REVIEW DRAFT

TECHNOLOGY SCREENING GUIDE FOR TREATMENT OF CONTAMINATED SOILS AND SLUDGES

Submitted to:

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1. INTRODUCTION

This guide for the screening of treatment alternatives for soils and sludges has been developed to assist CERCLA site managers in identifying potentially applicable treatment technologies. The guide is not designed to select the best technology for a particular waste, but rather to identify all of the treatment technologies potentially applicable to that waste.

The matrices and technology summaries screen potentially applicable technologies by:

1. Identifying the treatment technologies that appear applicable to remediate the many types of wastes found at CERCLA sites; and
2. Identifying restrictive waste/substrate characteristics, treatment process limitations, and pretreatment options that must be considered when evaluating a potential treatment system in detail.

The above information is provided in three groups of tables: (1) waste technology matrices for specific waste groups, (2) technology summary tables for each technology, and (3) pretreatment tables to identify potential pretreatment and materials handling systems. The tables are designed to be used by both technical and nontechnical personnel; therefore, no specific technical background is required to identify applicable technologies.

The tables assist in identifying waste, site, and technology factors that should be considered in the evaluation or implementation of treatment systems. Specifically, this guide's tables identify the data necessary for a more detailed evaluation of the technologies. Once these data are collected, the guide can be used to identify potentially applicable technologies warranting continued evaluation and eliminate technologies that are not technically feasible. A more detailed analysis of each potentially applicable alternative identified by this guide would include cost, performance, and environmental impacts. This guide is not meant to be used for such an in-depth analysis, but rather, is designed to provide a preliminary screening of treatment alternatives and to identify data needs. EPA is currently developing detailed guidance on the in-depth evaluation of treatment alternatives for superfund wastes.

The remaining contents of this guide are organized as follows:

- Section 2 outlines the waste characterization process;
- Section 3 describes the waste/technology matrices and defines how a technology's effectiveness was determined;
- Section 4 discusses the content and utility of the technology summary tables;
- The purpose and use of the pretreatment tables are summarized in Section 5;
- A step-by step approach for the proper use of this guide is contained in Section 6;
- Section 7 presents an example of how to use the guide with a hypothetical waste;
- References are presented in Section 8;
- Following the above sections, are the waste/technology matricies, Tables 1 and 2, which identify the applicability of the technologies for each waste group;

- Table 3 presents examples of each waste group;
- Then, for each technology a process schematic (where available), a technology description, and a technology summary table is presented.
- Finally, Tables 24 and 25 present pretreatment methods.

2. WASTE CHARACTERIZATION

The potentially applicable technologies are identified on the basis of the characteristics of the waste to be treated and (1) must be able to destroy or remove the contaminants found in the waste and (2) must be compatible with or applicable to the waste matrix.

Therefore, in order to properly use the matrices and tables in this guide, data on the physical form and contaminants of the waste must be obtained. The waste characterization process involves identification of the physical form or waste matrix (soil or sludge for this guide) and the contaminants or waste group for which treatment is required.

This guide is designed to be used for two general categories of physical form or matrix common to wastes encountered at CERCLA sites: soils and sludges. For the purpose of this guide, sludges are defined as pumpable materials of both natural and man-made origin with a solids content of 10 to 85 percent, the remainder being liquid. Soils are defined as nonpumpable inert dirt, sand, silt, clay, rock, and similar earth materials with a solids content of greater than 85 percent. Wastes with a solids content of less than 10 percent are defined as liquids and are not covered in this guide.

The waste contaminants or waste group(s) to be treated have to be identified, usually through chemical analysis. The waste groups used in this document are listed in the left margin of the waste/technology matrices. Table 3 has been included to assist the reader in selecting the appropriate waste group(s). The majority of CERCLA soils and sludges will be contaminated with more than one waste group; therefore, if this guide is to be used properly, all waste groups must be identified. Once potential treatment methods are identified based on the information obtained from a waste characterization, the guide can be used to ascertain other waste characteristics that must be determined for a more thorough evaluation of the potentially applicable alternatives.

3. WASTE/TECHNOLOGY MATRICES

This guide contains two waste/technology matrices, Table 1 for soils and Table 2 for sludges, designed to identify the potential applicability and effectiveness of technologies on specific waste groups. The waste/technology matrices assume that the user has completed the waste characterization described in Section 2. The waste characterization allows the user to identify the waste as a soil or sludge and determine the major contaminants or waste groups. The waste groups are listed vertically down the left margin, and the technologies are listed horizontally across the top of the tables.

The waste groups in the waste/technology matrices are organized according to their basic chemical nature, which often reflects similar treatability characteristics (e.g., volatility, biodegradability, Btu content). High profile contaminants such as PCBs and pesticides are presented separately from other halogenated organics because of their unique characteristics and the special emphasis placed on their remediation.

The following criteria were used to evaluate the applicability of the technologies to each waste group:

1. Demonstrated effectiveness - (Symbol ●) The technology has been used successfully on a commercial scale for treating hazardous CERCLA waste in repeated applications (e.g., rotary kiln incineration of most organics).

2. Potential effectiveness - (Symbol ◐) The technology appears to have the basic characteristics needed for successful application but has not been proved for CERCLA waste on a commercial scale or on a continuous basis. Effectiveness may depend on specific waste or soil characteristics (e.g., soil flushing of organics), or pretreatment may be required. Economic or environmental feasibility is uncertain. A decision on feasibility requires careful consideration of waste-related limitations or mixture interferences and may require bench and/or pilot testing.

3. No effectiveness - (Symbol O) The technology is not expected to remove or destroy the contaminant to a significant degree, but the contaminant does not generate interference or adverse impacts on the process (e.g., vacuum extraction for metal contaminated soils).

4. Adverse impacts - (Symbol X) The contaminant is likely to generate significant interference or adversely impact either the environment or the effectiveness, safety, cost, or reliability of the treatment process (e.g., in-situ biodegradation for soils contaminated with biotoxic metals or pesticides).

4. TECHNOLOGY SUMMARY TABLES

Following the identification of potentially applicable treatment technologies, the user should refer to the appropriate technology summary tables to identify potentially restrictive contaminant or substrate characteristics that can interfere with process feasibility and/or operation. To determine whether these restrictive characteristics apply to the specific waste to be treated, additional data on the waste or soil may be required.

Where available, quantitative data on restrictive characteristics have been included in the tables only to assist the user in evaluating potential technologies. The data have been extracted from general and specific sources and should only be used as a guidline or crude estimate for applicability purposes, and are therefore not transferable to every application.

The data collection tasks, or at least the requisite sampling tasks, should be undertaken early in the remedial investigation/feasibility study (RI/FS) process. Thus, data collection will be more efficient and economical and potential treatment alternatives can be identified early. Also, the feasibility study process is expedited by having pertinent treatability and/or process data available. Viable treatment alternatives can be evaluated more efficiently, and infeasible alternatives will be screened out early.

These tables can be used at several stages of the remedial investigation or site sampling process to further refine the technically feasible treatment method. However, this guide is designed only to screen alternatives and identify data needed to evaluate technical feasibility. The potential technologies identified must be further evaluated using the references provided, contacts with technology experts (including vendors), bench and/or pilot scale testing, etc.

5. PRETREATMENT TABLES

Identification of materials handling or pretreatment requirements that may be applicable to the wastes under consideration is also useful. Pretreatment, materials handling, or processing requirements for a waste are often not recognized until the advanced stages of pilot testing or implementation of a treatment system. This may cause significant delays and escalate costs while the waste and/or equipment is modified. For example, vendors of mobile incineration systems consider materials handling and processing to be the key problems at a site rather than the technical performance of the incineration system itself. Handling of dense, viscous sludges can be particularly problematic because of adhesion, equipment fouling, and variation in pumpability.

When materials handling requirements are identified early in the planning process, systems can be designed or modified to handle the particular physical or chemical characteristics of the waste. The pretreatment tables (Tables 24 and 25) are provided to give a general overview of materials handling systems for soils and sludges. Specific systems are highly dependent on the characteristics of the waste and the conditions at the site. The necessary information on site conditions and physical characteristics can be collected concurrently with data collection or sampling conducted to identify restrictive chemical and physical characteristics of the wastes.

6. APPROACH TO USE

The use of this guide varies depending on whether the waste soil or sludge contains one or more major contaminants or waste groups. Therefore, the first step is to complete the waste characterization described in Section 2. This allows the user to identify the waste matrix, i.e., soil or sludge, and the contaminants or waste groups in a soil or sludge. Section 6.1 describes the approach for soils and sludges containing a single waste group, while Section 6.2 discusses soils and sludges containing multiple waste groups.

6.1 Single Waste Contaminant

After identifying the waste matrix and waste group (contaminant), the user should then consult the appropriate waste/technology matrix, i.e, Table 1 for soils or Table 2 for sludges. The next step is to find the contaminant or waste group in the left margin, read across the table, and list those technologies identified as having demonstrated or potential effectiveness. Next, the technology summary table for each potential technology should be evaluated to identify possible restrictive waste characteristics, process limitations, and data collection requirements needed for further evaluation. A number of tables direct the user to the pretreatment tables, Table 24 for soils or Table 25 for sludges. These tables contain common material handling, processing, and pretreatment options that may eliminate or reduce restrictive waste characteristics

6.2 Multiple Waste Contaminants

This guide can also be used to evaluate the treatability of waste soils or sludges containing more than one contaminant or waste group. When evaluating wastes with multiple waste groups, the first step is to evaluate each waste group independentaly, as described in Section 6.1.

The next step is to use the waste/technology matrices to compare against the list of technologies identified for the waste groups. The ideal solution would be to find one or more technologies that have demonstrated effectiveness on all of the waste groups of concern. If such a technology can be identified, its technology summary table should be carefully evaluated against each waste group for possible restrictive characteristics and data collection requirements.

The next best alternative would be a technology that has at least potential effectiveness on all of the waste groups. As above, the technology summary tables should be carefully evaluated against each waste group.

If a single technology with demonstrated or potential effectiveness cannot be identified, combinations of technologies or treatment trains that can successfully treat the waste should be identified. A treatment train is composed of two or more technologies used in series. Each technology is included to remove or destroy a certain waste group or contaminant; therefore, each technology need be effective only on its target waste group. Technologies that are effective on one waste group but are adversely impacted by another can be used as part of a treatment train provided the impacting waste group is treated or pretreated prior to reaching the impacted technology. Each technology summary table should, therefore, be thoroughly evaluated against each waste group to identify contaminants that must be treated prior to application of particular technologies. This step allows the user to develop the order of the technologies within a potential treatment train.

Following review of the matrices, technology tables, and pretreatment tables, the user should be familiar with possible treatment systems, the restrictive waste characteristics that can affect the system, the data collection requirements necessary to identify potential problems, and the pretreatment needed to resolve various waste handling problems. By using this information and the referenced documentation, it is then possible to initiate advanced planning for in-depth feasibility studies and/or bench/pilot testing of potential treatment technologies.

7. APPLICATION OF THE TECHNOLOGY SCREENING PROCEDURES TO A HYPOTHETICAL WASTE

To illustrate the use of this guide, this section screens a hypothetical waste for potential treatment technologies. The procedure used is described in Section 6; the example is a soil contaminated with trichloroethylene (TCE) and nickel.

The two waste groups are initially screened separately. From the waste characterization, TCE is identified as a halogenated volatile organic and nickel as a nonvolatile metal.

Table 1 identifies the following technologies as having demonstrated or potential effectiveness on soils contaminated with halogenated volatiles such as TCE:

- Rotary kiln incineration (demonstrated);
- Cement-based immobilization (demonstrated);
- Fluidized bed incineration;
- Infrared thermal treatment;
- Advanced electric reactor;
- Soil washing;
- Dechlorination;
- Low temperature thermal stripping;
- Vacuum extraction; and
- In-situ biodegradation.

According to Table 1, three technologies have demonstrated or potential effectiveness on soils contaminated with nonvolatile metals such as nickel:

- Cement-based immobilization (demonstrated);
- Soil washing; and
- Lime stabilization.

Comparison of the two lists reveals three technologies that could potentially treat both waste groups in a single step. Cement-based immobilization is identified as having demonstrated effectiveness on both waste groups, and soil washing and lime stabilization are potentially effective on both waste groups.

The next step is to consult the technology summaries for these three technologies to determine restrictive waste characteristics.

Cement-based Immobilization (Table 18) - The table indicates that volatile organics are not effectively immobilized and recommends analysis for volatile organics and bench-scale testing. The waste characterization has already identified a volatile organic, TCE; therefore, bench-scale testing would be required to further evaluate this technology's effectiveness on TCE. No restrictive characteristics are identified for nickel.

Lime Stabilization (Table 19) - The table states that volatile organics are not immobilized and that metals may not be permanently immobilized.

Soil Washing (Table 14) - The table indicates the formulation of a suitable washing fluid would be difficult for wastes containing mixtures of organics (i.e., TCE) and metals (i. e., nickel). The technology's effectiveness also appears highly dependent upon the soil's characteristics.

From the review of the technology summary tables, it is unlikely that a single technology can effectively treat soil contaminated with both TCE and nickel. Cement-based immobilization and lime stabilization cannot immobilize volatile organics (TCE) and treatment of wastes containing organics and metals would be difficult with soil washing. The next step, therefore, is to identify and evaluate each possible multistep treatment process or treatment train. Obviously, there are too many possibilities to cover here; however, one possible treatment train will be investigated to illustrate the process.

One possible TCE-nickel treatment train is low temperature thermal stripping of TCE followed by cement-based immobilization of the nickel compounds. Table 1 indicates that low temperature thermal stripping is potentially effective on TCE but has no effect on nickel. Table 16 indicates that the technology is not effective on metals. This restrictive characteristic would preclude the use of this technology for removing both contaminants; however, the soil flushing segment of the train is included only for TCE removal. No restrictive characteristics are listed in Table 16 for volatile organics (TCE), although the technology's effectiveness appears highly dependent on soil characteristics. Therefore, further evaluation of this technology should concentrate on defining site-specific soil characteristics.

The second segment of the treatment train would involve cement-based immobilization of the nickel. Table 18 states that volatile organics are not effectively immobilized. However, the majority of the volatile organic, TCE in this example, would have been removed by the low temperature thermal treatment step of the treatment train. Furthermore, this segment of the treatment train is only targeted at nickel removal, and therefore, its effectiveness on TCE is not important.

Based upon the information contained in this guide, a low temperature thermal treatment/cement-based immobilization treatment train would appear to be potentially feasible and warrant further investigation as part of a RI/FS.

