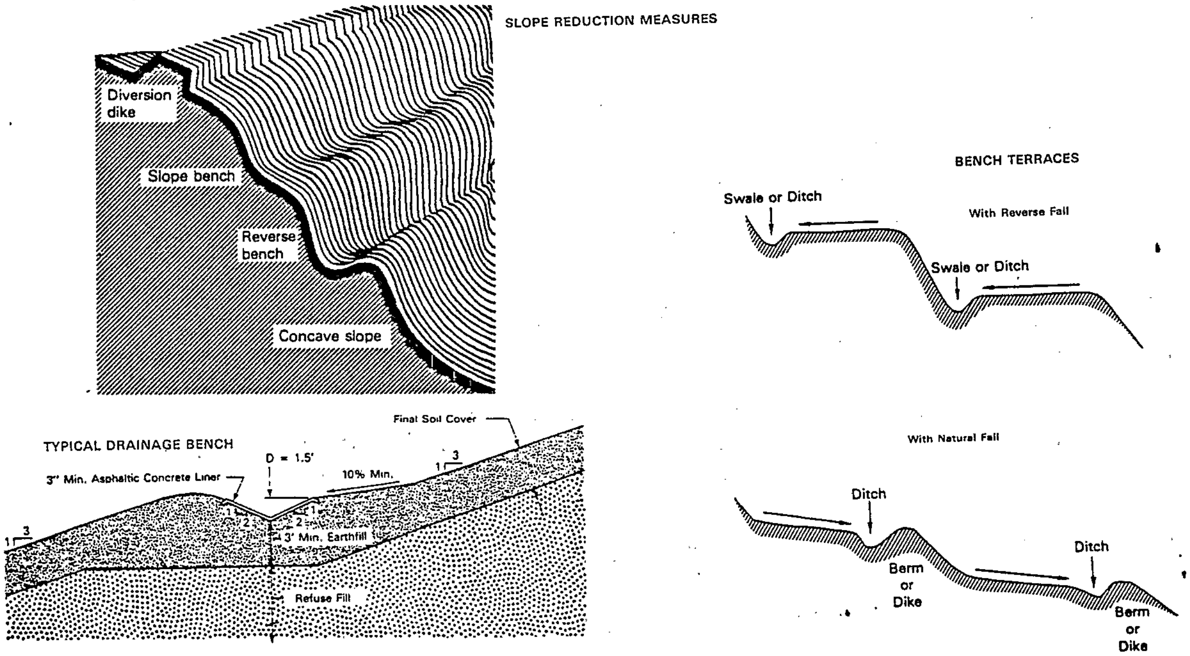


Figure 5.3. Typical terrace and bench applications. Source: U.S. EPA 1985b.

Design Considerations: Benches are generally designed with sufficient height and width to withstand a 24-hour, 25-year storm. Generally, the spacing between drainage benches should be more frequent for long, steep slopes with erodible soil cover. Structures must be stabilized as soon as possible after grading and compaction.

Limitations: Terraces and benches are an effective control in areas of high precipitation and can be used for long and steep slopes above, on, or below disposal sites. Terraces and benches should be periodically inspected, especially after heavy rainfall events.

Technology Status: Conventional, demonstrated.

Associated technologies: Diversions, dikes and berms, ditches, channels, capping, revegetation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Climate	Inspections required after heavy rainfall events	National Climatic Center (NCC), local weather bureau.	Nominal
Topography	Cost-effective for long and steep slopes above, on, or below disposal sites; steeper slopes require more benches/terraces.	Topography map, site inspection, site survey.	200-300/ acre (2,500 minimum)
Soil type	Closer bench placement for erodible soil covers	Sampling and sieve analysis; plasticity tests	50/test; 50/test
Soil permeability	Low permeability soils preferred	Triaxial permeameters	50/test
Runoff volumes & flow velocities	Proper sizing and placement of terraces/ benches	Gauge stations; meters; USDA records; field measurements	400

References: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984a; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984; JRB, 1984; Phelps, 1986; Brady, 1974.

5.0 DIVERSION/COLLECTION SYSTEMS

5.4 CHUTES AND DOWNPIPES

Type of Control: Surface Water

Function: Chutes and downpipes are used to convey concentrated flows of surface water from one level of a site to a lower level without erosive damage.

Description: Chutes (also referred to as flumes) are open channels that have compacted, smooth linings placed over undisturbed soil or well-compacted fill. Downpipes (also called downdrains or pipe slope drains) consist of rigid piping laid in slope areas. Generally, downpipes extend downslope from earthen embankments (i.e., dikes and berms) and convey water to stabilized waterways or outlets at the base of the slope.

Design Considerations: Chutes and downpipes are temporary structures, often used in conjunction with other technologies, that do not require formal design. Chutes and downpipes are useful in emergency situations because they can be quickly constructed.

Limitations: Chutes and downpipes are temporary measures only. Periodic inspection and maintenance is required, particularly after storm events. Downpipes are only suitable for 5-acre drainage areas. Chutes are limited to heads of about 18 ft or less.

Technology Status: Conventional, demonstrated.

Associated Technologies: Channel, diversions, waterways, ditches, dikes and berms.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Topography and local drainage patterns	For downpipes limited to 5-acre drainage areas; chutes limited to 8 ft heads or less	Topographic map; site inspection, site survey	200-300/ acre (2,500 minimum)
Climate	Inspection and maintenance required after heavy storm events	National Climatic Center (NCC); local weather bureau	50
Soil type	Clays or compacted sands and gravels are preferred	Sampling and sieve analysis; plasticity tests; proctor compaction	50/test
Soil permeability	Low permeability soils are preferred	Triaxial permeameters	50/test
Site size	Needs to be large enough for installation inspection, and maintenance	Site inspection; site survey; town/ city/county records	Nominal

References: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984a; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984; JRB, 1984; Phelps, 1986; Brady, 1974.

5.0 DIVERSION/COLLECTION SYSTEMS

5.5 SEEPAGE/RECHARGE BASINS AND DITCHES

Type of Control: Surface Water, Ground Water

Function: Intercept runoff and recharge the water downgradient from the site to minimize ground water contamination and leachate problems.

Description: As shown in Figure 5.5, there are several construction designs for seepage basins and ditches. Typically, a seepage basin consists of an excavated basin, a sediment trap, a bypass for excess flow, and an emergency overflow area. The sidewalls of the basin are constructed of previous material to allow for recharge.

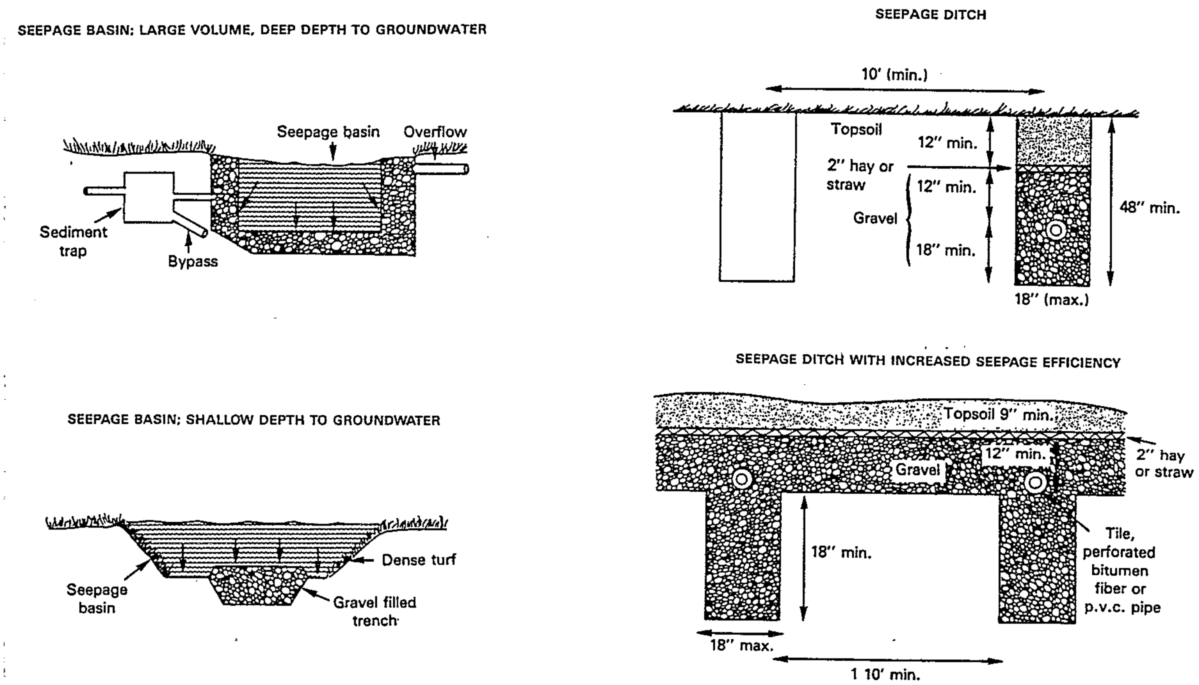


Figure 5.5. Typical designs for seepage basins and ditches.
Source: U.S. EPA 1985b.

Design Considerations: Seepage ditches are usually constructed in parallel with runoff moving through drains set in gravel ditches. Improved percolation occurs when gravel-filled trenches are constructed along the basin floor. Dense turf on the basin sidewalls will prevent erosion while permitting a high infiltration rate.

Limitations: Seepage/recharge basins and ditches are susceptible to clogging (particularly in areas of heavy precipitation) and, therefore, require periodic monitoring and cleaning. They are not effective in poorly permeable soils, best used for soils where permeability exceeds 0.9 in./day.

Technology Status: Conventional, demonstrated.

Associated Technologies: Diversions, revegetation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Soil type (Atterberg limits)	Sands and gravels preferred	Plasticity tests; sieve analysis	50/test
Soil permeability	Not effective in poorly permeable soils; best where permeability exceeds 0.9 in./day	Triaxial permeameter	50/test
Topography	Presence of dense turf and vegetation allows for high rate of infiltration and prevents erosion	Topography map; site inspection, site survey	Nominal
Climate	Areas where frequent and heavy rainfall occurs are generally not suitable	National Climatic Center (NCC); local weather bureau	50

References: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984a; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984; JRB, 1984; Phelps, 1986; Brady, 1974.

5.0 DIVERSION/COLLECTION SYSTEMS

5.6 SEDIMENTATION BASINS/PONDS

Type of control: Surface Water, Ground Water

Function: Used to control suspended solids entrained in surface flows (impedes surface runoff carrying solids, allows sufficient time for particulate matter to settle); used in control of diverted surface runoff.

Description: Sedimentation basins remove suspended solids from waterways through gravitational settling. A sedimentation basin is constructed by placing an earthen dam across a waterway or excavated area. It consists of the basin, a principal spillway, an anti-vortex device, and an emergency (overflow) spillway. As shown in Figure 5.6, the principal spillway consists of a vertical pipe (or riser) jointed to a horizontal pipe (barrel) that extends through the dike and outlets beyond the basin. The riser is topped by the anti-vortex device which improves the flow of water into the spillway and prevents floating debris from exiting the basin. Water discharge from the sediment action basin is typically directed toward an existing, stable stream. Additional measures (such as impact basin, rip-rap, excavated plunge pools, and stone facing) may be implemented to protect against scour (erosism).

Design Considerations: The size of the sedimentation basin is dependent upon the particle size distribution of the suspended solids, the inflow concentration, the volumetric flow rate, the desired concentration of suspended solids, and the water flow rate to the pond. Given this information, the required area of the sedimentation basin can be calculated. An explanation of the calculation can be found in U.S. EPA, 1985.

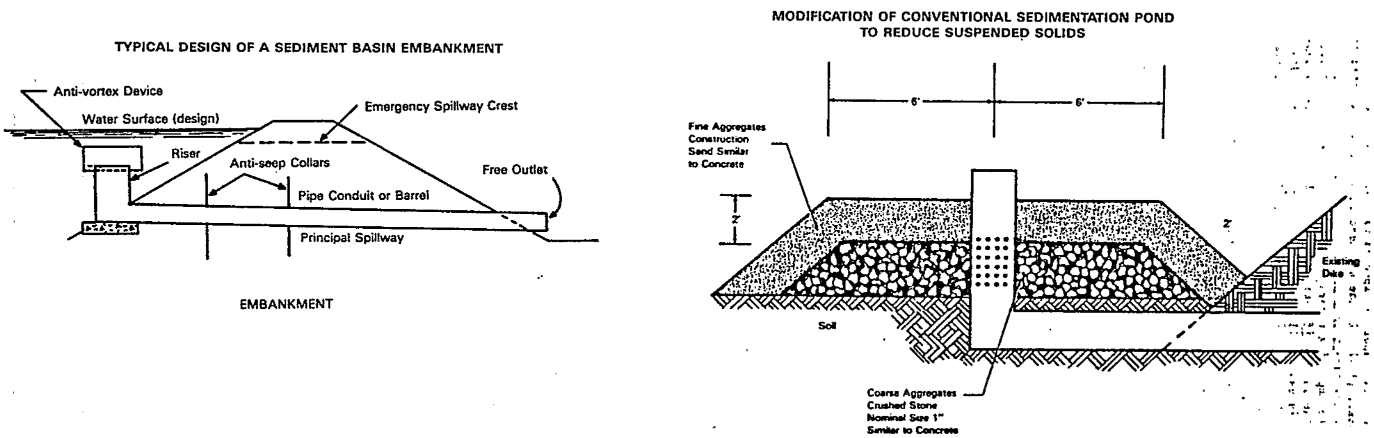


Figure 5.6. Sedimentation basin designs.
Source: U.S. EPA 1985b.

Limitations: Regular inspections and maintenance, including periodic cleanings, are required. Sedimentation basins/ponds perform poorly during periods of heavy rains. Fine-grained suspended solids and chemicals that are not sorbed to suspended particulates are not removed by sedimentation basins/ponds.

Technology Status: Conventional, demonstrated.

Associated Technologies: Waterways, excavation and removal, site clearing.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Climate	Basin siting and design	National Climatic Center (NCC); local weather bureau.	50
Land use	Land area needs to be free of roots, woody vegetation, large stones, etc. (sacrification may be necessary	Site inspection; site survey	400
Soil/sediment characteristics (Atterberg limits)	Fine-grained suspended solids are not removed	Plasticity tests; sampling and sieve analysis	50/test
Waste characteristic	Chemicals sorbed to suspended particulates are not removed	Laboratory analysis; CRC Handbook of Chem. & Physics	Sample analysis 500/sample

References: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984a; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984; JRB, 1984; Phelps, 1986; Brady, 1974.

5.0 DIVERSION/COLLECTION SYSTEMS

5.7 LEVEES AND FLOODWALLS

Type of Control: Surface Water

Function: Flood protection structures in areas subject to inundation from tidal flow or riverine flooding.

Description: Levees are earthen embankments that create a barrier to confine floodwaters to a floodway and to protect structures behind the barrier. Levees are constructed of erosion-resistant, low-permeability soils (i.e., clay), or compacted, impervious fill. Floodwalls are similar to levees, except that they are constructed of concrete. Levees generally require a very large base width; therefore, in areas where there is limited space and fill material, concrete floodwalls are preferred. Various designs for levees and floodwalls are diagrammed in Figure 5.7

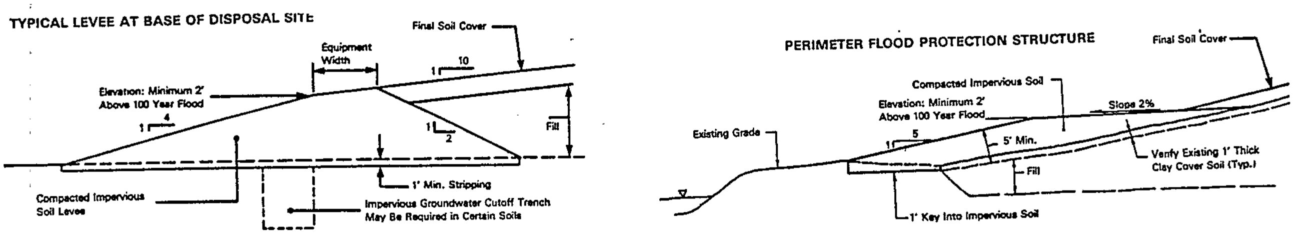


Figure 5.7. Levees at disposal sites.
Source: U.S. EPA 1985b.

Design Considerations: Levees and floodwalls are generally designed with a height capable of withstanding a 100-year flood (usually 2 ft of freeboard above the 100-yr flood elevation). A 10 ft minimum top width is required for levees to allow access for construction and maintenance equipment. Availability of fill materials onsite reduces construction cost. Drainage structures are often needed to drain the area behind the levee or floodwall. Typically used drainage structures include: diversion ditches, gravel-filled trenches, tile drains, sumps, and/or pressure conduits. If seepage problems occur, it may be necessary to construct a compacted impervious core or sheet-pile cut-off extending below the levee to bedrock. Excess seepage can be collected with gravel-filled trenches or drains along the interior edge of the levee or floodwall. Vegetation or rip-rap can be used to protect levee bank slopes from erosion. Upslope interceptor ditches, diversions, or grassed waterways may be used to prevent backwater flooding from runoff falling on the drainage area behind the levee or floodwall.

Limitations: Levees and floodwalls are most suitable in flood fringe areas or areas subject to storm tide flooding. They are not suitable for areas with direct open floodways. Federal Emergency Management Agency (FEMA) regulations may limit the use or placement of floodwalls and levees. Hydraulic analysis of the impact of the embankment on flooding characteristics of the waterway may be required. Flooding from storm runoff behind a levee and/or floodwall may be a problem; reduced flow storage capacity increases potential for downstream flooding.

Technology Status: Conventional, demonstrated.

Associated Technologies: Ditches, diversions, waterways, sheet piling, gabion walls.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
100-year floodplain elevation	Cannot be constructed in the FEMA-designated floodway	Topography map; FEMA flood study; USDA records	Nominal
Site map	Levees require large land areas; floodwalls can be used in areas with limited space	Site inspection; site survey; town/city/county records	Nominal
Flow patterns and velocity	Reduced flow storage capacity increases potential for down-stream flooding	Gauge stations; meters; USDA records; field measurements	400
Soil type	Fine-grained clays or compacted sand and gravel for levees	Sampling and sieve analysis; plasticity tests	50/test
Soil permeability	Low permeability soils for levees	Triaxial permeameter	50/test
Topography	Additional drainage structures may be required in areas with steeper slopes	Topography map; site inspection site survey	200-300/ acre
Geologic chacteristics	Bedrock suitable for sheet-pile cut-off is preferrable	Existing geological maps, surveys; bore hole logs	Boreholes 50/linear ft; test trench: 50/cu yd

References: U.S. EPA, 1985a; U.S. EPA, 1985b; U.S. EPA, 1984a; U.S. EPA, 1984b; Ehrenfeld and Bass, 1984; JRB, 1984; Phelps, 1986; Brady, 1974.

6.0 SUBSURFACE CONTAINMENT

6.1 SLURRY WALLS

Type of Control: Ground Water, Leachate

Function: Contain, capture, or redirect ground water and/or leachate in the vicinity of a site.

Description: Slurry cut-off walls are low-permeability, fixed walls installed to contain or divert ground water flow. The slurry maintains trench stability during excavation, and also prevents fluid losses to the surrounding ground by forming a filter cake on the trench walls. The primary types of slurry walls are soil-bentonite slurry walls, cement-bentonite slurry walls, and diaphragm walls. Soil-bentonite walls are constructed by backfilling the vertical trench with soil materials (often trench spoils) mixed with a bentonite and water slurry. Cement-bentonite slurry walls are composed of a slurry of Portland Cement and bentonite which is allowed to set, thereby forming a stronger but more permeable wall. Diaphragm walls are reinforced concrete panels that are either cast in-place or pre-cast and then placed in the trench. Slurry walls can be configured in a variety of ways. Slurry walls may either be keyed into the underlying bedrock (key-in walls) to prevent vertical and/or horizontal movement of contaminants within the aquifer, or placed to intercept only the upper portion of the aquifer (hanging walls) to control contaminants which float on top of the ground water. The slurry wall may be placed upgradient, downgradient, or circumferential to the area of contamination. Upgradient slurry walls are used to divert uncontaminated ground water around the site. Downgradient and circumferentially placed walls are used to contain contaminated ground water (usually for subsequent pumping and/or treatment).

Design Considerations: Soil-bentonite walls require a larger land area and a relatively flat topography. Cement-bentonite walls are better suited for more extreme topographies. Cement-bentonite walls are more permeable than soil-bentonite walls; permeabilities less than 10^{-6} cm/sec are generally not achievable with cement-bentonite walls. However, diaphragm walls are much more costly to install than cement-bentonite walls. Soil-bentonite walls are the least costly of the slurry wall alternatives.

Limitations: Slurry wall characteristics should be compatible with in situ soil, ground water, and leachate conditions. The soil-bentonite wall is not suitable for leachate or contaminated ground water containing strong acids and/or bases and alcohols. The cement-bentonite wall is not applicable for wastes or leachate containing chlorinated hydrocarbons, organic acids, or acid chlorides. The durability of the diaphragm wall decreases over time when there is continued contact with inorganic salts, acids and bases, and nonpolar organics.

Technology Status: Conventional, demonstrated; new techniques being developed.

Associated Technologies: Ground water pumping, surface and subsurface collection, surface sealing, grouting, sheet piling, grout curtains.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Accessibility of site materials	Cost, implementability	Site inspection	Nominal
Topography	Soil-bentonite walls require larger land area, relatively flat topography	USGS topography map; site investigation; site survey	Survey: 200-300/ acre (2,500 min.)
Depth to impermeable strata	Cost, implementability	Borings	50/lin. ft
Seismic history	Cement-bentonite wall not applicable in areas subject to seismic activity	USGS geologic maps, records, field surveys, aerial photos.	Nominal
Heterogeniety of subsurface formation	Difficult to install diaphragm wall with rocky subsurface material	Test trench, geologic maps	Test trench, 50/cu yd
Soil conditions	Suitability for backfill	Plasticity, size, permeability tests	50/test
Ground water depth, rate and direction of flow	Implementability	Existing geologic maps, boreholes, observation wells, logging & mapping, piezometers	Boreholes, 50/lin. ft wells, 30/vert. ft
Soil chemistry	Cement-bentonite wall unsuited for highly acidic or high sodium soil	Soil sampling and analysis	25/test
Chemistry of waste and ground water	Compatibility with wall material	GW sampling and analysis	100-500/ sample

References: U.S. EPA, 1985b; Ehrenfeld and Bass, 1984; GCA, 1985; Anderson and Jones, 1983; Canter and Knox, 1985; Kirk and Othmer, 1979; Ryan, 1980.

6.0 SUBSURFACE CONTAINMENT

6.2 GROUT CURTAINS

Type of Control: Ground Water, Leachate

Function: Contain or divert ground water by sealing fissures, and other voids in rock.

Description: Grout curtains are fixed, subsurface barriers formed by injecting a liquid, slurry, or emulsion under pressure into the ground through well points. Typically, the grout is injected into pipes arranged in a pattern of two or three adjacent rows as shown in Figure 6.2. The injected fluid fills open pore spaces and sets or gels into the rock or soil voids, thereby greatly reducing the permeability of the grouted area. Particulate grouts consist of water plus Portland Cement, bentonite, or a mixture of the two which solidifies within the soil matrix. Chemical grouts consist of two or more liquids which gel when mixed together. Often, particulate grouts are used as "pre-grouts" with a second injection of a chemical grout to seal the finer voids.

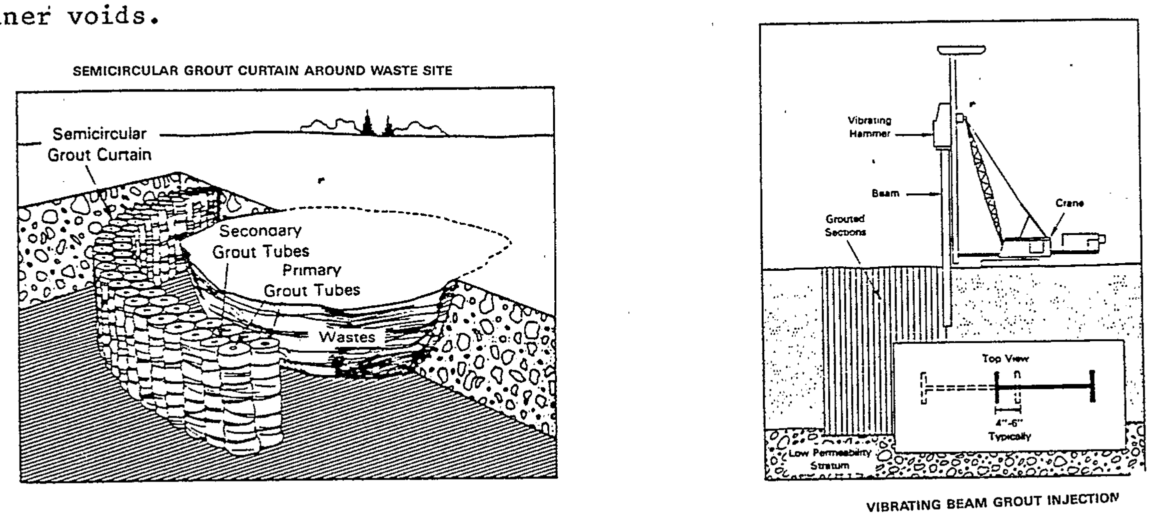


Figure 6.2. Grout curtain and vibrating beam injector.
Source: U.S. EPA 1985b.

Design Considerations: It is important to test the compatibility of the wastes with the grouts to ensure an adequate seal. Grout curtains should extend to bedrock (or impervious layer) to be effective. Since it is difficult to verify the continuity of the curtain once installed, implementation of this technique is difficult.

Limitations: Grout curtains are not applicable where heterogeneous geologic conditions exist (e.g., glacial till). Also, very permeable soils or very fine-grained soils are not suitable for grout curtains.

Technology Status: Demonstrated.

Associated Technologies: Ground water pumping (well systems), surface and subsurface collection/drainage systems, surface sealing, slurry or sheet pile cut-off walls.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Accessibility of materials	Implementability and costs	Site visit/ investigation	400
Soil moisture content	Implementability	Volume-weight analysis	50/test
Soil permeability	Not applicable in very permeable soils	Triaxial permeameter	50/test
Grain Size distribution	Suitable if through No. 200 sieve; if 10% through No. 200 sieve; then low viscosity grout material required	Sieve analysis	50/test
Soil/waste chemistry	Compatibility with grout	Sampling and analysis	50/test
Subsurface geology	Not suitable for heterogeneous subsurface	Test trench	50/cu.yd.
Depth to bedrock (impermeable strata)	Optimal depth of wall	Existing geologic maps, surveys bore-holes, logging and mapping	Boreholes, 50/lin. ft
Depth to ground water table	Implementability	Existing geologic maps, observation wells, boreholes, logging & mapping piezometers.	Boreholes, 50/lin. ft wells, 50/vert. ft
Direction and rate of ground water flow	High GW flow adversely affects curtain integrity	Pump tests; injection tests; town/city/county records	Wells, 50/vert. ft
Ground water pH, sulfides, calcium	Integrity of grout curtain	Sampling and analysis	100/sample

References: U.S. EPA, 1985b; Ehrenfeld and Bass, 1984; GCA, 1985; Knox, 1984; U.S. EPA, 1984; JRB, 1984.

6.0 SUBSURFACE CONTAINMENT

6.3 SHEET PILING

Type of Control: Ground Water, Leachate

Function: Used to contain or divert ground water flow around or below contaminated areas; controls hazardous leachate generation for locations where wastes are in contact with a permanent or seasonal water table.

Description: Sheet piling cut-off walls are constructed by driving lengths of interlocking steel into the ground with a pneumatic or steam driven pile driver to form a thin impermeable barrier to ground water flow. Steel is most commonly used; wood or precast concrete are used, depending on site characteristics. Figure 6.30 shows various configurations used in construction of sheet pile walls. Soon after being driven into the ground, the joint connections fill with fine to medium-grained soil particles which hinder ground water flow.

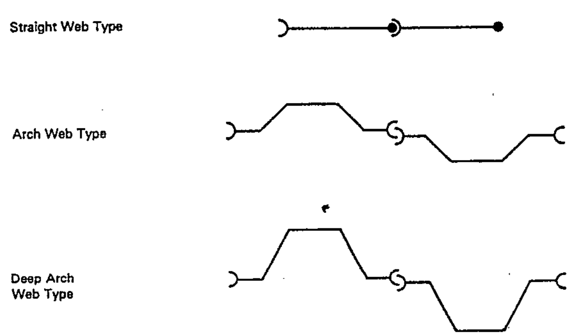


Figure 6.3. Steel piling configurations.
Source: U.S. EPA 1985b.

Design Considerations: Soil type and waste characteristics are important factors to consider, because there is a high potential for leakage through interlocking piles. Sheet piles are typically used in loosely packed soils that predominantly consist of sands and gravels. A penetration resistance of 4 to 10 blows/foot for medium to fine-grained is recommended. To be effective, sheet piles should extend to bedrock or low-permeability strata. The maximum depth to which sheet piles can be driven without damaging the sheet pile wall material is generally 15 feet. The characteristics of the waste constituents and/or leachate strongly affect the lifetime of the sheet-pile wall (particularly the pH of the waste material).

Limitations: Sheet piles are not be suitable for rocky soils, which could damage the sheet piles during installation, or for ground water containing high concentrations of salts or acids.

Technology Status: Conventional, demonstrated.

Associated Technologies: Grout curtains, slurry cut-off walls, ground water pumping, surface sealing.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Depth to bedrock (impermeable strata)	Optimal wall depth	Geologic maps, boreholes, logs	Boreholes-50/lin. ft
Grain size distribution	Fine- to medium-grained soil particles optimum filling sheet pile joints	Sieve analysis	50/test
Compaction	Penetration resistance affects feasibility	Proctor compaction	50/test
Depth to ground water table	Maximum depth to which sheet piles can be effectively driven is approximately 15 feet	Geologic maps, observation wells, boreholes, logs, geologic survey, piezometers.	Boreholes-50/lin. ft wells 50/vert. ft
pH of ground water and waste	Sheet pile lifetime (neutral pH is best)	Sampling and analysis	50/test
Leachate/ground water chemistry	Compatibility with sheet pile wall	Sampling and analysis	100/sample

References: U.S. EPA, 1985; Ehrenfeld and Bass, 1984; GCA, 1985; Knox, 1984.

6.0 SUBSURFACE CONTAINMENT

6.4 BOTTOM SEALING

Type of Control: Ground Water, Leachate

Function: Contain contaminated ground water, direct uncontaminated ground water flow away from contaminated area, or lower water table inside isolated area.

Description: Bottom sealing consists of placing a horizontal barrier beneath the hazardous waste site to prevent downward migration of contaminants. Possible approaches include grout injection and block displacement. Both of these techniques are in the developmental stages; some laboratory and field testing has been performed.

The grout injection technique involves drilling a series of holes across the site and injecting grout to form a horizontal or curved barrier. The block displacement method is used to isolate and raise a contaminated block of earth. A slurry trench or grouting is used to form a barrier around the perimeter of the block of contaminated earth to be isolated. Grout is then injected into holes bored through the site. The grouting and slurry pumping is continued until the contaminated block is displaced and a bottom seal is formed beneath the block.

Limitations: The block displacement technique is not applicable to areas where heterogeneous geologic conditions exist. Also, this technique is not suitable for ignitable wastes because explosives may be used during construction.

Technology Status: Developmental, not demonstrated.

Associated Technologies: Slurry cut-off walls, grout curtains, sheet pile cut-off walls.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Accessibility of site materials	Costs and implementability	Site inspection site investment	Nominal
Subsurface geology	Not applicable for heterogeous subsurface geology	Test trench; geologic maps	Test trench, 50/cu.yd.
Thickness of subsurface strata	Implementability	Geologic maps; boreholes, logging	Boreholes-50/lin. ft
Depth to bedrock (impervious strata)	Optimal depth of associated walls	Geologic maps; boreholes; logging	Boreholes-50/lin. ft
Hydraulic conductivity	Implementability	Piezometers; pump tests	Wells-50/vert. ft
Soil type (texture)	Suitability for backfill	Plasticity tests	50/test
Soil grain size distribution	Determine viscosity of grout material required	Sieve analysis	50/test

References: U.S. EPA, 1985; Ehrenfeld and Bass, 1984; JRB, 1984.

7.0 GROUND WATER PUMPING

Type of Control: Ground Water, Leachate

Function: Contain or remove a contaminant plume or alter direction of ground water movement; less frequently used to adjust ground water levels.

Description: Ground water pumping involves the extraction of water from, or the injection of water into wells to manage contaminated ground water. A series of wells is used for this purpose. The types of wells used for ground water pumping include: well points, suction wells, ejector wells, and deep wells, as shown in Figure 7.0. Typical components of ground water well systems include: casing (to encase the well and pump), screening (to stabilize the hole, facilitate flow, and keep particles out of the well), gravel pack (to fill the annular space surrounding the screen), and pumps (e.g., turbine submersible pump, vertical line shaft pump, and ejector pumps).