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TABLE 1

WASTE / TECHNOLOGY MATRIX

SOILS

Contaminant	Fluidized Bed Incineration	Infrared Thermal Treatment	Rotary Kiln Incineration	Advanced Electric Reactor	Soil Washing	In-situ Soil Flushing	KPEG Dechlorination	Low Temp. Thermal Stripping	In-situ Vacuum Extraction	Cement-based Immobilization	Lime Stabilization	In Situ Biodegradation
TABLE #	5	6	7	9	13	14	15	16	17	18	19	23
Organic												
Halogenated Volatiles	◒	◒	●	◒	◒	◒	◒	◒	◒	●	○	◒
Halogenated Non-Volatiles	◒	◒	●	◒	◒	◒	◒	○	○	●	○	◒
Non-Halogenated Volatiles	◒	◒	●	◒	◒	◒	○	◒	◒	●	○	◒
Non-Halogenated Non-Volatiles	◒	◒	●	◒	◒	◒	○	○	○	●	○	◒
PCBs / Dioxins	◒	◒	●	◒	○	○	◒	○	○	●	○	◒
Pesticides	◒	◒	●	◒	◒	◒	◒	○	○	●	○	◒
Organic Corrosives	◒	◒	●	◒	◒	◒	○	○	○	●	○	X
Inorganic												
Volatile Metals (Cd, Zn, Ag, Hg, Sn, Pb)	X	X	X	X	◒	○	○	○	○	●	◒	X
Non-Volatile Metals (Cr, Ni, Cu, Be)	○	○	○	○	◒	○	○	○	○	●	◒	X
Asbestos	○	○	○	○	○	○	○	○	○	●	○	○
Radioactive	○	○	○	○	◒	○	○	○	○	●	○	○
Inorganic Corrosives	○	○	○	○	◒	◒	○	○	○	●	●	X
Nonmetallic Toxic Elements (As, F, Sb, Bi)	X	X	X	X	○	○	○	○	○	●	◒	X
Cyanides	X	◒	●	◒	◒	○	○	○	○	●	◒	X
Reactive												
Oxidizers	◒	◒	●	◒	◒	○	○	○	○	●	○	X
Reducers	◒	◒	●	◒	◒	○	○	○	○	●	○	X
Explosives	◒	◒	●	◒	◒	○	○	○	○	●	○	X

● Demonstrated Effectiveness

◒ Potential Effectiveness

○ No Effectiveness

X Potential Adverse Impacts to Process or Environment

TABLE 2

WASTE / TECHNOLOGY MATRIX
SLUDGES

Contaminant	Fluidized Bed Incineration	Infrared Thermal Treatment	Rotary Kiln Incineration	Wet Air Oxidation	Evaporation / Dewatering	Basic Extractive Sludge Treatment	Filtration	Cement-based Immobilization	Lime Stabilization	Chemical Reduction Oxidation	Neutralization	Composting
TABLE #	5	6	7	8	10	11	12	18	19	20	21	22
Organic												
Halogenated Volatiles	◒	◒	●	○	◒	◒	◒	◒	○	○	○	◒
Halogenated Non-Volatiles	◒	◒	●	○	◒	◒	◒	◒	○	○	○	◒
Non-Halogenated Volatiles	◒	◒	●	◒	◒	◒	◒	◒	○	○	○	◒
Non-Halogenated Non-Volatiles	◒	◒	●	◒	◒	◒	◒	◒	○	○	○	◒
PCBs / Dioxins	◒	◒	●	○	◒	◒	◒	◒	○	○	○	◒
Pesticides	◒	◒	●	◒	◒	◒	◒	◒	○	○	○	◒
Organic Cyanide	◒	◒	●	◒	◒	○	◒	◒	○	●	○	◒
Organic Corrosives	◒	◒	●	◒	◒	○	◒	◒	◒	◒	●	×
Inorganic												
Volatile Metals (Cd, Zn, Ag, Hg, Sn, Pb)	×	×	×	○	◒	○	◒	●	◒	◒	○	×
Non-Volatile Metals (Cr, Ni, Cu, Be)	○	○	○	○	◒	○	◒	●	◒	◒	○	×
Asbestos	○	○	○	○	◒	○	◒	●	○	○	○	○
Radioactive	○	○	○	○	◒	○	◒	●	○	○	○	×
Inorganic Corrosives	○	○	○	◒	◒	○	◒	●	◒	○	●	×
Nonmetallic Toxic Elements (As, F, Sb, Bi)	×	×	×	○	◒	○	◒	●	◒	◒	○	×
Cyanides	×	◒	●	◒	◒	○	◒	●	○	●	○	×
Reactive												
Oxidizers	◒	◒	◒	◒	◒	○	◒	●	◒	◒	○	×
Reducers	◒	◒	◒	◒	◒	○	◒	●	◒	◒	○	×
Explosives	◒	◒	◒	○	◒	○	◒	◒	○	◒	○	×

● Demonstrated Effectiveness

◒ Potential Effectiveness

○ No Effectiveness

× Potential Adverse Impacts to Process or Environment

Table 3. Waste Group Examples

HALOGENATED VOLATILES

Carbon tetrachloride
Chlorobenxene
1,2-Dichloroobenzene
1,1,1-Trichloroethane
1,1-dichloroethane
1,1-Dichloroethylene
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Chloroethane
2-Chloroethyl Vinyl Ether
Chloroform
1,2-Dichloropropane
1,3-Dichloropropene
Methylene Chloride
Methyl chloride
Methyl bromide
Bromoform
Dichlorobromomethane
Dichlorodifluoromethane
Chlorodibromomethane
Tetrachloroethylene
Trichloroethylene
Vinyl Chloride
1,2-trans-Dichloroethylene
Bis(Chloromethyl)ether

HALOGENATED NONVOLATILES

1,2-Di-chlorobenzene
1,3-Di-chlorobenzene
1,4-Di-chlorobenzene
Hexachlorobenzene
Hexachloroethane
Hexachlorobenzene
1,2,3-Trichlorobenzene
Bis(2-Chloroethyoxy)methane
2-Chloronaphthalene
4-Bromophenyl Phenyl Ether
4-Chlorophenyl Phenyl Ether
3,3-Dichlorobenzidine
Bis(2-Chloroethyl) Ether
Hexachlorocyclopentadiene
Bis(2-Chloroisopropyl) Ether

NONHALOGENATED VOLATILES

Acrolein
Acrylonitrile
Benzene
Toluene
Ethylbenzene

NONHALOGENATED NONVOLATILES

Naphthalene
Isophorane
Nitrobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Bis(2-Ethylhexyl)Phthalate
Di-n-octyl phthalate
Dimethyl phthalate
Diethyl phthalate
Di-n-butyl phthalate
Acenaphthylene
Acenaphthene
Butyl Benzyl phthalate
Fluorene
Fluoranthene
Chrysene
4,6-Dinitro-o-creosol
2,4-Dimethylphenol
Pyrene
Phenanthrene
Anthracene
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-c,d)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
Benzidine
1,2-Diphenylhydrazine
N-Nitrosodiphenylamine
N-Nitrosodimethylamine
N-Nitrosodimethylamine
N-Nitrosodi-n-propylamine
Phenol
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol

Table 3. (continued)

PESTICIDES

Endosulfan (2 isomers)
Endosulfan Sulfate
BHC (4 isomers)
Aldrin
Dieldrin
4,4'-DDE
4,4'-DDD
4,4'-DDT
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
Chlordane
Toxaphene

VOLATILE METALS

Cadmium
Zinc
Silver
Mercury
Tin
Lead

NONMETALLIC TOXIC ELEMENTS

Arsenic
Antimony

OTHER CATEGORIES

Asbestos

INORGANIC CORROSIVES

Hydrochloric acid
Nitric acid
Hydrofluoric acid
Sulfuric acid
Sodium hydroxide
Calcium hydroxide
Calcium carbonate
Potassium carbonate

EXPLOSIVES

Trinitrotoluene (TNT)
Nitroglycerine
Cyclotrimethylene trinitramine (RDX)

PCBs/DIOXINS

Arochlor (1016, 1221, 1232, 1242, 1248, 1254, 1264)
2,3,7,8-Tetrachloro-dibenzo-p-dioxin (TCDD)

ORGANIC CORROSIVES

Acetic acid
Formic acid
Acetyl chloride
Aromatic Sulfonic acids

NONVOLATILE METALS

Chromium
Nickel
Copper
Beryllium
Selenium

RADIOACTIVES

Radioactive isotopes of Iodine, Barium, Uranium

CYANIDES

Cyanide
Metallic cyanides (ferricyanide, sodium cyanide)

OXIDIZERS

Chlorates
Chromates

REDUCERS

Sulfides
Phosphides
Nitrides

Table 4. Technology Summary

Waste Type: Soils and Sludges
Technology: High Temperature Thermal Treatment (General)

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
High moisture content	Moisture content affects handling and feeding and has major impact on process energy requirement.	Percent moisture	12
Elevated levels of halogenated organic compounds	Halogens form HCl, HBr, or HF when thermally treated; acid gases may attack refractory material and/or impact air emissions.	Quantitative analysis for organic Cl, Br, and F	4,10,11
Presence of PCBs, Dioxins	PCBs and dioxins are required to be incinerated at higher temperatures and long residence times. Thermal systems must receive special permits for incineration of these wastes.	Analysis for priority pollutant	4,10
Presence of toxic elements	Elements (either pure or as oxides, hydroxides, or salts) that volatilize at high temperatures (e.g., Cd, As, Hg, Pb, Sn, Ag) may vaporize during incineration. These emissions are difficult to remove using conventional air pollution control equipment.	Analysis for heavy metals	4,10,11
Presence of other toxic elements (e.g., Cr, Ni, Be, Cu)	Elements cannot be broken down to nonhazardous substances by any treatment method: Therefore, thermal treatment is not useful for soils with heavy metals as the primary contaminant. Additionally, an element such as trivalent chromium (Cr^{+3}) can be oxidized to a more toxic valence state, hexavalent chromium (Cr^{+6}), in combustion systems with oxidizing atmospheres.	Analysis for heavy metals	4,10,11

Table 4. (continued)

Waste Type: Soils and Sludges
Technology: High Temperature Thermal Treatment (General)

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Elevated levels of organic phosphorus compounds	During combustion processes, organic phosphorus compounds form phosphoric acid anhydride (P_2O_5), which contributes to refractory attack and slagging problems.	Analysis for phosphorus	4,10

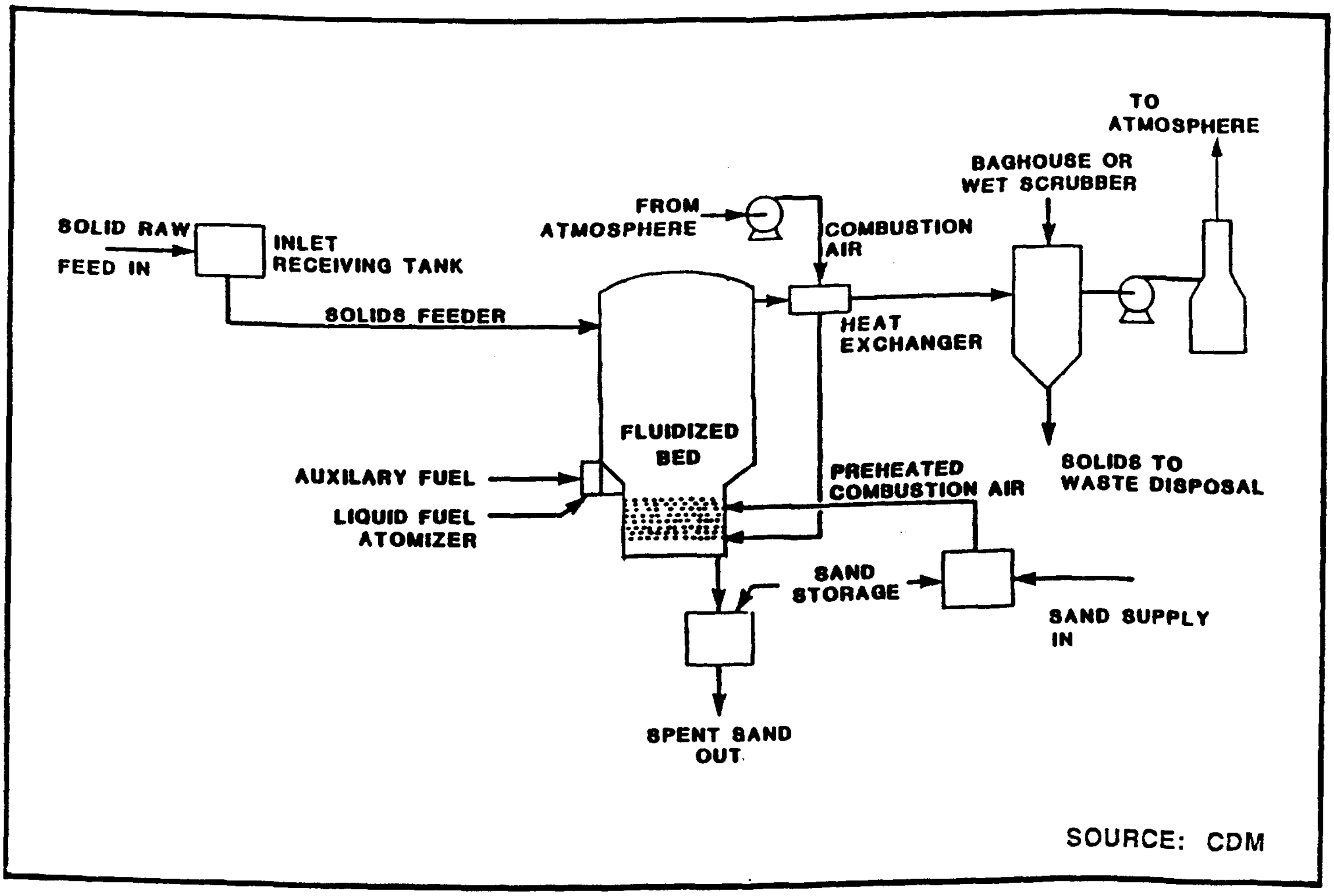

Figure 1. Fluidized Bed Incineration

Technology Description

Fluidized bed incinerators are used to incinerate organic solids, sludges, slurries, and liquids. Contaminants such as halogenated and nonhalogenated organics, PCBs, and phenolic wastes can be potentially processed. Fluidized bed systems can also process contaminated soil.

The fluidized bed consists of a refractory lined vessel containing a bed of inert granular material, such as silica sand. Combustion air is forced upward through the bed, heating the granular bed. Waste material is injected radially into the bed and quickly heated, dried, and burned. The heat of combustion from the waste is transferred back to the bed. Secondary combustion chambers are employed to permit adequate time for complete combustion. If contaminated soil is being processed, the soil acts as a bed material. Detoxified soil is withdrawn from the bottom of the fluidized bed.

Table 5. Technology Summary

Waste Type: Soils and Sludges
Technology: Fluidized Bed Incineration*

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Feed particle size	Large particle size affects feeding and solids removal from the bed. Solids greater than 1 inch (2.5cm) must be reduced in size by shredding, crushing, or grinding (see Tables 24 and 25). Soil feeds containing fine particles (clays, silts) result in high particulate loading in flue gases.	Size, form, quantity of solid material. Size reduction engineering data. Soil particle size distribution, USGS soil classification	4,10,11,12
Low-melting point (less than 1600 F) constituents, particularly alkali metal salts and halogens	Defluidization of the bed may occur at high temperatures when particles begin to melt and become "sticky." Melting point reduction (eutectics) may also occur. Alkali metal salts greater than 5% (dry weight) and halogens greater than 8% (dry weight) contribute to such refractory attack, defluidization, and slagging problems.	Ash fusion temperature	4,11
Ash content	Ash contents greater than 64% can foul the bed.	Ash content	11
Waste density	As waste density increases, particle size must be decreased for intimate mixing and heat transfer to occur.	Waste-bed density comparison	11
Presence of chlorinated or sulfonated wastes	These wastes require the addition of sorbents such as lime or sodium carbonate into the bed to absorb acidic gases.	Analysis for priority pollutants	11

* See also: Table 4, High Temperature Thermal Treatment (General).

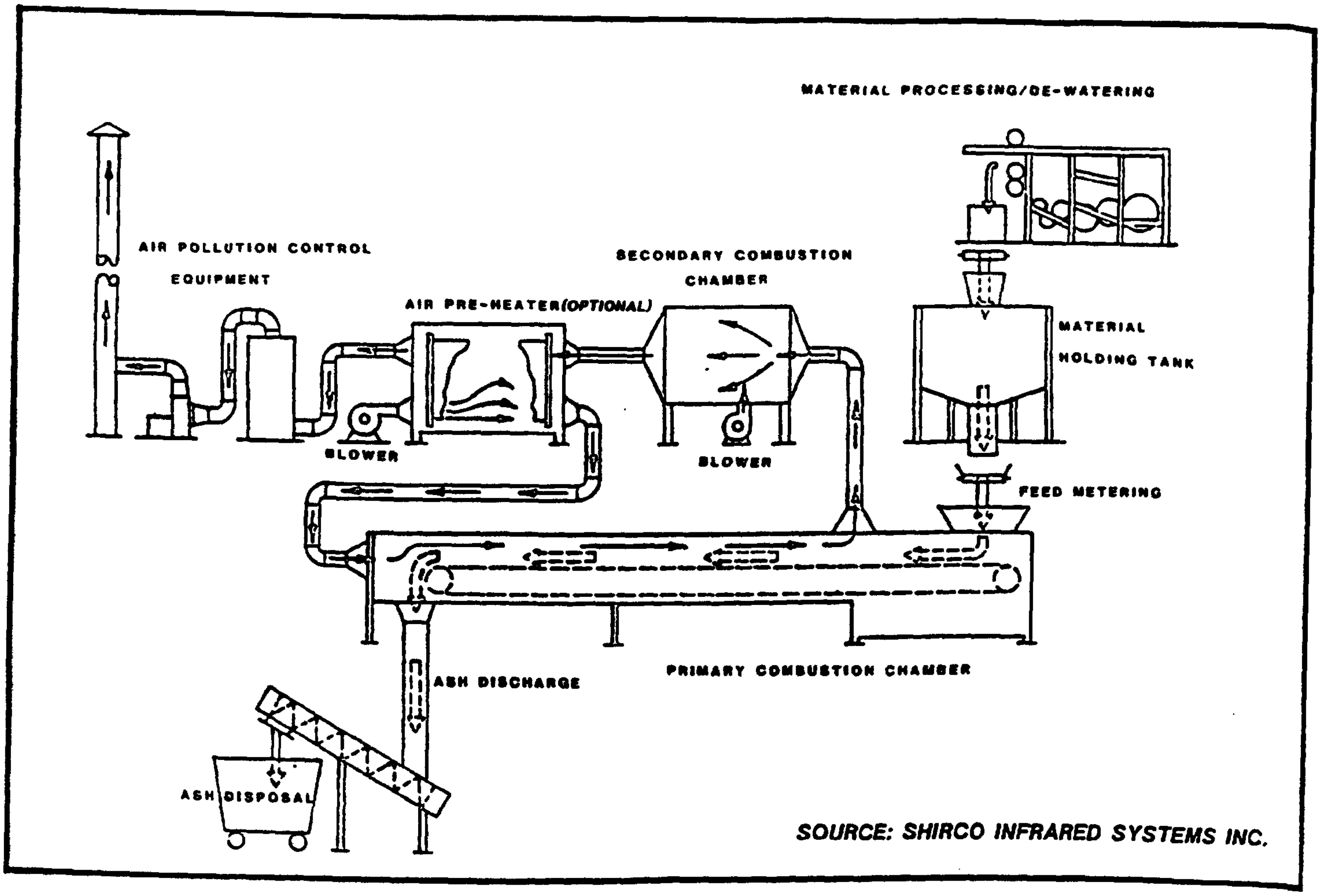

Figure 2. Infrared Thermal Treatment

Technology Description

Infrared processing systems are designed to destroy hazardous wastes with infrared energy generated from heating elements. Most types of solid wastes and sludges (including contaminated soils and spent activated carbon) can be treated with the total system (i.e., including use of the primary and secondary combustion chamber). Liquids and gaseous wastes may also be processed.

Wastes travel on a woven, metal alloy conveyor belt through the furnace for a precise residence time. After the wastes pass under infrared heating elements, ash residue is discharged to a hopper and the off-gases are exhausted to a secondary chamber (fired with oil or gas) to ensure complete combustion. Exhaust gases from the secondary chamber then pass through appropriate air pollution control equipment prior to release through a stack.

Table 6. Technology Summary

Waste Type: Soils and Sludges
Technology: Infrared Thermal Treatment*

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Nonhomogeneous feed size	Nonuniform feed size affects remediation, feeding, and conveyance through the system. The largest solid particle size processable is 1 to 1-1/2 inches (such as rocks, roots, containers); must be crushed or shredded to allow for feeding.**	Size, form, quantity of solid material. Size reduction engineering data	10
Moisture content	Since waste material is conveyed through the system on a metal conveyor belt, soils and sludges must be firm enough (usually >22% solids) to allow for proper conveyance. Soils and sludges with excess water content (e.g., lagoon sediments) require dewatering prior to feeding.**	Percent moisture	10

* See also: Table 4, High Temperature Thermal Treatment (General).
** See Tables 24 and 25.

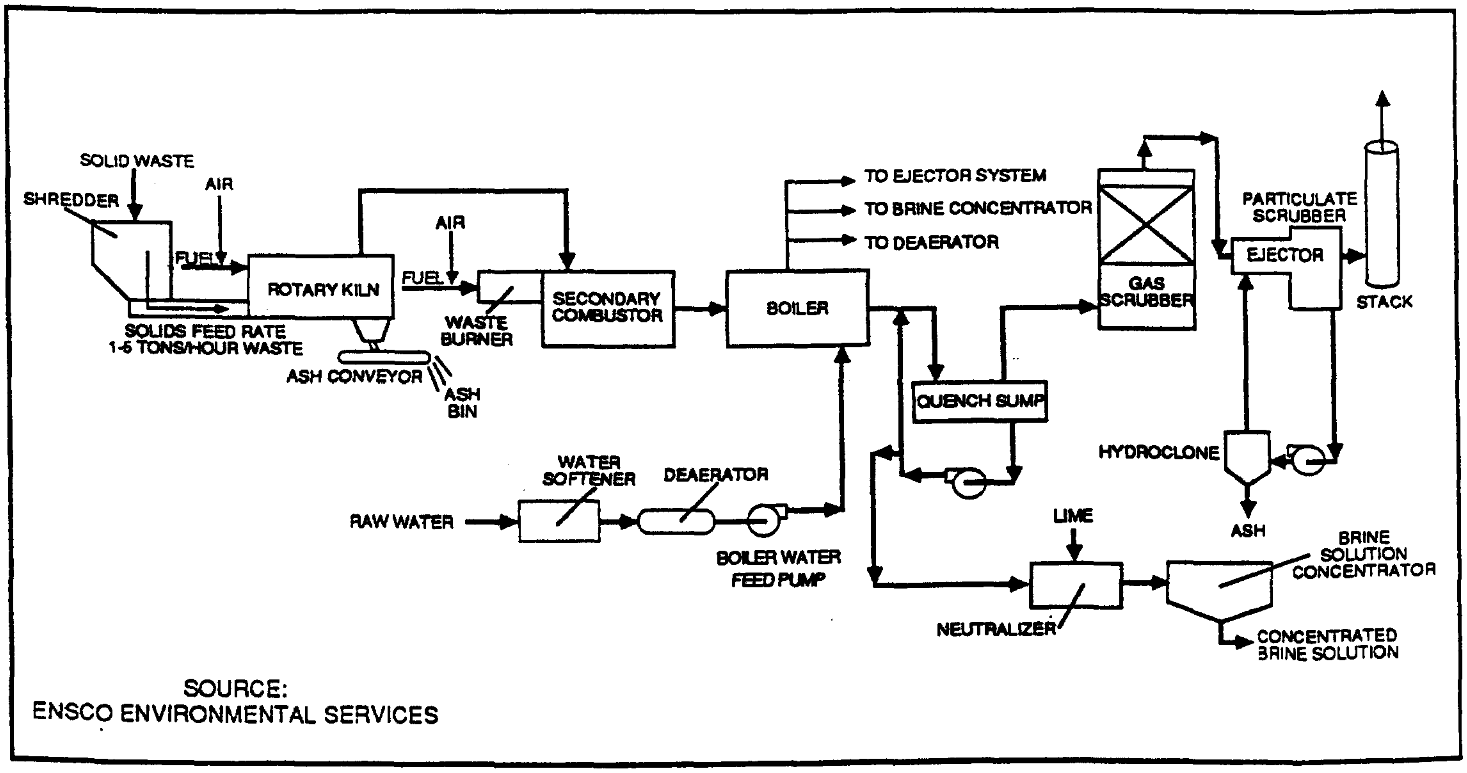

Figure 3. Rotary Kiln Incineration

Technology Description

Rotary kiln incinerators are inclined, refractory-lined cylinders used primarily for the combustion of organic solids and sludges, including contaminated soils.

Wastes are injected into the high end of the kiln and passed through the combustion zone as the kiln rotates. Rotation of the combustion chamber creates turbulence and improves the degree of burnout of the solids. Wastes are substantially oxidized to gases and inert ash within this zone. Ash is removed at the bottom end of the kiln. Flue gases are passed through a secondary combustion chamber and then through air pollution control units for particulate and acid gas removal.

Although organic solids combustion is the primary use of rotary kiln incinerators, liquid and gaseous organic wastes can also be handled by injection into either the feed end of the kiln or the secondary chamber. Wastes having high inorganic slat content (e.g., sodium sulfate) are not recommended for incineration in this manner because of the potential for degradation of the refractory and slagging of the ash. Similarly, the combustion of wastes with high toxic metal content can result in elevated emissions of toxic air pollutants, which are difficult to collect with conventional air pollution control equipment.

Table 7. Technology Summary

Waste Type: Soils and Sludges
Technology: Rotary Kiln Incineration*

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Oversized debris such as rocks, tree roots, fiber, and steel drums	Difficult to handle and feed; may cause refractory loss through abrasion. Size reduction equipment such as shredders must be provided to reduce solid particle size.** Most current systems have a maximum feed chute opening of 13 inches.	Size, form, quantity of oversized debris. Size reduction engineering data	4,10,11
Alkali metal salts, particularly sodium and potassium sulfate ($NaSO_4$, KSO_4)	Cause refractory attack and slagging at high temperatures. Slagging can impede solids removal from the kiln.	% Na, K	4,11
Fine particle size of of soil feeds such as clay, silts	Results in high particulate loading in flue gases due to the turbulence in the rotary kiln.	Soil particle size distribution, USGS soil classification	11,12
Spherical or cylindrical wastes	Such wastes may roll through the kiln before complete combustion can occur.	Physical inspection of the waste	11
Ash fusion temperature of waste	Operation of the kiln at or near the waste ash fusion temperature can cause melting and agglomeration of inorganic salts.	Ash fusion temperature	11
Heating value of waste	Auxiliary fuel required to incinerate wastes with a heating value of less than 8,000 Btu.	Btu content	17

* See also: Table 4, High Temperature Thermal Treatment (General).
** See Tables 24 and 25.

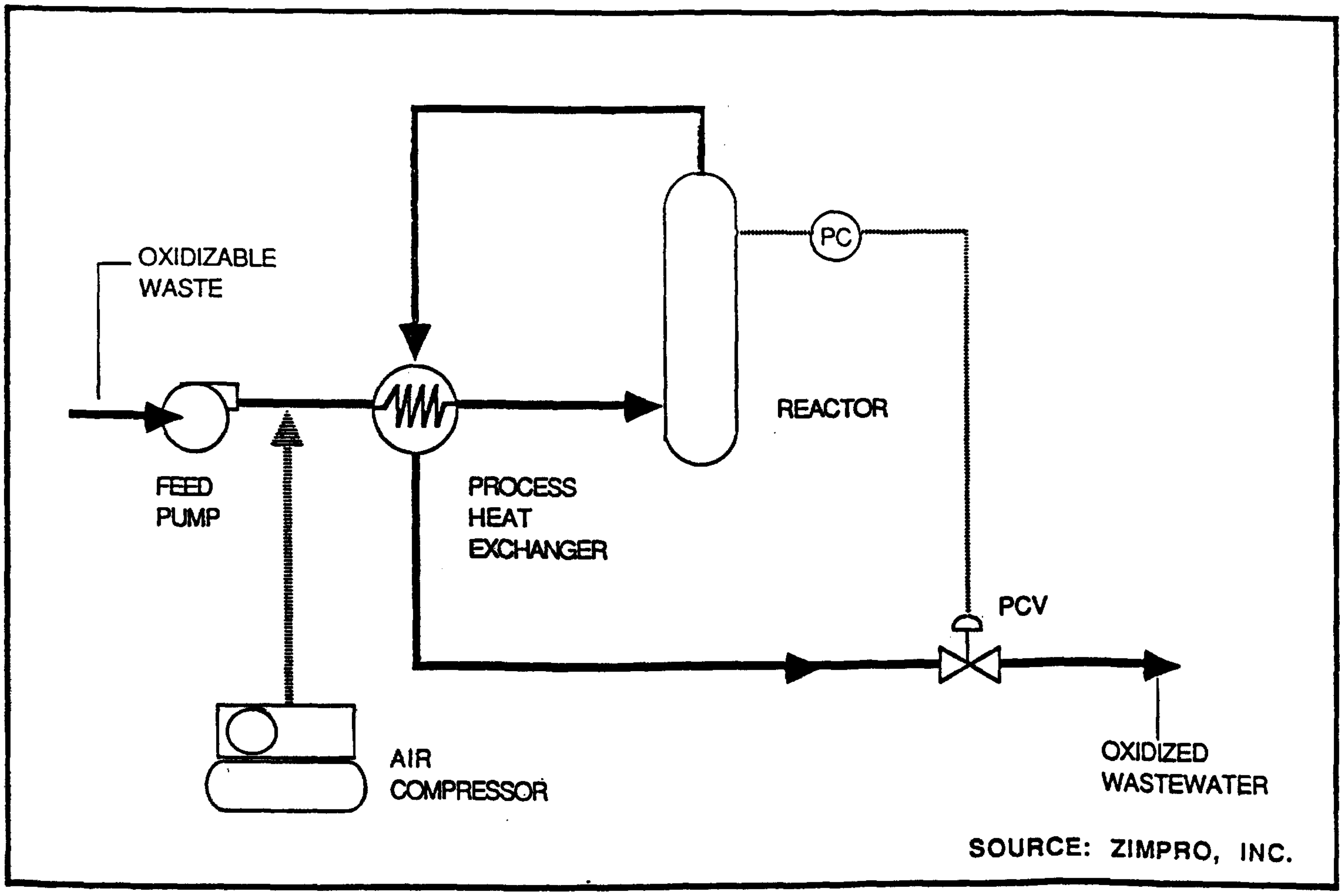

Figure 4. Wet Air Oxidation

Technology Description

Wet air oxidation is a thermal treatment technology that breaks down organic materials by oxidation in a high temperature, high pressure, aqueous environment. Wet air oxidation is used primarily to treat biological wastewater treatment sludges. It has, however, potential application to concentrated waste streams containing organic and oxidizable inorganic wastes (including halogenated organics, inorganic/organic sludges, inorganic/organic cyanide, and phenols).