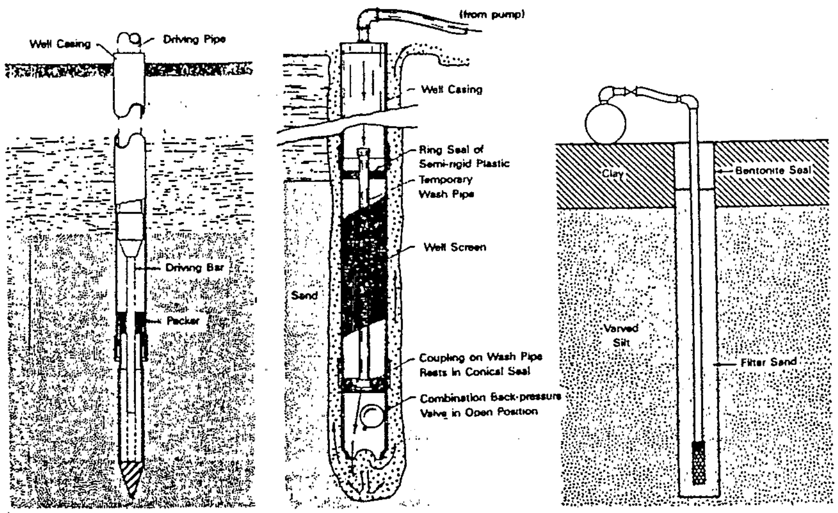


Figure 7.0. Ground water pumping wells.
Source: U.S. EPA 1985b.

Design Considerations: Wellpoint systems and suction wells are best suited for shallow, unconfined aquifers where extraction below 22 feet is not required. Wellpoint systems are effective in most hydraulic situations. Suction wells tend to perform poorly with low hydraulic conductivities, but have a higher capacity than wellpoints. Deep wells and ejector well systems are used for deeper aquifer systems. Deep wells perform best in homogeneous aquifers with high hydraulic conductivities, and where large volumes of water are to be pumped. Ejector wells are better suited for heterogeneous aquifers with low hydraulic conductivities.

Limitations: Operation and maintenance costs for pumping systems are high, which may limit their use for long term remediation. Long-term pumping may affect local ground water levels; recharge of the aquifer may be necessary.

Technology Status: Conventional, demonstrated.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Depth to impermeable strata (bedrock)	Drain spacing and feasibility	Geologic maps; logs; boreholes	Boreholes-50/lin. ft
Subsurface geology	Not cost-effective if substantial hard rock excavation is necessary	Geologic maps; boreholes; logs	Boreholes-50/lin. ft
Soil permeability	Drain spacing and pipe inflow; not suited for soils with high permeability	Triaxial permeameter	50/test
Depth to water table	Drain spacing	Geologic maps; observation wells; boreholes; logs; piezometers	Wells, 30/vert. ft
Ground water and leachate chemistry	Selection of pipe material (compatibility)	GW sampling and analysis	100/sample
Drainage area of pipes	Inflow to pipe	Site visit/inspect.; site investigation; topography map	Site survey: 200-300/acre (2,500 min.)
Waste viscosity	Unsuited for viscous wastes	Sampling and analysis	100/sample

References: U.S. EPA, 1985; Ehrenfeld and Bass, 1984; JRB, 1984.

9.0 SURFACE WATER/SEDIMENT CONTAINMENT BARRIERS

9.1 COFFERDAMS

Type of Control: Surface Water, Sediment

Function: Hydraulically isolates a portion of the water body; can be used to isolate contaminated surface water for subsequent pumping to treatment systems, or to isolate uncontaminated surface water for subsequent dredging/sediment removal operations in the surrounding (contaminated) area.

Description: Cofferdams are surface water barriers, which are anchored to the soil/sediment at the bottom of a surface water body. They may be constructed of various materials including soil, sheet piling (usually black steel, but galvanized or aluminum coatings are also available), earth-filled sheet pile cells (single-walled or cellular), and sand bags (for short-term structures). Pre-assembled (interlocked) sections of sheet piling are also available. The sheet-piling can be hand-driven using a hand maul or a light pneumatic hammer. Heavy driving equipment such as a drop hammer, pneumatic pile driver, or steam pile driver are also used.

Depending upon site conditions, various installation patterns may be utilized. In areas where the entire stream channel bed is contaminated, a pair of cofferdams (upstream and downstream) can be used to isolate the contaminated area while diverting the stream flow to the temporary channel, as shown in Figure 9.1a. Alternatively, if only a portion of the stream channel bed is contaminated, a single curved or rectangular cofferdam may be used to isolate the contaminated area without the necessity of constructing a temporary diversion channel, as shown in Figure 9.1b.

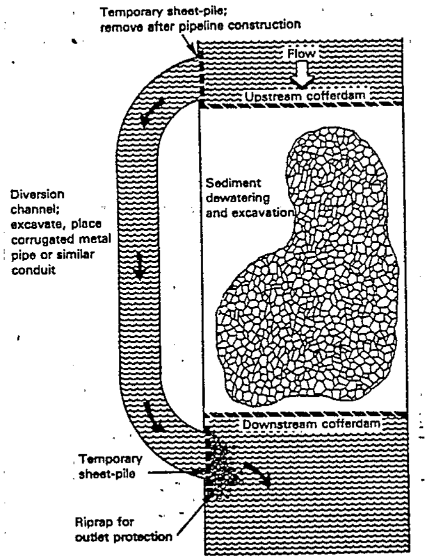


Figure 9.1a. Streamflow diversion using two cofferdams. Source: U.S. EPA 1985b

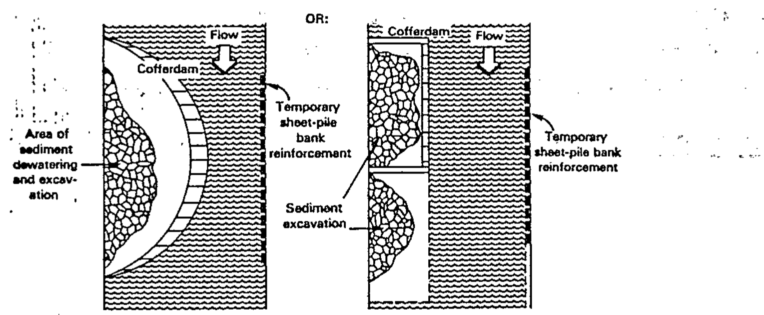


Figure 9.1b. Streamflow diversion using single cofferdams. Source: U.S. EPA 1985b.

Design Considerations: Sheet-pile cofferdams are typically constructed of black steel sheeting with a 5 to 12 gauge thickness and a 4 to 40 ft length. Factors affecting the selection of dimensions include: stream depth, stream flow velocity, and the characteristics of the soil/sediment beneath the surface water body. In general, the length of the exposed sheeting should be roughly equivalent to the driven length (i.e., unexposed, anchored into soil), with an additional 1 to 3 feet of freeboard above the water surface. It may be necessary to have a longer anchored length if there is a significant layer of soft, muddy, or unconsolidated sediments overlying the stable soil stratum.

Limitations: Areas enclosed by cofferdams may require dewatering (e.g., in areas of high precipitation). Flow velocities in the area adjacent to the cofferdam will increase, thereby potentially causing bed scour and bank erosion if bank reinforcement measures are not deployed. Underlying bedrock may hinder the sheet-pile driving operations.

Associated Technologies: Dredging, dewatering, diversions, streambank stabilization.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Soil/sediment characteristics	Longer, anchored length for sheet-pile for soft, muddy or unconsolidated sediments	Volume-weight analysis, grain size distribution, plasticity tests	50/test (each)
Geologic conditions	Underlying bedrock may hinder sheet pile-driving operations	Existing geologic maps; geologic surveys; bore hole logs.	Boreholes, 50/lin. ft
Dimensions and stream flow of surface water body	Influences installation configuration and resulting costs	Site investigation, field measurements, maps	400
Climate	Dewatering of area contained by cofferdam may be required	National Climatic Center (NCC); local weather bureau	50
Area of contamination	Influences of installation configuration, and resulting costs	Sampling and analysis	100/ sample

References: Brady, 1974; GCA, 1985; JRB, 1984; U.S. EPA, 1984b; U.S. EPA, 1985a; U.S. EPA, 1985b.

9.0 SURFACE WATER/SEDIMENT CONTAINMENT BARRIERS

9.2 FLOATING COVERS

Type of Control: Surface Water, Air Pollution Control

Function: A temporary measure used to prevent overtopping of a waste lagoon prior to final closure; mainly used to cover drinking water supply reservoirs. Also controls voltile air emissions.

Description: A floating cover consists of a synthetic liner placed over an impoundment. The liner is held up by floats, and anchored at the edges of the impoundment. The synthetic liner consists of a 36-mil or 45-mil thick, reinforced Hypalon, chlorinated polyethylene (CPE), or XR-5 material. The material must be tested for compatibility with the waste prior to use. Two basic types of floating cover designs are used. The most commonly used configuration, shown in Figure 9.2a, consists of a large center float with several smaller floats attached perpendicularly to the center float. Rainwater is directed to a sump around the perimeter of the floating cover. The rainwater collected in the sump is periodically drained or pumped.

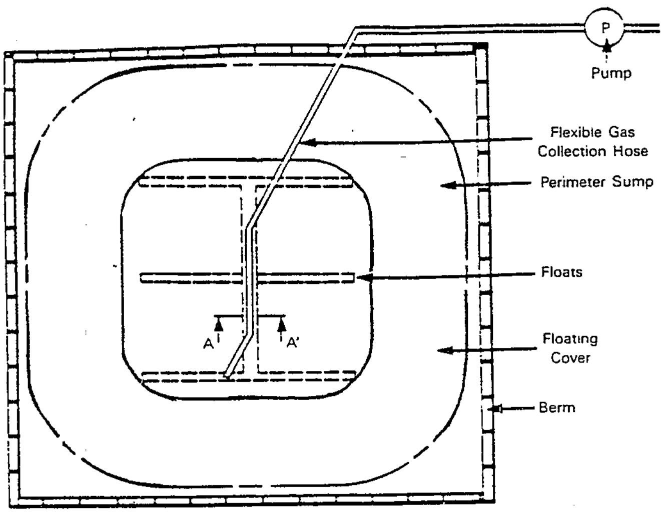


Figure 9.2a. Schematic plan of a patented globe floating cover. Source: U.S. EPA, 1985b.

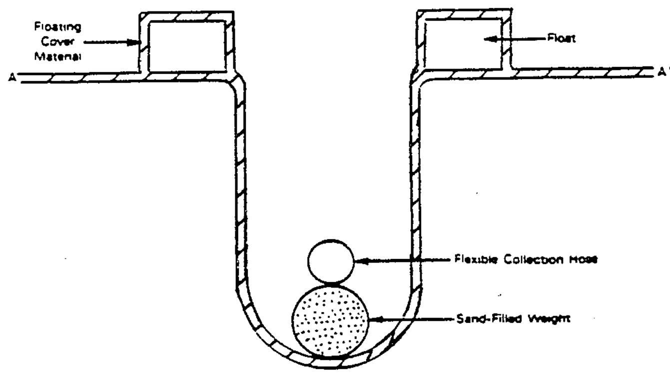


Figure 9.2b. Cross-section of a floating cover incorporating the patented Burke design. Source: U.S. EPA 1985b.

Another type of configuration, shown in Figure 9.2b, directs rainwater through channels in the middle of the cover. The channels consist of sand-filled tubes held at constant depth by floats on either side of the channel. Perforated collection tubes are connected above and parallel to the sand tubes. The collection tubes drain the rainwater off the cover.

Design Considerations: Depending on the characteristics of the waste, it may be necessary to include a gas collection system in the cover design. An example of a typical gas collection system is diagrammed in Figure 9.2c. Gases are channeled beneath the floating cover to an air chamber which is connected to a manifold pipe so that gases can be pumped and collected.

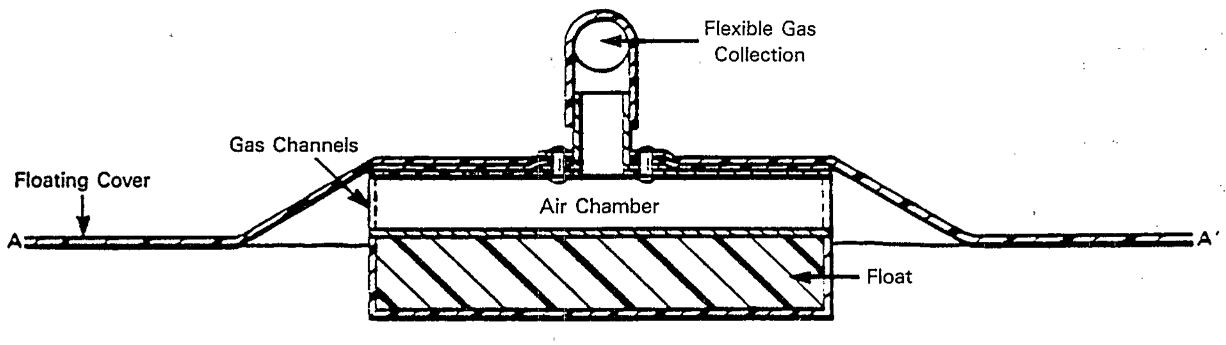


Figure 9.2c. Cross-section of a gas collection system design. Source: U.S. EPA 1985b.

Limitations: Floating covers are temporary (interim) measures until final closure actions are taken.

Technology Status: Conventional, demonstrated.

Associated Technologies: Land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste characteristics	If gases are released, need a collection system; selection of compatible liner	Sampling and analysis	100/ sample
Climate	Frequent heavy storms may cause problems; need adequate drainage for the cover top; selection of appropriate configuration	National Climatic Center (NCC); local weather bureau.	50

References: Brady, 1974; GCA, 1985; JRB, 1984; U.S. EPA, 1984b; U.S. EPA, 1985a; U.S. EPA, 1985b.

9.0 SURFACE WATER/SEDIMENT CONTAINMENT BARRIERS

9.3 SILT CURTAINS AND BOOMS

Type of Control: Surface Water, Sediment

Function: Used to contain suspended sediments during dredging operations (silt curtains), and to contain contaminants that float (booms).

Description: Silt curtains are low permeability floating barriers that extend vertically from the surface of the water to a specified depth. A silt curtain is comprised of a flexible skirt (made of polyester-reinforced PVC, nylon-reinforced PVC, or KEVLAE/polyester blend), a ballast chain to keep the skirt in a vertical position, a tension cable to absorb stress caused by currents, and anchored lines to hold the curtain in place. End connectors are used to attach two or more curtain sections. Silt curtains can have several possible configurations (maze, instream, U-shaped, circular, and elliptical) as shown in Figure 9.3, depending upon the specific surface water body conditions.

Booms are similar to silt curtains, and are used to confine contaminants that float (i.e., specific gravity less than 1). Booms tend to decrease advection, dispersion, and photolysis development configurations processes, and may increase volatilization.

Design Considerations: The maze configuration, illustrated in Figure 9.3, is generally not recommended. The instream, U-shaped configuration is suitable for rivers or other water bodies where the current does not reverse. Circular or elliptical configurations are more suitable for open waters and areas with reversing tides. Silt curtains are typically used for small dredging and capping operations where frequent curtain movement does not occur.

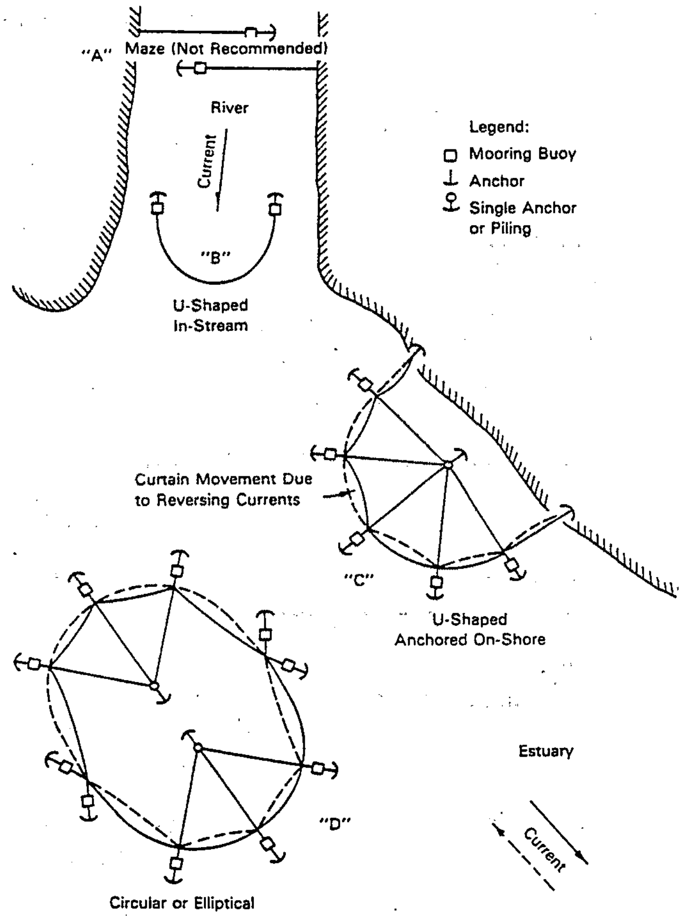


Figure 9.3. Typical silt curtain development configurations. Source: U.S. EPA, 1985b.

Limitations: Surface wave action and (strong) currents limit the effectiveness of silt curtains. Silt curtains are generally not effective when used in open waters, or where currents exceed one knot, or in areas exposed to high tides and large waves. Booms are most effective immediately following a release (i.e., before the contaminant plume has dispersed), and are frequently used as an emergency measure to contain oil spills.

Technology Status: Conventional, demonstrated.

Associated Technologies: Dredging, capping.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs
Water depth	Silt curtains not suitable for large depths	Field measurements	400
Tidal flow	Surface wave action limits effectiveness; not suitable for open oceans, high tides, or large waves	Gauge measurements	400
Stream/current flow velocity	Strong currents limit effectiveness; unsuitable when current exceeds 1 knot	Gauge measurements	400
Bottom sediment characteristics, quantity and type of material in suspension	Compatibility with barrier material	Sampling and analysis	100/ sample

References: Brady, 1974; GCA, 1985; JRB, 1984; U.S. EPA, 1984b; U.S. EPA, 1985a; U.S. EPA, 1985b.

10.0 STREAMBANK STABILIZATION

Type of Control: Surface Water, Leachate

Function: Prevents bank undermining and erosion from stream flow and from surface runoff. Applicable to areas where bank erosion poses a threat of introducing contaminated materials to a surface water body.

Description: Various methods of stabilizing streambanks are available. Surface water diversion trenches or berms constructed on the upslope edge of the streambank intercept upslope runoff and prevent it from running over the streambank. Sheet piling walls, rip-rap, gabion walls, or other revetment of the bank itself prevent erosion of the bank by the stream.

Sheet piling walls consist of interlocking sheet piles driven into the ground along the edge of the stream such that the height of the wall is approximately equivalent to the height of the bank. The space between the wall and the bank is backfilled, thereby creating a new bank which prevents contact between the water and the bank soils.

Rip-rap is comprised of large pieces of rock which cover the streambank and reduce or prevent contact between water and soils. Sometimes grouting issued to seal the rip-rap material.

Gabion walls are a series of chain link steel mesh boxes filled with stones. These stone-filled boxes are then placed and/or stacked along the bank to prevent contact of water with the bank. It may be necessary to construct a stable foundation to support the gabion wall.

Design Considerations: Common construction equipment can be used in the construction of sheet piling walls, gabion walls, or rip-rap along a streambank. Depending on the size of the stream and the steepness of the bank, barges may be needed to provide a working surface for the equipment.

Limitations: A stable foundation (i.e., consolidated soils or bedrock) along the stream bank is necessary in order to prevent undermining by the stream and eventual failure. However, sheet piles should not be considered for use with rocky soils which could damage the sheet pile units during installation.

Technology Status: Conventional, demonstrated.

Associated Technologies: Dredging, surface water/sediment containment barriers (e.g., cofferdams), diversions (e.g., trenches, berms), sheet piling.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs
Soil characteristics (of streambank)	Selection of stabilization technique	Plasticity tests	50/test
Geologic characteristics	Stream bank construction requires a stable foundation to prevent undermining and eventual failure	Existing geologic map; geologic survey; bore hole logs	Boreholes-50/lin. ft
Site accessibility	Barge and/or crane may be required for access	Site inspection; site survey; town/city/county records	Nominal
Hydrogeologic characteristics -100-yr floodplain -Flow velocity -Surface runoff	Applicability of stabilization technique	USGS records; FEMA flood study; topography map	Nominal

References: Brady, 1974; GCA, 1985; JRB, 1984; U.S. EPA, 1984b; U.S. EPA, 1985a; U.S. EPA, 1985b.

11.0 GAS COLLECTION/RECOVERY

11.1 PASSIVE SUBSURFACE GAS CONTROL

Type of Control: Gas Migration

Function: Prevents subsurface migration of landfill-generated gases beyond the landfill property line.

Description: Passive gas control systems alter subsurface gas flow paths without using mechanical components. Generally, subsurface flow is directed to points of controlled release through the use of high permeability systems, while flow paths to protected areas are blocked through the use of low permeability systems. High permeability systems consist of trenches or wells excavated at the boundary of the landfill and backfilled with a highly permeable material (e.g., coarse, crushed stone), as shown in Figure 11.1a. Gas flow is directed to the trench area because its higher permeability is more conducive to gas flow than the surrounding less permeable areas. Low permeability systems, consisting of clay-lined or synthetic-lined trenches are used to block the paths of diffuse gas flow (see Figure 11.1b). Gases will then travel through either the ground surface between the barrier and the landfill or through the surface of the landfill. Often, high permeability and low permeability systems are used in combination to control subsurface gas flow.

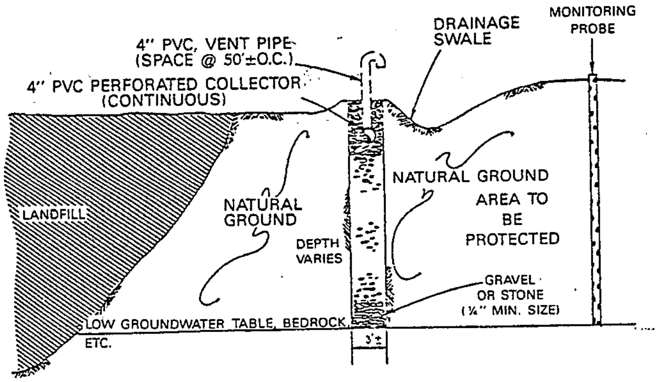


Figure 11.1a. Passive gas control using a permeable trench. Source: U.S. EPA, 1985b.

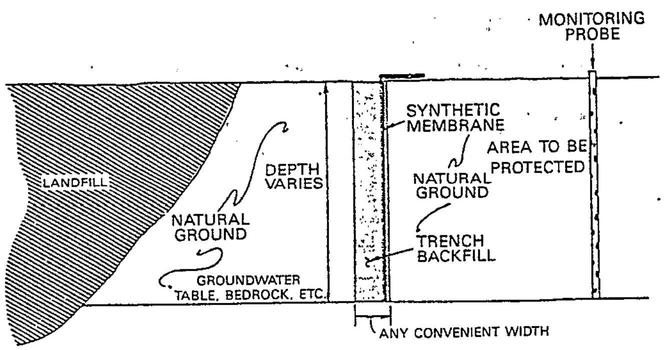


Figure 11.1b. Passive gas control synthetic membrane. Source: U.S. EPA 1985b.

Design Considerations: The maximum recommended depth for the trench is 3 feet. Trench effectiveness is improved by constructing a low permeability system at the perimeter of the high permeability trench to prevent migration past the high permeability trench. Migration underneath the trench can be prevented by extending the trench to bedrock (or impervious strata). Installation of riser pipes and capping of the landfill further facilitates gas movement by enhancing the trench as the path of least resistance.

Limitations: Infiltration of precipitation and/or runoff limits the effectiveness of trench vents. If capping is not employed in conjunction with passive trench vents, then the trenches should not be located in areas of low relief (a slope can be constructed along the trench to control runoff).

Periodic monitoring of subsurface gas samples collected from probes installed in the protected area is required. Passive systems generally require little operation and maintenance.

Technology Status: Conventional, undemonstrated at hazardous waste sites (primarily used to control methane at municipal landfills).

Associated Technologies: Capping, diversions.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs
Topography	Trench placement to avoid surface runoff infiltration	Topographic map; site inspection; site survey	Survey: 200-300/acre (2,500 min.)
Soil characteristics/ permeability	Effectiveness of subsurface gas transport; vapor flux	Triaxial permeameter	50/test
Geologic characteristics (type of subsurface strata, pH, temperature, depth to bedrock)	Presence of rock strata may limit effectiveness	Geologic maps; boreholes, logs	Boreholes-50/lin. ft
Climate	Less effective in areas with high rainfall or prolonged freezing temperatures	Natl. Climatic Center (NCC); local weather bureau	50
Depth to ground water	Presence of perched water table may limit effectiveness	Geologic maps; piezometers; observation wells; boreholes	Boreholes-50/lin. ft Wells-50/vert. ft
Waste characteristics (composition, moisture content)	Trench placement	Sampling & analysis, including volume weight analysis	50/test
Microorganisms present (gas-producing)	Trench placement	Sampling and analysis	100/sample
Oxygen availability	Vapor flux	COD analysis; BOD analysis	50/test 50/test

References: U.S. EPA, 1985b; JRB, 1984; Ehrenfeld and Bass, 1984.

11.0 GAS COLLECTION/RECOVERY

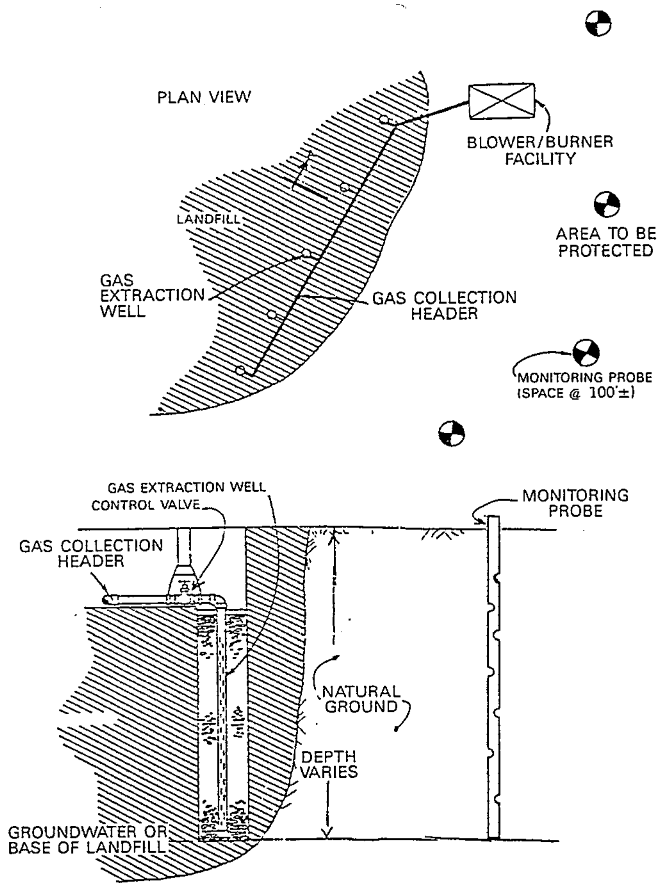
11.2 ACTIVE SUBSURFACE GAS CONTROL SYSTEMS

Type of control: Gas Migration, Air Pollution

Function: Controls subsurface migration of landfill-generated gases; prevents offsite migration of subsurface gases.

Description: Active perimeter gas control systems use mechanical means to alter pressure gradients to redirect the paths of subsurface gas flow. As shown in Figure 11.2, major components generally include: gas extraction wells, gas collection headers, vacuum blowers or compressors, and gas treatment or utilization systems.

Figure 11.2. Active gas extraction. Source: U.S. EPA, 1985b.



Gas extraction wells can be installed in the landfill or in the soil area surrounding the landfill. They are normally drilled to either the depth of the seasonally low ground water table or to the base of the landfill. A pipe, which is solid at the top and perforated at the level where the gas is to be collected, is set in crushed gravel (or other permeable material). The area surrounding the pipe at the top of the well is sealed with concrete or clay. The upper portion of the pipe is connected to a gas collection header. The gas collection header is connected to several extraction wells spaced at regular intervals. Vacuum blowers or compressors are used to create a negative pressure area, which causes gases to be drawn up from the extraction well. The gases may subsequently be treated and released to the atmosphere, or recovered for use as fuel.

Design Considerations: Applicable where site conditions allow drilling through landfilled material to the required depth. Well spacing is a critical factor in the design of the systems. Typically, 100 ft spacing is used. However, appropriate spacing depends upon several factors, including: landfill depth, type of waste, moisture content of waste and surrounding soils, percent compaction of waste, grain-size distribution of surrounding soil, stratigraphy, and soil permeability.

Limitations: Limiting factors include: presence of free-standing leachate (i.e., saturation) or impenetrable materials within the landfill. Not sensitive to freezing or saturation of surface or cover soils.

Technology Status: Conventional, undemonstrated (primarily used to control methane at municipal landfills).

Associated Technologies: Capping.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs
Subsurface geology	Difficult installation with rocky strata	Geologic maps; boreholes, logs	Boreholes-50/lin. ft.
Depth to ground water	Selection of drilling depth for extraction wells	Geological maps; logs, Piezometers, observation boreholes	Boreholes-50/lin. ft; Wells-50/vert. ft.
Soil permeability	Effectiveness limited with low permeability soils	Triaxial permeameter	50/test
Waste Constituents	Selection of appropriate well spacing and appropriate subsurface gas control technology	Sampling and analysis	100/sample
Moisture content of waste and soil	Well-spacing	Volume-weight analysis	50/test
Percent compaction of waste	Well-spacing	Proctor compaction	50/test
Soil grain site distribution	Well-spacing	Sieve analysis	50/test

References: U.S. EPA, 1985b; JRB, 1984; Ehrenfeld and Bass, 1984.

12.0 EXCAVATION/REMOVAL

Type of Control: Surface Water

Function: Removes (generally by mechanical digging) contaminated surface and subsurface soils for subsequent treatment and/or disposal.

Description: Mechanical equipment such as a backhoe (hydraulically-powered digging unit), a crane-mounted dragline (crane-fitted with a drag bucket and connected to a boom by a cable), and a clamshell bucket (similar to a dragline, but able to dig at depths of 50 ft or more), are generally used to excavate solids and thickened sludge material; examples of these types of equipment are shown in Figure 12.0. During excavation activities, the excavated material is either contained onsite for treatment, storage, or disposal, or is loaded directly into trucks for transport offsite for treatment, storage, or disposal.

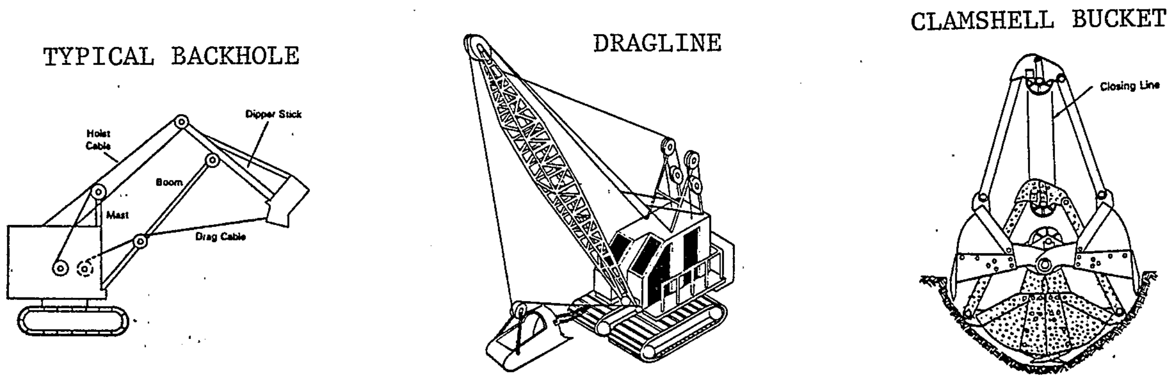


Figure 12.0. Examples of commonly used excavating equipment. Source: U.S. EPA, 1985b.

The major types of excavating techniques are casting and loading, hauling, pumping, and industrial vacuum loading. Loading and Casting is the most commonly used excavation technique. The equipment generally used for this technique includes: backhoes, bulldozers, and front-end loaders. Hauling excavation techniques are used when wastes are to be transported to onsite and/or offsite areas. Typical equipment used for excavation hauling includes: scrapers, haulers, bulldozers, and front-end loaders.