In this process, waste is mixed with compressed air. The waste-air mixture passes through a heat exchanger and then into the reactor where exothermic reactions increase the temperature to a desired level. The exit stream from the reactor is passed through the heat exchanger, heating the incoming material. A separator is then used to separate the resultant gas stream (primarily air and carbon dioxide) from the oxidized liquid stream.

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Table 8. Technology Summary

Waste Type: Sludges
Technology: Wet Air Oxidation

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Solids content	Solids should not unduly foul heat transfer surfaces.	Physical inspection	4,10
Viscosity of sludge	The waste must be in a pumpable liquid or liquid-like form, with a viscosity of less than 10,000 SSU.	Viscosity, total solids analysis	4,10
COD J 15,000 mg/liter COD : 200,000 mg/liter	Wastes with COD concentrations outside this range are either too dilute or too concentrated for a feasible application.	COD analysis	4,10
Toxic metals	Toxic metals are not treated, but are passed through the system.	Analysis for heavy metals	4,10
Abrasive and/or acidic characteristics	Wastes that have high abrasive and/or acidic characteristics (e.g., titanium) may require more expensive equipment and materials.	Treatability testing	4,10
Highly chlorinated organics (e.g., PCBs)	Highly chlorinated organics are not effectively destroyed by this process due to the relatively low operating tempertures.	Analysis for organic chlorine	4,10
Organic content	Uncatalyzed systems can treat wastes containing up to 3% organics, catalyzed systems can treat wastes containing up to 8% organics.	Analysis for total organic carbon	11

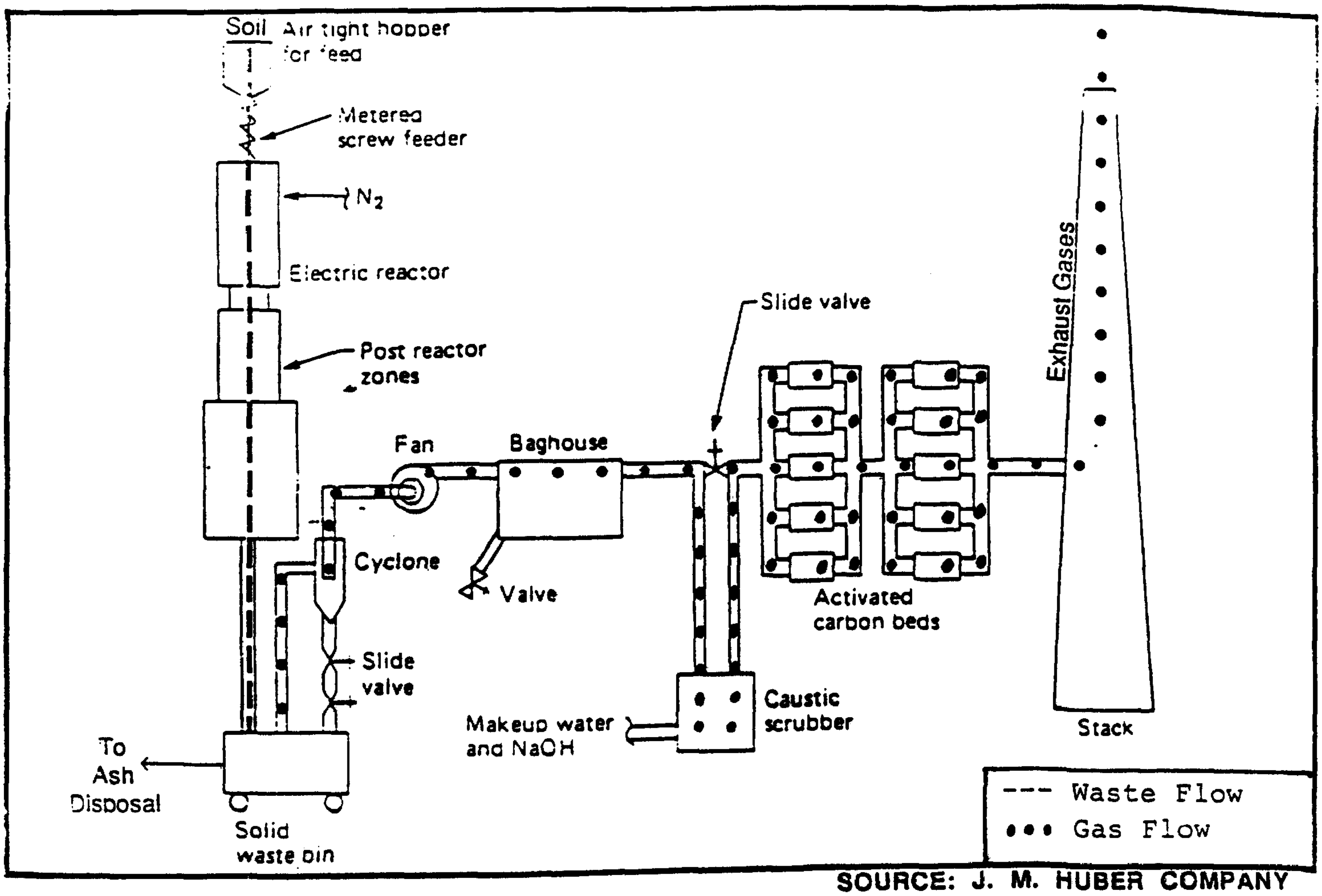


Figure 5. Advanced Electric Reactor

<u>Technology Description</u>

An advanced electric reactor (AER) is a relatively new thermal technology being developed specifically for the detoxification of contaminated soils, although other solid and liquid wastes may also be destroyed. The destruction is achieved in a reactor vessel where intense radiation is used to reduce toxic compounds to their elemental constituents.

The reactor vessel consists of a porous carbon core surrounded by carbon electrodes. The core and electrodes are enclosed by a radiation heat shield inside a double wall cooling jacket. Reactants are isolated from the reactor core by a gaseous blanket that is formed by nitrogen flowing radially inward through the porous core wall. The inert gas also serves as a heat transfer medium between the electrodes and the core.

For solid waste treatment, the solid feed is introduced at the top of the reactor with a metered screw feeder. The wastes pass through the core via gravity where they are exposed to a temperature of approximately 4000°F. The exit gases and waste solids from the reactor then enter two post-reactor treatment zones to ensure complete destruction. After passing through these zones, the remaining solid residue is collected in a bin. Exit gases pass through air pollution control equipment for removal of particulates and other emissions prior to discharge.

TABLE 9. Technology Summary

Waste Type: Soils
Technology: Advanced Electric Reactor*

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Feed particle size	Size reduction is required, nominally to -10 mesh. Destruction removal efficiency is a function of particle size, and tests have not been performed to determine maximum particle size at given destruction rates.	Particle size distribution	18
Maintainability and reliability	Full-scale units need to be operated in the field to demonstrate technology effectiveness.	Field operating data	18
Sludge wastes	Can be fed; however, require extensive feed pretreatment (i.e., solidification of sludges).	Treatment data for sludges	18

*See also: Table 4, High Temperature Thermal Treatment (General).

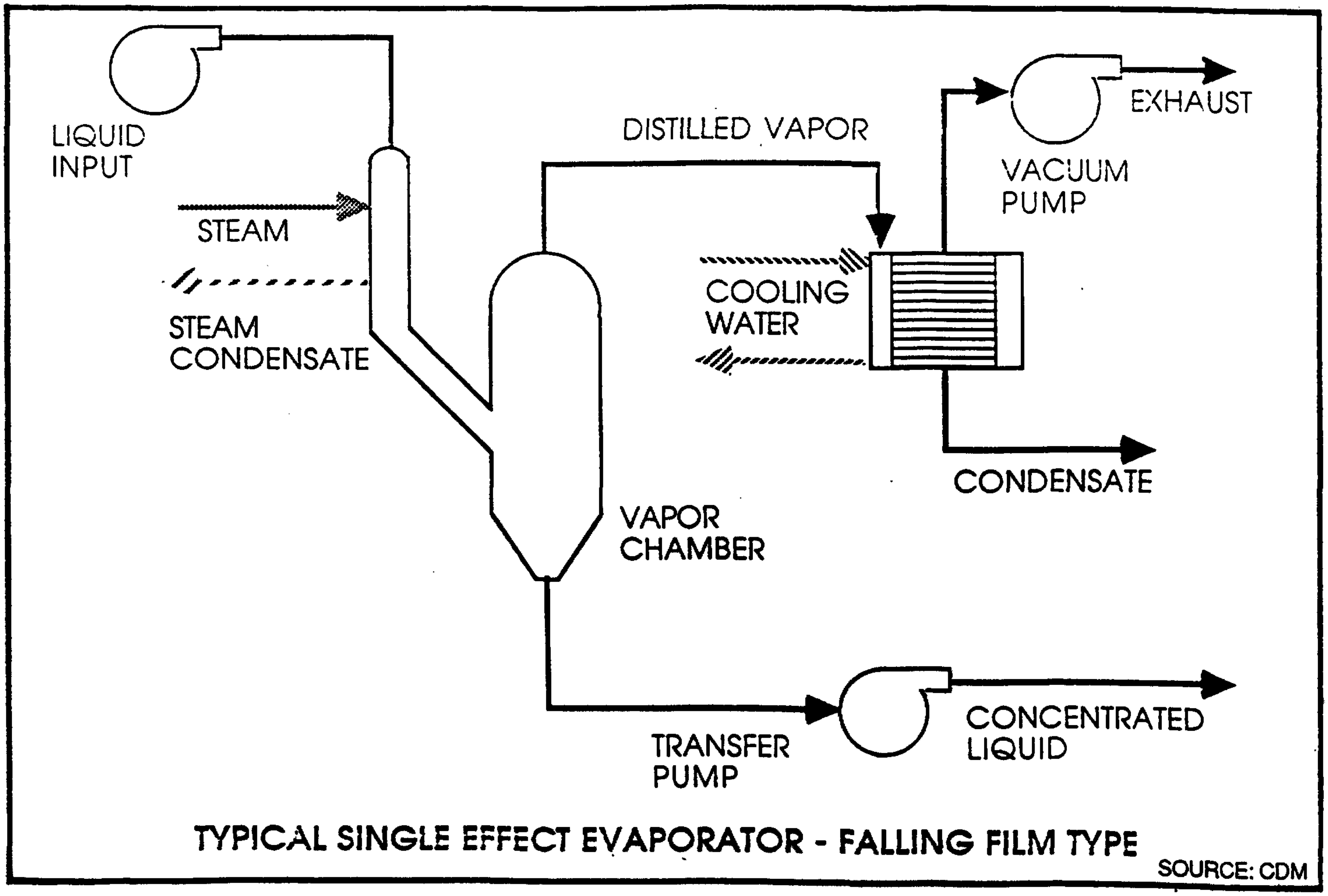


Figure 6. Evaporation/Dewatering

<u>Technology Description</u>

Evaporation/dewatering is a unit process used to reduce the moisture content of liquid solutions, slurries, or sludges by vaporizing the more volatile components of the waste. The result of this process is a concentrated slurry or semi-solid that can be handled and treated more effectively.

An agitated thin-film evaporation process is most commonly used for evaporation/dewatering. Basically, this system consists of a large diameter heating surface on which a thin film of material is continuously wiped. The volatile components are vaporized leaving concentrated semi-solids behind.

The process works efficiently only when applied to liquid solutions, because solids tend to foul the heat transfer surfaces as the volatile components are driven off. Special techniques have been developed to counter this problem (e.g., the Carver-Greenfield Process), but there is little or no experience in the application of these techniques to the processing of CERCLA wastes. Dewatering of sludges with a high solids content can be better accomplished using the filtration techniques described in Figure 8 and Table 11.

Table 10. Technology Summary

Waste Type: Sludges
Technology: Evaporation/Dewatering

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Sludge viscosity greater than 100 poise	Thickness of sludge prevents organics from volatilizing effectively.	Viscosity	15
Size of solids in sludge >2.5 mm	Solids >2.5 mm do not fit below the clearance of agitator blades.	Analysis of solids size	15
Reactive wastes that polymerize	Cause foaming and restrict dewatering.	Analysis for priority pollutants	4
Finely divided solids	Become entrainer in vaporized organics.	Total suspended solids	4
Certain sulfonated organic compounds, i.e., ammonium lauryl sulfate, sodium lauryl sulfate	Sulfates can cause foaming and entrainment of solids.	Sulfate analysis	4
Variation in waste composition	Evaporation/dewatering is not selective. Hazardous and nonhazardous wastes may not be completely separated.	Statistical sampling, analysis for priority pollutant	14
Dissolved solids	Crystallization of dissolved solids forms an insulating layer on the equipment, thereby inhibiting heat transfer.	Total dissolved solids	11
Boiling point	Technology most effective on wastes with boiling points less than 200 C.	Boiling point	11
Suspended solids	High solids content can cause erosion of the equipment.	Total suspended solids	11
Vapor pressure	Technology most effective on low vapor pressure wastes.	Vapor pressure	11

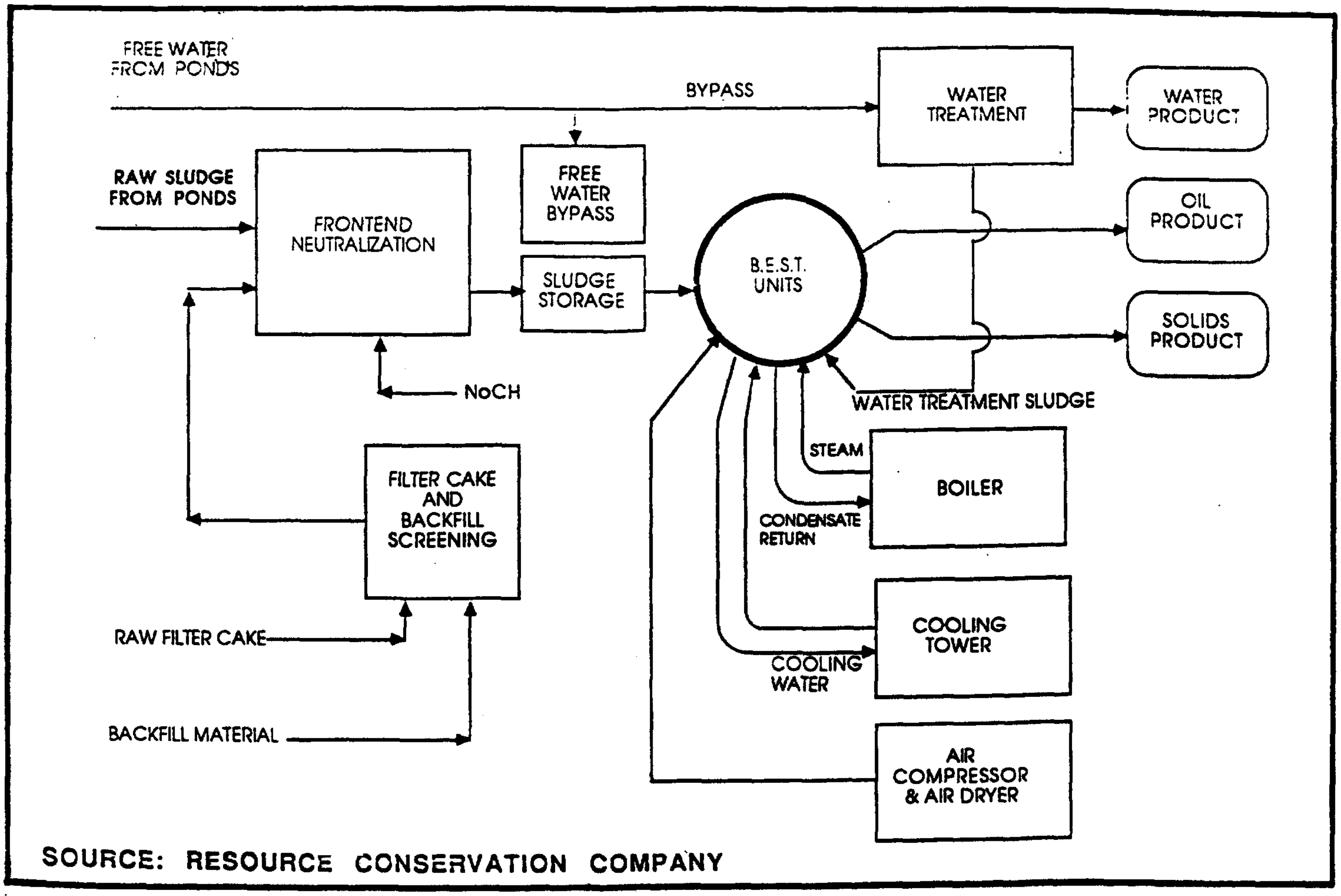


Figure 7. Basic Extractive Sludge Treatment

Technology Description

The Basic Extractive Sludge Treatment (BEST) process is used to separate contaminants from hydrocarbon sludges. It can be modified to handle a range of sludge types containing insoluble organics and water.

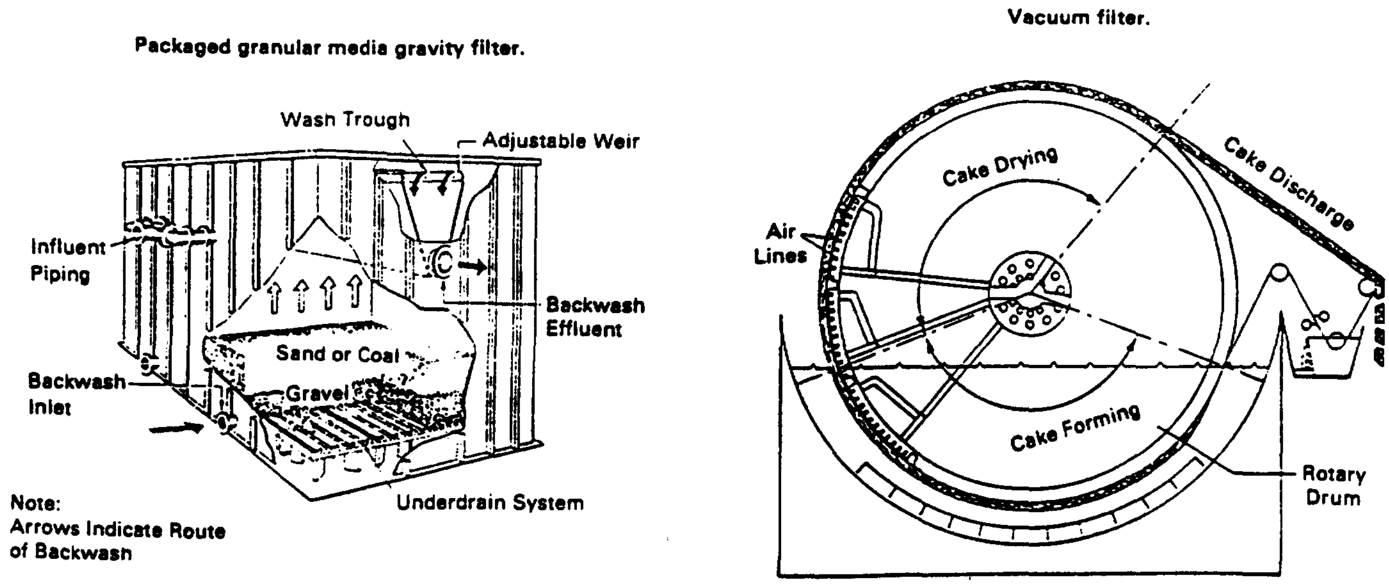
In the BEST units, an aliphatic amine solvent is mixed at low temperature with oil and water present in many sludges. The solvent breaks oil-water emulsions and releases bound water. The solids are separated in a centrifuge or filter and sent to a dryer from which the solids emerge free of oil, water, and amine solvent.

The aliphatic amine solvent solution is then warmed, resulting in the separation of solvent and oil from the water. This allows the water to be removed for biotreatment. The remaining solvent and oil are separated by stripping to recover the solvent for recycle.

Table 11. Technology Summary

Waste Type: Sludges
Technology: Basic Extractive Sludge Treatment

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Presence of high molecular weight asphaltic compounds	Requires excessive time for breakdown of sludge by solvent.	Full physical characterization of sludges	16
Acidic pH	Metals removal optimized at alkaline pH. Sludge pH adjustment required.	pH and alkalinity measurement	16
Presence of elevated levels of volatiles	Volatiles combine with process solvent requiring an additional separation step.	Volatile organic analysis	16
Metal compounds soluble in organics (e.g. tetraethyl lead)	Metals will not be separated from organic phases during treatment.	Pilot testing	16
Metals (e.g. aluminum) or other compounds reacting under highly alkaline conditions.	Uncontrolled reactions may occur during treatment process due to alkaline pH.	Metals analysis	16
Presence of highly water soluble organics (e.g. acetone, methyl ethyl ketone)	Organics soluble in water will not be separated by process solvent.	Solubility data for organics	16



SOURCE: CDM

Figure 8. Filtration

Technology Description

The two primary uses of filtration processes are: (1) removal of suspended solids from a fluid by passage of the fluid through a bed of granular material, and (2) dewatering of sludges and oils using a vacuum, high positive pressure, or gravity system. It should be noted that filtration is not a destructive process, as it does not separate hazardous and nonhazardous wastes. Filtration is often used as a pretreatment operation to increase the suspended solids content of sludges, thereby reducing the volume of sludge that must be treated.

Pressurized and gravity fed granular media filtration systems are used for aqueous waste streams containing suspended solids.

Vacuum, belt press, and chamber pressure filtration processes are primarily used to dewater sludge.

Table 12. Technology Summary

Waste Type: Sludges
Technology: Filtration

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Solids contents of sludge (<5%)	Require pretreatment operation that will increase solids concentration.	Settling/ thickening characteristics, bench-scale testing	1
Toxicity of sludge	Filtration is a non-destructive process. After filtration, a highly concentrated sludge must be treated.	Analysis for priority pollutants	1
Variation in waste composition	Filtration is not selective. Hazardous and nonhazardous wastes are not separated. Additional treatment is necessary.	Statistical sampling, priority pollutant analysis	2
Filtration	Clogging of filter media necessitates addition of chemicals to improve dewatering characteristics.	Pilot scale test	
Oil and grease content	Oil and grease concentrates of greater than 200 ppm will adversely affect filtration.	Oil and grease analysis	17
Particle size	To achieve solid/liquid separation, the particles must be much larger than the size of the filters pores.	Particle size distribution, filter pore size (from manufacturer)	11
Viscosity	Filters are limited to pumpable waste streams with a viscosity of less than 10,000 SSU.	Viscosity	11
Suspended solids	Most filters can treat sludges with suspended solids of 10 to 20%.	Total suspended solids	11

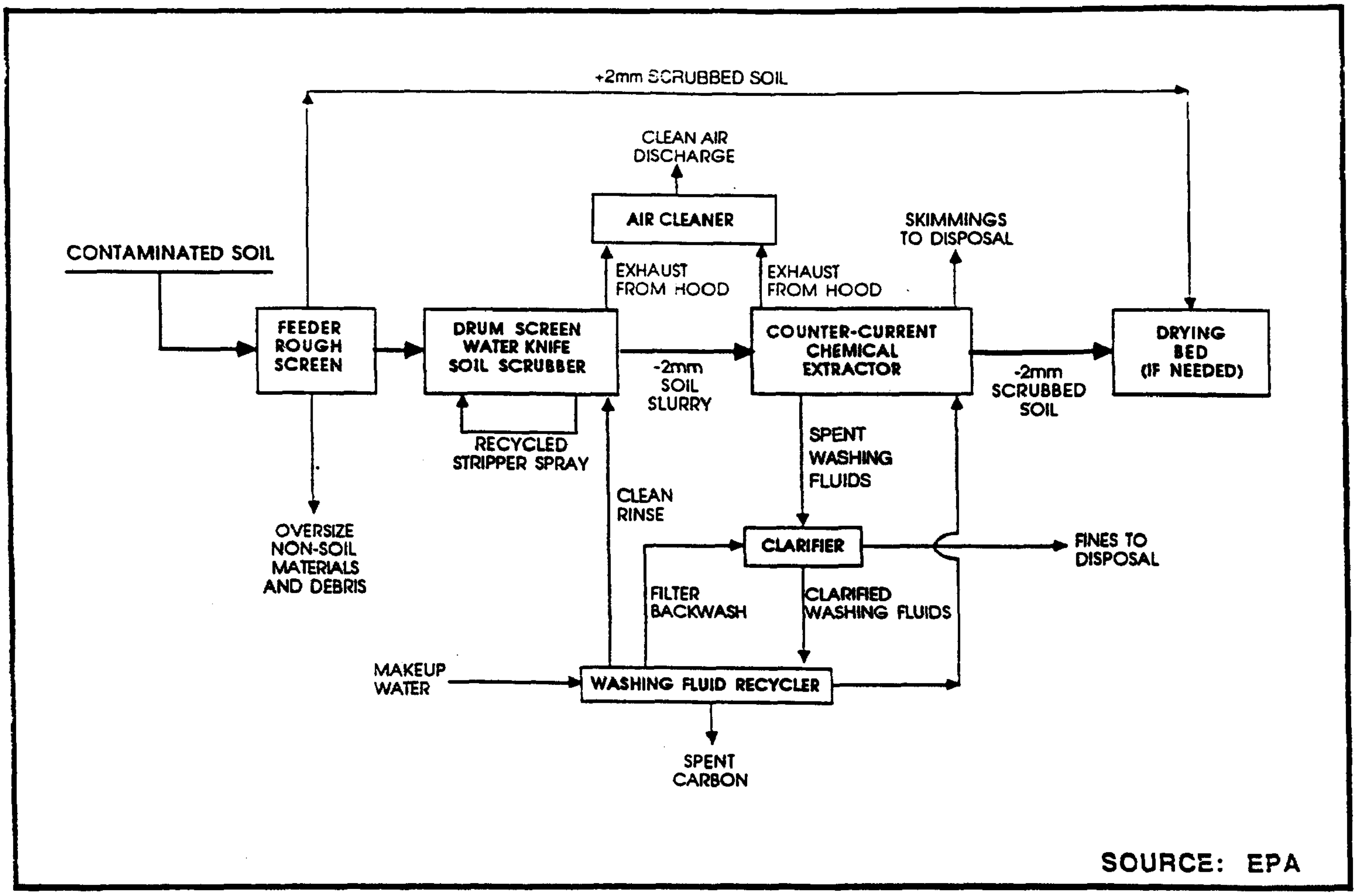


Figure 9. Soil Washing

Technology Description

The soil washing process extracts contaminants from sludge or soil matrices using a liquid medium as the washing solution. This process can be used on excavated soils that are fed into a washing unit. The washing fluid may be composed of water, organic solvents, waster/chelating agents, water/surfactants, acids, or bases, depending on the contaminant to be removed.

Contaminated soil enters the system through a feeder where oversized non-soil materials and debris that cannot be treated are removed with a coarse screen. The waste passes into a soil scrubber where it is sprayed with washing fluid. Soil particles greater than 2 mm in diameter leave the scrubber and are settled on a drying bed. The remaining soil enters a countercurrent chemical extractor where washing fluid is passed countercurrent to it, removing the contaminants. The treated solids are then settled on a drying bed. The remainder of the process is a multistep treatment for removal of contaminants from the washing fluid prior to its recycling.