Pumping is used to remove liquids and sludges from ponds, waste lagoons, and surface impoundments. The liquid wastes are then either pumped to an onsite treatment system or a tank truck for transport offsite to a commercially operated treatment facility. The two major types of pumps are dynamic pumps (i.e., centrifuge pumps), and displacement pumps (i.e., reciprocating or rotary pumps). Industrial vacuum loaders can be used in large-scale cleanup operations to remove soil or pools of liquid waste. Vacuum loaders can be vehicle-mounted or portable skid-mounted.

Design Considerations: The site must be accessible to heavy equipment used for excavating the contaminated materials.

Limitations: Excavation is not well-suited for materials with a low solids content. Dewatering techniques may need to be employed in conjunction with excavation. Excavation is generally not cost-effective for large areas of contamination (but alternative control technologies are not always available).

Technology Status: Conventional, demonstrated.

Associated Technologies: Dewatering, subsurface and surface water barriers, diversions, grading, capping, revegetation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste characteristics	Not suited for materials with a low solids content, may need to employ dewatering techniques	TSS analysis; TDS analysis	50/test
Nature and extent of contamination	Determines feasibility and cost-effectiveness	Sampling and analysis	100/sample
Topography	Accessibility to heavy equipment	Site inspection, site survey; town/city/county records	Nominal
Geologic characteristics	Difficulty of excavation	Geologic maps; borings, logs	Boreholes-50/lin. ft.
Soil/sediment percent-moisture content	Dewatering may be necessary	Volume-weight analysis	50/test
Climate	Frequent and heavy rains lower efficiency	National Climatic Center (NCC); local weather bureau	50

References: GCA, 1985c; Ehrenfeld and Bass, 1984; U.S. EPA, 1985a; U.S. EPA, 1985b.

13.0 DREDGING

Type of Control: Surface Water, Sediment

Function: Used to recover contaminated sediments beneath a water body (i.e., contaminants that have been deposited in, or adsorbed by sediments in natural water bodies).

Description: The choice of method; mechanical, hydraulic, and pneumatic, depends on the size of the water body, flow rates, and sediment characteristics. Diversion techniques and dredge spoil management technologies are used in conjunction with dredging operations. Mechanical dredging is used for smaller water bodies with depths of 10 ft or less, and stream flows of 2 ft/sec or less. Mechanical dredging equipment includes backhoes, crane-mounted draglines, bucket loaders, and clamshell buckets. Mechanical dredging can be performed directly in-stream or on barges. Typically, mechanical dredging is performed in conjunction with water body diversion techniques.

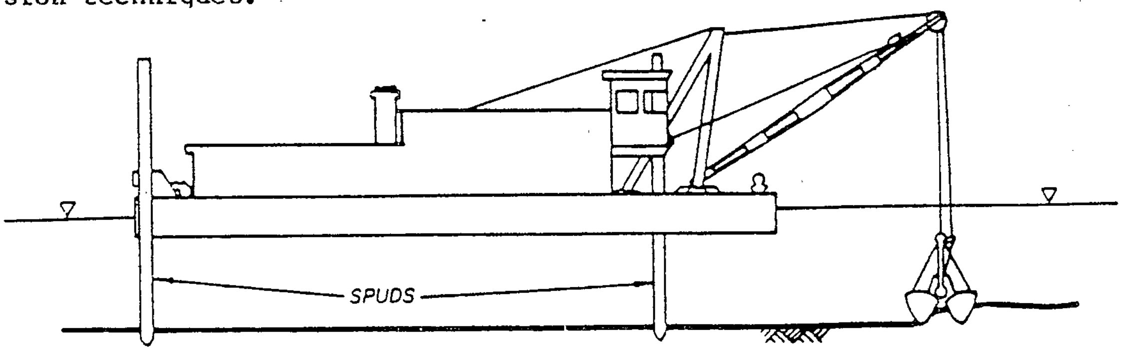


Figure 13.0. Example of mechanical dredging equipment.
Source: U.S. EPA, 1985b.

Hydraulic dredging is performed in-stream using specialized floating equipment and removes sediments using a cutting and/or suction apparatus. The material is collected and suction-removed through a floating pipeline to land-based temporary storage, dewatering, treatment, and/or disposal facilities. Hydraulic dredging can be used in several types of water bodies and waste impoundments, and effectively removes liquid, slurries, semi-solid sludges, and sediments.

Pneumatic dredges are very similar to hydraulic dredges. Pneumatic dredges have a pump that operates on compressed air and hydrostatic pressure to draw sediments to the collection head and through the transport piping. Examples of pneumatic dredges include the airlift, the pneuma, and the oozer. Pneumatic dredges, are able to yield denser slurries than conventional hydraulic dredges with lower levels of turbidity and solids resuspension. However, pneumatic dredges have lower production rates (maximum of 390 cu. yd/hour).

Design Considerations: Dredge spoil management is usually required prior to final disposal. If a pumping system transports the dredged sediments, booster pumps are used for distances greater than 0.5 miles.

Limitations: In-stream sediment dredging activities can cause resuspension of sediment particles in the water; therefore, barriers and diversions should be used to prevent uncontrolled downstream transport of contaminated sediments.

Technology Status: Conventional, demonstrated.

Associated Technologies: Surface water/sediment containment barriers, diversions, pumping, sedimentation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs
Nature and extent of aquatic ecosystem	Some ecosystem disruption, particularly in wetlands; fill placement and revegetation may be required	Wetlands assessment	400-1,000
Geologic characteristics	Near surface bedrock and large boulders; may restrict cofferdams as barriers during mechanical dredging operations	Existing geologic maps; geologic survey; bore hole logs	Boreholes-50/lin. ft
Topography/site accessibility	May limit the type and size of dredging equipment	Site inspection; site survey; town/city/county records	Nominal
Dimensions of water body	Mechanical dredging is used for smaller water bodies with depths of 10 ft or less	Field measurements	400
Stream flow velocity	Mechanical dredging best suited for stream flows of 2 ft/sec or less	Stream gauge measurements, USGS records.	400
Phys. and chem. characteristics of the waste	Protective measures may be required	Sampling and analysis	100/sample
Phys. and chem. characteristics of soil/sediment	Selection of dredging techniques	Sieve analysis; volume-weight analysis	50/test
Climate	Frequent and heavy rains lower efficiency	National Climatic Center (NCC); local weather bureau	50

References: GCA, 1985c; Ehrenfeld and Bass, 1984; U.S. EPA, 1985a; U.S. EPA, 1985b.

14.0 BIOLOGICAL TREATMENT

14.1 ACTIVATED SLUDGE

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to aerobically break down organic wastes in aqueous waste streams through the activity of microorganisms. This technology is most efficient in removing alcohols, phenols, phthalates, cyanides, and ammonia.

Description: Activated sludge processes break down organic wastes in aqueous streams by aerobic oxidation and hydrolysis, and separate into a liquid effluent and a concentrated biomass sludge. As diagrammed in Figure 14.1, aqueous wastes are placed in a tank equipped with an aeration device. Sludge with air or pure oxygen pumped into the tank through nozzles or mechanical aerators. The aerated sludge/waste mixture is transferred to a clarification unit where the sludge biomass and treated aqueous waste are separated by sedimentation. Treated effluent is discharged from the process. A portion of the sludge is returned to the aeration unit to provide a continuing source of microorganisms. Excess sludge is periodically removed from the tank for disposal.

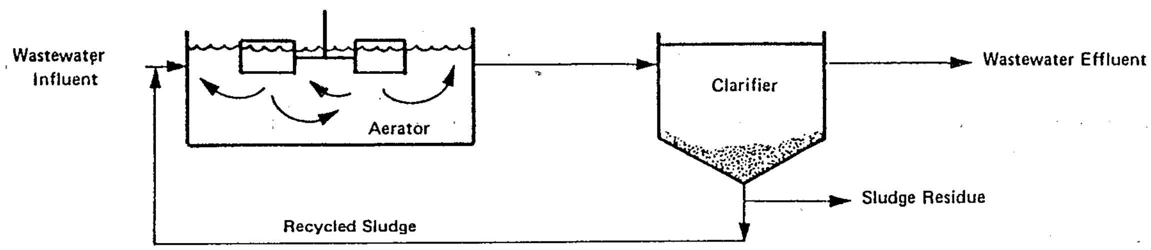


Figure 14.1. Activated sludge system diagram.
Source: ADL, 1976.

Factors affecting the removal efficiency of activated sludge systems include: the type of organics present, type of aeration, retention time, pH level and waste loading. Because of the importance of a near neutral pH, most systems employ an equalization tank and pH adjustment as pretreatment steps. Performance of the system is typically determined by BOD or COD removal efficiency. In hazardous waste applications, the removal of specific compounds is often the required performance criteria. Existing activated sludge treatment plants have been used to treat leachate from hazardous waste facilities. Removal efficiencies of up to 65 percent have been achieved in studies conducted on landfill leachate.

Design Considerations: Design parameters for activated sludge treatment are: BOD and toxic constituent removal rate, detention time in the aeration unit, clarifier surface area and design, nutrient requirements to sustain biological activity, and sludge production.

Limitations: Some heavy metals and some organic compounds at concentrations above a few ppm are toxic to activated sludge organisms. Pre-treatment processes may be required. Activated sludge processes may have difficulty in removing highly chlorinated organics, aliphatics, amines, and aromatic compounds from wastewater.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Pre-treatment pH adjustment, sludge filtration, incineration, land disposal.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components (BOD,TOC)	Suitability for treatment	Sampling and analysis	100/sample
Specific organic constituents	Suitability for treatment	Organic pollutant scan	1,500-2,000/ sample
Influent pH	Effect on efficiency and microorganisms	Sampling and analysis	Nominal
Effluent requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; Kosson, 1985.

14.0 BIOLOGICAL TREATMENT

14.2 TRICKLING FILTER

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to decompose organic matter in aqueous liquid wastes with less than 1 percent suspended solids. Most efficient in removing alcohols, phenols, phthalates, cyanides, and ammonia.

Description: Liquid aqueous wastes are sprayed over a bed of rocks or synthetic media upon which a slime of microbiological organisms is grown. The microbes decompose organic matter aerobically at the outer slime surface by natural updrafts of air through the bed. Anaerobic decomposition may occur within the microbial mass adjacent to the trickling bed media. Design factors which influence the removal efficiency of this system are: type, number, size, and configuration of the filter units used, recycling of effluent, pre- and post-treatment, and BOD of pollutant load.

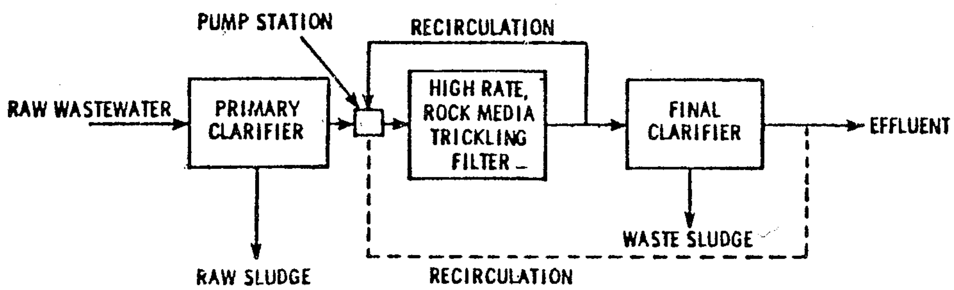


Figure 14.2. Trickling filter treatment system.
Source:

Design Considerations: Design parameters for trickling filters include: size, type, number and configuration of the filters, pollutant BOD load, waste constituents and volume, necessity for pre- and post-treatment, hydraulic load, recirculation method, and sludge generation rate. Secondary design considerations may be associated with clarifier requirements, nutrient needs of the system, bed depth, and media type.

Limitations: A disadvantage of trickling filters is the requirement for very uniform waste composition, flow rate and a consistent temperature above 0 degrees C. Odors from the filter and flies can be a problem. Clogging and surface ponding in the filter can result from inadequate liquid flow through the system. If the filter must be covered for odor control, forced air ventilation is often necessary.

Technology Status: Conventional technology, as yet undemonstrated for the treatment of hazardous wastes. The use of mixed microbial populations in soils to biodegrade leachate from hazardous waste lagoons has been investigated. This method involved the use of soil as the microbial growth media rather than the usual filter design.

Associated Technologies: Activated sludge treatment, filtration, incineration, land disposal.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components (BOD,TOC)	Suitability for treatment	Sampling and analysis	100/sample
Influent temperature	Effect on efficiency and microorganisms	Process management	Nominal
Waste volume	Adequate treatment capacity	Site survey processes	Variable

References: Ehrenfeld, 1983; Kosson, 1985.

14.0 BIOLOGICAL TREATMENT

14.3 AERATED LAGOONS

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to aerobically break down hazardous organic wastes in lagoons (surface impoundments) through microbial oxidation, and photosynthesis. This technology is most efficient in removing alcohols, phenols, phthalates, cyanides, and ammonia.

Description: Aerated lagoons break down aqueous organic wastes by aerobic oxidation and hydrolysis as diagrammed in Figure 14.3. An aerated lagoon is very much like a eutrophic lake. The lagoon is equipped with an aeration device, or aeration may be provided by wind action and algae. The aerator provides movement of the liquid to cause mixing with air. The oxygen supplied by aeration is used by the microorganisms to oxidize organic matter to carbon dioxide. Algae use carbon dioxide for photosynthesis which, in turn provides more oxygen. Secondary clarification can be carried out in a lagoon by physical and chemical means.

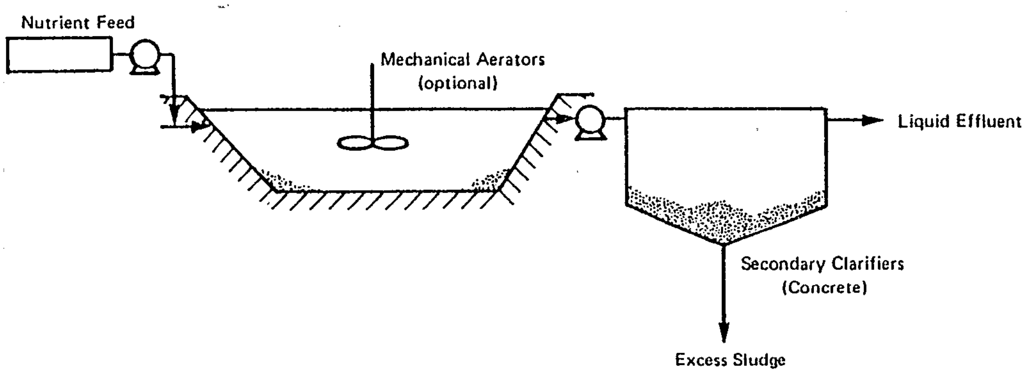


Figure 14.3. Aerated lagoon (surface impoundment).
Source: Ehrenfeld, 1983.

Factors effecting the removal efficiency of aerated lagoon systems include: the type of organics present, type of aeration, detention time, depth, and BOD levels. Lagoons can typically handle BOD levels of 200-500 mg/l; systems with anaerobic digestion can handle somewhat higher levels. Performance of the system is typically determined by BOD or COD removal efficiency, usually in the range of 60-90 percent. Often, lagoons are used to polish low BOD effluent from activated sludge or trickling filters before discharge.

Design Considerations: Design parameters for aerated lagoons are: composition of wastes to be treated, volume of wastes to be treated, BOD removal rate, detention time in the lagoon, surface area of the lagoon, effluent limitations, local weather, and sludge generation rate to determine the need for secondary clarification.

Limitations: Some heavy metals and some organic compounds at concentrations above a few ppm are toxic to microorganisms. If such toxic substances are present in sufficiently high concentrations, pre-treatment processes may be required to remove them. Impoundments are most efficient during warm weather; cold weather or ice formation significantly reduce efficiency, and requiring longer detention times. To reduce excess sludge generation, suspended solids in the influent must be kept below 1.0 percent. There may be odor from chemical volatilization.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Pre-treatment pH adjustment, activated sludge, trickling filters, sludge filtration, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components (BOD, TOC)	Waste strength for treatment duration	Sampling and analysis	100/sample
Specific organics	Suitability for treatment	Organic pollutant scan	1,500-2,000/ sample
Dissolved heavy metals	Toxic impact	Sampling and analysis	900-1,200/ sample
Temperature	Feasibility in climate	Meterological data	Nominal
Priority pollutant analyses (organics, metals, pesticides, CN, phenols)	Suitability for treatment, toxic impact assessment	Sampling and analysis	1,300-1,500/ sample
Waste volume	System capacity	Varies with waste stream	Variable 0-50,000
Effluent requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; Kosson, 1985.

14.0 BIOLOGICAL TREATMENT

14.4 WASTE STABILIZATION PONDS

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to aerobically break down hazardous organic wastes in lagoons (surface impoundments) through microbial oxidation, and photosynthesis. This technology is most efficient in removing alcohols, phenols, phthalates, cyanides, and ammonia.

Description: Stabilization lagoons break down aqueous organic wastes by aerobic oxidation and hydrolysis of the wastes. The lagoon is not equipped with an aeration device; mixing and aeration are provided by wind and algal action. The oxygen supplied by mixing is used by the microorganisms to oxidize organic matter to carbon dioxide. Algae use the carbon dioxide for photosynthesis which, in turn provides more oxygen. This type of lagoon is usually shallow, from 0.3 to 0.6 meters in depth. Secondary clarification can be carried out in a lagoon by physical and chemical means or in a secondary clarification unit as shown in Figure 14.4.

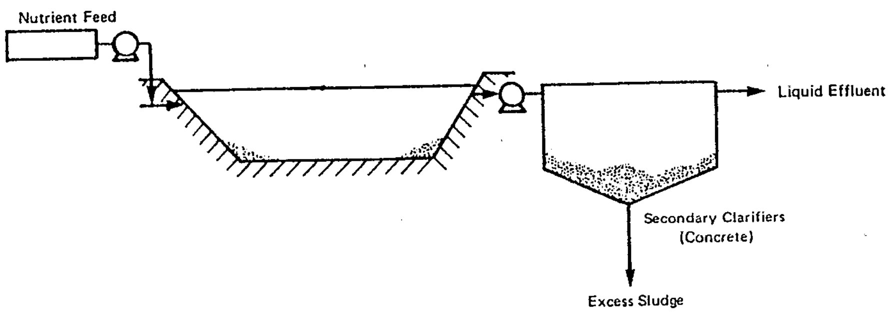


Figure 14.4. Stabilization lagoon (surface impoundment).
Source: Ehrenfeld, 1983.

Factors affecting the removal efficiency of lagoon systems include: the type of organics present, type of aeration, detention time, depth, and BOD levels. Lagoons can typically handle BOD levels of 200-500 mg/L; systems with anaerobic digestion can handle somewhat higher levels. Performance of the system is typically determined by BOD or COD removal efficiency, usually in the range of 60-90 percent.

Design Considerations: Design parameters for stabilization lagoons are: nature of the wastes to be treated, volume of wastes to be treated, BOD removal rate, detention time in the lagoon, surface area of the lagoon, effluent limitations, local weather, and sludge generation rate to determine the need for secondary clarification.

Limitations: Some heavy metals and some organic compounds at concentrations above a few ppm are toxic to microorganisms. If such toxic substances are present in sufficiently high concentrations, pre-treatment processes may be required to remove them. Impoundments are most efficient during warm weather; cold weather or ice formation will significantly reduce efficiency, requiring longer detention times. To reduce excess sludge generation, suspended solids in the influent must be kept below 1.0 percent. There may be odor from chemical volatilization.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Pre-treatment pH adjustment, activated sludge, trickling filters, sludge filtration, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components (BOD, TOC)	Waste strength, treatment duration	Sampling and analysis	100/ sample
Specific organics	Suitability for treatment	Organic pollutant scan	1,500-2,000/ sample
Dissolved heavy metals	Toxic impact	Sampling and analysis	900-1,200/ sample
Temperature	Feasibility in climate	Meteorological data	Nominal
Waste volume	Adequate treatment volume	Capacities of processes producing wastes	Variable
Effluent requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; Kosson, 1985.

14.0 BIOLOGICAL TREATMENT

14.5 ROTATING BIOLOGICAL DISKS

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Rotating biological discs (RBD) are used to aerobically break down organic wastes in aqueous waste streams through the activity of microorganisms. This technology is most efficient in removing alcohols, phenols, phthalates, cyanides, and ammonia.

Description: RBD processes facilitate aerobic oxidation and hydrolysis, and separate wastes into a liquid effluent and a concentrated biomass sludge in a secondary clarifier (Figure 14.5). Aqueous wastes are first subjected to primary treatment, then pumped in a tank equipped with the RBD. A series of discs, 2-3 meters in diameter, coated with a microbial film, rotate through troughs containing effluent. About 40-50 percent of the disc area is immersed in the effluent, while the remainder of the disc exposes the microbial film to the atmosphere. The shearing motion of the disc through the effluent keeps the biological floc from becoming too dense. Discs are usually arranged in series in groups of four. The aerated sludge/waste mixture is transferred to a secondary clarification unit.

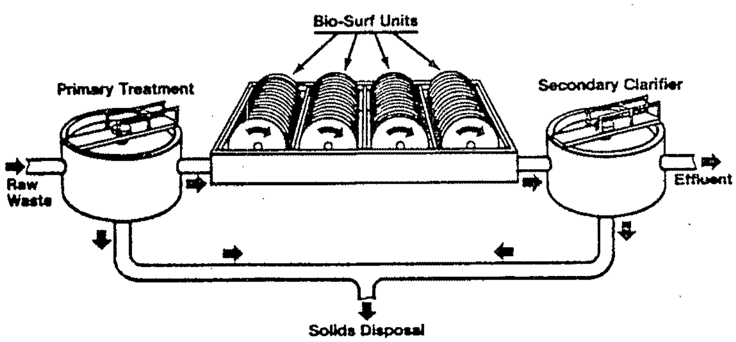


Figure 14.5. Rotating biological disk system diagram.
Source: Ehrenfeld, 1983.

Factors effecting the removal efficiency of RBD systems include: the type and concentration of organics present, waste volume, discrotational speed, media surface area exposed and submerged, and pre- and post-treatment facilities. Like other biological treatment units, RBDs are temperature sensitive and removal efficiency falls with temperature. RBD systems, like activated sludge units, are typically designed to remove between 85 to 90 percent of wastewater BOD load.

Design Considerations: Design parameters for RBD treatment systems are: organic and hydraulic loading, design of disc train(s), rotational velocity, tank volume, media area submerged and exposed, detention time in the unit, primary treatment and secondary clarifier capacity, and sludge production.

Limitations: Some heavy metals and some organic compounds at concentrations above a few ppm are toxic to microorganisms. If such toxic substances are present in sufficiently high concentrations, pre-treatment processes may be required to remove them. RBD processes may have difficulty in removing highly chlorinated organics, aliphatics, amines, and aromatic compounds.

Technology Status: Conventional, not demonstrated. Activated sludge treatment plants have been used to treat leachate from hazardous waste facilities. Since RBD systems should be capable of treating the same types of wastes as activated sludge or aerated impoundment systems, they should be able to treat similar types of hazardous wastes.

Associated Technologies: Primary treatment, secondary clarification, sludge filtration, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components (BOD,TOC)	Waste strength, treatment duration	Sampling and analysis	100/sample
Priority pollutant analyses (organics, metals, pesticides, CN, phenols)	Suitability for treatment, toxic impact assessment	Sampling and analysis	1,300-1,500/ sample
Temperature	Feasibility in climate	Sampling and analysis	Nominal
Waste volume	System capacity	Varies with waste stream or hydrogeological investigation	Variable 0-50,000
Effluent requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; Kosson, 1985.

14.0 BIOLOGICAL TREATMENT

14.6 LAND APPLICATION

Type of Control: *In situ* Treatment

Function: Direct application of biodegradable wastewater onto land for microbial decomposition.

Description: Ground level application is conducted by pipe distributors, under pressure, in which liquid wastewater discharges 15-30 cm above the ground. There are currently four common modifications on the distribution system: high and slow rate irrigation, overland flow, and rapid infiltration. Figure 14.6 illustrates irrigation and over land flow. The waste constituent separation and conversion occurs through filtration and oxidation by physical, chemical or biological means. High/slow rate land treatment irrigation is the application of wastewater to crops where effluent percolation depth and vegetation are critical components. Overland flow treatment consists of vegetated, sloped terraces and relatively impermeable runoff ditches. After percolation, more than 50 percent of the applied wastewater is then returned for reuse or secondary treatment. Rapid infiltration is the high rate application of wastewater to rapidly permeable ground tables such as sand or loam where treatment occurs through the soil matrix.

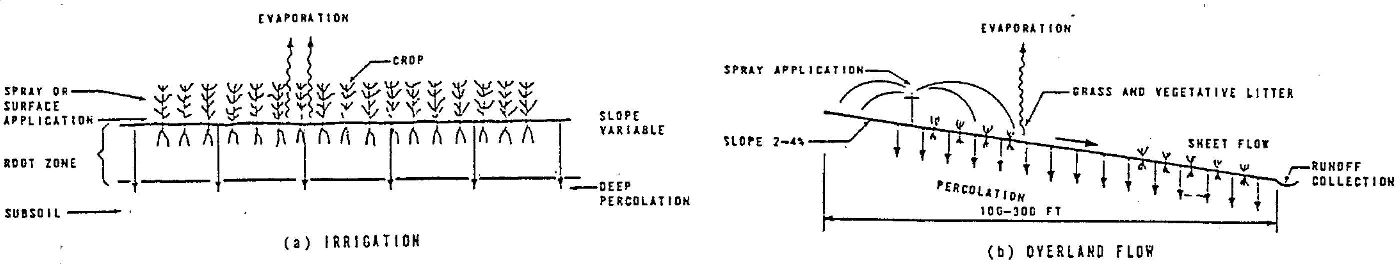


Figure 14.6. Land application techniques.
Source: Ehrenfeld, 1983.

Design Considerations: Prior to process selection or implementation, the following factors must be determined: application techniques, preapplication techniques, preapplication treatments, soil type and permeability, topography, depth to ground water, wastewater characteristics, and climatic restrictions such as number of days above freezing, annual rainfall, etc.

Limitations: Critical limitations of land application include siting (soil characteristics, land use conflicts, etc.), and potential environmental pollution (soil sealing, runoff, plant poisoning, etc.).

Technology Status: Land application is a proven removal method for biological oxygen demand, suspended solids, and nutrients.

Associated Technologies: Excavation and removal, revegetation, dikes and berms, terraces and benches, ditches and diversions.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Soil permeability	Determine type of treatment	Triaxial permeater	100
Soil type	Detemine crop cover, harvesting and use, if any	Sampling and sieve analysis, plasticity tests	150
Topography, site area site accessibility	Selection of area large enough for installation	Site inspection site survey; area records	150-250/ acre
Priority pollutant analysis	Determine toxicity to plants and food chain	GC/MS/AAS	1,100
pH of wastewater	Determine adequacy for plants (6.4-8.4)	pH probe	Nominal

References: Overcash, 1981; U.S. EPA, 1977.

14.0 BIOLOGICAL TREATMENT

14.7 BIORECLAMATION

Type of Control: *In situ* Treatment

Function: Technique for treating zones of contamination by microbial degradation.

Description: Two general types of bioreclamation systems include injection/extraction wells and gravity flow (subsurface drains). A typical injection and recovery system, illustrated in Figure 14.7, extracts ground water downgradient of a contamination zone and reinjects it upgradient. *In situ* aeration supplies oxygen directly while nutrients are added inline by way of mixing tanks. Subsurface drains are limited to depths of 40 feet or less under conditions of moderately low permeability. A typical collection drain would be a lined trench, 10 feet deep by 4 feet wide, whose length would encompass the hypothetical ground water plume. Construction would be in such a manner that reinjected water flows out of the downgradient side of the well.

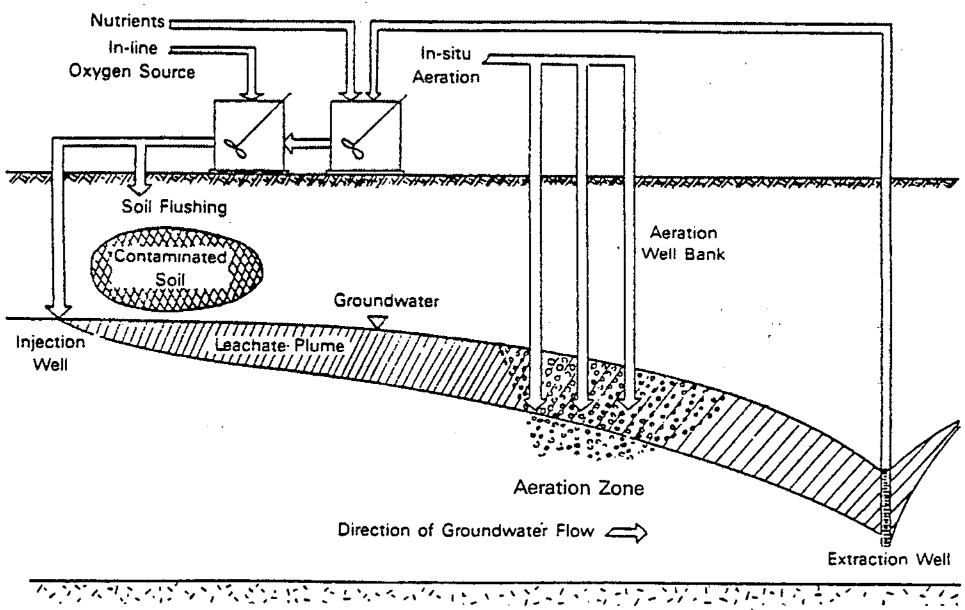


Figure 14.7. Treatment of contaminated ground water with the bioreclamation technique.
Source: EPA, 1985b.

Design Considerations: Prior to implementation it is recommended that a thorough site hydrogeological and geochemical investigation be conducted. Data to be determined include size, flow rate, and chemical composition of the contaminated plume. Other factors affecting microbial size and activity include pH, temperature, soil permeability, and degree of water saturation.

Limitations: The operating period will depend on the biodegradation rate and potential of the contaminants and the amount of recycle. Under adverse hydrogeological conditions of excessively long operating periods, other aquifer restoration methods may be more appropriate.

Technology Status: Aerobic bioreclamation has been demonstrated to be effective at more than 30 organic spill sites (U.S. EPA, October 1985). Although not yet tested at hazardous waste sites, the method should prove effective if the organics are amenable to biodegradation and aquifer hydraulic conductivity is sufficiently high.

Associated Technologies: Excavation and removal, drainage structures, injection/extraction wells and ground water pumping.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components (BOD,TOC)	Waste strength treatment duration	BOD_5 test; TOC analyzer	50/sample
Priority analysis	Identify refractory and biodegradable compounds, toxic impact	Sampling and analysis	1,300-1,500/ sample
Microbiology cell enumerations	Determine existence of dominant bacteria	Bacterial aerobic heterotrophic plate counts	50/test
Temperature	Feasibility in climate	*In situ* water quality monitoring	100/sample point
Dissolved oxygen	Rate of reaction	D.O. meter	10/sample
pH	Bacteria preference	pH meter	10/sample
Nutrient analysis NH_3, NO_3, PO_4, etc.	Nutrient requirements	Field test kits Lab analysis	100/sample

References: U.S. EPA, 1985a; U.S. EPA, 1985b; Flatham, et al., 1986; Pope Scientific, Inc. 1976.

14.0 BIOLOGICAL TREATMENT

14.8 PERMEABLE TREATMENT BEDS

Type of Control: In situ Treatment

Function: Used to produce a nonhazardous soluble product or a solid precipitate upon adequate contact between treatment agents and contaminated ground water or leachate.

Description: As shown in Figure 14.8, permeable treatment beds are essentially excavated trenches placed perpendicular to contaminated ground water flow. The beds are filled with a reactive, permeable medium to behave as an underground reactor. Currently, four types of reactive media can be feasibly utilized in permeable beds, i.e., limestone or crushed shell, activated carbon, glauconitic green sands, and synthetic ion exchange resins. Limestone or crushed shell have been shown by a laboratory study (Artiola and Fuller, 1979) to be effective in neutralizing acidic ground water and removing heavy metals such as cadmium, iron and chromium. The effectiveness of limestone as a barrier depends primarily on the pH and volume of the solution passing through the limestone (Artiola and Fuller, 1979). Activated carbon has the capability of removing nonpolar organic compounds, while glauconitic green sands have the potential for the removal of 60 to 90 percent of many heavy metals (e.g., copper, mercury, nickel, arsenic, cadmium). Zeolites and synthetic ion exchange resins are also effective in removing heavy metals, but short lifetimes and high costs make them unattractive.