Table 13. Technology Summary

Waste Type: Soils
Technology: Soil Washing

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Unfavorable separation coefficient for contaminant	Excessive volumes of leaching medium required.	Equilibrium partition coefficient	3
Complex mixtures of waste types (e.g., metals with organics)	Formulation of suitable washing fluids difficult.	Analysis for priority pollutants, solubility data	4
Variation in waste composition.	May require frequent reformulation of washing fluid.	Statistical sampling, analyses for priority pollutants	4
Unfavorable soil characteristics			
- High humus content	Inhibition of desorption.	Analysis for organic matter	1,2,3,4
- Soil, solvent reactions	May reduce contaminant mobility.	Pilot testing	3,4
- Fine particle size (silt and clay)	Fine particles difficult to remove from washing fluid.	Soil particle size distribution, USGS soil classification	
Unfavorable washing fluid characteristics			
- Difficult recovery of solvent or surfactant	High cost if recovery low.	Bench-scale testing	3
- Poor treatability of washing fluid	Requires replacement of washing fluid.	Bench-scale testing, conventional analysis*	3
- Reduction of soil permeability	Surfactant adheres to soil to reduce effective porosity.	Permeability pilot testing	3

Table 13. (continued)

Waste Type: Soils
Technology: Soil Washing

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
High toxicity of washing fluid	Soil may require additional treatment for detoxification. Fluid processing requires caution.	Toxicity of washing fluid	4

*Conventional analysis should include organic content (i.e., BOD, COD, TOC), solids content iron, manganese, and leachate pH.

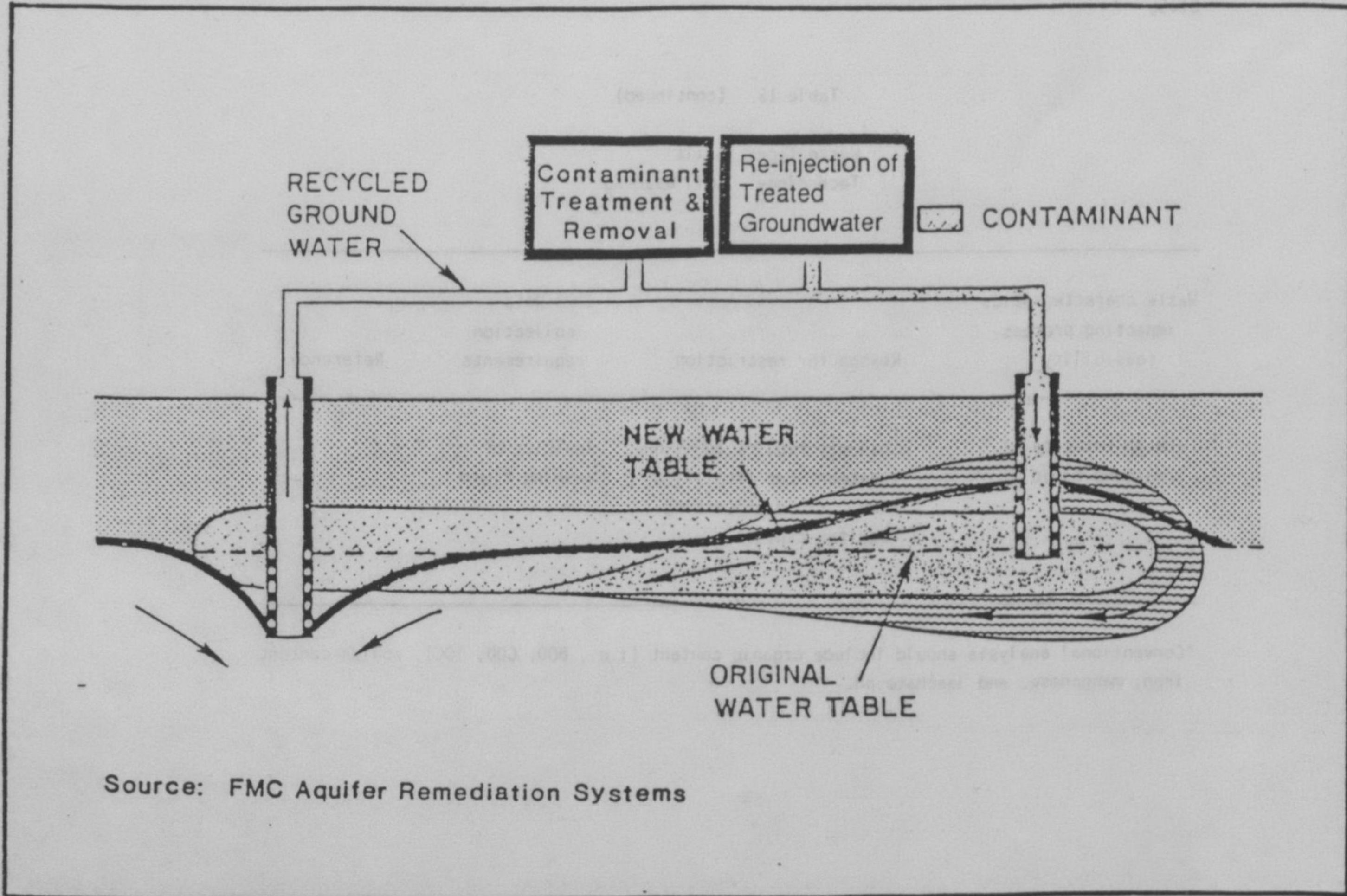


Figure 10. In-Situ Soil Flushing

Technology Description

Soil flushing is a process applied to unexcavated soils using a ground water extraction/re-injection system. The technology is often used for removal of volatile organics from permeable soils.

Pump and treatment systems for ground water are often combined with re-injection of treated ground water upgradient of the extraction wells to produce accelerated flushing and decontamination of soils in situ. Surfactants or chelating agents may be added to the re-injected ground water, provided these compounds do not pose risks of additional contamination.

Table 14. Technology Summary

Waste Type: Soils
Technology: In-Situ Soil Flushing

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Presence of: - metals - heavy organics	Flushing process only effective for mobile or soluble contaminants.	Analysis for priority pollutants	
Unfavorable separation coefficient for contaminant	Excessive volumes of surfactants required.	Equilibrium partition coefficient	3
Complex mixtures of waste types (i.e., metals with organics)	Formulation of suitable washing fluids difficult.	Analysis for priority pollutants, elemental analysis	4
Variation in waste composition	May require frequent reformulation of washing fluid.	Statistical sampling, analyses for priority pollutants	4
Unfavorable soil characteristics			
- Variable soil conditions	Inconsistent flushing.	Soil mapping	3,4
- High organic content	Inhibition of desorption.	Analysis for organic matter	1,2,3,
- Low permeability (high clay content)	Reduces percolation.	Percolation test·	1,4
- Soil, solvent reactions	May reduce contaminant mobility.	Pilot testing	3,4
Unfavorable site hydrology	Groundwater flow must permit recapture of soil flushing fluids.	Site hydrogeology must be well defined	3,4
Unfavorable washing fluid characteristics			
- High toxicity or volatility	Health risks.	Solvent characterization	3,4

Table 14. (continued)

Waste Type: Soils
Technology: In-situ Soil Flushing

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
- Difficult recovery of solvent or surfactant	High cost if recovery low.	Bench-scale testing	3
- Poor treatability of washing fluid	Requires replacement of washing fluid.	Bench-scale testing, conventional analysis*	3
- Reduction of soil permeability	Surfactant adheres to soil to reduce effective porosity.	Permeability pilot testing	3

*Conventional analysis should include organic content (i.e., BOD, COD, TOC) solids content iron, manganese, and leachate pH.

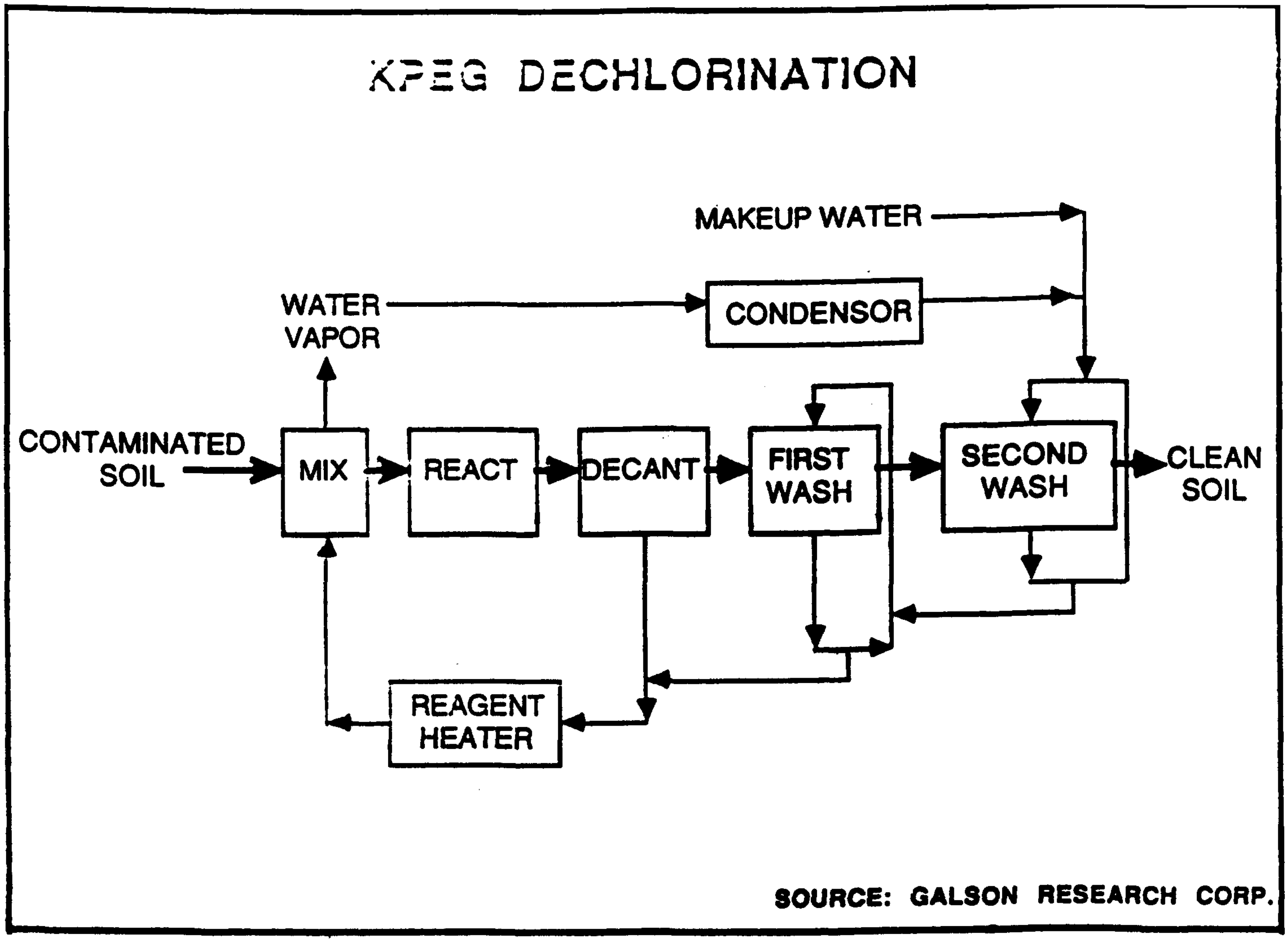


Figure 11. Potassium Polyethylene Glycol (KPEG) Dechlorination

Technology Description

Potassium/polyethylene glycol (KPEG) dechlorination is a process useful for dechlorination of soils contaminated at low levels with certain classes of chlorinated organics (i.e., aromatic halides), which includes PCBs, dioxins, chlorophenols, and chlorobenzenes. The dechlorination process includes excavation of contaminated soil, contacting the soil with the KPEG reagent in a pub mill or cement mixer, removal of the reagent solution, and finally a two to three cycle rinsing of the treated soil with water in a countercurrent extractor.

The KPEG dechlorination process is still in the development stages. It is currently being tested on dioxin contaminated soils in Gulfport, Mississippi.

Table 15. Technology Summary

Waste Type: Soils
Technology: Potassium/Polyethylene Glycol (KPEG) Dechlorination

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Elevated concentrations of chlorinated organics	Concentrations greater than 5% require excessive volumes of reagent (low ppm is optimum).	Analysis for priority pollutants	13
Presence of: - aliphatic organics - inorganics - metals	Reagent only effective with aromatic halides (PCBs, dioxins, chlorophenols, chlorobenzenes).	Analysis for priority pollutants	13
High moisture content (greater than 20%)	Water requires excessive volumes of reagent.	Soil moisture content	13
Low pH (pH less than 2)	Process operates under highly alkaline conditions.	pH testing	13
Presence of alkaline reactive metals (e.g., Al)	Uncontrolled reactions with these metals could occur under highly alkaline conditions.	Metals analysis	13

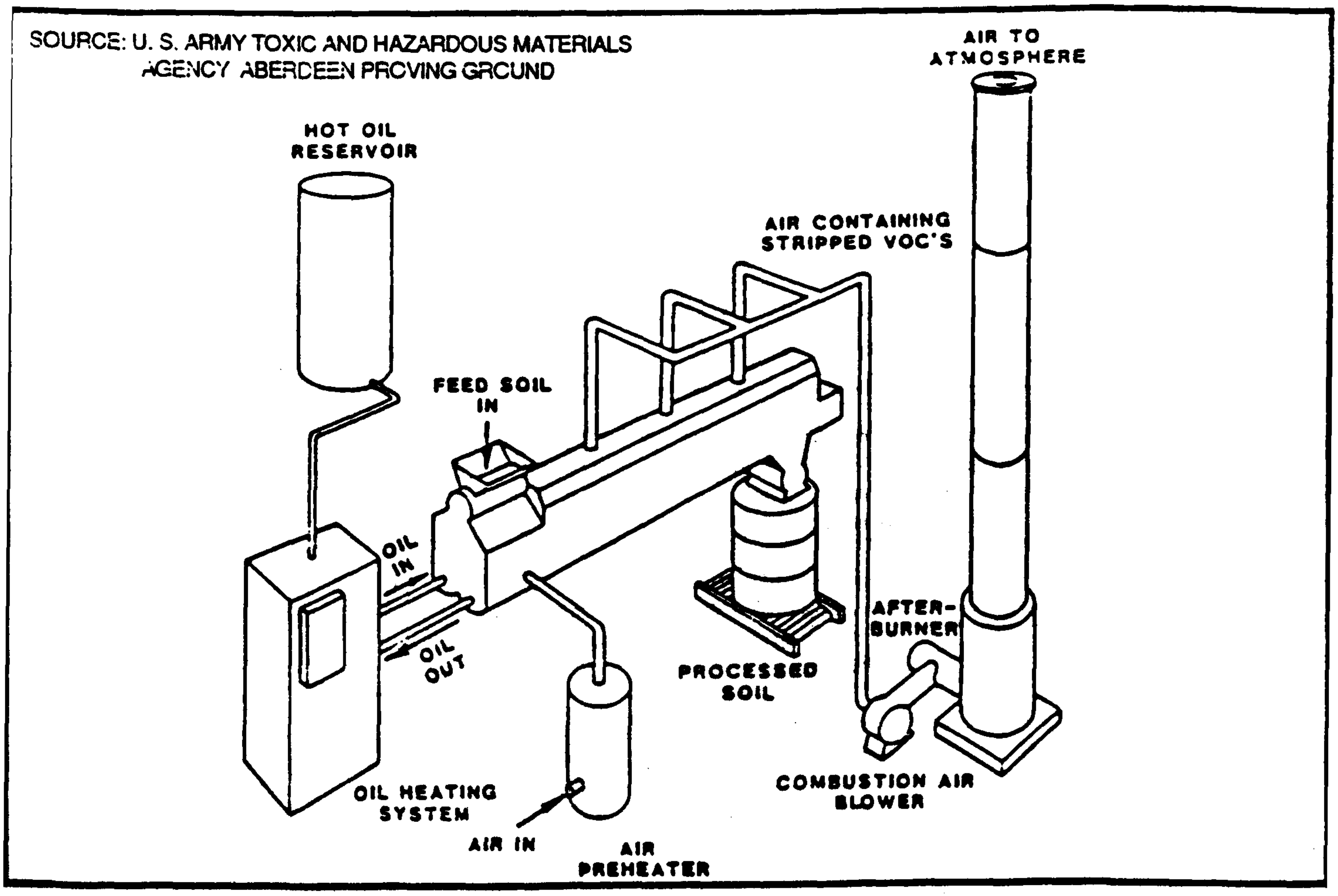


Figure 12. Low Temperature Thermal Stripping

Technology Description

Low temperature thermal stripping systems consist of mixing contaminated soils in a pug mill or rotary drum system equipped with heat transfer surfaces. An induced air flow conveys the desorbed volatile organic/air mixture through a carbon adsorption unit or combustion afterburner for the destruction of the organics. The air stream is then discharged through a stack.