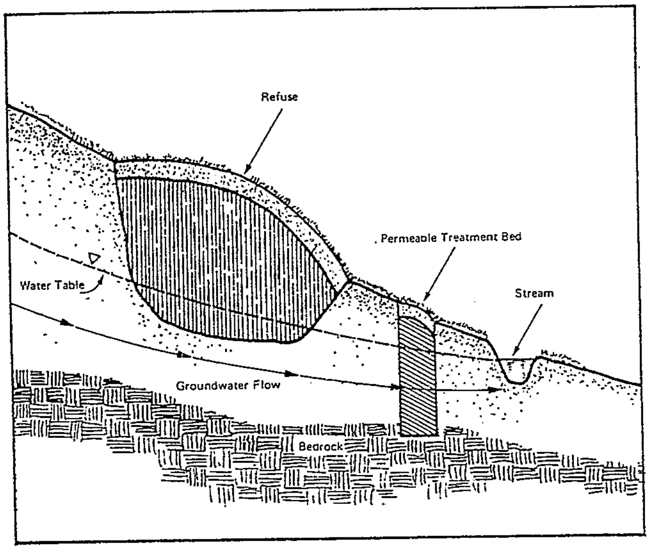


Figure 14.8. Permeable treatment bed.
Source: EPA, 1982.

Design Considerations: In addition to plume characteristics, soil permeability, waste characteristics (pH, volume of solution) and reaction rate should be determined to select the proper reaction medium and bed design.

Limitations: Permeable treatment beds are only applicable to relatively shallow ground water tables since the trench must be constructed down to the level of an impermeable strata. Also, due to short life (resulting from saturation of bed materials, plugging of bed with precipitates and short life of treatment materials), high cost, and reactivation difficulties, permeable beds are feasible only on a temporary basis.

Technology Status: Permeable treatment beds are in the conceptual stage for use at hazardous waste sites; many potential difficulties currently affect implementation.

Associated Technologies: Excavation and removal ditches, channels or trenches, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Depth to bedrock	Define extent of bed	Soil borings	50 ft.
Plume cross section	Define extent of bed	Ground water sampling wells	50 ft.
Hazardous constituent	Define reactive media	Full pollutant scan	1,100
Hydraulic gradient	Define bed residence time	Monitoring well, ground water elevation	50 ft.
Soil permeability	Define bed residence time	Triaxial permeater	100/test

References: U.S. EPA, 1985a; U.S. EPA, 1985b.

15.0 CHEMICAL TREATMENT

15.1 NEUTRALIZATION

Type of Control: Direct Waste Treatment, Aqueous Treatment, In situ Treatment

Function: Used to adjust basic or acidic wastewater to a neutral pH.

Description: Neutralization adjusts a waste stream to an acceptable pH level for discharge (usually between pH 6.0 and pH 9.0). Neutralization may also be used as a pre- or post-treatment step with other treatment processes. The adjustment of pH is done by adding alkaline wastes or chemical reagents to acidic streams and vice versa. Figure 15.1 shows a three-stage neutralization system schematic including initial neutralization, equalization and final adjustment. The system consists of a multiple compartment, concrete basin, lined or coated with a corrosive-resistant material (e.g., acid brick). Mixers installed in each compartment provide adequate contact between the waste and neutralizing agents, which increases reaction times. In the first stage, the neutralizing agent is added to the waste. Equalization takes place during the second stage where further mixing occurs, allowing time for the neutralization reactions to stabilize. In the final stage, additional neutralizing agent may be added to insure that the pH of the waste stream is properly adjusted. In situ neutralization techniques involve injecting dilute acids or bases into the ground water (see Section 15.8 - Solution Mining) to optimize pH for further treatment (e.g., biodegradation, oxidation, reduction), or to neutralize basic or acidic plumes that do not require further treatment.

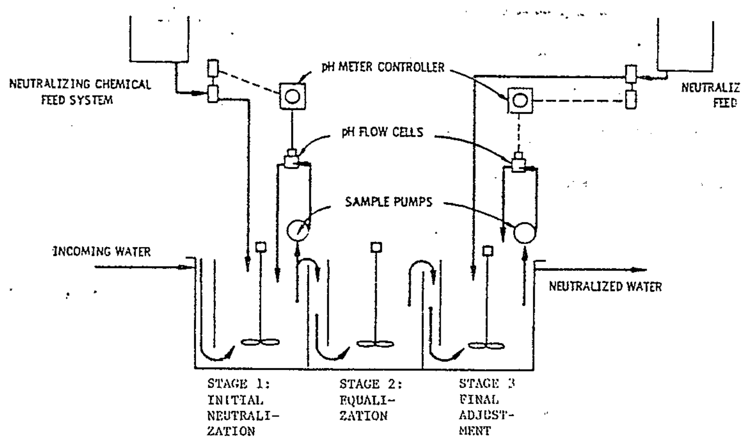


Figure 15.1. Flow diagram for neutralization process.
Source: U.S. EPA.

Design Considerations: The factors to be considered when choosing the most suitable reagent include: purchase cost, neutralization capacity, reaction rate, storage and feeding requirements, and neutralization products. The most common acidic reagents are sulfuric acid and hydrochloric acid. The most common alkaline reagents are various limes and sodium hydroxide. Reagents used in neutralization of untreated wastes may be quite corrosive, it is important to select compatible plant construction materials.

Limitations: Hazardous air emissions can be produced from the neutralization of certain hazardous waste streams (e.g., wastes containing sulfide salts). Feed tanks should be totally enclosed to prevent the release of acid fumes.

Technology Status: Conventional, demonstrated.

Associated Technologies: Carbon adsorption, ion exchange, air stripping, oxidation, reduction.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Expected average, variations in daily wastewater flow rate	Volume of waste to be neutralized; system size requirements	H model	400
Wastewater acidity or alkalinity	Reagent requirements	Sampling and analysis, GC/MS	900-1,000 (10 or more samples)
pH of wastewater	Reagent requirements	Sampling and analysis	10/sample

References: Ehrenfeld and Bass, 1984; U.S. EPA, 1980.

15.0 CHEMICAL TREATMENT

15.2 PRECIPITATION

Type of Control: Direct Waste Treatment, Agueous Treatment, *In situ* Treatment

Function: A physiochemical process in which some or all of a substance is removed from wastewater by conversion to an insoluble (solid) form.

Description: Precipitation is a treatment technique used for removal of heavy metals including zinc, cadmium, chromium, copper, lead, manganese, mercury, phosphate, sulfate, and fluoride. It involves alteration of the ionic equilibrium to produce insoluble precipitates that can easily be removed by sedimentation or filtration. Removal of metals as hydroxides or sulfides is the most common precipitation application in wastewater treatment. Generally, lime or sodium sulfide is added to the wastewater in a rapid mixing tank along with flocculating agents. As depicted in Figure 15.2, the precipitation initiation step is typically followed by flocculation and sedimentation or filtration. Flocculation describes techniques whereby precipitate particles become agglomerated. Sedimentation is used to separate the liquid and solid phases via settling in a basin (for further descriptions of these associated technologies see Section 16.2- Flocculation, Section 16.3 - Sedimentation, and Section 16.13 - Filtration).

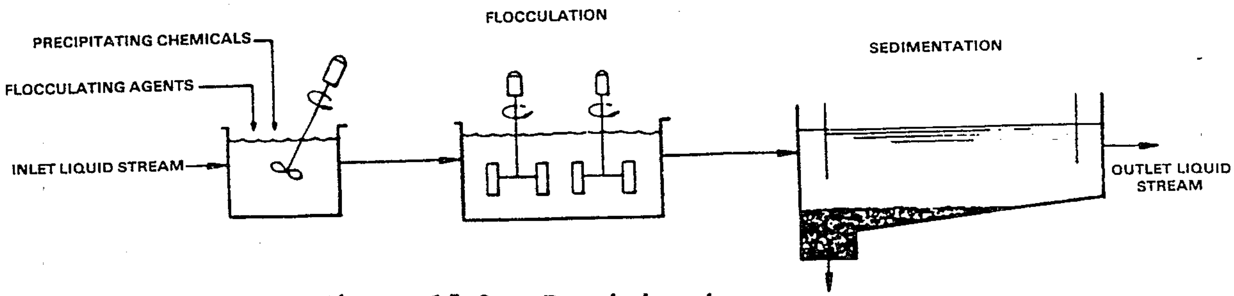


Figure 15.2. Precipitation process.
Source: EPA, 1985.

Design Considerations: Precipitation treatment can either be a batch or continuous operation. A mixing tank is sized based on wastewater flow and precipitation chemical/wastewater contact time required. Flocculation tank sizes are based on flow and retention time. Sedimentation tank size is based on laboratory experiments to determine the settling rate. The solubility of metal hydroxides and sulfides is greatly affected by pH, therefore, proper control of pH is essential for favorable performance of precipitation technologies. Neutralization techniques can be used to aid in the control of pH.

Limitations: Precipitation is inhibited by the presence of organic constituents that form organometallic complexes with metals. Cyanide may also complex with metals, reducing the efficiency of the precipitation process. Variable flow rates, pH, and metal concentrations can make precipitation reactions difficult to control.

Technology Status: Conventional, demonstrated.

Associated Technologies: Neutralization, flocculation, sedimentation, filtration.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Variations in daily wastewater flow rate	Implementability; precipitation is inefficient with highly variable flow rates	Flow monitoring; stream guaging	Variable
Wastewater characteristics	Reagent requirements, precipitable constituents, interfering species, sludge production rate	Sampling and analysis, GC/MS	900-1,000 (10 or more samples)
pH of wastewater	Reagent requirement and reaction success	Sampling and analysis	10/sample
Settling rate	Sedimentation tank size	Lab. analysis, Imhoff cone test	Variable

References: U.S. EPA, 1985; Ehrenfeld and Bass, 1984; U.S. EPA, 1980.

15.0 CHEMICAL TREATMENT

15.3 OXIDATION (CHLORINATION)

Type of Control: Direct Waste Treatment, Aqueous Treatment, In situ Treatment

Function: Uses chlorine in wastewater treatment to oxidize cyanides to cyanates and ultimately to carbon dioxide and nitrogen.

Description: Chlorine as elemental or hypochorite salt is a strong oxidizing agent in an aqueous solution. Chlorination of alkaline cyanide-containing wastes involves a two-stage process to remove cyanide. In the first stage, cyanide is oxidized to the less toxic cyanate ion. During the second stage, cyanates are oxidized to nontoxic bicarbonates and nitrogen. Figure 15.3 presents a two stage reactor, a configuration often used to minimize size or retention time by optimizing the reaction stages through pH control. During both stages, caustic and chlorine are added to act as the oxidizing agent.

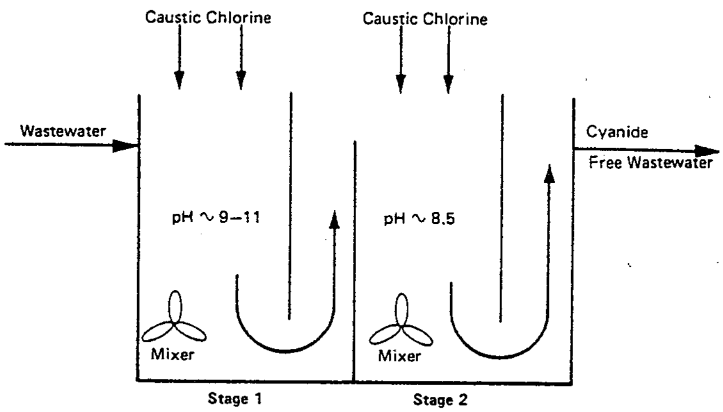


Figure 15.3. Two-stage chlorination reactor.
Source: Ehrenfeld and Bass, 1984.

Design Considerations: Requirements include vessels with agitators, storage vessels, and chemical metering equipment. Some instrumentation is required to determine pH and degree of completion of the oxidation reaction. The pH must be closely monitored to avoid development of acid conditions. Reagents must also be added in small amounts to avoid violent reactions.

Limitations: Excess chlorine may react with other constituents in the wastewater to form hazardous compounds. Another limitation is the potential hazard of storing and handling chlorine gas.

Technology Status: Conventional, demonstrated.

Associated Technologies: Ultraviolet/ozonation, oxidation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Variations in daily wastewater flow rate	Volume of water to be oxidized	Flow monitoring, stream gauging	Variable
Variations in contaminant concentrations	Reagent requirements to minimize formation of other hazardous compounds	Sampling and analysis, GC/MS	900-1,000 (10 or more samples)
Climate	Adequate temp. for reaction to proceed	National Climatic Center (NCC), Local weather bureau	10-20
pH	Suitable pH necessary for reaction to proceed	Sampling and analysis	10/sample

References: Ehrenfeld and Bass, 1984; GCA, 1985.

15.0 CHEMICAL TREATMENT

15.4 HYDROLYSIS

Type of Control: Direct Waste Treatment, Aqueous Waste Treatment, *In situ* Treatment

Function: *In situ* degradation on amines, carbonates, alkyl halides, sulfuric and sulfonic acid esters, phosporic and phosponic acid esters, nitriles, and pesticides typically via acid- or base-catalyzed reactions.

Description: Hydrolysis involves the displacement of a functional group on an organic molecule with a hydroxyl group from water. The reaction can be represented as follows:

$$RX + H_2O \rightleftharpoons ROH + HX$$

where R is the organic group, and X is the leaving group. Hydrolysis of organic compounds can result from a neutral reaction with water, or it can be catalyzed in the presence of an acid or a base. An alkali can also function as a stoichiometric reactant. A typical hydrolysis unit appears in Figure 15.4.

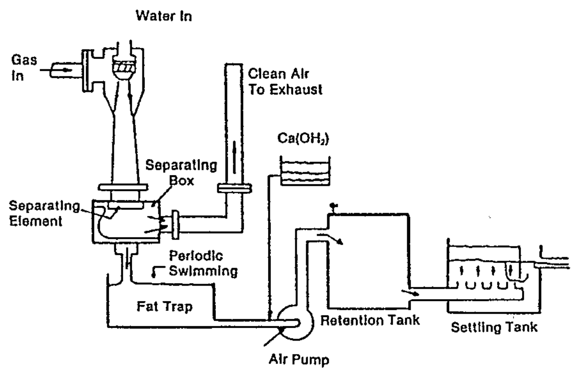


Figure 15.4. Hydrolysis unit.
Source: Kiang and Metry, 1982.

Design Considerations: Performance characteristics will be specific at each site. Factors which affect performance are temperature, pH, the homogeneity of the waste mixture, the availability of the waste constituents to react with the detoxifying agent, and the ability to mix waste and the detoxifying agent. Mixing is achieved by utilizing stirrers for surface impoundments or ultivators for landfills.

Limitations: The waste to be treated should be isolated from waste which is not compatible with the treatment reagent to prevent the formation of toxic byproducts. Environmental conditions of concern include pH and water temperature. Another limitation is the need for numerous, closely spaced injection wells, even in coarse-grained deposits.

Technology Status: Developmental. The basic methods using hydrolysis to treat hazardous waste have been developed and applied in an industrial setting. However, application at uncontrolled sites has been limited.

Associated Technologies: Neutralization.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Wastewater average and variable flow rates	Volume of water to be treated	H model	250/day
Wastewater analysis	Constituents applicable to technology, reaction rate	Sampling and analysis, GC/MS	900-1,000/ 10 samples
Soil permeability	Permeable soils best	Triaxial permeater	50/test
Soil type	Clay soils difficult to decontaminate	Sampling and sieve analysis, plasticity test, proctor compaction	50/test
Geohydrologic site survey	Establish potential for constituent contamination and well placement sites	Site survey	Variable, 5,000-50,000
pH of wastewater	Reagent requirements	Sampling and analysis	50/test
Climate	Determine suitable and and water temperature	National Climatic Center (NCC), Local weather bureau	50/test

References: EPA, 1974; EPA, 1983; EPA, 1985; EPA, 1985; EPA (Treatability Manual Vol. III), 1981; GCA , 1986; (Hazardous Waste Processing Technology) Kiang and Metry, 1982.

15.0 CHEMICAL TREATMENT

15.5 REDUCTION

Type of Control: Direct Waste Treatment, Aqueous Treatment, *In situ* Treatment

Function: Lowers the oxidation state of metals (primarily hexavalent chromium, mercury, and lead) to reduce toxicity or solubility, or to transform waste to a form which can be easily handled.

Description: Reduction is accomplished by addition of a reducing agent, which lowers the oxidation state of a substance. Base metals such as iron, aluminum, zinc, and sodium compounds, are commonly used as reducing agents. Sulfur compounds may also serve as effective reducing agents. A flow diagram for a typical reduction process is presented in Figure 15.5. Initially, the pH of the waste is adjusted to an appropriate level for efficient reduction to occur (e.g., pH 2 to 3 for sulfur dioxide treatment of chromium). Following pH adjustment, the reducing agent is added. The solution is then mixed to provide adequate contact between the reducing agent and the waste. Upon completion of the reduction reaction, the reduced solution is typically subjected to additional treatment to settle or precipitate the reducing agent. Filtration may be used to improve separation. The effluent stream is typically acidic and must be neutralized prior to discharge

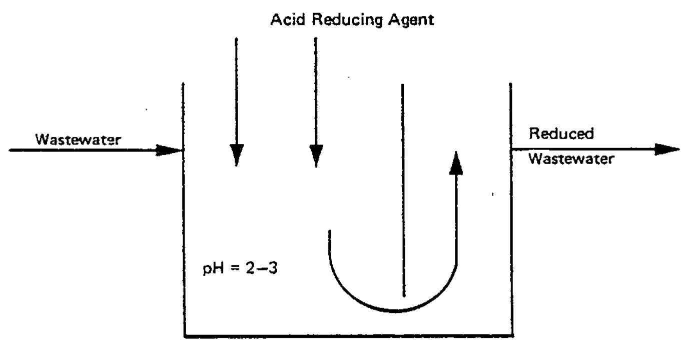


Figure 15.5. Reduction process schematic.
Source: Ehrenfeld and Bass, 1984.

Design Considerations: Reduction can be performed using simple, readily available equipment and reagents. Equipment requirements include: storage vessels for the reducing agents and wastes, metering equipment for both streams (flow control), contact vessels with agitators to provide suitable contact of reducing agent and waste, and monitoring instrumentation (i.e., pH meter, and oxidation-reduction potential electrode). Laboratory and pilot-scale tests should be performed for complex waste streams containing other potentially reducible compounds in order to determine appropriate feed rates and reactor retention times.

Limitations: Currently, there are not any practical methods for the reduction of organic wastes; reduction treatment methods are generally limited to metals. Another problem is the potential for introducing additional hazardous ions into the solution. Wastes containing high concentrations of contaminants may make reduction a cost-prohibitive option.

Technology Status: Conventional and demonstrated for industrial applications. However, *in situ* application at uncontrolled hazardous waste sites has been limited.

Associated Technologies: Oxidation, neutralization, precipitation.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Variations in daily wastewater flow rate	Volume of water to be treated	Flow monitoring, stream gauging	Variable
Wastewater analysis for contaminants	Reagent requirements	Sampling and analysis, GC/MS	900-1,000 (10 or more samples)
pH of wastewater	Reagent requirement reaction success	Sampling and analysis	10/sample

References: U.S. EPA, 1985, U.S. EPA, 1980; Ehrenfeld and Bass, 1984.

15.0 CHEMICAL TREATMENT

15.6 CHEMICAL DECHLORINATION

Type of Control: Direct Waste Treatment, Aqueous Waste Treatment, In situ Treatment

Function: Uses chemical reagents to break apart chlorinated molecules, or rearrange their structure, to form less hazardous compounds.

Description: Dechlorination techniques have been developed for the treatment of oils and liquid wastes. Conventional techniques involve filtering the liquid waste, and then transferring it to a reactor tank. In the reactor tank, a reagent (usually a sodium reagent) is mixed with the waste. Following dechlorination of the waste, the mixture is usually centrifuged and filtered. Effluent streams typically consist of the treated material, a salt (e.g., sodium chloride), a polyphenyl and/or a hydroxide (e.g., sodium hydroxide). Processes for in situ treatment of soils and solids are under development. These processes generally involve adding a sodium reagent to the waste. The reaction of the waste with the reagent results in the formation of a solid polymer, which is subsequently filtered out as shown in Figure 15.6. A variation of this technique involves excavating the contaminated soil, extracting the contaminant from the soil with a solvent, and dechlorinating the resulting extract.

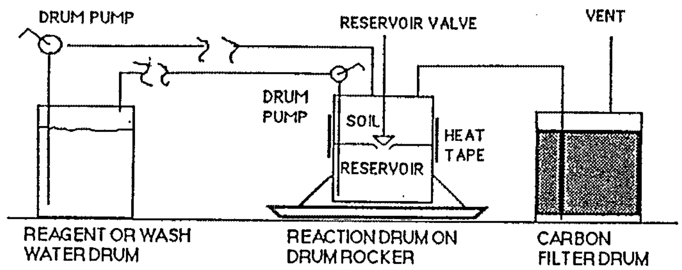


Figure 15.6. Dechlorination reactor system.
Source: Peterson, 1986.

Design Considerations: Performance characteristics will be specific at each site application. The ability to mix reagent and waste, the homogeniety of the waste mixture, the area requiring treatment, characteristics of the waste material to be treated, and the concentration of contaminants, are all factors to be considered. Laboratory-scale testing should be performed with the specific waste to insure that the treatment reagent is compatible with the waste, and that hazardous residues are not formed. Waste constituents which are not compatible with the treatment reagent should be physically isolated from the waste to be treated.

Limitations: Most of the dechlorination techniques have been developed for PCB-containing wastes. Some testing has been performed on dioxin-containing wastes, with promising results. Although dechlorination techniques could potentially be used for other chlorinated compounds, their use has been limited.

Technology Status: Chemical dechlorination of aqueous wastes has been demonstrated. *In situ* applications are in the developmental stage.

Associated Technologies: Oxidation, reduction, neutralization.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Cost ($)
Wastewater average and variations of daily flow rate	Volume of water to be processed	Help model	400
Wastewater and soil analysis	Reagent requirements; implementability	Sampling and analysis; GC/MS	900-1,000/ (10 samples)
Soil type	Not as effective in clayey soils	Plasticity tests; sieve analysis	50/Test
Hydrogeologic site survey	Establish potential for migration	Existing records and surveys; site survey	Minimal for existing information 100,000 for full survey and invest.
Site area/ extent of contamination	Feasibility and cost-effectiveness of implementation	Site invest; sampling and analysis	900-1,000/ 10 samples

References: GCA, 1985a; Berry, 1981; Peterson, 1986.

15.0 CHEMICAL TREATMENT

15.7 ULTRAVIOLET/OZONATION

Type of Control: Aqueous Treatment

Function: Uses simultaneous application of ultraviolet light and ozone for the oxidation of chlorinated hydrocarbons, chlorinated aromatics, pesticides, and phenolic compounds.

Description: Ultraviolet (UV) radiation is electromagnetic radiation having a wave length shorter than visible, but longer than x-ray radiation. UV radiation causes rearrangements of molecular structures such that new chemical compounds result. Ozone (O_3) is an unstable, highly reactive oxidizing agent. Ultraviolet-activated ozone has been shown to be successful in the degradation of certain organics.

Conventional UV ozonolysis techniques utilize a liquid-phase reaction. Ozone gas is bubbled into liquid waste or a liquid solution containing the contaminant. The mixture is then exposed to UV radiation in a mixing tank. The UV radiation not only degrades the contaminant directly, but also causes the ozone to be split into free oxygen, which further oxidizes the contaminant.

Design Consideration: Some key design parameters include: ozone dose rate, ultraviolet light dosage, and retention time. Ozone dosage is expressed as either ppm or pounds of ozone/pound of contaminants. Retention times range from 10 minutes to 1-hour, and ultraviolet light dosages range from 1 to 10 watts/liter.

Limitations: UV/ozonation is generally restricted to wastewaters with a 1 percent or lower concentration of hazardous contaminants. In addition, since ozone is a non-selective oxidant, the waste stream should contain primarily the compound of concern. If other oxidizable compounds are present, they will exert an additional demand for ozone. Since supplying ozone at a sufficiently fast rate can be difficult when treating concentrated wastes, this treatment method is not generally used for wastes which contain high levels of hazardous components. The waste to be treated should also be relatively free of suspended solids. A high concentration of suspended solids can impede the passage of ultraviolet radiation, and the waste treatment efficiency will be adversely affected.

Technology Status: Conventional, undemonstrated

Associated Technologies: Oxidation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Expected average, variations in daily wastewater flow rate	System capacity	Volume of flow rate measurement	Variable (0-10,000)
Concentration of oxidizable organics	Determine reagent requirements;	Sampling and analysis, GC/MS	900-1,000 (10 or more samples)
Climate	Adequate temperature for reaction to proceed	National Climatic Center (NCC), Local weather bureau	Nominal
pH	Suitable pH necessary for reaction to proceed	Sampling and analysis	Nominal

References: GCA, 1985; Ehrenfeld and Bass, 1984; GCA, 1984.

15.0 CHEMICAL TREATMENT

15.8 SOLUTION MINING (EXTRACTION)

Type of Control: Direct Waste Treatment, Aqueous Waste Treatment

Function: Removes and/or treats hazardous waste constituents by application of a solvent to a waste solid or sludge, and collection of the leachate at well points.

Description: As diagrammed in Figure 15.8, water or an aqueous solution is injected through an injection well point into the area of contamination. Sorbed contaminants are mobilized into solution via solubility, formation of an emulsion, or a chemical reaction with the flushing solution. The resulting leachate is pumped to the surface for removal, recirculation, or onsite treatment and reinjection. Typical flushing solutions include water, dilute acid solutions, and/or complexing and chelating agents. Water is generally used to flush water-soluble or water-mobile organics. Solubilities and octanol/water partition coefficients (which can be used to estimate water solubilities), are available for a number of compounds in Lyman, et al., 1982; and CRC, 1986.

Dilute acid solutions (e.g., sulfuric, hydrochloric, nitric, phosphoric, and carbonic acid) are widely used in industrial treatment/recovery processes to extract metal ions by dissolving basic metal salts (e.g., hydroxides, oxides, carbonates). For in situ treatment, weak acids (e.g., dihydrogen phosphate, acetic acid) should be used because of the toxicity of many of the stronger acids. Stronger dilute acid solutions (i.e., sulfuric acid) may be used if the soil or leachate is sufficiently alkaline to neutralize it. Acid solutions can be used to flush basic organic contaminants such as amines, ethers, and anilines.

Complexing and chelating agents, such as citric acid, EDTA, and DTPA, may be used to remove heavy metals. For metals which are strongly adsorbed to manganese and/or iron oxides, reducing agents can be used to release the heavy metal into solution. Chelating agents or acids can then be used to retain the metals in solution. Examples of these types of treatment combinations include: hydroxylamine with a dilute acid solution, and sodium dithionite/citrate. Surfactants can improve the effectiveness of solution mining techniques by enhancing the solubilities of aqueous solutions, and creating more effective transport. Various surfactants and their specific uses are presented in U.S. EPA, 1985.

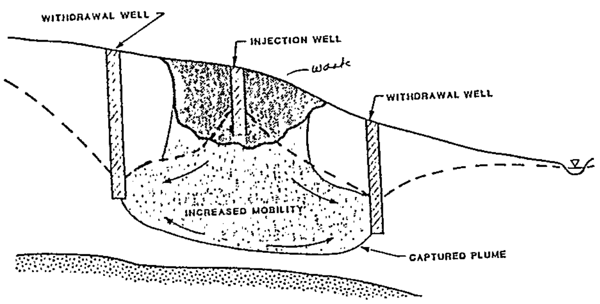


Figure 15.8. Solution mining using injection/withdrawal wells (cross-section). Source: EPA, 1985.

Design Considerations: Injection and withdrawal wells must be designed and placed such that contamination of surrounding ground water with extracting solvents and extracted material is prevented.

Limitations: Solution mining is not suitable for treating soils and leachate which are contaminated at low levels, or which are contaminated with complex waste mixtures. Additionally, it is generally not practical to treat large volumes of contaminated solids by this method.

Technology Status: This technology has been used extensively by the chemical processing and mining industries. However, its use for in situ treatment of hazardous waste is very limited. EPA has developed a mobile soils flushing system which has been tested on PCB-contaminated and dioxin-contaminated soils. A more complete description of this mobile system and the results of pilot tests can be found in U.S. EPA, 1983.

Associated Technologies: Precipitation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Wastewater volume and aquifer response characteristics	Volume of water for treatment, feasibility of pumping/extraction	Hydrogeologic modeling	Variable (10,000-10,000)
Waste analysis (volatile and semi-volatile organics)	Extraction efficiency of various solvents; presence of constituents which are incompatible with solvent	Sampling and analysis, GC/MS	1,200/sample
Soil organic content	Adsorption potential of soil	Sampling and TOC analysis	50/sample
Soil permeability	Permeable soils best	Triaxial permeameter	50/test
Soil type	Clay soils are more difficult to contaminate	Sampling and sieve analysis; plasticity test; proctor compaction	50/test

References: EPA, 1983; EPA, 1985a; EPA, 1985b; EPA, 1985c; EPA, 1981; GCA, 1986; Kiang-Metry, 1982; GCA, 1985; Ehrenfeld and Bass, 1984.

16.0 PHYSICAL TREATMENT

16.1 FLOCCULATION

Type of Control: Direct Waste Treatment (Aqueous Treatment), Solids Handling and Treatment

Function: Agglomerates fine suspended particles in an aqueous waste stream to larger, more settleable particles prior to sedimentation or other treatment; used primarily for the precipitation of inorganics (i.e., removal of metals as hydroxides or sulfides).

Description: Flocculation is a process which uses chemical and physical means to agglomerate small, unsettleable suspended particles into larger, more settleable particles. Initially, a flocculating agent is added to the waste stream. This step is followed immediately by rapid mixing to disperse the flocculating agent. The flocculating agent chemically induces destabilization of the repelling forces between the particles. After this step, the waste stream is mixed more slowly to allow for contact between the small particles. The non-repelling particles agglomerate into large, more settleable particles. Following flocculation, the agglomerated particles are usually removed from the liquid by sedimentation (see Section 16.2) or subjected to further treatment (Figure 16.1).

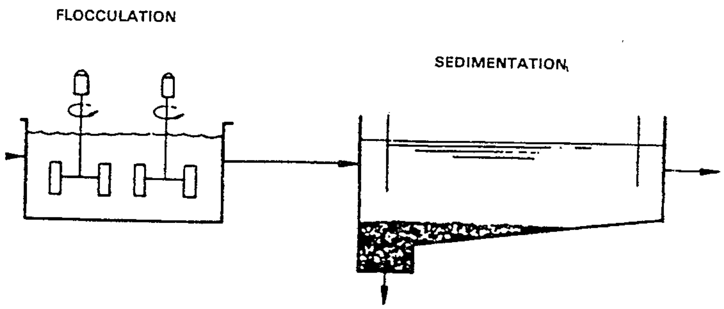


Figure 16.1. Typical flocculation system.
Source: U.S. EPA, 1985b.

Design Considerations: The flocculation process can be easily integrated into more complex treatment systems, and uses readily available and easily operated equipment (i.e., chemical pumps, metering devices, and mixing and settling tanks). Selection of the proper flocculating agent should be made on the basis of laboratory tests. Several types of flocculating agents may be used, including: alum, lime, iron salts, (ferric chloride, consisting of long-chain, water-soluble polymers such as polyacrylamides).

Limitations: Flocculation is not suitable for highly viscous waste streams, which tend to inhibit settling of solids. The performance and reliability of flocculation is significantly reduced for wastes with highly variable flow rates, composition, and pH.

Technology Status: Conventional, demonstrated.

Associated Technologies: Precipitation, sedimentation, filtration, dissolved air flotation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
pH of waste	Selection of flocculating agent	pH analysis	50/test
Viscosity of waste stream	Affects settling of agglomerated solids; high viscosity not suitable	Viscosity	50/test
Sludge flocculation, settling, and dewatering characteristics	Selection of flocculating agent	Laboratory scale tests	300
Leachate variability	Not suitable for wastes with highly variable pH, flow, and composition	Laboratory tests; sampling and analysis	100/sample

References: Ehrenfeld and Bass, 1984; JRB, 1984; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

16.0 PHYSICAL TREATMENT

16.2 SEDIMENTATION

Type of Control: Direct Waste Treatment (Aqueous Treatment), Solids Handling and Treatment

Function: Removes suspended solids from an aqueous waste stream.

Description: Sedimentation occurs by using gravitational forces to allow suspended solids in an aqueous solution to settle. The apparatus used for sedimentation includes a basin to maintain the aqueous waste to be treated in acquiescent state, a means of directing the aqueous waste to the basin that is able to maintain a relatively quiescent state, and a means of physically separating the liquid and the settled particles (i.e., either removing the settled particles, or removing the liquid). The sedimentation system can be designed as either a batch or a continuous process. The settling vessel can be a lined surface impoundment, a conventional settling basin, or a clarifier (usually circular). Figure 16.2 diagrams these design configurations. Sedimentation basins and clarifiers are typically designed with built-in solids removal devices such as a sludge scraper and/or a sludge draw-off mechanism.

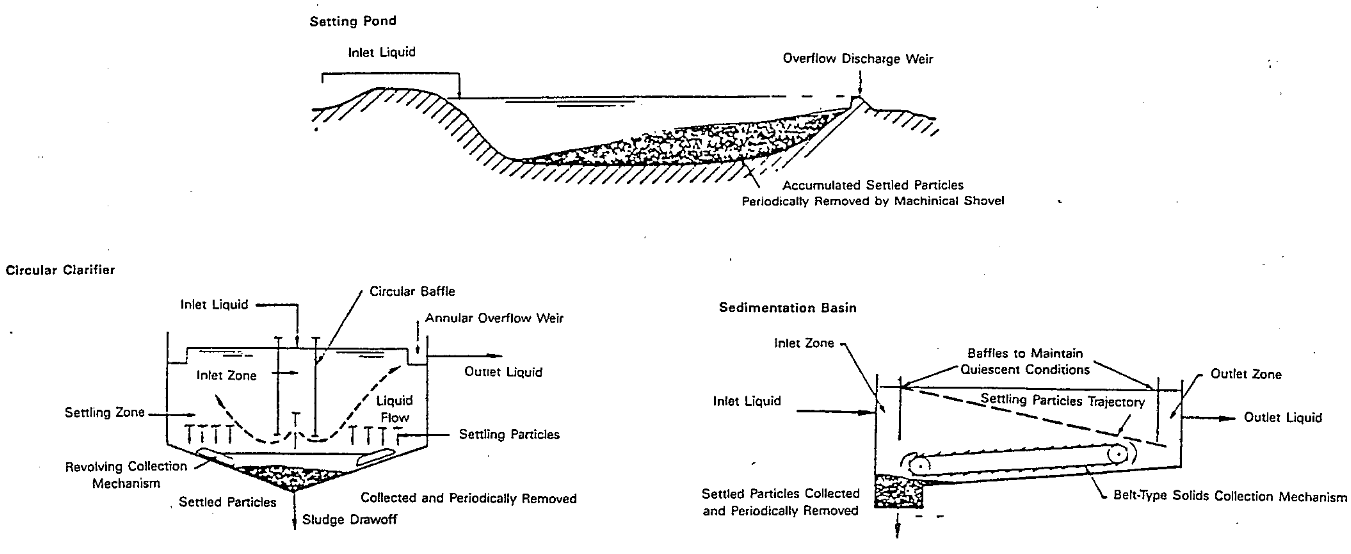


Figure 16.2. Representative types of sedimentation.
Source: U.S. EPA, 1985b.

Design Considerations: Important considerations in the design of a sedimentation system include: the ability to contain surges in flow, and allowing time for settling. Baffles are often installed to maintain quiescent conditions and to prevent reentrainment of settling particles. Particle removal is dependent upon basin depth, detention time, flow rate, surface area, and particle size.

Limitations: Sedimentation is limited to the removal of suspended solids which are heavier than water (i.e., specific gravity > 1). This technique is not suitable for wastes containing emulsified oils. The solids and/or liquids resulting from sedimentation generally require further treatment. Sedimentation is frequently used as a pretreatment step for many chemical processes (e.g., carbon adsorption, filtration).

Technology Status: Conventional, demonstrated.

Associated Technologies: Precipitation, flocculation, biological treatment, carbon adsorption, ion exchange, air or steam stripping, reverse osmosis, filtration, and dredging.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Viscosity of aqueous waste	High viscosity hinders sedimentation	Viscosity analysis	50/test
Oil and grease content of waste stream	Not applicable to wastes containing emulsified oils	Oil and grease analysis	50/test
Specific gravity suspended solids	Must be >1 for sedimentation to occur	Density analysis, or observation	50/test
Performance tests	To predict performance for flocculating particles	Laboratory-scale settling tests	300

References: Ehrenfeld and Bass, 1984; JRB, 1984; Sundstrom and Klei, 1979; U.S. EPA, 1985b.

16.0 PHYSICAL TREATMENT

16.3 CARBON ADSORPTION/ACTIVATED CARBON

Type of Control: Direct Waste Treatment (Aqueous Treatment), Gaseous Waste Treatment

Function: Used to remove dissolved organic compounds from contaminated ground water; effectively treated compounds include chlorinated pesticides, phenols, aliphatic chlorinated hydrocarbons, and aromatics (such as benzene, toluene, and xylene); effective and reliable means of removing low-solubility organics over a broad concentration range.

Description: Carbon adsorption can be designed for either column or batch applications, but ground water treatment is usually performed with columns. In column applications, adsorption involves the passage of contaminated water through a bed of activated carbon which selectively adsorbs the hazardous constituent (adsorbate) onto the carbon (adsorbent). When the activated carbon has been utilized to its maximum adsorptive capacity (exhaustion "spent"), it is then removed for disposal, destruction, or regeneration.

Design Considerations: Design factors affecting removal efficiencies include: carbon exhaustion (usage) rate, contact time, hydraulic loading rate, and column size. Adsorption efficiencies are affected by both the characteristics of the hazardous constituent and the characteristics of the aqueous waste streams in which they are contained. Characteristics of the hazardous constituent which affect adsorption include polarity, molecular weight, solubility, and molecular structure. In general, non-polar, high molecular weight organics with limited solubility are preferentially adsorbed. Structurally, branched-chain compounds are more readily adsorbable than straight-chain compounds. Characteristics of the aqueous stream which affect adsorption efficiency include: pH, temperature, suspended solids concentration, and oil and grease concentration. Generally, the compound will adsorb at the pH which imparts the least polarity to the molecule. Adsorption is an exothermic process, and therefore increased adsorption will occur as temperatures increase.

Limitations: To prevent clogging, it is necessary that the suspended solids concentration of the aqueous stream be less than 50 ppm, and the oil and grease concentration should be less than 10 ppm. Often, pretreatment techniques (e.g., granular filtration or sedimentation) are used in conjunction with carbon adsorption.

Technology Status: Conventional, demonstrated.

Associated Technologies: (Granular) filtration, reverse osmosis, sedimentation, biological treatment, air stripping.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Biological organisms in leachate	Can aid in treatment through biodegradation, or can hinder operation via clogging or odor generation	Sampling and analysis	100/sample
Leachate TSS concentration	Should not exceed 50 ppm; may need pretreatment	TSS analysis	50/test
Leachate oil and grease concentration	Should not exceed 10 ppm; may need pretreatment	Oil and grease analysis	50/test
Leachate components, and characteristics	Treatability via carbon adsorption	GC/MS analysis; CRC Handbook of Chemistry and Physics	approximately 100/sample

References: Ehrenfeld and Bass, 1984; GCA, 1985a; JRB, 1984; Kaufman, 1982; Lyman, 1980; Troxler, et al., 1983; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

16.0 PHYSICAL TREATMENT

16.4 ION EXCHANGE

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to remove cationic and anionic metallic elements, halides, cyanides, nitrates, carboxylics, sulfonics, and some phenols.

Description: Ion exchange is a reversible process in which an interchange of ions occurs between a solution and an essentially insoluble solid in contact with the solution. Toxic ions are removed from the aqueous phase by being exchanged with the relatively non-toxic ions held by the ion exchange material. The exchange material can consist of natural clays or zeolites; or synthetic resins are more commonly used. The extent to which removal of anions and/or cations occurs depends on the nature and volume of the ion, the type of resin and its saturation, and the ion in the contaminated aqueous solution. Ions with a higher charge will form more stable salts with the exchanger than those with a lower charge; thus allowing for selective removal of polyvalent species from a solution of monovalent species.

The ion exchange process may be operated using a batch or continuous technique. In a batch process, the ion exchange resin is stirred with the waste until the reaction is complete. The spent resin is removed by settling and is subsequently regenerated and reused. In a continuous process, the exchange material is placed in a bed or packed column, and the waste is passed through it. As diagrammed in Figure 16.4, various modes of operation are possible with the continuous technique, including: concurrent fixed bed, countercurrent fixed bed, and countercurrent continuous. Often, exchange columns are used in a series.

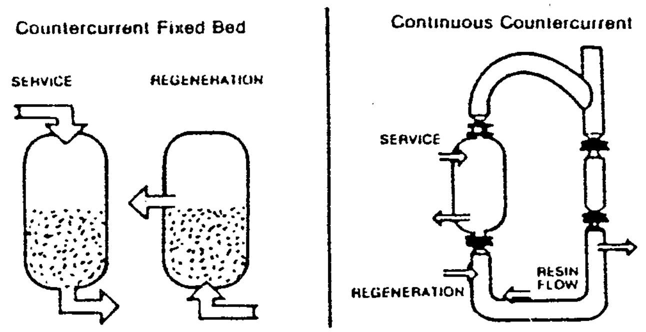


Figure 16.4. Ion exchange systems.
Source: U.S. EPA, 1985b.

Design Considerations: Important factors to consider in the design of an ion exchange system include: selection of appropriate resin to remove contaminants of concern, optimization of column flow-through rates, and determination of required regeneration rate. Laboratory scale experiments are generally performed to aid in the selection of the proper design parameters.

Limitations: Ion exchange is not suitable for removal of high concentrations of exchangeable ions (above 2,500 mg/L) because the resin material is rapidly exhausted during the exchange process and costs for regeneration become prohibitively high. Pretreatment of the wastewater is often necessary to remove any constituents which would adversely affect the resin. Certain organics (e.g., aromatics) become irreversibly sorbed by the resin. Oxidants (such as chromic or nitric acid) can also damage the resin.

Technology Status: Conventional, demonstrated.

Associated Technologies: Filtration, carbon adsorption, air stripping, sedimentation.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Leachate characteristics	Resin selection	Sampling and analysis	100/sample
TDS concentration	TDS should be 2,500 mg/l for efficient operation	TDS	50/test
TSS concentration	Suspended solids clog resin	TSS analysis	50/test
Treatability study	Flow through rate and resin regeneration frequency	Laboratory scale trial	300

References: Ehrenfeld and Bass, 1984; GCA, 1984; GCA, 1985a; JRB, 1984; Skoog and West, 1979; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

16.0 PHYSICAL TREATMENT

16.5 REVERSE OSMOSIS

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to remove dissolved organic and inorganic materials, and to reduce the concentration of soluble metals, total dissolved solids (TDS) and total organic carbon (TOC).

Description: The process of reverse osmosis involves filtering the contaminated water through a semi-permeable membrane at a pressure greater than the osmotic pressure caused by the dissolved materials in the water. Operating pressures generally range from atmospheric to 1,500 psi. The semi-permeable membrane is typically fabricated either in the form of a flat sheet (plane) or tube. As shown in Figure 16.5, the wastewater (feed) flows over the surface of the membrane. Treated water passes through microscopic pores in the membrane. The concentrated waste stream passes over the membrane to further treatment or disposal.

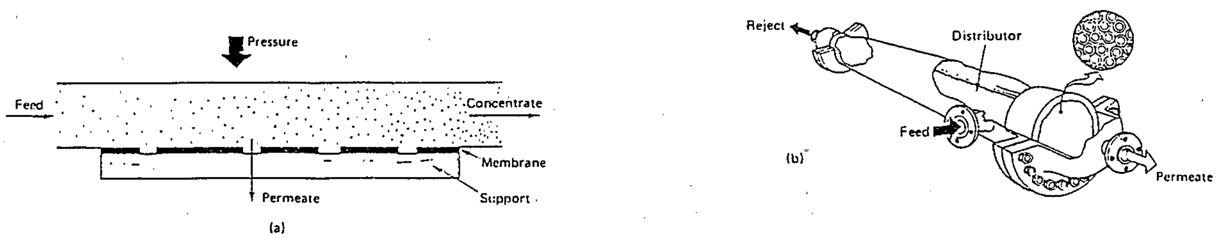


Figure 16.5. Membrane processes using a pressure driving force in (a) plane, and (b) tubular designs.
Source: GCA, 1985b.

Design Considerations: The amount of material which can be removed using the reverse osmosis technique is dependent on the membrane type, operating pressure, and the specific contaminant of concern. Multicharged cations and anions are easily removed from the wastewater with this technique. However, most low molecular weight dissolved organics are not removed or are only partially removed with this method. Selection of the proper membrane material and configuration is essential. Cellulose acetate membranes are used most commonly, but other types are available. Factors to consider in selecting a membrane type include: cost, ease of fabrication, serviceability, and resistance to variations in leachate properties (pH, temperature, etc.).

Limitations: Colloidal and organic matter can clog the membrane surface, thus reducing the efficiency of the process. Biological growth may form on a membrane fed an influent containing biodegradable organics. Low-solubility salts may precipitate on the membrane and reduce the level of product water. Pretreatment techniques (e.g., TSS removal, pH adjustment, oil and grease removal, and removal of oxidizers) may be necessary. Reverse osmosis is not a suitable treatment technique for wastes containing high concentrations of organics since the membrane may dissolve in the waste. Residual chlorine oxidizes polyamide membranes; dechlorination pretreatment may be required.

Technology Status: Conventional, undemonstrated. Reverse osmosis has not been widely used for the treatment of hazardous wastes.

Associated Technologies: Carbon adsorption, chemical precipitation, filtration, sedimentation.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Treatability study	Optimize design parameters	Laboratory-scale trial	300
Waste constituents	Not suitable for most low molecular weight dissolved organics; also not suitable for high concentrations of organics	Sampling and analysis, (GC/MS)	100/sample
Leachate variability	Pretreatment (e.g., equalization) required if pH, temp., TSS change rapidly	Sampling and analysis	50/test
Leachate pH	Membrane operation is limited to certain pH ranges	pH analysis	50/test
TSS	Suspended solids should be 10 to prevent plugging of membrane	TSS analysis	50/test
Biological organisms in leachate	Organic films reduce permeability	Sampling and analysis	100/sample
Residual chlorine	Oxidizes polyamide membranes	Sampling and analysis	100/sample

References: Ehrenfeld and Bass, 1984; Fair, et al., 1968; GCA, 1984; GCA, 1985a; JRB, 1984; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

16.0 PHYSICAL TREATMENT

16.6 LIQUID/LIQUID (SOLVENT) EXTRACTION

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to separate the components of a liquid solution by contact with another immiscible liquid for which the impurities have a high affinity.

Description: The liquid/liquid extraction process generally involves three basic steps: solvent extraction, solute removal from the extracting solvent, and solvent recovery from the treated stream (raffinate). The process can be operated continuously. A simplified flow diagram of the liquid/liquid extraction process is presented in Figure 16.6. The extraction step involves bringing the liquid waste feed and the solvent into intimate contact to allow solute transfer either by forced mixing or by countercurrent flow caused by density differences. Various types of solvent extraction unit designs can be used, including: a single-stage combination mixing/settling unit, several single-stage units in series, or a multi-stage unit which uses counter current flows within a single device (e.g., a column or differential centrifuge). Two output streams are released from the extractor; the solute-laden solvent, and the treated stream (raffinate). Usually, a secondary solvent extraction, or a distillation step must be performed on the extracting solvent to remove the solute so that the solvent can be either disposed or recycled.

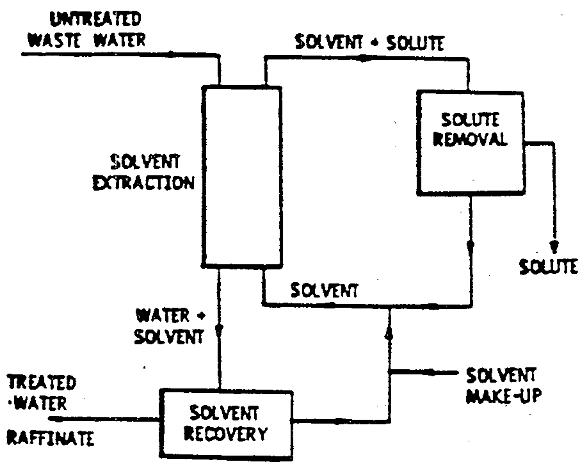


Figure 16.6. Flow diagram for liquid/liquid extraction.
Source: U.S. EPA, 1980.

Design Considerations: Design is specific to the solute being recovered and the characteristics of the waste stream. Criteria for solvent selection include: low cost, high extraction efficiency, low solubility in the raffinate, easy separation from the solute, adequate density difference with raffinate, no tendency for emulsion formation, non-reactive, and non-hazardous. It is difficult to find a solvent that will meet all the desired criteria, and therefore, some compromise is generally made.

Limitations: Liquid/liquid extraction systems seldom produce an effluent suitable for direct discharge to surface waters. Therefore, the process usually requires the use of other unit processes such as distillation or stripping to effectively recover solvent and solute from the two effluent streams. Valuable products can be recovered using a liquid/liquid extraction process. However, in some cases process costs may limit the actual applications for solvent recovery.

Technology Status: Liquid/liquid extraction is a proven method for the separation of liquid components of a waste. It has also been demonstrated as a solvent recovery technique.

Associated Technologies: Steam distillation, air or steam stripping.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste stream characteristics (e.g., solvent immiscibility, flow rate, etc.)	Selection of appropriate solvent	GC/MS	900
Choice of solvent	Design for optimum recovery	Lit. search; lab test	Nominal
Distribution coefficient	Design for optimum extraction	Lit. search	Nominal

References: King, 1980; U.S. EPA, 1977; U.S. EPA, 1980.

16.0 PHYSICAL TREATMENT

16.7 OIL/WATER SEPARATION

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Remove oil and grease from wastewater by utilizing the difference in terminal velocities that can exist between substances of different densities.

Description: Oil/water separation is accomplished through the use of a gravity oil separator, which consists of a separation chamber and a skimming system. The standard oil/water separation unit is the API separator, which is based upon design standards published by the American Petroleum Institute. As diagrammed in Figure 16.7, the oil and any other floating matter (e.g., grease) rise to the top of the separation chamber after a sufficient retention time, while the liquid (i.e., water) flows continuously out of the chamber. A system of scrapers and rotating drums is used to remove the oil that floats to the surface. A secondary skimmer pulls a belt vertically through the water to skim the floating oil, which is subsequently scraped off and collected. Coalescing techniques can be used to increase the amount of oil removal from the liquid medium (i.e., water); thereby improving the efficiency of separation. Coalescing involves the addition of a coagulant (coalescing medium) which causes oil droplets to accumulate on the medium and rise to the surface as larger droplets. In situations where a stable oil-in-water emulsion is encountered prior to gravity separation, an emulsion breaking step is required. This step is achieved through chemical (interactive charge neutralization, precipitation, etc.) or thermal (water evaporation) means.

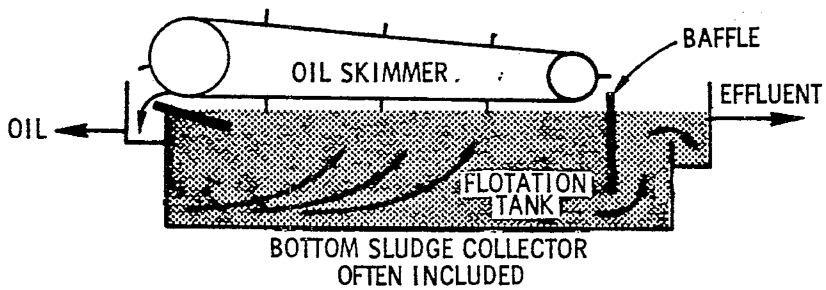


Figure 16.7. Oil/water separator.
Source: U.S. EPA, 1980a.

Design Considerations: Oil/water separators can be operated as batch vats, or as continuous flow-through basins, depending upon the volume of waste to be treated. Information on specific gravity, overflow rates, viscosity, presence of additional constituents, etc., should be obtained so that the system can be designed to effectively separate the oil from the water. These factors are used to determine proper retention times, to select coalescing agents, and to select appropriate emulsifying techniques (if needed).

Limitations: Variable wastewater characteristics such as flow, temperature, and pH can adversely affect process performance. Also, if oil skimmings can not be reused, then they will require subsequent treatment and/or disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Temperature	Determine rise rate of oil globules	Thermometer	Nominal
Viscosity	Determine susceptibility to oil separation	Viscometer	Nominal
Specific gravity	Determine stream density	Baume test	Nominal
Pollutant analysis	Determine presence of auxiliary pollutants	GC/MS	1,100
Settable solids	Determine amount of residual sludge	Field test	50

References: U.S. EPA, 1977; GCA, 1980; U.S. EPA, 1980a.

16.0 PHYSICAL TREATMENT

16.8 STEAM STRIPPING

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to remove volatile components from an aqueous waste stream by passing steam through the waste. Steam stripping is essentially steam distillation of the waste with the volatile components ending up in the distillate. This technology is most efficient in removing volatile organic compounds, water-immiscible compounds, hydrogen sulfide, and ammonia.

Description: Steam stripping processes involve a batch still, an overhead vapor line, a condenser, a condensate receiver, and a gravity separator. Steam is admitted through a perforated pipe in the bottom of the still to provide maximum contact with the waste. The steam provides the heat of vaporization to the waste. All vapor blown through the liquid is then passed out of the unit with the product and the nonvolatile impurities remain behind in the still. The vapor stage is passed through the condenser unit to return it to liquid state and then the stripped product is collected in the condensate receiver. Gravity separation may be employed to separate liquids with similar boiling points and different densities.

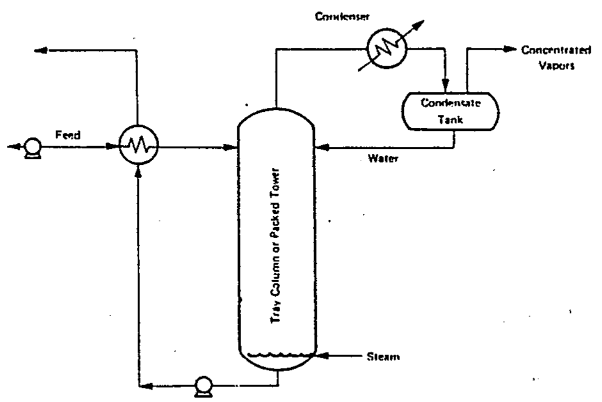


Figure 16.8. Steam stripping system diagram.
Source: ADL, 1976.

Factors affecting the removal efficiency of steam stripping systems include: the type of volatile organics present, concentration of volatile components, and wastewater flow. Removal efficiencies of volatile organic compounds from wastewaters range from 10 to 99 percent.

Design Considerations: Design parameters for steam stripping systems are site specific. Considerations for this type of system include wastewater flow, steam requirements, height and diameter of stripping column and air emission control.

Limitations: Steam stripping processes pose problems in air pollution control if volatile components remain in the leachate. Through the use of various types of emission control technologies, these problems can be minimized.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Air emission controls, carbon adsorption, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Gross organic components	Suitability for treatment	Sampling and analysis	100/sample
Specific organic components	Suitability for treatment	Organic pollutant scan	1,500-2,000/ sample
Leachate analysis	Gas flow efficiency	Sampling and analysis	Nominal
Column packing	Calculation of pressure drop	Manufacturer's data	Nominal
Process Size	Calculation of necessary column length	Capacities of processes producing wastes	Variable
Effluent requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; McCabe, 1976.

16.0 PHYSICAL TREATMENT

16.9 FILTRATION

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Used to remove suspended solids from the aqueous phase; often employed as pre-treatment technique (intermediate process) or as a final polishing step.

Description: Filtration is a physical process whereby suspended solids are removed from solution by forcing the fluid through a porous medium. Granular media filtration is commonly used for treating aqueous waste streams. The filtration apparatus typically contains sand (or sand with anthracite or coal) which is supported by an underdrain system that collects the filtrate (Figure 16.9). As the filtration process proceeds, suspended particles become trapped on top of, and within the bed, which gradually reduces the efficiency of the process. Eventually, it becomes necessary to regenerate the filter media by means of a back-washing (scouring) technique. During this step, the underdrainage system doubles as a water distribution system. Back-washing water rises into the filter bed in the reverse direction of the original flow causing the filter bed to become fluidized. Commonly used methods for scouring the filter media include: high-velocity wash, surface scour, air scour, and mechanical scour. During the scouring process the solids become dislodged from the sand and are discharged in the spent wash cycle. The bed is then allowed to resettle. The coarser, heavier grains tend to settle at the bottom while the finer, lighter grains remain at the top.

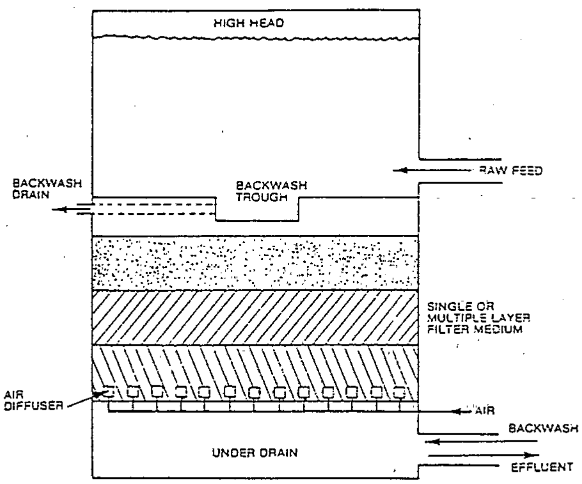


Figure 16.9. Typical filtration bed.
Source: U.S. EPA, 1985b.

Design Considerations: Various modifications to the filtration bed may be employed, including dual-media filtration (bed consists of anthracite underlain by sand), and multi-media filtration (bed consists of several layers of different materials). Commonly used filter materials include: natural silica sand, crushed anthracite, (hard) coal, crushed magnetite (ore), and garnet sands.

Filtration systems can consist of multiple compartment concrete or steel units aligned horizontally or vertically. The flow through the filtration units occurs by using the available head from the previous treatment unit, or by pumping to a flow-split box and then using the effects of gravity to allow flow to the filter cells. Pressure filters use pumping to increase the available head.

Limitations: High solids content (100 to 200 mg/L) in the waste to be treated may cause clogging of the filtration media. Granular media filtration is often preceded by sedimentation to reduce suspended solids loading on the filter. Another limitation of granular media filtration is that it is only marginally effective in treating colloidal size particles; particles can be made larger by flocculation. Also, the liquid effluent resulting from filtration may contain hazardous materials necessitating further treatment.

Technology Status: Conventional, demonstrated.

Associated Technologies: Carbon adsorption, ion exchange, reverse osmosis, air stripping, biological treatment, precipitation, flocculation, sedimentation, dissolved air flotation.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Leachate TSS concentration	High concentration of suspended solids (100 to 200 mg/l) may cause clogging, decreasing efficiency	TSS analysis	50/test
Leachate TDS concentration	Effluent may require further treatment	TDS analysis	50/test
Performance tests	Optimization of design criteria	Laboratory-scale tests	300
Water solubility of waste constituents	Applicability, feasibility	CRC Handbook of Chemical and Physics; U.S. EPA Treatability Manual	Nominal

References: Fair, et al., 1968; Ehrenfeld and Bass, 1984; GCA, 1985b; JRB, 1984; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

16.0 PHYSICAL TREATMENT

16.10 DISSOLVED AIR FLOTATION

Type of Control: Direct Waste Treatment (Aqueous Treatment)

Function: Removes insoluble, suspended fine particulates or globules of oils and greases from an aqueous phase.

Description: Dissolved air flotation involves saturating the aqueous waste mixture with air at high pressures (25 to 70 psi). The pressurized wastewater is kept at this pressure for 0.5 to 3.0 minutes in a retention chamber, and is then transferred to a flotation chamber which is under atmospheric pressure. The rapidly reduced pressure causes small air bubbles to rise to the surface. These bubbles carry the fine particles and small oil and grease globules to the surface. A skimmer is used to remove the surface particulates and globules.

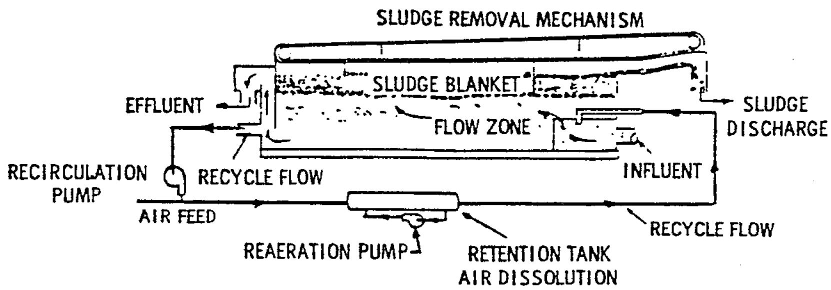


Figure 16.10. Flow diagram of dissolved air flotation process. Source: U.S. EPA, 1980a.

Design Considerations: With more uniform distribution of water and bubbles, the flotation unit can be shallower. Typically, depths of effective flotation units range from 4 to 9 feet. The sweeping action of the air bubbles can often be enhanced by the addition of surface active chemicals and pH adjustments. Other modifications include the use of nitrogen instead of air in order to reduce fire hazards.

Limitations: Dissolved air flotation is only suitable for treating wastes which have a specific gravity close to that of water (i.e., 1.0). Waste streams containing volatile organic constituents may require additional air emission controls.

Technology Status: Conventional, demonstrated.

Associated Technologies: Chemical precipitation, flocculation, filtration.

Important Data Needs For Screening:

Data need	Purpose	Collection method	Costs ($)
Specific gravity of waste	Process suitable for specific gravity near 1.0	Viscometer	50/test
Waste constituents	Volatile organics may require additional air emission controls	Sampling and analysis	100/sample

References: Fair, et al., 1968; Ehrenfeld and Bass, 1984; GCA, 1985b; JRB, 1984; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

17.0 SOLIDS HANDLING/TREATMENT

17.1 SOLIDS SEPARATION

Type of Control: Direct Waste Treatment (Solids Handling and Treatment)

Function: Used to separate solids from slurries and/or to classify contaminated soils or slurries according to grain size.

Description: Various techniques are available for solids separation, including sieves and screens, hydraulic and spiral classifiers, cyclones, settling basins, and clarifiers. Settling basins and conventional clarifiers are described in Section 16.2. Sieves and screens are constructed of bars, woven wire, or perforated plate surface (see Figure 17.1a). The waste is passed through the screen or sieve, and particles of a specified (by design) size range are retained by the screen or sieve. Classifiers are used to separate soils/sediments according to grain size. Separation occurs due to differences in settling velocities. Hydraulic classifiers are typically used to separate sand and gravel from slurries. Spiral classifiers are primarily used to separate clay and silt from the sand and gravel fractions. An example of a classifier is shown in Figure 17.1b.

Cyclones and hydroclones use centrifugal forces to separate solids which are more dense than water (greater than 1.0 g/L). The slurry is fed into the unit at rate sufficient to create a spiral. The liquid and fine particulates spin out through the overflow outlet while the larger solids to move via centrifugal force to the outside of the wall and then to exit through the apex at the bottom of the unit.

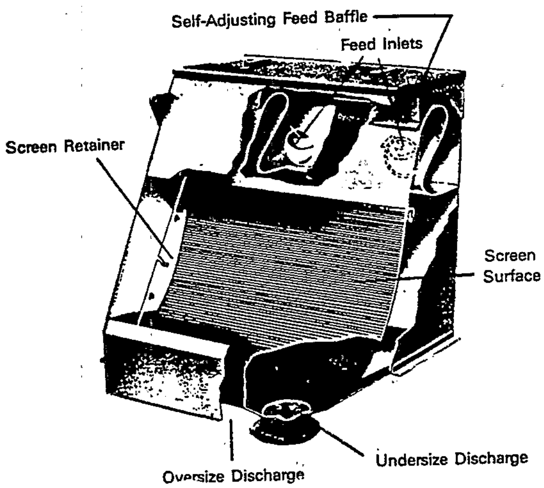


Figure 17.1a. Wedge bar screen. Source: U.S. EPA, 1985b.

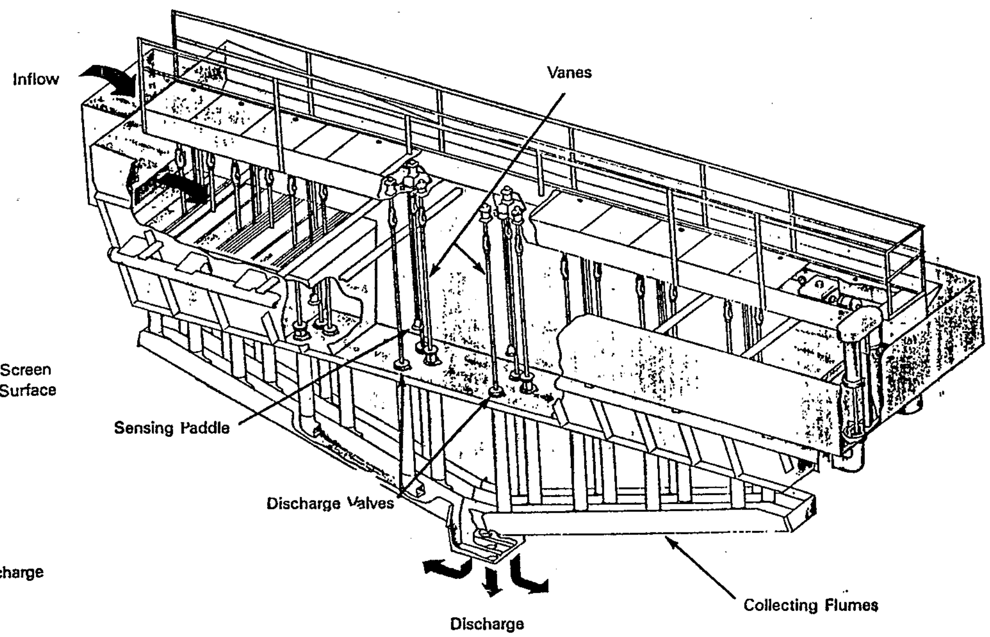


Figure 17.1b. Hydraulic classifier. Source: U.S. EPA, 1985b.