Low temperature thermal stripping may be used to remove volatile organic compounds (Henry's Law constant > 3.0×10^{-3} atm-m^{-3}/mole) from soils or similar solids.

Table 16. Technology Summary

Waste Type: Soils
Technology: Low Temperature Thermal Stripping

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Presence of: - metals - inorganics - nonvolatile organics	Process effective only for volatile organics.	Analysis for priority pollutants	4
Presence of mercury (Hg)	Boiling point of mercury (356 C) close to operating temperature for process (100 to 300 C).	Analysis for mercury	4
Unfavorable soil characteristics			
- high . of clay or silt	Fugitive dust emissions during handling.*	Grain size analysis	9
- tightly aggregated soil or hardpan	Incomplete devolatilization during heating.	Soil sampling and mapping	9
- rocky soil or glacial till	Rock fragments interfere with processing.	Soil mapping	9
- high moisture content	High energy input required. Dewatering may be required as pretreatment.*	Soil moisture content	9

* See Table 25.

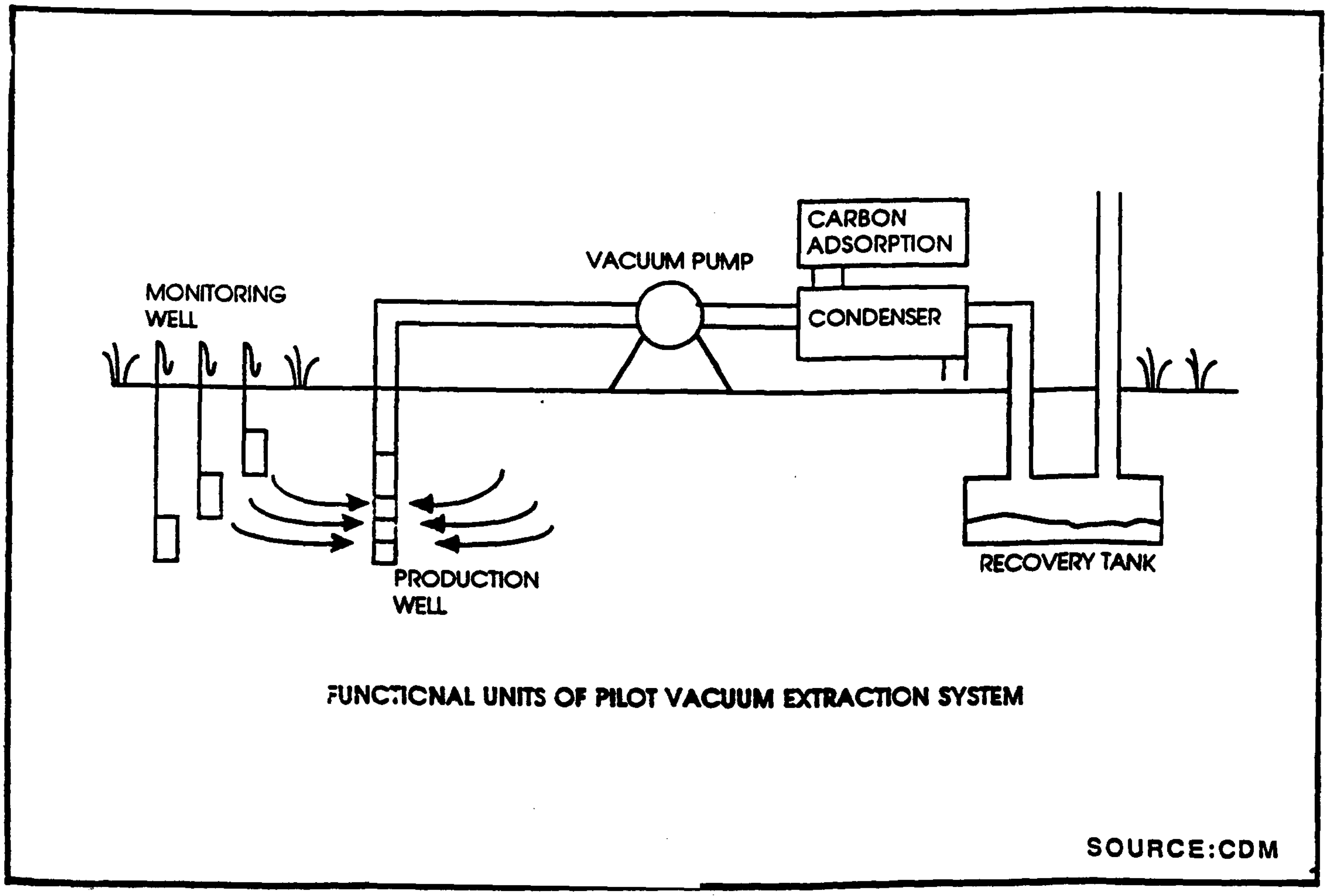


Figure 13. In-Situ Vacuum Extraction

<u>Technology Description</u>

Vacuum extraction systems consist of a high volume vacuum pump connected via a pipe system to a network of boreholes or wells drilled in the contaminated soil zone. Excavation is not required for this system. The vacuum pulls air through the contaminated soils, stripping volatile organics. The air is subsequently fed through a condenser to recover free product, and/or through an emissions control system (i.e., a water scrubber or vapor phase carbon adsorption system).

Vacuum extraction may be used to strip volatile organic compounds (Henry's Law constant > 3.0 x 10^{-3} atm-m^3/mole) from soils or porous solids.

Table 17. Technology Summary

Waste Type: Soils
Technology: In-Sutu Vacuum Extraction

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Presence of - nonvolatile organics - metals - cyanides - inorganics	Only volatile compounds can be removed (Henry's Law constant greater than 3×10^{-3} atm-m^3/mole).	Analysis for priority pollutants, Henry's Law constant, or vapor pressures for organics	6
High solubility of volatile organics in water	Dissolved organics are more mobile and harder to remove from aqueous phase.	Contaminant solubilities	6
Unfavorable soil characteristics			
- Low permeability	Hinders movement of air through soil matrix.	Percolation test, pilot vapor extraction tests	8
- Variable soil conditions	Inconsistent removal rates.	Soil mapping	8
- High humic content	Inhibition of volatilization.	Analysis for organic matter	6
- High moisture content	Hinders movement of air through soil.	Analysis of soil moisture content	6
- Depth to the water table	Air flow only effective above water table.	Water table mapping	6

Cement-based Immobilization

Technology Description

Immobilization methods are designed to render contaminants insoluble, prevent leaching of the contaminants from the solidified soil or sludge, improve waste handling characteristics, and detoxify the waste.

Equipment required for treatment includes standard cement mixing and handling equipment and excavation equipment. Because the techniques of cement mixing and handling are well developed, this process can handle many variations in the soil and sludge composition.

Immobilization is well suited for solidifying sludges and soils containing heavy metals, inorganics (generally no more than 20 percent by volume), asbestos, solidified plastic, resins, and latex.

Table 16. Technology Summary

Waste Type: Soils and Sludges
Technology: Cement-Based Immobilization

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Organic content should be no greater than 20-45% by weight	Organics interfere with waste materials bonding.	Analysis for volatile solids, total organic carbon	4,5
Wastes with less than 15% solids	Large volumes of cement required for immobilization.	Analysis for total solids	4
Fine particle size	Insoluble material passing through a No. 200 mesh sieve can delay setting and curing. Small particles can also coat larger particles, weakening bonds between particles and cement.	Soil particle size distribution	4
Soluble salts of manganese, tin, zinc, copper, lead	Reduced physical strength of final product, causes large variations in setting time.	Analysis for inorganics	4,5
Sodium arsenate, borate, phosphate, iodate, sulfide	Retards setting and curing and weakens strength of final product.	Bench-scale testing	4,5
Sulfates	Retards setting and causes swelling and spalling.	Analysis for sulfate	4,6
Volatile organics	Volatiles not effectively immobilized.	Analysis for volatile organics, bench-scale testing	
Presence of highly soluble metals	New stringent requirements for leach tests could make delisting difficult.	Analysis for priority pollutants, bench-scale testing	4,5
Presence of coal or lignite	Coals and lignite can cause problems with setting, curing, and permanence of the end product.	Soil type distribution	6

Lime Stabilization

Technology Description

Lime stabilization is a process frequently used as a pretreatment step for sludges or contaminated soils. Lime serves to neutralize acids that are present, and, by raising the pH into the alkaline range (pH 8-10), can immobilize heavy metals and reduce leaching. Lime stabilization is similar to cement-based immobilization in many ways, but is not as permanent as immobilization and cannot handle organics at any level. Lime stabilization is primarily a pretreatment step used prior to other treatment steps.

Table 19. Technology Summary

Waste Type: Soils and Sludges
Technology: Lime Stabilization

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Presence of: - volatile organics - nonvolatile organics - cyanides	Lime used primarily as a pretreatment step or interim measure. Lime only acts to reduce metal solubilities; it does not immobilize organics, cyanides, or metals.	Analysis for priority pollutant	6
Unfavorable soil Characteristics			
- variable soil conditions	Inconsistent stabilization.	Soil mapping	5, 6
- low permeability	Reduction of percolation.	Percolation test	5, 6
Variable waste distribution	Inconsistent stabilization.	Contaminant distribution	5, 6
High leaching or flushing rate	Lime may not immobilize metals permanently.	Surface hydrology and precipitation patterns, bench-scale test, leachate testing	6

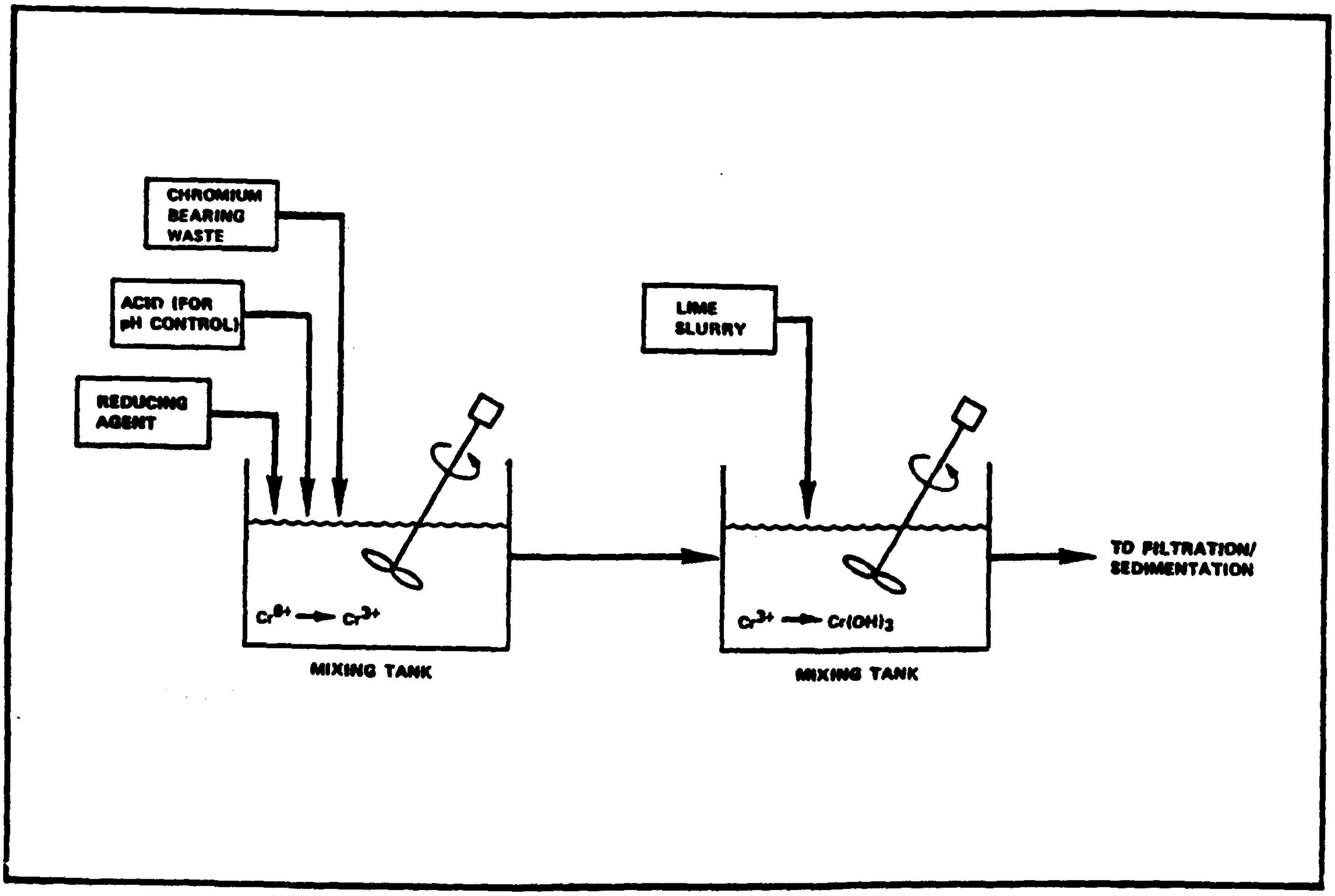


Figure 14. Chemical Reduction-Oxidation

Technology Description

The chemical reduction-oxidation (redox) process is employed for the chemical transformation of reactants in which the oxidation state of one reactant is raised while that of another is lowered. The net result is the destruction or reduction of the toxicity of hazardous constituents. A significant use of chemical redox is the reduction of hexavalent chromium to the less toxic chromium Cr^{3+}.