Design Considerations: Different types of solids separating techniques are often used in combination for handling large volumes of solids. The most appropriate solids separation method depends upon several factors including the following: volume of contaminated soils, composition of soils or sediments (gradation, percent clays, percent total solids), types of dredges or excavation equipment used (determines the feed rate to solids separation, and the percent-solids for slurries), and site location and surroundings.

Limitations: The available land area and ultimate or present land use may limit the type of system that can be utilized.

Technology Status: Conventional, demonstrated.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Volume of soil/sediment to be treated	Selection of appropriate technology	Site investigation report	Nominal
Soil/sediment grain size distribution, total solids	Selection of appropriate technology	Sieve analysis	50/test
Land use	Available land area	Site inspection, site visit	Nominal
Type of equipment available	Selection of solids separation technology	Telephone calls to vendors	Nominal

References: E.C. Jordan, 1985; Ehrenfeld and Bass, 1984; GCA, 1985a; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

17.0 SOLIDS HANDLING/TREATMENT

17.2 DEWATERING

Type of Control: Direct Waste Treatment (Solids Handling and Treatment)

Function: Facilitates the handling and disposal of sediments; often used to remove liquids from dredge spoils.

Description: Dewatering is the process of removing liquids and concentrating suspended solids in sludges without changing the chemical characteristics of the waste. Several methods are available for dewatering sludges. The method chosen depends upon the volume of slurry (waste), solids content of the slurry (waste), the sludge characteristics, available space, subsequent treatment/disposal operations, and costs. Typical units are dewatering beds, vacuum pumping, vacuum filtration, pressure filtration, centrifugation, and thermal drying. Some of the equipment used for these techniques is illustrated in Figure 17.2.

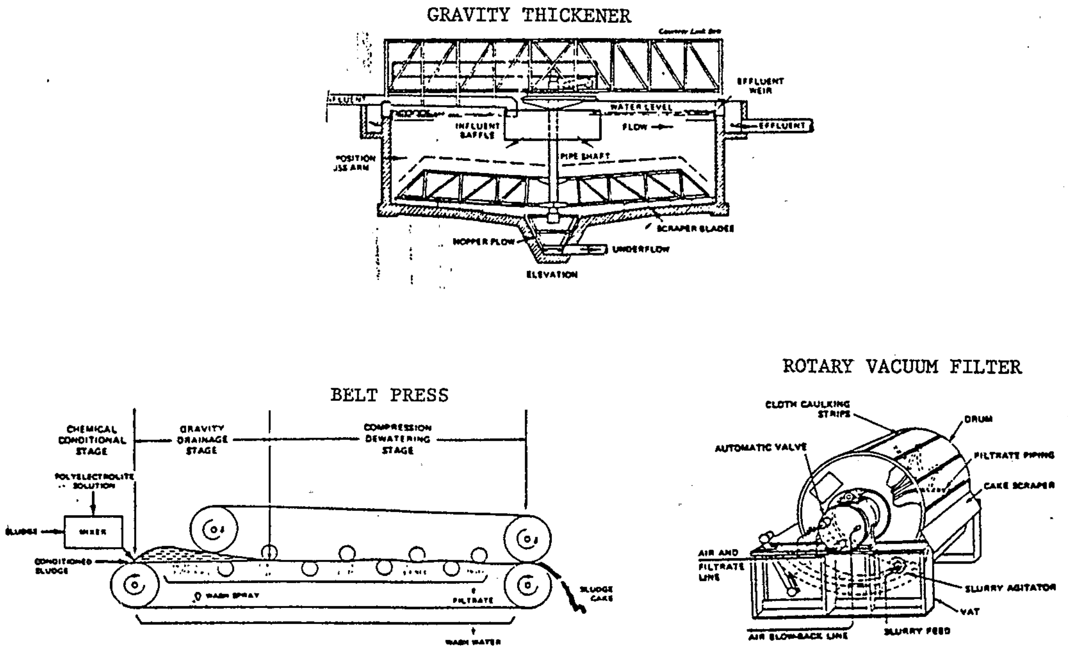


Figure 17.2. Various types of dewatering equipment.
Source: U.S. EPA, 1985b.

Design Considerations: Sludge conditioning techniques (i.e., chemical conditioning, and sludge thickening methods), and management of dewatered sludge (i.e., transportation , disposal, and/or incineration) are usually considered in conjunction with dewatering. It is often necessary to pre-filter a sediment before employing dewatering equipment because some dewatering techniques can only process fine-grained silts.

Limitations: Centrifugation and thermal drying must be performed at special processing facilities. Drying beds are the most economical dewatering method (with the exception of gravity drainage), but the drying bed technique requires more time and more land area than other dewatering methods. Further treatment to fixate or solidify the wastes may be necessary before the solids are able to meet requirements for disposal. Also, the liquids generated during dewatering generally contain hazardous constituents and will usually require additional treatment.

Technology Status: Conventional, demonstrated.

Associated Technologies: Dredging, excavation, surface water and sediment containment barriers, diversions, transport, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Topography/site accessibility	Need access for equipment	Site inspection site survey town/city/county records	Nominal
Physical and chemical characteristics of sludge/sediment	Select technique	TSS, TDS analyses	50/test
Site area	Drying beds often require a large area	Site inspection, site survey, town/city/county records	Nominal
Land use	Drying beds may emit unpleasant odors, depending on waste characteristics	Site inspection town/city/county records	Nominal
Climate	Frequent and heavy rains may hinder operations	Natl. Climatic Center (NCC); local weather bureau	50
Waste characteristics	Selection of dewatering technique	Sampling and analysis	100/sample

References: E.C. Jordan, 1985; Ehrenfeld and Bass, 1984; GCA, 1985a; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1985b.

17.0 SOLIDS HANDLING/TREATMENT

17.3 SOLIDIFICATION/STABILIZATION

Type of Control: Direct Waste Treatment (Solid Handling and Treatment)

Function: Alters the physical and/or chemical state of the hazardous constituents within the soil rendering them less leachable, less toxic, and more easily handled, transported, and disposed.

Description: Solidification processes include: cementation, pozzolanic (silicate-based) cementation, sorbents, vitrification, thermoplastic binding, and organic polymer binding (surface microencapsulation). Each of these processes results in the formation of a hardened mass, which is generally stable and inert. The solid mass is easier to handle and/or dispose. Cement-based processes involve the mixing of Portland cement with a soil/slurry. This mixture hardens to form a rock-like mass which incorporates the hazardous constituents into the crystalline structure. Pozzolanic or silicate-based solidification consists of reacting lime with fine-grained silaceous (pozzolanic) materials and water to produce a concrete-like mass. Disposal of solidified hazardous waste from the pozzolanic process may require a specially designed landfill that will contain and remove any leachate produced. Sorbents are natural or synthetic solid materials which are used to eliminate free liquid, which in turn improves the handling characteristics of the waste. Commonly used sorbents include: fly ash, kiln dust, vermiculite, bentonite, activated carbon, Hazorb, and Locksorb. Vitrification involves combining wastes with molten glass typically at temperature of 1350°C or greater. The melt is cooled to a stable, non-crystalline solid.

Both thermoplastic binding and organic polymer binding (also called surface microencapsulation) were developed as disposal methods for radioactive wastes. Thermoplastic binding involves the use of bitumen, paraffin, and polyethylene to bind the waste material. Organic polymer binding uses polymer-forming organic chemicals, such as urea and formaheldehyde, to physically encapsulate the wastes by sealing them in an organic binder or resin.

Design Considerations: Important design factors include: selection of appropriate solidification agent, solidification mixing ratios, curing time, and volume increase of solidified product. Specific design factors are based on the specific waste being treated. Vitrification is often more effective than other solidification techniques, but is very costly and requires specialized equipment.

Limitations: Solidification processes are more successful with inorganics; organics do not tend to be amendable to solidification. Some types of wastes interfere with solidification processes. Sulfates and borates tend to interfere with cementation and pozzolanic processes. Nitrates, chlorates, perchlorates, and organic solvents tend to interfere with thermoplastic binding processes. Certain metal salts will interfere with organic polymer binding processes. Additionally, there may be a loss stability of any solidified product over the course of several freeze/thaw cycles; research in this area is currently being conducted.

Technology Status: State-of-the-art solidification/stabilization methods are rapidly advancing as manufacturers develop new processes.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Soil properties	Compatibility with solidification agent	Soil sampling and analysis	100/sample
Waste characteristics constituents, pH, TOC, etc.	Selection of appropriate solidification agent	Sampling and analysis	50/test
Treatability studies	Suitability for solidification	Laboratory studies	400
Climate	May be a loss of stability with several freeze/thaw cycles	Natl. Climatic Center (NCC), local weather bureau	50

References: E.C. Jordan, 1985; Ehrenfeld and Bass, 1984; GCA, 1985a; Sundstrom and Klei, 1979; U.S. EPA, 1980a; U.S. EPA, 1980b; U.S. EPA, 1985b

18.0 GASEOUS WASTE TREATMENT

18.1 FLARING

Type of Control: Direct Waste Treatment, Air Pollution Control

Function: Thermally oxidizes gaseous wastes into less harmful products.

Description: Flaring is a combustion technique which exposes wastes to an open flame. A flare consists of an ignition chamber in which an ignitable gas is allowed to combust in a controlled air environment. Gases are ignited by a pilot burner. With flaring, no special features are used to control temperatures or combustion time; supplemental fuels may, however, be needed to sustain continuous combustion. Equipment such as flame sensors, pilot flames, automatic sparkers (to attempt reignition upon loss of flame), and alarms (to alert operators to performance problems) are frequently used to monitor the flaring operation. Shields may be used as windbreaks for containing the flame and to prevent it from blowing out.

Design Considerations: The diameter and height of the flare stack and the number of flares required are determined by the flow rate of the waste/fuel. For proper mixing of gas and air, and also for adequate safety, the flare stack should be designed such that the flame is contained within the body of the flare stack. The air/gas ratio is influenced by the oxygen content of the gas.

Limitations: Supplementary fuels may be required to sustain continuous combustion with gases that have a low heating value. Due to the large quantities of natural gas which are consumed in the flaring process, operating costs are high. Flaring systems perform inconsistently because they have minimal control mechanisms. Destruction and removal efficiencies (DREs) required by current regulations generally can not be attained with flaring, with the possible exception of gaseous waste streams consisting of simple hydrocarbons (e.g., fuel tank emissions, landfill methane gas, etc.).

Technology Status: Conventional and demonstrated technique. However, flaring is more commonly used to dispose of fumes from oil and gas refineries, digestor gas from sewage treatment plants, and landfill gas (methane) from municipal landfills. Flaring is generally applicable to hazardous wastes.

Associated Technologies: Thermal destruction (incineration).

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Heat content of waste	Should be 100 Btu/cu. ft.	Btu analysis	50/Test
Waste constituents	Implementability, capacity	Sampling and analysis	100/sample
Performance tests	Adequacy of destruction and removal efficiencies	Bench or pilot tests	300

References: Bonner, 1981; Ehrenfeld and Bass, 1984; GCA, 1984; GCA, 1985a; U.S. EPA, 1985b.

18.0 GASEOUS WASTE TREATMENT

18.2 ADSORPTION

Type of Control: Direct Waste Treatment, Air Pollution Control

Function: Used to remove organic compounds and some inorganic compounds from gaseous waste streams.

Description: Adsorption involves the transfer of contaminants from a gas (or liquid) to an adsorbent. Various types of adsorbents can be used, including activated carbon (see Section 16.4), and resins. Adsorption systems for the treatment of gaseous waste streams generally consist of containerized beds of adsorbent. The waste stream flows through the bed, leaving behind contaminants which become sorbed to the adsorbent material. This process continues until the adsorbent material reaches capacity and needs to be replaced or regenerated. Multiple adsorbent beds are often used so that operation can be continuous while adsorbent material is being regenerated or replaced.

Design Considerations: Carbon adsorption is used to control volatile hydrocarbons, sulfur-related emissions, mercury, vinyl chloride, halogenated organics, and radioactive materials. It is widely used as an air pollution and odor control technique with solvent recovery/reuse systems. Although applicable, resins are less frequently used for treating gaseous waste streams. Resins tend to be used for aqueous waste streams.

Limitations: The adsorbent material eventually reaches capacity and must either be disposed of in an appropriate landfill or regenerated via heating or solvent washing. Upon reaching capacity, the adsorption process slows or stops, and some contaminants may be released (through desorption) back to the waste stream.

Technology Status: Conventional, demonstrated.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
TSS concentration	Usage rate for adsorbent	TSS analysis	50/sample
Btu content of waste stream	Need for supplementary fuel	Btu analysis	50/sample
Leachate components	Treatability via adsorption	Sampling and analysis	100/sample

References: Bonner, 1981; Ehrenfeld and Bass, 1984; GCA, 1984; GCA, 1985a; JRB, 1984; Kaufmann, 1982; Lyman, 1980; McGaughey, et al., 1984; Sundstrom and Klei, 1979; Troxler, et al., 1983; U.S. EPA, 1980a; U.S. EPA, 1985b.

18.0 GASEOUS WASTE TREATMENT

18.3 AFTERBURNERS

Type of Control: Direct Waste Treatment, Air Pollution Control

Function: Most frequently used in conjunction with thermal destruction (incineration) technologies to remove vapor-phase residuals.

Description: Afterburners are secondary incinerators for combustion of gases resulting from incineration (via the techniques described in Section 19.0). A supplemental fuel is added to the gas steam to generate the high temperatures necessary to decompose (in the presence of oxygen) the hazardous constituents present in the stream to carbon dioxide, water, and other combustion products.

Design Considerations: Afterburners are only applicable to gaseous waste streams that can be oxidized at temperatures of 870°C or less at retention times of 0.5 to 1.0 seconds. Catalysts may be used to lower oxidation temperatures to 540 to 870°C.

Limitations: Afterburners should only be used for gaseous waste streams which will not produce undesirable oxidation products. Scrubbers may be required to further control air emissions.

Technology Status: Conventional, demonstrated.

Associated Technologies: Thermal destruction (incineration).

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Concentration of waste constituents	Feasibility, capacity	Sampling and analysis	100/sample
Volume of gas to be treated	Feasibility, capacity	Site investigation report	Nominal
Destruction efficiencies	Suitability of technology	Bench or pilot-scale tests	1,200

References: Bonner, 1981; Ehrenfeld and Bass, 1984; GCA, 1984; GCA, 1985a; McGaughey, et al., 1984; U.S. EPA, 1985b.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.1 ROTARY KILN INCINERATION

Type of Control: Direct Waste Treatment

Function: Uses high temperature oxidation under controlled conditions to destroy organic constituents in liquid, gaseous, and solid waste streams; preferred incineration method for treating mixed hazardous solid residues.

Description: Rotary kiln incinerators are refractory-lined cylinders fueled by natural gas, oil, or pulverized coal. As shown in Figure 19.1, the kiln is mounted at a slight angle from the horizontal. Rotary kiln incinerators are typically used in conjunction with an afterburner and a wet scrubber emission control system.

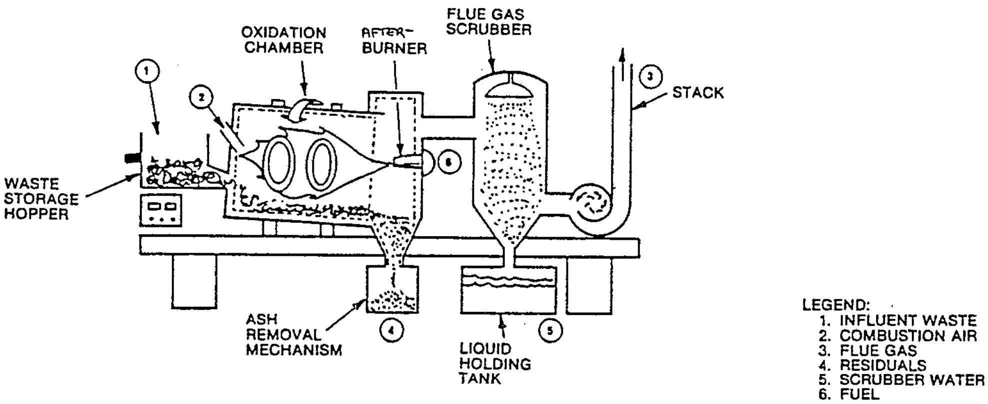


Figure 19.1. Rotary kiln incinerator schematic.
Source: U.S. EPA, 1985b

Wastes are injected (fired) at the top of the rotating kiln. The rotation creates turbulence and improves combustion. An afterburner is connected to the discharge end of the kiln and is used to complete the gas-phase combustion reactions. Following this stage, a wet scrubber emission control system may be employed to prevent the emissions of inorganic acids to the atmosphere.

Design Considerations: The rotary kiln typically has a length-to-diameter ratio between 2 and 10; a peripheral rotational speed ranging from 1 to 5 rpm; an incline ratio ranging from 1/16 to 1/4 in./ft.; operating temperatures ranging from 1500 to 3000°F; and residence times varying from a few seconds to several hours (depending on the waste characteristics). Varying the rotational speed and the operating temperatures can be used to alter residence times and combustor air mixing. Auxiliary fuel systems may be required to bring the kiln up to the desired operating temperatures. Various types of auxiliary fuel system may be used including: dual-liquid burners designed for combined waste/fuel firing, or single-liquid burners equipped with a pre-mix system. Both cocurrent and countercurrent firing designs may be used; liquid wastes can be fired at either the feed or discharge end of the kiln.

Limitations: Rotary kiln incineration is not suitable for treating waste streams which have a high concentration of inorganics. Rotary kiln incinerator systems are susceptible to thermal shock, require careful maintenance, need additional air due to leakage, have a relatively low thermal efficiency, high particulate emissions, and a high cost for installation.

Technology Status: Conventional. Demonstrated for use with wastes containing PCBs, dioxins, tars, obsolete munitions, polyvinyl chloride, solvent reclamation stillbottoms.

Associated Technologies: Afterburner, scrubbers.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste constituents	Not suitable for treating waste streams with a high concentration of inorganics	Sampling and analysis (ICAP)	100/ sample
Heat content of waste	Need for auxiliary fuel	Btu analysis	50/test
Waste feed TSS concentration	May require pre-treatment to avoid clogging of the nozzles	TSS analysis	50/test

References: Bonner, 1981; Ehrenfeld and Bass, 1984; GCA, 1984; GCA, 1985a; Hitchcock, 1979; Metcalf and Eddy, 1972; McGaughey, et al., 1984; U.S. EPA, 1980a; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.2 FLUIDIZED-BED INCINERATION

Type of Control: Direct Waste Treatment

Function: Uses high temperature oxidation under controlled conditions to destroy organic constituents in liquid, gaseous, and solid waste streams; typically used for slurries and sludges.

Description: As diagrammed in Figure 19.2a, the fluidized bed incinerator consists of a vertical refractory-lined cylindrical vessel containing a bed of inert granular material (typically, sand) on a perforated metal plate. The granular bed particles are fluidized by blowing low velocity air upward through the medium. The rate of air movement is directly proportional to the particle size, and acts to suspend the bed in a fluid-like manner. Combustion occurs within the fluidized material. Auxiliary fuel is often injected into the bed. Heat is transferred from the bed to the wastes (which are generally in the form of slurries or sludges). The solid materials in the waste become suspended fine particulate matter and are separated in a cyclone when exhaust gases pass through an afterburner to destroy vapor-phase residuals.

A recently developed modification of this technique, is the circulating fluidized-bed combustor (Figure 19.2b) which utilizes contaminated soil as the bed material and uses an air flow three to five times greater than the conventional system. The increased air flow causes increased turbulence which allows for efficient combustion at lower operating temperatures, and precludes the use of an afterburner.

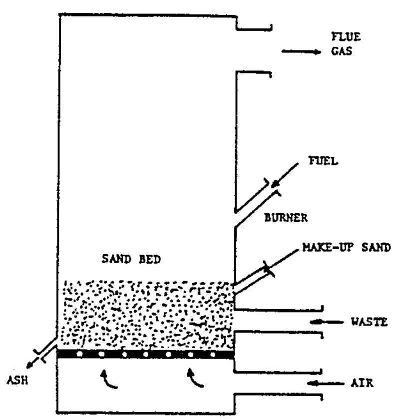


Figure 19.2a. Fluidized-bed incinerator.
Source: U.S. EPA, 1985b.

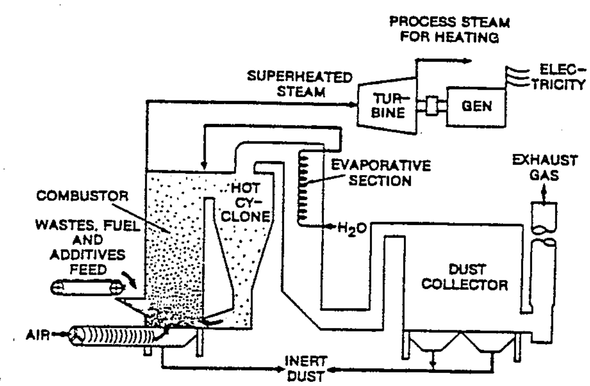


Figure 19.2b. Circulating bed combustor.
Source: U.S. EPA, 1985b.

Design Considerations: The diameter of the fluidized bed unit typically ranges from a few meters to 15 meters. Operating temperatures normally range from 450°C to 980°C, and are limited by the softening point of sand which is 1100°C. Residence times are generally on the order of 12 to 14 seconds for a liquid hazardous waste. Problems caused by low ash fusion temperatures can be avoided by keeping operating temperatures below the ash fusion level, or by using chemical additives to raise the fusion temperature of the ash.

Limitations: Operating costs are relatively high (in particular, electric power costs). Regular preparation and maintenance of the fluid bed must be performed. It is often difficult to remove residual materials from the bed. The fluidized-bed incineration technique is not well-suited for irregular or bulky wastes, tarry solids or other highly viscous wastes, or wastes with a fusible ash content. Formation of eutectics (compounds with low melting or fusion temperatures) can be a problem. Wastes containing bulky or irregular solids may require pretreatment in the form of drying, shredding, and sorting, prior to entering the incinerator.

Technology Status: Fluidized-beds have been used to treat municipal wastewater treatment plant sludge, oil refinery waste, pulp and paper mill waste, pharmaceutical waste, phenolic waste, and methyl methacrylate. Pilot-scale demonstrations have been performed for other hazardous wastes (including PCBs and dioxins).

Associated Technologies: Afterburner.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Ash content of waste	Not suitable for wastes with a fusible ash content	Dry ash analysis	50/test
Viscosity of waste	Not suitable for highly viscous wastes	Viscosity tests	50/test
Solids content of wastes	Wastes with irregular or bulky solids may require pretreatment	TSS analysis	50/test

References: Barner, 1985; Bonner, 1981; Ehrenfeld and Bass, 1984; Freeman, 1985; GCA, 1981; GCA, 1984; GCA, 1985a; McGaughey, et al., 1984; Rasmussen, 1986; Rickman, 1985; U.S. EPA, 1980a; U.S. EPA, 1985a; Vrable, et al., 1985.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.3 MULTIPLE HEARTH INCINERATION

Type of Control: Direct Waste Treatment

Function: Uses high temperature oxidation under controlled conditions to destroy organic constituents in liquid, gaseous, and solid waste streams (including sludges and tars); best suited for hazardous sludge destruction.

Description: As diagrammed in Figure 19.3, a multiple hearth incinerator consists of refractory-lined circular steel shell, a rotating central shaft, a series of solid flat hearths, a series of hearth-mounted rabble arms with teeth, an air blower, fuel burners on the walls, an ash removal system, and a waste feed system. Additionally, side ports for fuel injection, liquid waste burners, and an afterburner are often included.

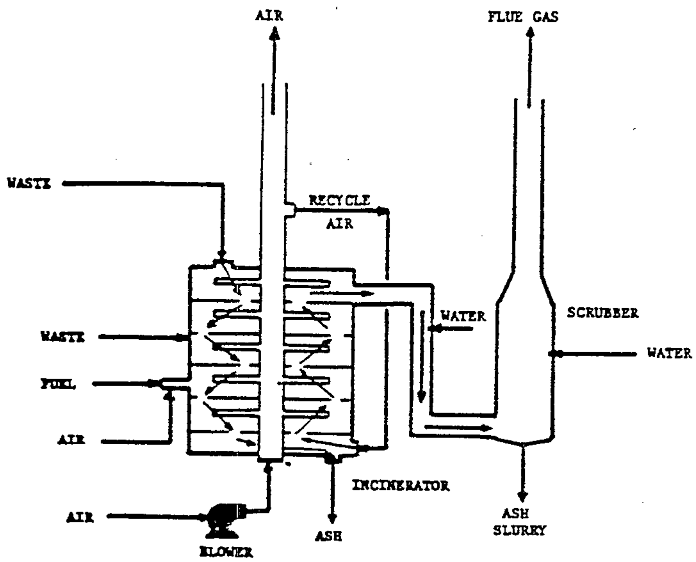


Figure 19.3. Multiple hearth incinerator.
Source: U.S. EPA, 1985b.

Design Considerations: Operating temperatures generally range from 1400 to 1800°F. Residence times can be up to several hours long.

Limitations: Multiple hearth incineration is highly susceptible to thermal shock and is not suitable for treating highly chlorinated organics or other wastes requiring high temperatures for destruction. Gases and bulky solids are not readily treated by this method. Solid waste often requires pretreatment methods such as shredding and sorting. Wastes containing ash which fuses into large rock-like structures are not suitable for destruction via multiple hearth incineration. Operating and maintenance costs are high. Operating costs may be reduced by using liquid or gaseous combustible wastes as an auxiliary fuel. However, control of the firing of supplemental fuels is difficult.

Technology Status: Conventional, demonstrated.

Associated Technologies: Afterburners.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste form	Solid wastes usually require pretreatment	Observation	Nominal
Waste constituents	Not suitable for wastes requiring high destruction temperatures	Sampling and analysis	100/sample
Ash content	Fusible ash not suitable	Dry ash content	50/test

References: Bonner, 1981; Ehrenfeld and Bass, 1984; GCA 1984; GCA, 1985a; Hitchcock, 1979; Metcalf and Eddy, 1972; McGaughey, et al., 1984; U.S. EPA, 1980a; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.4 LIQUID INJECTION INCINERATION

Type of Control: Direct Waste Treatment

Function: Uses high temperature oxidation under controlled conditions to destroy organic constituents in liquids or slurries which have a low enough viscosity to be pumped.

Description: As diagrammed in Figure 19.4, the general components of a liquid injection incineration system include: burner, primary combustion chamber, secondary (unfired) combustion chamber, quench chamber, scrubber, and stack. The liquid injection incinerator system can be configured either vertically or horizontally. With the vertical configuration, the incinerator acts as its own stack and a portion of the stack may serve as a secondary combustion chamber. Horizontal incinerators are connected to a stack, and are better suited for tall stacks than the vertically configured system. To ensure efficient combustion, the liquid must be atomized prior to entering the combustor. Atomization is typically accomplished either mechanically through rotary cup or pressure atomization systems, or via gas fluid nozzles using high pressure air or steam. Waste feed storage and blending tanks aid in maintaining a steady, homogeneous waste flow.

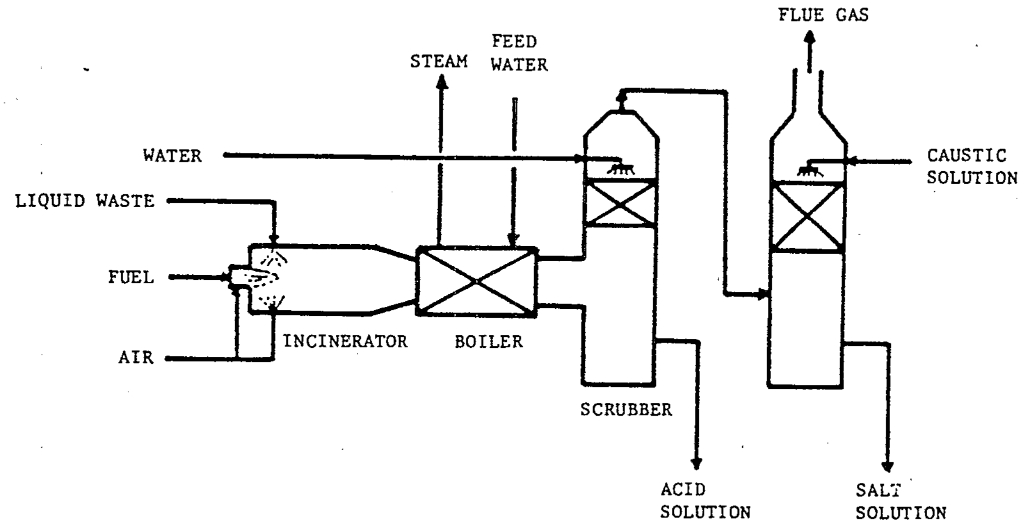


Figure 19.4. Liquid injection incineration system.
Source: U.S. EPA, 1985b.

Design Considerations: Combustion chamber residence times generally range from 0.5 to 2.0 seconds. Operating temperatures depend on the waste type and destruction requirements, but typically range from 650 to 1750°C (or 1200 to 3180°F). The heat capacity (Btu) of the waste liquid must be adequate for ignition and incineration, or a supplemental fuel must be added. Liquid injection incinerators are highly sensitive to waste composition and flow changes. Therefore, storage and mixing tanks are necessary to ensure a reasonably steady and homogeneous waste flow.

<u>Limitations</u>: Particle size in slurries is a critical factor for successful operation because the burners are susceptible to clogging by particulate or caked material at the nozzles. The use of liquid injection incinerators is limited to wastes which can be atomized. Also, heavy metal wastes and wastes which have high inorganic content are not suitable for treatment via liquid injection incineration.

<u>Technology Status</u>: Conventional, demonstrated. Liquid injection incinerators can be used to destroy virtually any pumpable waste or gas and have been used to destroy PCBs, solvents, still reactor bottoms, polymer wastes, and pesticides.

<u>Associate Technologies</u>: Afterburner.

<u>Important Data Needs for Screening</u>:

Data need	Purpose	Collection method	Costs ($)
Viscosity of wastes	Viscosity of greater than 10,000 SSU required in order to be pumpable	Viscometer	50/test
Percent-moisture content	Not suitable for wastes with a high moisture content, or for wastes that cannot be atomized	Volume-weight analysis	50/test
Waste constituents	Not suitable for wastes with high inorganic content	Sampling and analysis	50/test
Particle size	Large particles may clog nozzles	Sieve analysis	50/test

<u>References</u>: Bonner, 1981; Ehrenfeld and Bass, 1984; GCA, 1984; GCA, 1985a; McGaughey, et al., 1984; U.S. EPA, 1978a; U.S. EPA, 1980a; U.S. EPA, 1983a; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.5 MOLTEN SALT COMBUSTION

Type of Control: Direct Waste Treatment

Function: Uses high temperature oxidation under controlled conditions to destroy organic constituents in liquid and solid waste streams; effective for chlorinated hydrocarbons including PCBs, chlorinated solvents, and malathion.

Description: Molten salt combustion occurs primarily in a bed of molten alkali metal salts. Air and waste (in the form of liquids, free-flowing powders, sludges, and/or shredded solid waste) are injected into the bed. Wastes subjected to the molten salt process undergo catalytic destruction when they contact the hot molten salt which is maintained at temperatures ranging from 1382 to 1832°F. As diagrammed in Figure 19.5, hot gases rise through the molten salt bath, pass into a secondary reaction zone, and finally through an air emission control system before being discharged to the atmosphere.

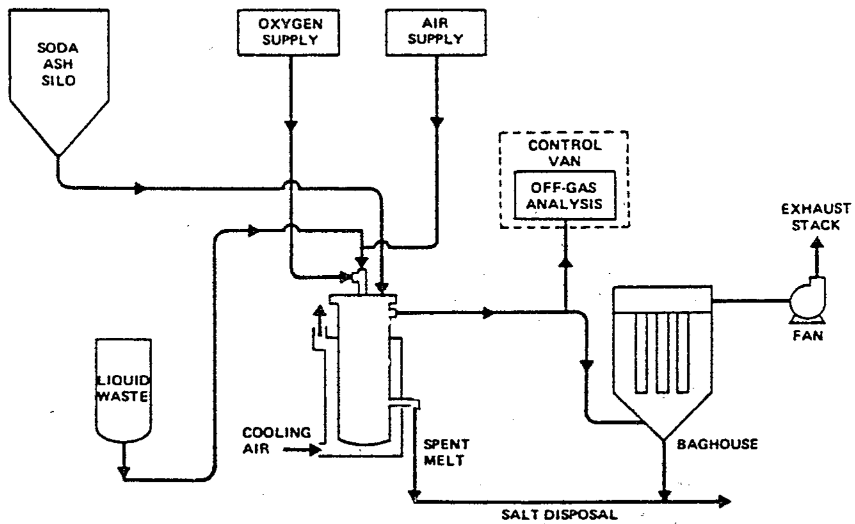


Figure 19.5. Simplified flow schematic of molten salt destruction. Source: U.S. EPA, 1985b.

Design Considerations: Auxiliary fuel may be required when wastes do not have a sufficient heat content to maintain combustion temperatures.

Limitations: The molten salt process is not suitable for wastes with a high ash content (greater than 20 percent) or high chlorine content, which must be removed in the purge system. Spent salt needs to be landfilled if it is not regenerated.

Technology Status: Developmental.

Associated Technologies: Thermal destruction (incineration).

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste constituents	Applicability	Sampling and analysis	100/sample
Heat content of waste	Need for auxiliary fuel	Btu test	50/test
Ash content of waste	Not suitable for wastes with greater than 20 percent ash content	Dry ash content	50/test
Chlorine content of waste	Not suitable for wastes with high chlorine content	Sampling and analysis	100/sample

References: Bonner, 1981; Freeman, 1985; GCA, 1984; GCA, 1985a; Johanson, et al., 1983; McGaughey, et al., 1984; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.6 HIGH TEMPERATURE FLUID WALL REACTOR/ADVANCED ELECTRIC REACTOR

Type of Control: Direct Waste Treatment

Function: Uses high temperatures to quickly pyrolyze organic wastes to their elemental state.

Description: As diagrammed in Figure 19.6, the process occurs in a reactor consisting of a tubular core of refractory material. Thermal radiation (in the near infrared region) supplied by large electrodes in the jacket of the vessel are used to heat the reactor to temperatures of 4000 to 5000°F (2200 to 2300°C). Prior to allowing the waste feed (in solid, liquid, or gaseous form) to enter the reactor, nitrogen (an inert gas) is fed into the reactor and forms a gaseous blanket which serves to isolate the waste feed from the reactor core walls, thereby preventing damage to the refractory material.

The resulting thermal radiation causes pyrolysis (as opposed to oxidation) of the organic constituents in the waste feed. At these high temperatures, inorganic compounds melt and are fused into vitreous solids. Most metal salt- sare soluble in these molten glasses and thus become locked up in a solid solution (vitrified beads). Following pyrolysis in the reactor, the granular solids and gaseous reactor emissions are directed to a post-reactor zone (PRZ) where radiative cooling occurs. The granular solid material (e.g., treated solid) is then collected in a sealed insulated collection vessel, while the cooled gases are collected in a baghouse.

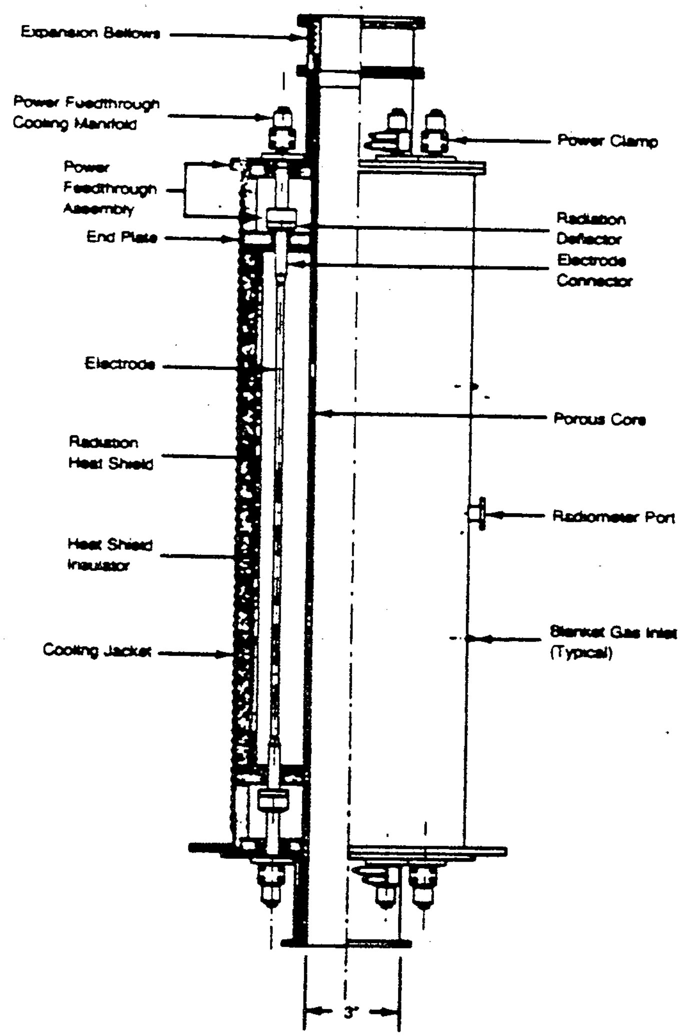


Figure 19.6. Cross-section of a typical high-temperature fluid-well reactor. Source: U.S. EPA 1985b.

Design Considerations: Post-treatment in the form of an activated carbon bed may be required to remove products of incomplete pyrolysis (PIPs) from gaseous emissions. Depending on the required destruction and removal efficiency, post-treatment is generally not required for granular solids.

Limitations: The process is not suitable for treating gases or bulky, irregular solids. Soils need to be dried and sized (approximately 10 mesh) before being fed into the reactor.

Technology Status: Developmental; demonstrated on a pilot scale for dioxin and PCBs.

Associated Technologies: Carbon adsorption.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Soil grain size distribution	Soils need to be less than 10 mesh	Sieve analysis	50/test
Percent-moisture content of soils	Soils need to be relatively dry for efficient combustion	Volume-weight analysis	50/test

References: Bonner, 1981; Boyd, 1986; Freeman, 1985; GCA, 1984; GCA, 1985a; Lee, et al., 1984; McGaughey, et al., 1984; Roy F. Weston, Inc., 1985; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.7 PLASMA ARC

Type of Control: Direct Waste Treatment

Function: Used to destroy either liquid or solid wastes by pyrolyzing them into combustible gases.

Description: The plasma arc process functions by contacting the waste feed (in the form of liquids or solids) with a gas which has been energized into its plasma state by an electrical discharge. A schematic of the process is shown in Figure 19.7. The plasma torch acts as an electrode and the hearth at the bottom of the reactor acts as the second electrode. The discharge of electricity between the two electrodes causes the centerline temperatures in the plasma to reach 90000°F. A small amount of gas is introduced into the centerline region through the torch, and is ionized. The ionized gas molecules transfer energy to the waste to cause pyrolysis of the waste.

Design Considerations: There are some technological limitations on the size of the plasma reactor that restrict industrial-scale use.

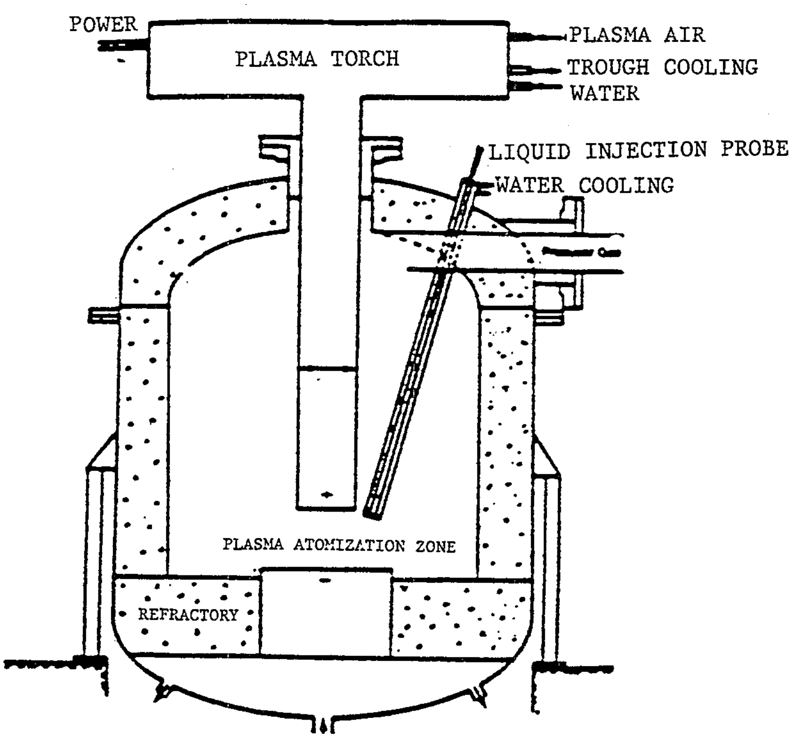


Figure 19.7. Plasma reaction vessel schematic.
Source: U.S. EPA, 1985b.

Limitations: Pretreatment techniques, such as blending and filtering, may be necessary to achieve the correct viscosity and to prevent clogging of the feed nozzle. The plasma arc process is not suitable for treating gaseous wastes.

Technology Status: Developmental. The technique has been demonstrated at the pilot-scale.

Associated Technologies: Filtration.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste form	Not suitable for gaseous wastes	Observation	Nominal
Viscosity of waste	Not suitable for highly viscous wastes	Viscometer	50/test

References: Bonner, 1981; Freeman, 1985; GCA, 1984; GCA, 1985a; McGaughey, et al., 1984; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINCERATION)

19.8 CEMENT AND LIME KILNS

Type of Control: Direct Waste Treatment (Physical Treatment)

Function: Used to destroy waste oils, solvents, and chlorinated organics and to recover available heat value from the wastes. Kiln temperatures are usually higher (2700°F) and gas residence time longer (6 to 10 seconds) than in conventional incinerators. Kilns provide adequate destruction of wastes with efficiencies of up to 99.9999 percent having been recorded.

Description: Cement and lime kilns operate as a waste incinerator by introducing a waste/air mixture as a secondary fuel into the flame produced by a burner powered by virgin fuel as shown in Figure 19.8. Many kilns are coal fired though some use fuel oil or a coal/coke mixture. The fuel/waste flame is directed at the cement mixture or lime in a rotating drum and heats it as it passes down the kiln. The exhaust gas from the process is often passed through a cyclone centrifugal separator or electrostatic dust precipitator then to a baghouse collection system for the removal of suspended particulates. Tests have been conducted using waste oils, chlorinated solvents, and PCB contaminated liquids. Conventional pollutants such as CO, NO_x Total hydrocarbons, and SO_2 seem to be independent of the inclusion of hazardous wastes in the fuel. Increased particulate emissions may be expected with higher chlorine content wastes, but kilns equipped with precipitators should experience no problems. HCl emissions may vary with waste components introduced and would require specific attention.

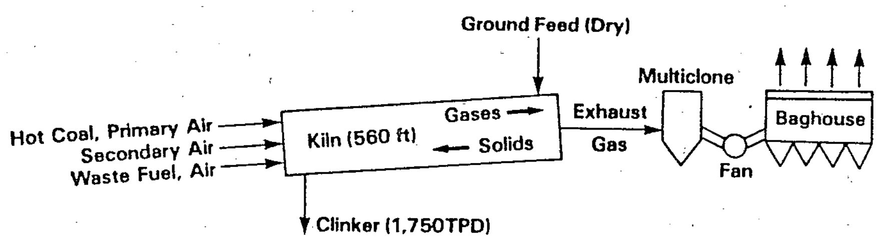


Figure 19.8. Cement kiln incineration system.
Source: Mourningham, 1985.

Factors affecting waste destruction efficiency of a cement of lime kiln include: waste components, volume viscosity, moisture content, BTU value, ash content, and particulate size, waste stream composition, and required air emission controls.

Limitations: Cement kiln incineration may pose problems in air pollution control. In the event of an upset, air quality standards may be violated. In general, kilns produce higher NO_x concentrations than conventional incinerators due to kiln burner design, not waste characteristics. Kilns may also experience problems with particulate and HCl emissions for wastes with high chlorine concentrations.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Air emission controls, electrostatic dust precipitation, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste identification	Suitability for treatment	Sampling and analysis	100/sample
Waste Btu value/	Suitability for treatment	Bomb calorimeter	45/sample
Chlorine content	Suitability for treatment	Sampling and analysis	30/sample
Available waste volumes	Process capacity	Market analysis	Nominal
Emission requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, et al., 1983; Mournigham, et. al., 1985.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.9 PYROLYSIS

Type of Control: Direct Waste Treatment, Solids Handling

Function: Used to destroy organic wastes in solids, liquids, and sludges by pyrolyzing them into combustible gases.

Description: Pyrolysis is accomplished in an oxygen deficient atmosphere. A pyrolytic incineration system principally consists of a pyrolyzer and a fume incinerator. The pyrolyzer is used to decompose the wastes, and the incinerator destroys the resultant organic compounds. Temperatures in the pyrolyzer range from 1000 to 1700°F. During pyrolysis, volatile compounds in the waste are driven off, forming a combustible gas consisting of hydrocarbons, hydrogen, and carbon monoxide. Inorganic constituents (i.e., salts and metals) will form a solid char in the pyrolyzer, which must be removed from the pyrolyzer prior to introducing additional untreated wastes. Combustible gases from the pyrolyzer are directed to the fume incinerator where organics are destroyed via incineration (rotary kiln or multiple hearth incineration).

Design Considerations: Pyrolysis is only applicable to wastes containing pure organics.

Limitations: Pyrolysis systems are usually designed for specific wastes and can not be readily adaptable to a variety of wastes. Pyrolysis of chlorophenols and chlorodibenzofurans can lead to the formation of chlorodibenzofurans and chlorodibenzo-p-dioxins.

Technology Status: Developmental.

Associated Technologies: Thermal destruction (incineration).

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste constituents	Not suited for inorganics; also certain chlorinated organics produce hazardous PIPs.	Sampling and analysis	100/sample

References: Bonner, 1981; Freeman, 1985; GCA, 1984; GCA, 1985a; McGaughey, et al., 1984; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.10 WET AIR OXIDATION

Type of Control: Direct Waste Treatment, Solids Handling

Function: Uses high temperature oxidation under controlled conditions to destroy dissolved or suspended organic waste constituents; used primarily to treat concentrated waste streams containing organic (e.g., pesticides, herbicides, etc.) and oxidizable inorganic wastes, and wastes with a high chemical oxygen demand/biological oxygen demand (COD/BOD) ratio (i.e., not readily ammenable to biological treatment).

Description: Aqueous phase oxidation of organic constituents is achieved at temperatures in the range of 350 to 650°F, and pressures ranging from 300 to 3,000 psi. The elevated pressures are used to keep the water in the liquid state so that the oxidation reactions can proceed at lower temperatures.

As diagrammed in Figure 19.10, liquid waste is pumped, using a high-pressure pump, into the system and mixed with compressed air (or oxygen). The air-waste mixture passes through a heat exchanger before entering the reactor where oxygen in the air reacts with the organic constituents in the waste. Residence time in the reactor varies from 30 minutes to 2 hours. The oxidation reactions cause the reactor temperature to rise. Following oxidation, the gas and liquid phases are separated. The hot liquid is recirculated through the heat exchanger to heat the new incoming wastes, before being discharged from the system. Gases are discharged to a baghouse filter and then to the atmosphere.

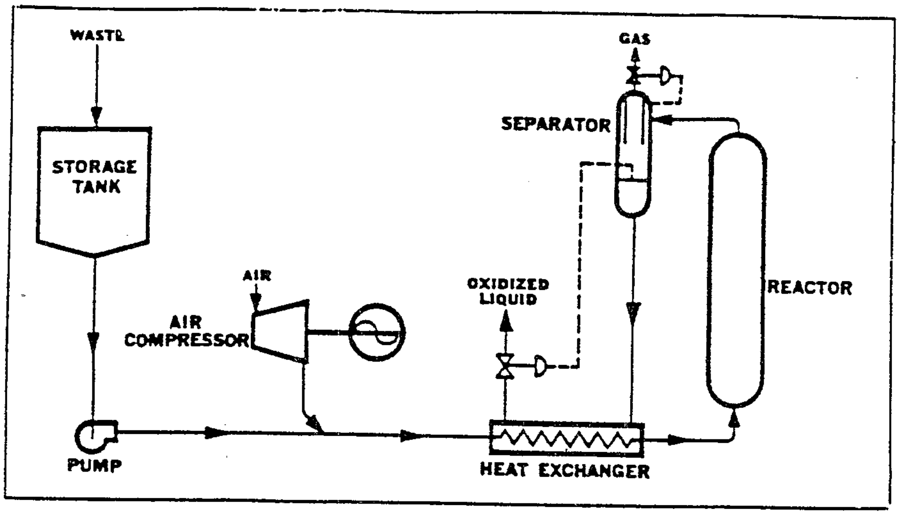


Figure 19.10. Flowsheet of wet air oxidation.
Source: U.S. EPA,A 1985b.

Limitations: The wet oxidation process is not suitable for inorganics or for wastes containing low concentrations of organics. The process has not yet been developed for treating large volumes of waste.

Technology Status: Developmental.

Associated Technologies: Biological treatment, scrubber, afterburner.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste volume	Not suitable for large volumes of waste	Site investigation report	Nominal
COD/BOD of the waste	Applicability; high COD/BOD ratio more efficiently treated via pyrolysis than biodegradation	COD analysis, BOD analysis	50/test
Waste constituents	Not suitable for inorganics or low concentrations of organics	Sampling and analysis (ICAP, GC/MS)	100/sample

References: Bonner, 1981; Freeman, 1985; GCA, 1984; GCA, 1985a; McGaughey, et al., 1984; U.S. EPA, 1985a.

19.0 THERMAL DESTRUCTION (INCINERATION)

19.11 INDUSTRIAL BOILERS

Type of Control: Other Direct Treatment

Function: Industrial boilers may be used to destroy waste oils, solvents, and other flammable, non-halogenated organics to recover available heat value from the wastes. Large boilers used for power generation with capacities larger than 10 million BTUs/hour have the greatest potential for use in hazardous waste destruction processes.

Description: Industrial boilers can operate as waste incinerators by introducing wastes as supplemental fuel for the flame produced by a burner powered by virgin fuel. Many boilers are coal fired though some use fuel oil or natural gas. Most boilers are capable of accepting any moderately halogenated liquid organic waste stream. It is possible to burn up to 3 percent halogenated wastes, but usually because of corrosive waste streams, only approximately 1 percent halogens are burned. A large boiler using organic wastes to replace 25 percent of the feed would consume approximately 500 gal/day of waste. Studies have indicated that approximately 10 percent of the feed is more typical in most applications. Under RCRA, the regulations and process performance standards for hazardous waste incineration do not apply to the use of combustible hazardous wastes as fuel in energy recovery operations such as power voilers. That makes the disposal of some waste streams in industrial boilers very attractive especially considering the energy value obtained. EPA has estimated that approximately 3.5 million tons of hazardous wastes were disposed of in this manner in 1981. An industrial boiler and a boiler circulation diagram are shown in Figure 19.11a and 19.11b, respectively. Factors affecting waste destruction efficiency of an industrial boiler include: halogen content, volume, viscosity, moisture content, Btu value, and ash content.

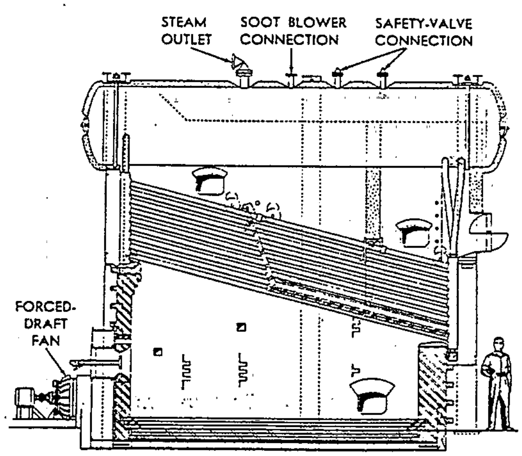


Figure 19.12a. Industrial boiler.

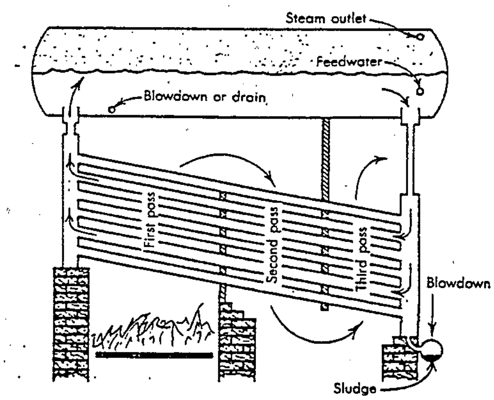


Figure 19.12b. Circulation flow.

Design Considerations: Design parameters for industrial boiler systems include: availability of appropriate waste streams, supply rate, consistency of waste stream composition, and required air emission controls.

Limitations: The use of industrial boilers for incineration may pose problems in air pollution control. It may be difficult to obtain high efficiencies of combustion depending on the type of fuel, waste, etc. Wastes with high halogen content or corrosive in nature may damage the boiler.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Air emission controls, electrostatic dust precipitation, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste identification	Suitability for coincineration	Sampling and analysis	100/sample
Waste Btu value	Suitability for treatment	Bomb calorimeter	45/sample
Chlorine content	Suitability for coincineration	Sampling and analysis	30/sample
Available waste volumes	Process capacity	Market analysis	Nominal
Effluent requirements	Design criteria	Regulatory assessment	Variable

References: Basilico, et al., 1985; Shields, 1961; U.S. EPA, 1985b.

20.0 LAND DISPOSAL

20.1 SECURE CHEMICAL LANDFILL

Type of Control: Land Disposal/Storage

Function: Used to provide a long-term, environmentally secure repository for the disposal of hazardous materials for which no alternative treatment or disposal alternative exists. Most efficient in the disposal of dewatered sludges, solid materials, contaminated soils, etc.

Description: Secure chemical landfills are a disposal technology with design and operating standards identified by the EPA. Landfill cells are constructed to contain drummed solid wastes or bulked solids in segregated areas for long-term storage. Each cell of a landfill is constructed with a bottom liner overlying a low permeability base material, covered with several feet of clay or other protective material. This is covered by another liner and protective layer. A diagram of the construction of a RCRA landfill is shown in Figure 20.10. Wastes are placed in the cell and surrounded by clay or earth and placed in layers until the cell is full. Once full, the cell is closed and covered according to RCRA regulations with more clay, synthetic liners and surface vegetative cover to limit erosion. Other provisions of a secure chemical landfill include leachate collection systems within the cell liners, containment and treatment systems for the leachate, gas venting, leak detection systems, and closure/post-closure care requirements. Current RCRA regulations also define other conditions and requirements for the operation of a secure chemical landfill.

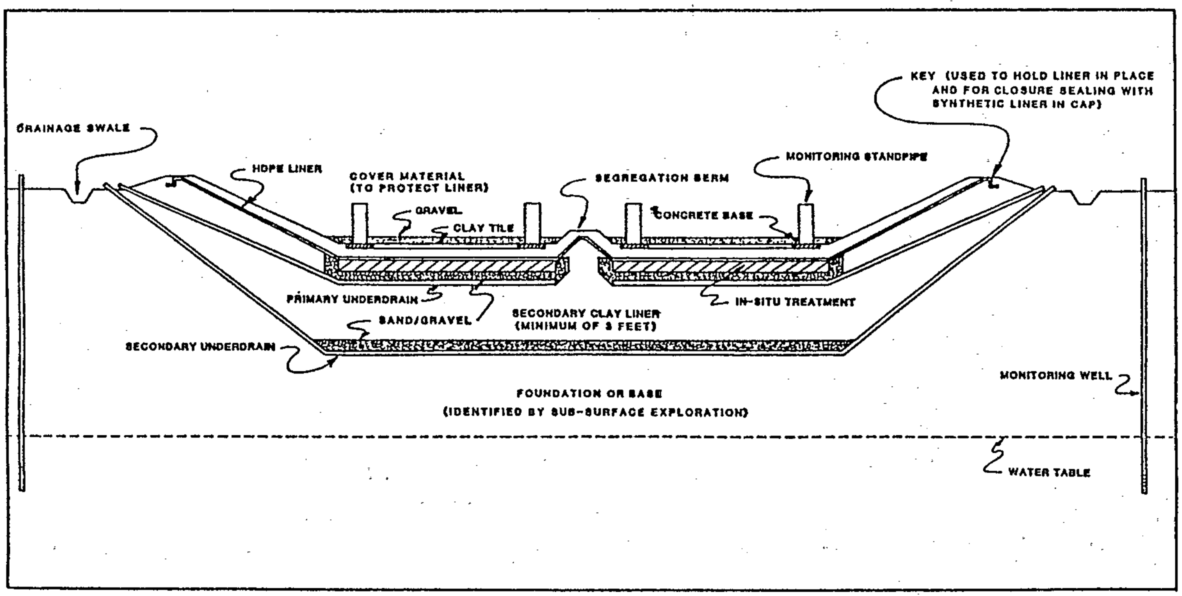


Figure 20.1. Secure chemical landfill design.
Source: Raboczynski, 1985; U.S. EPA, 1985c.

Design Considerations: Design parameters for secure chemical landfills include: waste types and compatibilities, volume of wastes, local topography, depth to ground water, ground water flow rate and use, flood zones, subsurface conditions such as geological structures, soil permeability, etc., and distance to populated areas.

Limitations: Despite comprehensive maintenance and monitoring, secure chemical landfills may release contaminants to the environment. Materials released from stored wastes may adversely react with clay or synthetic liners causing gaps in the integrity of the cell. Liner damage caused by animal, geologic, or other actions, may contribute to accidental releases. Improperly maintained or installed liners, leachate collection systems, or caps also add to the risk of release.

Technology Status: Conventional, well demonstrated. Minimum technology requirements of the 1984 RCRA Hazardous and Solid Waste Amendments for liners and leachate systems may affect the use of this technology for onsite applications.

Associated Technologies: Wastewater treatment, capping/surface sealing, dust control, grading, revegetation, diversion/collection systems.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste characteristics	Suitability for storage	Sampling and analysis	100/sample
Property survey	Suitability of area for landfill	Topographic maps	Nominal
Local geology	Subsurface structures and ground water levels	State geological survey data	Nominal
Waste volume	System capacity	Capacities of processes producing wastes	Variable 0-50,000
RCRA construction requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; Raboczynski, 1985; Muteh, 1984.

20.0 LAND DISPOSAL

20.2 SURFACE IMPOUNDMENTS/GRAVITY SEPARATION

Type of Control: Land Disposal/Storage

Function: Used to store or to pre-treat a variety of industrial wastes. An impoundment may be a natural topographic feature, a man-made excavation, or diked area. Impoundments can be used for the temporary storage of sludges, wastewaters, and wastes stored in waste piles. Waste piles may be stored in surface impoundments to meet the regulatory requirements for leachate collection. Waste may be stockpiled before or after treatment or while awaiting disposal.

Description: Surface impoundments may be constructed above, below or partially in the ground with surface dimensions greater than depth. Impoundments should be lined with an appropriate synthetic liner and are designed to contain an accumulation of wastes with free liquids. Although estimates of capacity vary, studies indicate impoundments vary in size from 0.1 to 5,300 acres. Although there is variation among state requirements, the most common is the requirement for the use of a liner to prevent seepage. The criteria in liner selection are permeability, hydrological conditions, and waste characteristics and compatibility. Buffer zones and monitoring wells are also used to protect adjacent ground water. Wastes stored in impoundments may separate into various layers depending on liquid content, solubilities, densities, and chemical composition. It may be possible to use a surface impoundment as a pre-treatment step in disposal of some types of materials.

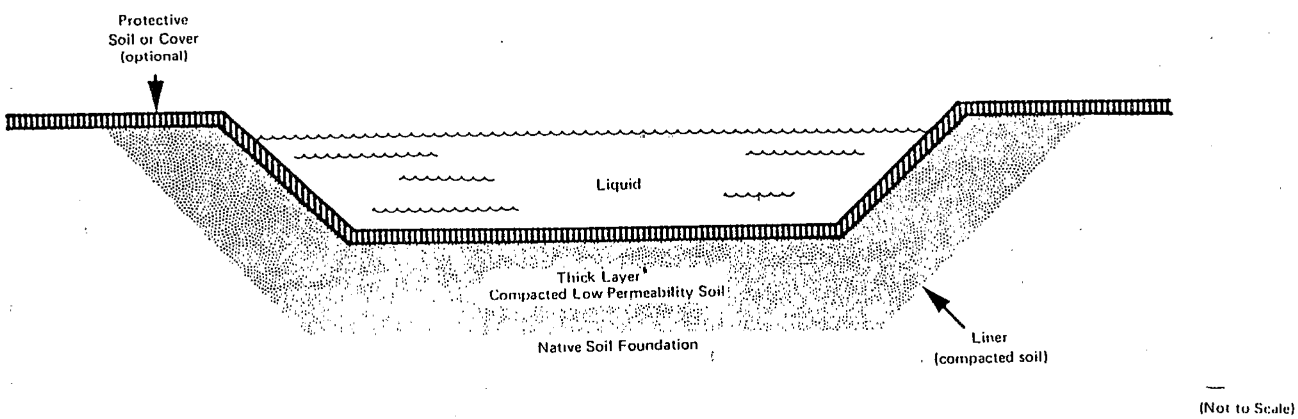


Figure 20.2. Surface impoundment.
Source: U.S. EPA, 1985c.

Design Considerations: Design parameters for surface impoundments include: waste types and compatibilities, volume of wastes, local topography, depth to ground water, ground water flow rate and use, flood zones, subsurface conditions such as geological structures, soil permeability, etc., and distance to populated areas.

Limitations: Despite comprehensive maintenance and monitoring, surface impoundments may release contaminants to the environment. Materials released from stored wastes may adversely react with clay or synthetic liners causing gaps in the integrity of the impoundment. Liner can be damage caused by animal, geologic, or other actions, may contribute to accidental releases.

Technology Status: Conventional, well demonstrated. Minimum technology requirements of the 1984 RCRA Hazardous and Solid Waste Amendments for liners and leachate systems may affect the use of this technology for onsite applications.

Associated Technologies: Wastewater treatment, capping/surface sealing, dust control, grading, revegetation, division/collection systems.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste characteristics	Compatibility	Sampling and analysis	100/sample
Property survey	Suitability of area for lagoon	Topographic maps	Nominal
Local geology	Subsurface structures and ground water levels	State geological survey data	Nominal
Waste volume	System capacity	Capacities of processes producing wastes	Variable 0-50,000
RCRA construction requirements	Design criteria	Regulatory assessment	Variable 0-50,000

References: Ehrenfeld, 1981; U.S. EPA, 1978b; U.S. EPA, 1983b; U.S. EPA, 1983c; U.S. EPA, 1985c.

20.0 LAND DISPOSAL

20.3 DEEP WELL INJECTION

Type of Control: Land Disposal/Storage

Function: Used to isolate certain types of wastes by injecting them in liquid form or mixed with a stabilizing material, deep underground into rock strata or salt domes. This technique has long been used by the petroleum industry for the disposal of pumping wastes and brines in well fields. It is an economical technique, but is very site dependent relative to the subsurface geological structure of the receiving strata.

Description: A deep-well injection system consists of a disposal zone, a well and surface storage and a pre-treatment facility. The injection well itself consists of an injection tube and a casing. Most wells in current use operate at approximately 300 psi, are in the area of 1,200 m deep, and can dispose of up to 400 gpm/well. The disposal zone must be located below any potable water aquifer and isolated from them by thick, relatively impervious strata such as dolomite or limestone as illustrated in Figure 20.3. Wastes injected may be mixed with cement or other stabilizing material to immobilize it after injection. The annular space between the injection tube and the casing can be filled with oil or fresh water to help detect leaks. Vertical migration of the wastes may take place by mean of natural fractures such as faults, abandoned wells, etc. Wastes most suited to deep well injection could be various heavy metals which could be precipitated to an insoluble form or chelated before mixing with a stabilizing agent and injection. Other chemically compatible stabilizers could be used with other types of wastes if required. Polymers mixed with wastes could be injected prior to polymerization.