Chemical redox has limited applications to sludges, because other reducible components, as well as the material to be reduced, may be attached, and because of difficulties in achieving intimate contact between the reducing agent and the hazardous constituent. Chemical reduction is used primarily for aqueous wastes containing <1% of the reducible compound.

Table 20. Technology Summary

Waste Type: Sludges
Technology: Chemical Reduction-Oxidation

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Organic content	A high organic in the sludge requires large amounts of oxidation/reduction reagent.	Analysis for priority pollutants	5
Variation in waste composition	Chemical redox is indiscriminate; unwanted side effects could occur.	Statistical sampling, priority pollutant analysis	1,4
Chromium (+3)	Organic oxidation of sludges will oxidize chromium (+3) to the more toxic and mobile chromium (+6).	Total chromium	1
High viscosity	Subsequent need for addition of liquid to aid mixing.	Bench-scale testing	2
Low pH of sludge	A low pH (<2) may interfere with redox reagents.	pH testing	2
Oil and grease content	Oil and grease content of greater than 1% by weight interferes with reactant/waste contact.	Analysis for oil and grease	11
Suspended solids content	A suspend solids content of greater than 3% by weight can interfere with reductant/waste contact inhibiting reduction. Sludges therefore will need to be slurried prior to treatment (see Table 24).	Total suspended solids	11

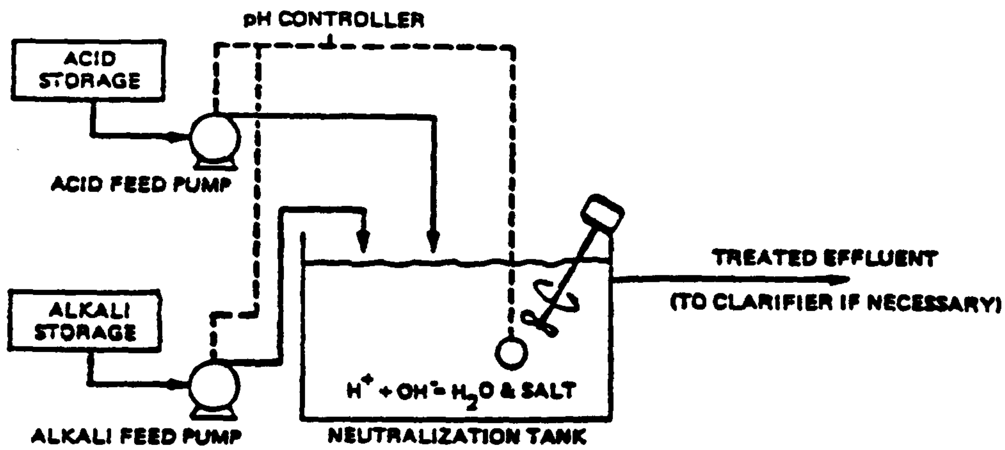


Figure 15. Neutralization

Technology Description

Neutralization is used to change the pH of waste streams. This change is accomplished through the interaction of an acid (pH <5) or a base (pH >9) with a waste stream. Acids are used to lower the pH; bases are used to increase it. The optimal range for the final pH is 6.5-9.0.

Changing the pH results in the breaking of emulsions, precipitation of certain chemical species, and provides control of chemical reaction rates.

The equipment for neutralization consists of a chemical feed and control system and a rapid mixing process. Sodium hydroxide, lime, or sulfuric acid are the most common reagents added to neutralize a waste. The quantity and concentration depend on the influent and desired effluent pH.

Table 21. Technology Summary

Waste Type: Sludges
Technology: Neutralization

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
High solids content, high viscosity	Sludge may require excessive dosages of chemicals because of the difficulty of achieving complete mixing and contacting. Sludges containing >3% by weight suspended solids must be slurried before treatment.*	Total suspended solids, viscosity	2, 11
High buffer capacity potential	Excessive dosage of neutralizing agent.	Alkalinity	1
High heavy metals concentration	Precipitation of significant volume of heavy metal sludge and subsequent additional treatment.	Metals analysis	1
Sulfuric acid content (>0.6%)	If neutralization is taking place in a limestone bed, $CaSO_4$ produced will coat the limestone and stop neutralization.	Sulfuric acid content	3
Al^{+3}, Fe^{+3} concentrations	Formation of hydroxide precipitates and cessation of neutralization.	Metals analysis	3

* See Table 24.

Composting

Technology Description

Composting involves the storage of high-strength organic sludges and solids in piles or pits for decomposition, and aerating by periodic turning. Composting is enhanced by waste size uniformity. Adequate aerating, optimum temperature, moisture and nutrient contents, and the presence of the mixed microbial population are necessary to accelerate decomposition of all organics, phosphorus- and nitrogen-containing compounds, and oil by hydrolysis or oxidation reactions. Aeration is accomplished by turning. This is the only biological treatment process relatively insensitive to toxicants, and it encourages adsorption of metals. Mesophilic and thermophilic bacteria are active when the ambient temperature is between 10 C and 45 C or 50 C and 70 C. Alkaline aerobic conditions are maintained to minimize metal toxicity to microorganisms. Metals are removed by either adsorption or precipitation. The process is unsuitable for halogenated aromatic hydrocarbons and refractory organics.

The process can be made environmentally safe by providing means to collect leachate and runoff water from the composting beds. The process is not widely used because an insufficient market exists for the resulting end product, humus.

Table 22. Technology Summary

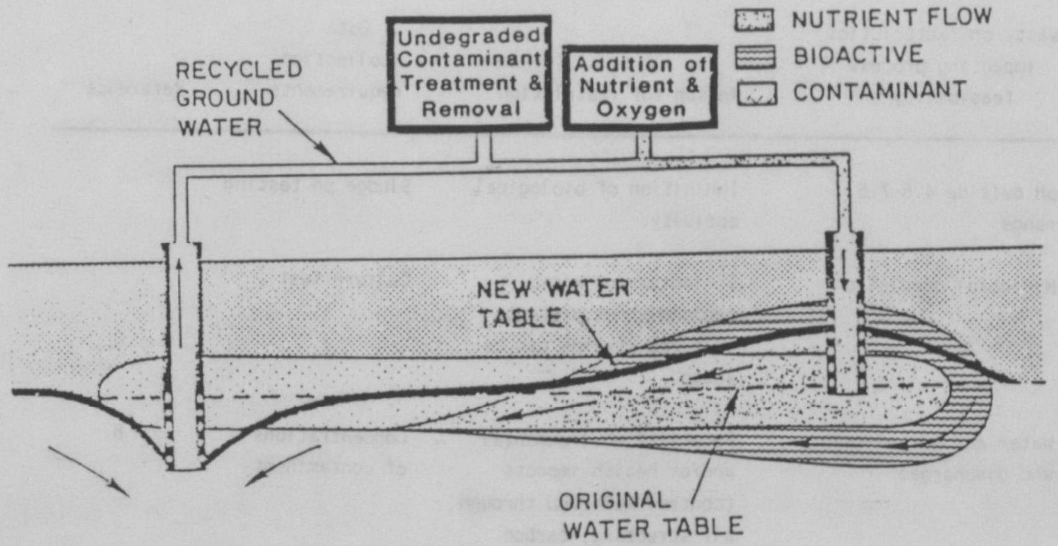
Waste Type: Sludges
Technology: Composting

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity.	Waste composition	6
Water solubility	Contaminants with low solubility are harder to biodegrade.	Solubility	6
Biodegradability	Low biodegradability inhibits process.	Chemical constituents, presence of metals/salts, bench-scale testing	6
High concentration of toxic contaminants (metals, complex organics)	High concentrations may be toxic to microbes.	Biotoxicity levels, bench-scale testing	
Temperature outside 25-70 C range	Larger, more diverse microbial population present in this range.	Temperature monitoring	6,11
Nutrient/deficiency	Lack of adequate nutrients for biological activity (although nutrient supplements may be added).	C/N/S ratio	
Moisture content	A moisture content of greater than 79% affects bacterial activity and availability of oxygen.	Ratio of air to water in interstices, porosity of composting mass	6,11
Halogen content	Halogenated organics are unsuitable for composting.	Analysis for total organic halogen	11

Table 22. (Continued)

Waste Type: Sludges
Tecnnology: Composting

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
pH outside 4.5-7.5 range	Inhibition of biological activity.	Sludge pH testing	
Microbial population	If indigenous micro-organisms not present, cultured strains can be added.	Culture test	
Water and air emissions and discharges	Potential environmental and/or health impacts (control achieved through air scrubbing, carbon filtration, forced aeration, cement liner).	Concentrations of contaminants	6
Compaction of compost	Particles tend to coalesce and form an amorphous mass that is not easily maintained in an aerobic environment (wood chips or shredded tires may be added as bulking agents).	Determine integrity, physical nature of material	
Nonuniform particle	Waste mixtures must be of uniform particle size.	Particle size distribution	11



Source: FMC Aquifer Remediation Systems

Figure 16. In-Situ Biodegradation

<u>Technology Description</u>

In-situ biodegradation is the process of biodegrading wastes in the soil using indigenous or introduced bacterial strains. The process can be optimized by controlling the dissolved oxygen level, adding nutrients, and adjusting environmental parameters such as pH and alkalinity.

In-situ biodegradation has been applied to spills of gasoline, fuel oils, hydrocarbon solvents, nonhalogenated aromatics, alcohols, ketones, ethers, and glycol.

Table 23. Technology Summary

Waste Type: Soils
Technology: In-Situ Biodegradation

Waste characteristics impacting process feasibility	Reason for restriction	Data collection requirements	Reference
Presence of elevated levels of:			
- heavy metals - highly chlorinated organics - some pesticides, herbicides - inorganic salts	Can be highly toxic to microorganisms.	Analysis for priority pollutant	4, 10
Unfavorable soil characteristics			
- low permeability	Hinders movement of water and nutrients through contaminated area.	Percolation testing	4, 10
- variable soil conditions	Inconsistent biodegradation due to variation in biological activity.	Soil mapping	4
- low soil pH (less than pH 5.5)	Inhibition of biological activity.	Soil pH testing	4
- low soil organic content	Lack of organic substrate for biological growth.	Soil humus content	4
- low moisture content (less than 10%)	Subsurface biological growth requires adequate moisture.	Soil moisture content	4
Unfavorable site hydrology	Groundwater flow patterns must permit pumping for extraction and reinjection.	Site hydrogeology must be well defined	4, 10
Unfavorable groundwater quality parameters			
- low dissolved oxygen	Oxygen necessary for biological growth.	Dissolved oxygen in ground water	4, 10
- low pH, alkalinity	Inhibition of biological activity.	pH and alkalinity of ground water	4, 10

Table 24. Pretreatment Methods

Sludge

Problem	Treatment/Solution	
Material transport and excavation	Dragline	- Crane-operated excavator bucket to dredge or scrape sludge from lagoons, ponds, or pits.
	Backhoes, excavators	- Useful for subsurface excavation at the original ground level.
	Mudcat	- A bulldozer or loader muck like a crawler capable of moving through sludge.
	Positive displacement pump (e.g., cement pump)	- This pump can handle high density sludges containing abrasives such as sand and gravel.
	Moyno pump	- A progressing cavity pump that can pump high viscosity sludges.
Excessive water content	Evaporator	- Excess water can be evaporated from sludge. The Carver-Greenfield process is a potentially applicable technology. The sludge is mixed with oil to form a slurry and the moisture is evaporated through a multiple-effect evaporator.
	Filter press	- Sludge is pumped into cavities formed by a series of plates covered by a filter cloth. The liquid seeps through the filter cloth, and the sludge solids remain.
	Belt filter	- Sludge drops onto a perforated belt, where gravity drainage takes place. The thickened sludge is pressed between a series of rollers to produce a dry cake.
	Vacuum filter	- Sludge is fed onto a rotating perforated drum with an internal vacuum, which extracts liquid phase.

Table 24. (continued)

Sludge

Problem	Treatment/Solution	
Excessive water content (continued)	Centrifuge (solid bowl)	- Sludge feeds through a central pipe that sprays sludge into the rotating bowl. Centrate escapes out the large end of the bowl, and the solids are removed from the tapered end of the bowl by means of a screw conveyer.
	Drying	- Rotary drying, flash drying, sand bed.
	Gravity thickening	- Slurry enters thickener and settles into circular tank. The sludge thickens and compacts at the bottom of the tank, and the sludge blanket remains to help further concentration.
Excessive sludge viscosity	Slurry	- Addition of water or solvent.
Extreme pH	Neutralization	- Lime is a widely used alkaline material for neutralizing acid wastes, and sulfuric acid is used to neutralize alkaline wastes.
Oversize material removal, disaggregation, sorting	See Table 25 (Soils)	

Table 25. Pretreatment Methods

Soils

Problem	Treatment/Solution	
Material transport and excavation	Dragline	- Crane-operated excavator bucket to scrape or dredge soil to depths and farther reaches.
	Backhoe	- Useful for subsurface excavation or at the original ground level.
	Heavy earth moving equipment	- Includes bulldozers, excavators, dumptrucks for excavation and transport.
	Conveyers	- May be useful for large volume transport or feed to treatment unit.
Oversize material removal, disaggregation, sorting	Vibrating screen	- Vibrates for screening of fine particles from dry materials. There is a large capacity per area of screen, and high efficiency. Can be clogged by very wet material.
	Static screen	- A wedge bar screen consists of parallel bars that are frame-mounted on accrued deck. A slurry flows down through the feed inlet and flows tangentially down the surface of the screen. The curved surfaces of the screen and the velocity of the slurry provide a centrifugal force that separates small particles.
	Grizzlies	- Grizzlies are parallel bars that are frame-mounted at an angle to promote materials flow and separation. Grizzlies are used to remove a small amount of oversized material from predominantly fines.
	Hammer mill	- Used to reduce particle size of softer materials.

Table 25. (continued)

Soils

Problem	Treatment/Solution	
	Impact crushers	- Break up feed particles by impact with rotating hammers or bars. Impact crushing works best with material that has several planes of weakness, such as impurities or cracks.
Fugitive emissions	Dust suppressant	- Natural (e.g., water) or synthetic materials that strengthen bonds between soil particles.
	Negative pressure air systems	- Vacuum systems may be used to collect vapors and or dust particles and prevent release into atmosphere.
Dewatering	Belt filter press, centrifuge	- Useful for dewatering of very wet soils (lagoon sediments, wetlands).
	Rotating dryer	- Additional drying may permit higher feed rates for thermal treatment systems.