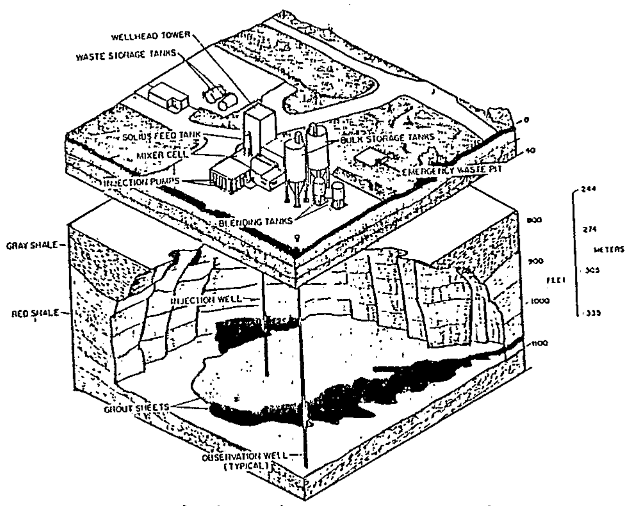


Figure 20.3 Deepwell injection system. Source: Stow, 1985.

Design Considerations: Design parameters for deep well injection include: waste types and compatibilities, volume of wastes, local geology, injection system and rate, monitoring systems, surrounding land use and water supplies, and current regulatory status.

Limitations: The most significant limitation to injection is lack of comprehensive knowledge of underground conditions without which long term confinement of the wastes can never be certain. Technical and operational difficulties exist in the pre-treatment of wastes for injection and in ensuring proper installation and maintenance of the well itself.

Technology Status: Conventional, well demonstrated in the petroleum and nuclear industries. Use of this technology for the treatment of hazardous wastes is divided into class I and class IV wells. Class I wells inject wastes below an aquifer used as a potable source. Class IV wells inject wastes into the same strata as the aquifer. The use of Class IV wells has recently been banned.

Associated Technologies: Excavation and removal, equalization, neutralization, stabilization, filtration.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste characteristics	Suitability for injection	Sampling and analysis	100/sample
Property survey	Suitability of area for site	Topographic maps	Nominal
Local geology	Subsurface structures and ground water levels	State geological survey data	Nominal
Location of potable water aquifer(s)	Potential for contamination	State geological survey data	Nominal
Waste volume	System capacity	Capacities of processes producing wastes	Variable 0-50,000
RCRA construction requirements	Design criteria	Regulatory assessment	Variable

References: Overcash, 1981; Stow, 1985; U.S. EPA, 1977; GCA, 1985b.

20.0 LAND DISPOSAL

20.4 SECURE CHEMICAL VAULTS

Type of Control: Land Disposal/Storage

Function: Used to provide an interim, environmentally secure repository for the storage of hazardous materials for which no alternative treatment or disposal alternative presently exits. Most efficient in the disposal of dewatered sludges, solid materials, contaminated soils, incinerator ash, etc.

Description: Secure chemical vaults have recently been developed to provide a technology for long term storage for materials that cannot be further reduced or destroyed and need to be isolated from the environment. The vault is an above-ground structure designed to separate hazardous materials from the environment without the problems and concerns associated with below-ground landfills. Material stored in vaults would be more easily accessible in the future if a reclamation or destruction technique is developed. The vault may be constructed of concrete for the outer containment structure and have several internal liners, each with leachate collection system as shown in Figure 20.4. Leachate monitoring and collection would be more reliable since no pumps would be required, only gravity collection and flow to an outside containment and treatment area. The vault itself could be visually inspected for any leakage since it is above ground. Once full, the vault would be capped by synthetic liners and provided with a runoff control system. Vents could be added if required. Vaults could be constructed to the necessary size and number for the application. A vault 1-1/2 acres in size and 25-feet high will provide approximately 45,000 cu. yds of capacity.

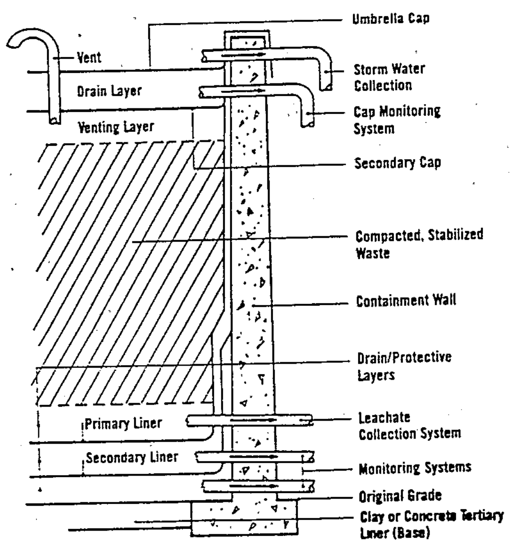


Figure 20.4. Secure Chemical Vault.
Source: Philipbar, 1985.

Design Considerations: Design parameters for secure chemical vaults include: waste types and compatibilities, volume of wastes, local topography, runoff control, liner leak detection systems, containment and treatment system for leachate.

Limitations: At present, storage as would be provided by a vault is considered "interim" and cannot be long term. As with a secure chemical landfill, the vault is intended only to provide storage for a certain time and at present is not a disposal method. The construction of vaults may present licensing problems in certain areas since it is intended as long term storage and would require post-closure monitoring and care.

Technology Status: Conventional, not well demonstrated. One type of vault was patented in 1984. Minimum technology requirements of the 1984 RCRA Hazardous and Solid Waste Amendments for liners and leachate systems may affect the use of this technology for onsite applications.

Associated Technologies: Wastewater treatment, capping/surface sealing, dust control, collection systems.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Waste characteristics	Suitability for storage	Sampling and analysis	100/sample
Property survey	Suitability of area for vaults	Topographic maps	Nominal
Local geology	Subsurface substructures and ground water levels	State geological survey data	Nominal
Waste volume	System capacity	Capacities of processes producing wastes	Variable 0-50,000
RCRA construction requirements	Design criteria	Regulatory assessment	Variable

References: Ehrenfeld, 1983; Philipbar, 1985.

21.0 PHYSICAL TREATMENT

21.1 SEWER CLEANING

Type of Control: Contaminated Water Supplies and Sewer Lines

Function: Used to remove deposits and debris from pipes to improve flow rate and capacity. Cleaning is usually necessary prior to any inspection and/or repair work on water or sewer lines, and may also be necessary if the line has been contaminated. Techniques for cleaning and inspection are generally applicable to water lines which are usually smaller than sewer lines.

Description: Sewer cleaning procedures involve the use of several types of equipment, or the combination of two or more procedures. Mechanical scouring techniques such as powered "snakes" which pull or push scrapers, augers, or brushes through the line are shown in Figure 21.1a. Bullet shaped plastic balls lined with scouring strips called "pigs" are hydraulically propelled at high velocity to scour the inner surface of the pipes. Hydraulic scouring can also be accomplished by running high pressure hoses into the sewer lines through manholes and flushing out a section of pipe with very high pressure water. Some systems include a directional nozzle. This technique is often used following mechanical scouring. Bucket cleaners can be used to dredge grit or contaminated soil from sewer lines. Winches pull sewer balls or "porcupine" scrappers from manhole to manhole through the sewer pipe. It is also a useful technique for obtaining samples from the line as illustrated in Figure 21.1b. Suction devices or vacuum trucks are also used in sewer cleaning operations.

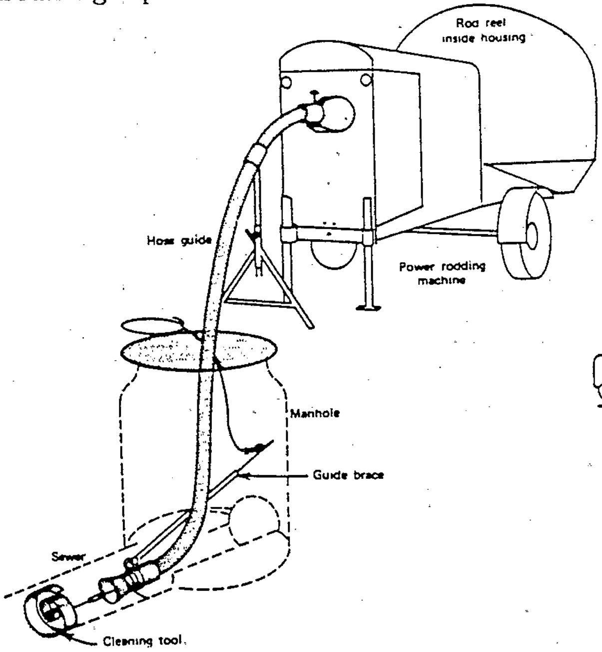


Figure 21.1a
Powered Snake.
Source: U.S. EPA, 1985b.

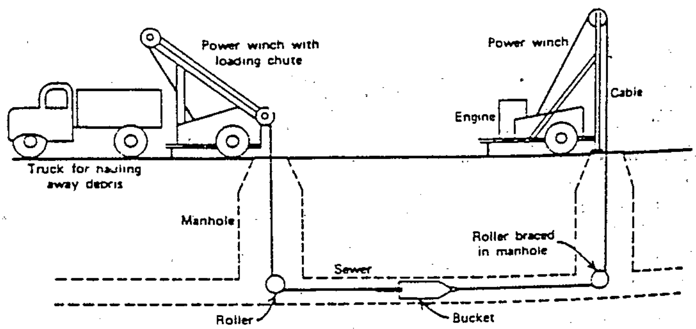


Figure 21.1b
Powered Bucket Cleaner.

Factors affecting the removal efficiency of cleaning equipment include: the type of material present, equipment type availability, access to the contaminated area, and configuration of the pipes to be cleaned. Removal of some types of hazardous constituents may be difficult if they have sorbed into the pipe itself.

Design Considerations: Design parameters for sewer cleaning systems are site specific. Considerations for this type of system include the type of material to be removed, accessibility, method of disposal and operator safety.

Limitations: Size of pipes may limit the use of some types of inspection and cleaning equipment that can be used. Pipes with diameters of less than 48 inches cannot be entered by workmen. Determining which section(s) of pipe are contaminated and planning logistics of implementation may also be difficult in some cases.

Technology Status: Well demonstrated for conventional uses, less so for hazardous applications.

Associated Technologies: Excavation/removal, land application, activated sludge, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Contaminant composition	Determine removal and disposal method	Sampling and analysis	100/sample
Location and area contaminated	Planning and logistics	Inspection of pipes	100-150/hr
Leakage points	Areas to be repaired	Inspection of pipes	100-150/hr
Ground water infiltration points	Areas to be repaired	Inspection of pipes	100-150/hr

References: Ehrenfeld, 1983; U.S. EPA, 1985b.

22.0 SEWER REHABILITATION AND REPAIR

Type of Control: Contaminated Water Supplies and Sewer Lines

Function: Several techniques can be used to relign, remove, or seal pipes that are in contact with contaminated substances or water. This will prevent further contamination of the water or sewer line and help to prevent ground water infiltration.

Description: Sewer and water lines can be rehabilitated by several types of procedures. Sliplining, or insertion of a new pipe inside an existing pipe is shown in Figure 22.1. This technique usually involves the insertion of a flexible liner pipe of slightly smaller diameter inside the damaged or contaminated pipe. Polyethylene is the most commonly used material. A similar process called "inversion lining" uses a flexible lining material that is thermally hardened inside the larger pipe after installation. Inversion lining is a process using a flexible liner inserted into the damaged or contaminated pipe and then thermally hardened once in place. Service connections are reopened by a camera-guided cutter after hardening. This technique is often used where excavation is impractical such as near large trees or below heavily travelled streets. Chemical grouts are commonly used for sealing leaking joints in otherwise sound sewer pipes. Small holes and radial cracks can also be repaired in this fashion. A grout is a low-viscosity liquid which cures to a form-fitting solid. Commonly used grouts include acrylamide gels, acrylate polymers, and polyurethane gels. If the pipes are so badly damaged or contamined that no rehabilitation is possible, it may become necessary to excavate and remove all of the pipe and replace it.

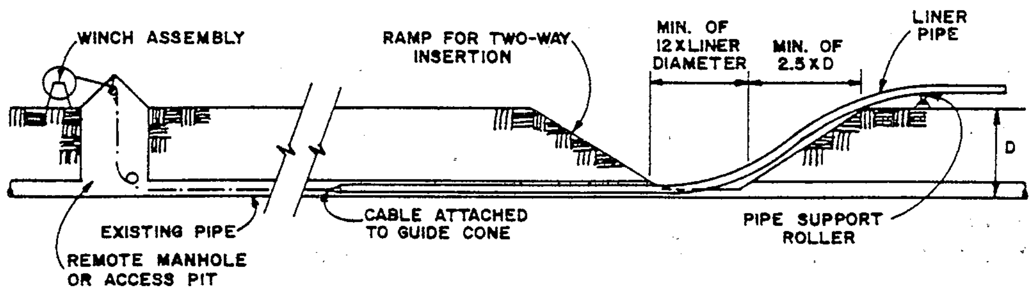


Figure 22-1. Sewer sliplining.
Source: U.S. EPA, 1985b.

There is little information on the use of these techniques for control of hazardous contaminants. Factors that could adversely affect the performance and reliability of such repairs are: incompatibility of the contaminants and the sealing material, and permeability of the repair materials to the pollutant(s).

Design Considerations: Design parameters for sewer rehabilitation are site specific. Considerations for this type of system include the type of contaminant, location of the area of pipe in question, accessibility, disruption of service or traffic and costs involved.

Limitations: Size of pipes may limit the use of some types of inspection, cleaning, and repair equipment that can be used. Pipes with diameters of less than 48 inches cannot be entered by workmen. Determining which section(s) of pipe are contaminated and planning logistics of implementation may also be difficult in some cases. The type of contaminant involved needs to be considered relative to the remedial action planned. Slip-lining requires that the pipe itself be relatively round since the lining pipe must be moved through it. Chemical grouting cannot be used to strengthen weak pipes or where the pipe is severely cracked or has large voids outside the pipe joint.

Technology Status: Well demonstrated for conventional uses, less so for hazardous applications.

Associated Technologies: Excavation/removal, diversion/collection, ground water pumping, sewer cleaning, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Contaminant composition	Determine removal and disposal method	Sampling and analysis	100/sample
Location and area contaminated	Planning and logistics	Inspection of pipes	100-150/hr
Leakage points	Areas to be repaired	Inspection of pipes	100-150/hr
Compatibility of sealant/repair material	Determine type of sealant/repair to be used	Manufacturer's data	
Ground water infiltration points	Areas to be repaired	Inspection of pipes	100-150/hr

References: Ehrenfeld, 1983; U.S. EPA, 1985b.

23.0 ALTERNATE DRINKING WATER SUPPLIES

Type of Control: Alternate Drinking Water Supplies

Function: The selection of alternate sources of drinking water may be a satisfactory solution to community water quality problems. This may also help prevent further contamination of the water or sewer lines. Use of bottled water is also a possibility in some applications.

Description: New water supplies may have to be selected for a community if the existing source(s) becomes contaminated. Many communities have existing facilities with alternate sources. The new supply should be located within a reasonable distance from the community and should be free of contaminants. If it is not, transportation or treatment costs may make the use of the alternate source as expensive as removing the contaminant from the original source. The use of bottled water is relatively costly and is usually only used for drinking and food preparation. Even though it is more costly, the delivery of bottled water to ensures all affected residents have safe drinking water. The use of bottled water is most commonly used as a temporary, emergency response to a contaminated source.

Design Considerations: Design parameters for alternative water supplies are site specific. Considerations include: possible contaminants in the alternate source, location of the source, distribution system(s) available, contamination of the distribution system, development cost of new reservoir, or development of new ground water wells.

Limitations: Availability and economics are the two prime factors in the development of an alternate source. If the source to be used is too far from the community, it may be either too expensive or impractical (or both) to use it as an alternative. Also, the cost of developing new impoundments, treatment systems, sludge disposal, and/or distribution systems may be prohibitive.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Excavation/removal, diversion/collection, ground water pumping, sewer cleaning, pipe replacement, incineration, land disposal.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Water quality	Determine suitability for use	Sampling and analysis	100/sample
Location of new source	Planning and logistics	Topographical maps	Nominal
Distance to new source	Distribution system	Topographical maps	Nominal
Required treatment of new source (if any)	Determine type of treatment needed	Water quality criteria	Variable
Expected duration of need	Source selection	Possibility for remediation of original source	Variable

References: Ehrenfeld, 1983; U.S. EPA, 1985b.

24.0 HOME WATER TREATMENT

Type of Control: Contaminated Water Supplies

Function: Point of use or home water treatment systems can be an option that is technically feasible for the removal of contaminants and may be the most economical alternative under some situations. Most units are reported to be most effective for the removal of organic compounds.

Description: There are a variety of devices available now designed for use in the home or office for the removal of contaminants at the point of use. Claims have been made for the removal of undesirable tastes, odors, purification, filtration of suspended matter, and removal of various types of VOCs. Installations are generally of three types: line bypass, where separate faucets are provided for treated and non-treated water; faucet-mounted, where all water through the faucet is treated; whole-house, where all water is treated. Most common home units involve the use of some type of small carbon adsorption units to accomplish the purification claimed. Several studies have concluded that these types of filters may provide a medium for bacterial growth. Since the small home units are not specifically designed for removal of VOCs, and generally do not provide the contact time necessary for effective removal their use for this purpose at this time is questionable. Home water distillation units have been shown to be extremely effective in reducing concentrations of inorganic materials, bacteria, and suspended matter. Efficiency in removal of VOCs is not well documented. Since these might evaporate with the water, they may also recondense with the product. As with the carbon units, there is insufficient data to make conclusions as to effectiveness of treatment.

Other point of use systems include; activated alumina, reverse osmosis, ion exchange, ozonation, and ultraviolet irradiation. Reverse osmosis and ion exchange are most commonly used where more stringent water quality standards must be met such as hospitals, laboratories, etc.

Design Considerations: Design parameters for home water purification systems include: selection of units appropriate for the contaminant(s) of concern, appropriate hydraulic capacity, and maintenance criteria and schedules.

Limitations: Activated carbon units may provide potential for excess bacterial growth, have short-lived effectiveness for some contaminants, could possibly release contaminants after exhaustion of the carbon, and do not indicate exhaustion. Distillation units may be ineffective in the removal of VOC compounds. Reverse osmosis units need high water pressure and flow rates.

Technology Status: Conventional, well demonstrated.

Associated Technologies: Filtration, chlorination, ultraviolet/ozonation, carbon adsorption, ion exchange.

Important Data Needs for Screening:

Data need	Purpose	Collection method	Costs ($)
Water quality	Determine purification method	Sampling and analysis	100/sample
Purification criteria	Type of system needed	Manufacturers data	Nominal
Installation requirements	Determine system	Manufacturer's data, applicability	Variable
Expected volume of need	Equipment selection	Manufacturer's data	Variable

References: Ehrenfeld, 1985; U.S. EPA, 1985b.

REFERENCES

Artiola, J., and W. H. Fuller. Effects of Crushed Limestone Barriers on Chromium Attenuation in Soils. Journal of Environmental Quality. Vol. 9, No. 4. pp. 503-510. 1979.

Ehrenfeld, J., and J. Bass. Evaluation of Remedial Action Unit Operations at Hazardous Waste Disposal Sites. Noyes Publications, New Jersey. 1984.

Ball, W. P., et al. Mass Transfer of Volatile Organic Compounds in Packed Transfer Aeration. Journal of the Water Pollution Control Federation, pp. 127-135. 1984.

Basilico, J. et al. Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes. Background Report II: Assessment of Alternative Technologies. U.S. EPA March 1985.

Barner, H. E., J. S. Chartier, H. Beisswenger, and H. W. Schmidt. Lurgi Corporation. Application of Circulating Fluid Bed Technology to the Combustion of Waste Materials. Environmental Progress, 4(2): 125-130. May 1985.

Berry, R. I. New Way to Destroy PCBs. Chemical Engineering 88(16):37-41. August 18, 1981.

Bonner, T. A., et al. Engineering Handbook for Hazardous Waste Incineration. Prepared for U.S. EPA, Cincinnati, Ohio. SW-899 June 1981.

Boyd, J., H. D. Williams, and T. L. Stoddard. Destruction of Dioxin Contamination By Advanced Electric Reactor. Preprinted Extended Abstract of Paper Presented Before the Division of Environmental Chemistry, American Chemical Society, 191st National Meeting. New York, New York: Vol. 26, No. 1. April 13-18, 1986.

Brady, N. C. The Nature and Properties of Soils, 8th edition. Macmillan Publishing Company, Inc., New York. 1974.

California Air Resources Board. Technologies for the Treatment and Destruction of Organic Wastes as Alternatives to Land Disposal. 1982.

Cantor, L. W. and R. C. Knox. Ground Water Pollution Control. Lewis Publishers Inc. Michigan. 1985.

Chillingworth, M., et al. Industrial Waste Management Alternatives and Their Associated Technologies/Processes, Volume IV. GCA Corporation/Technology Division. GCA-TR-80-80-G. February 1981.

Crittenden, J. C., G. Friedman, D. W. Hand, and M. Dobrzelewski. Design of Fixed Beds to Remove Multicomponent Mixtures of Volatile Organic Chemicals. Paper submitted for presentation at the 1985 AWWA Meeting, Washington, D.C. June 23-27, 1985.

E. C. Jordan Company. Corrective Measures for Releases to Surface Water. Final Report prepared under subcontract to GCA Corporation/Technology Division for the U.S. EPA-OSW, Land Disposal Branch, under EPA Contract No. 68-01-6871, Work Assignment No. 51. GCA-TR-85-66-G. August 1985.

Arthur D. Little, Incorporated. Handbook for Evaluating Remedial Action Plans. Final Report prepared for U.S. EPA-ORD, MERL, under EPA Contract No. 68-01-5949. PB84-118249. EPA-600/2-83-076. August 1983.

Fair, G. M., J. C. Geyer, and D. A. Okun. Water and Wastewater Engineering, Volume 2: Water Purification and Wastewater Treatment and Disposal. John Wiley and Sons, Inc., New York. 1968.

Flathman, P.E., and J.A. Caplan. Cleanup of Contaminated Soils and Ground Water Using Biological Techniques. Paper presented at the Hazardous Waste and Hazardous Materials Conference, Atlanta, Georgia. 1986.

Freeman, Harry M. U.S. EPA-HWERL, Thermal Destruction Branch. Project Summary: Innovative Thermal Hazardous Waste Treatment Processes. EPA-600/S2-85/049. 1985.

GCA Corporation, Technology Division. Final Report: Technology Overview - Circulating Fluidized Bed Combustion. Prepared for U.S. EPA, Office of Research and Development, under EPA Contract No. 68-02-2693. GCA-TR-81-91-G. June 1982.

GCA Corporation, Technology Division. Final Report: Technical Assessment of Treatment Alternatives for Wastes Containing Halogenated Organics. Prepared for U.S. Environmental Protection Agency, Office of Solid Waste, Waste Treatment Branch, under EPA Contract No. 68-01-6871, Work Assignment No. 9. GCA-TR-84-149-G. October 1984.

GCA Corporation, Technology Division. Identification of Remedial Technologies. Detailed Review Draft Report prepared for U.S. EPA, Office of Waste Programs Enforcement, under EPA Contract No. 68-01-6769, Work Assignment No. 84-120. GCA-TR-84-109-G(O). March 1985a.

GCA Corporation, Technology Division. Corrective Measures for Releases to Ground Water from Solid Waste Management Units. Draft Final Report prepared for U.S. EPA-OSW, Land Disposal Branch, under EPA Contract No. 68-01-6871, Work Assignment No. 51. GCA-TR-85-66-G. August 1985b.

GCA Corporation, Technology Division. Corrective Measures for Releases to Soil from Solid Waste Management Units. Draft Final Report prepared for U.S. EPA-OSW, Land Disposal Branch, under EPA Contract No. 68-01-6871, Work Assignment No. 51. GCA-TR-85-66-G. August 1985c.

Gross, R. L., and S. G. Termaath. Packed Tower Aeration Strips Trichloroethylene from Ground Water. Presented at the 1984 Summer National Meeting of the American Institute of Chemical Engineers. August 1984.

Hitchcock, D. A. Solid Waste Disposal: Incineration. Chemical Engineering, 86(11): 185-194. May 21, 1979.

Johanson, J. G., S. J. Yosim, L. G. Kellog, and S. Sudar. Elimination of Hazardous Waste by the Molten Salt Destruction Process. In: Incineration and Treatment of Hazardous Waste, Proceedings of the Eighth Annual Research Symposium. EPA-600/9-83-003. April 1983.

JRB Associates. Methodology for Screening and Evaluation of Remedial Responses. Draft Report prepared for U.S. EPA-MERL, Cincinnati, Ohio, and U.S. EPA-OERR, Washington, D.C. March 16, 1984.

Kaufmann, H. G. Granular Carbon Treatment of Contaminated Ground Water Supplies. Second Annual Symposium on Aquifer Restoration and Ground Water Monitoring, sponsored by the National Well Water Association. 1982.

Kiang, Y. and A. A. Metry. Hazardous Waste Processing Technology Ann Arbor Science Publishers Inc. Michigan. 1982.

Kirk and Othmer. Chemical Grouts, Volume 5, pp. 368-874. John Wiley & Sons, Inc., New York. 1979.

Kosson, D.C. et al., Development and Application of Onsite Treatment Technologies for Sludge Filled Lagoons. In: International Conference on New Frontiers for Hazardous Waste Management EPA-600/9-85/025 September 1985.

Lee, Kenneth W., William R. Schofield, and D. Scott Lewis. Mobile Reactor Destroys Toxic Wastes in "Space". Chemical Engineering. April 2, 1984.

Lutton, R., G. Regan, and L. Jones. Design and Construction of Covers for Solid Waste Landfills. EPA-600/12-79-165. 1979.

Lutton, R. Evaluating Cover Systems for Solid and Hazardous Waste. U.S. Army Engineers Waterways Experiment Station. Prepared for U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio. SW-867. 1982.

Lyman, W. J. Applicability of Carbon Adsorption to the Treatment of Hazardous Industrial Wastes. Carbon Adsorption Handbook. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. 1980.

McCabe, W. L. and J. Smith. Unit Operations of Chemical Engineering, Third Edition. McGraw-Hill, Inc. New York. 1976.

McCarty, P. L., et al. Volatile Organic Hazardous Constituents Removal by Air Stripping. American Water Well Association Seminar Proceedings: Controlling Organics in Drinking Water. San Francisco. June 1979.

Metcalf & Eddy, Inc. Wastewater Engineering: Collection, Treatment, and Disposal. McGraw-Hill Book Company, New York. 1972.

Mournigham, R.E., et al. Hazardous Waste Incineration in Industrial Processes: Cement and Lime Kilns. In: Proceedings: International Conference on New Frontiers for Hazardous Waste Management. U.S. EPA-600/9-85/025 September 1985.

Muteh, R.D. et al. Recent Advances in Secure Landfill Technology. Paper presented at Hazardous Wastes and Environmental Emergencies, Houston, TX 1984.

Overcash, et al. Design of Land Treatment Systems for Industrial Wastes, 2nd edition, Ann Arbor Science Publishers, Inc. 1981.

Peterson, R., et al. Comparison of Laboratory and Field Test Data in the Chemical Decontamination of Dioxin Contaminated Soils Using the Galston PKS Process. Presented before the Division of Environmental Chemistry, American Chemical Society. April 1986.

Phelps, R. GHR Engineering Corporation. Telephone Conversation with T. J. Nunno, GCA/Technology Division. Re: Topographical Survey Costs. March 14, 1986.

Philipbar, W.B. Environmental Vault - A New Concept in Land Storage. In: Proceedings: International Conference on New Frontiers for Hazardous Waste Management. EPA/600/9-85/025 September 1985.

Pope Scientific, Inc. Menomonee Falls, Wisconsin, Bio-oxidation of Sewage and Industrial Wastes: An Annotated Computerized Bibliography. 1976.

Raboczynski, R.W. Advanced Secure Chemical Landfill Design. In: International Conference on New Frontiers for Hazardous Waste Management. EPA-600/9-85/025 September 1985.

Rasmussen, George P. Waste-Tech Services, Inc. Another Option: Onsite Fluidized-Bed Incineration. Hazardous Materials & Waste Management Magazine. January-February 1986.

Rickman, William S. GA Technologies, Inc. Circulating Bed Incineration of Hazardous Wastes. Chemical Engineering Progress, March 1985.

Roberts, P. V., G. D. Hopkins, C. Munz, and A. A. Riojas. Evaluating Two Resistance Models for Air Stripping of Volatile Organic Contaminants in a Countercurrent, Packed Column. Environmental Science & Technology, 19(2): 164-173. 1985.

Rosbury, K. D., and S. C. James. Control of Fugitive Dust Emissions at Hazardous Waste Cleanup Sites. In: Proceedings of the Eleventh Annual Research Symposium on Land Disposal of Hazardous Wastes. EPA-600/9-85-013. April 29 - May 1, 1985.

Roy F. Weston, Inc., and York Research Consultants. Times Beach, Missouri: Field Demonstration of the Destruction of Dioxin in Contaminated Soil Using the J. M. Huber Corporation Advanced Electric Reactor. Weston Project No. 255-01-01. February 11, 1985.

Ryan, C. R. Slurry Cut-Off Walls Methods and Applications. Geo-Con, Inc., Pittsburgh, Pennsylvania. March 1980.

Shields, C.D. Boilers Types, Characteristics and Functions McGraw-Hill. 1961.

Shilling, R. D. Air Stripping Provides Fast Solution for Polluted Well Water. Pollution Engineering. February 1985.

Skoog, D. A., and D. M. West. Fundamentals of Analytical Chemistry, 3rd Edition. Holt, Rinehart, and Winston Publishers, New York. 1979.

Stow, S.H. et al. Waste Disposal by Hydrofracture and Application of the Technology to the Management of Hazardous Wastes. In: Proceedings: International Conference on New Frontiers for Hazardous Waste Management. EPA/600/9-85/025. September 1985.

Sundstrom, D. W., and H. E. Klei. Wastewater Treatment. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 1979.

Swanson, M. L., J. Dollimore, and H. H. Schobert. University of North Dakota, Energy Research Center. Supercritical Solvent Extraction. Prepared for U.S. Department of Energy. DOE/FE/60181-96. June 1984.

Thagard Research Corporation Irvine, California. Mobile High Temperature Fluid Wall Reactor. Draft Report Prepared for U.S. EPA-MERL, Cincinnati, Ohio. 1984.

Troxler, W. L., C. S. Parmele, and G. A. Barton. Survey of Industrial Applications of Aqueous Phase Activated Carbon Adsorption for Control of Pollutant Compounds from Manufacture of Organic Compounds. Prepared by IT Enviroscience for the U.S. EPA Office of Research and Development. EPA-600/2-83-034. 1983.

U.S. EPA. Physical, Chemical, and Biological Treatment Techniques for Industrial Wastes. Vol II. NTIS Report PB 275 287. 1977.

U.S. EPA. Office of Research and Development. At-Sea Incineration of Herbicide Orange Onboard the M/T Vulcanus. Prepared by TRW Inc., Redondo Beach, California. EPA-600/2-78-086. April 1978a.

U.S. EPA Manual for Evaluating Contamination Potential of Surface Impoundments EPA 570/9-78-003. 1978b.

U.S. EPA. Treatability Manual, Volume III: Technologies for Control/Removal of Pollutants. EPA-600/8-80-042c. July 1980a.

U.S. EPA. Guide to the Disposal of Chemically Stabilized and Solidified Waste. Washington, D.C. SW-872. September 1980b.

U.S. EPA. Office of Research and Development. At-Sea Incineration of PCB-Containing Wastes Onboard the M/T Vulcanus. Prepared by TRW Inc., Redondo Beach, California. EPA-600/7-83-024. April 1983a.

U.S. EPA. Surface Impoundment Assessment National Report. EPA-570/9-84-002 1983b.

U.S. EPA. Office of Technology Assessment. Technologies and Management Strategies for Hazardous Waste Control. EPA. March 1983c.

U.S. EPA. Soil Properties, Classification, and Hydraulic Conductivity Testing. Draft Technical Resource Document for Public Comment. SW-925. March 1984a.

U.S. EPA. Review of In-Place Treatment Technologies for Contaminated Surface Soils, Volume 1: Technical Evaluation. EPA-540/2-84-003a. September 1984b.

U.S. EPA. Modeling Remedial Actions at Uncontrolled Hazardous Waste Sites. EPA/540/2-85/001. April 1985a.

U.S. EPA. Handbook for Remedial Action at Waste Disposal Sites (Revised). EPA/625/6-85/006. October 1985b.

U.S. EPA. Minimum Technology Guidance on Double Liner Systems for Landfills and Surface Impoundments -- Design, Construction and Operation. Draft Guidance. EPA-530/SW-85-014. Second version. May 24, 1985c.

U.S. EPA. Handbook; Dust Control at Hazardous Waste Sites. EPA-540/2-85-003. November 1985d.

Vrable, D. L., D. R. Engler, and W. S. Rickman. Application of Transportable Circulating Bed Combustor for Incineration of Hazardous Waste. Presented at HAZMAT 1985, West Long Beach, California. December 1985.

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