



**International Centre for
Science and High Technology**

SURVEY OF SEDIMENT REMEDICATION TECHNOLOGIES

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1. INTRODUCTORY PART

1.1 Introduction

Contaminants originated by discharges or accidents from industry, mining and agriculture activities have represented a source of ecological degradation in many of the world's freshwater and marine ecosystems, reducing water bodies' quality and impacting human health and aquatic life. Contaminants such as Polynuclear Aromatic Hydrocarbons (PAHs), Pesticides (DDT), Chlorinated Hydrocarbons (PCBs), Mononuclear Aromatic Hydrocarbons (benzene and its derivatives), Phthalate Esters, Metals (mercury and lead), cyanides and organo-metals may represent a long-standing problem because not dissolve or dissolve only partially in the water and sink to bottom of an aquatic environment. Physicochemical properties, such as particle size and shape, organic content and ecology of benthic organisms, may influence sediments to accumulate these contaminants in aquatic ecosystems over long periods of time. As a consequence, many toxic contaminants barely detectable in the water column can accumulate in sediments at much higher levels, contaminating the water column even for a long time after the source of pollutants is controlled. This potentially exposes benthic organisms (insects, worms, molluscs and bottom-dwelling fish) to contaminants and may causes a bioaccumulation of toxics through the food chain.

Many technologies for sediment remediation are emerging, based on the better comprehension of the relationships among contaminated sediment and ecosystem quality. Strategies for source control and natural recovery, such as removal and containment, removal and treatment, in situ capping, and in situ treatment have been employed as a form of environmental remediation. Generally, the most common way of dealing with sediment contamination is to scoop or vacuum up the sediment with a barge-mounted dredger and haul it away for long-term storage or for treatment. Otherwise, is absolutely essential that the choice of remediation technique should be guided by considerations of suitability and accuracy of technology, thorough the application of risk-based cleanup levels in accordance with the potential for natural resource damage assessment claims. In fact, the perception of the importance of the contaminated sediment management is increasing not only because ecological impairment, but also because sediments contamination have the potential to cause severe economic damage.

1.2 Sediment Characteristics

Sediments are generally constituted by clay, organic matter, hydrated iron and manganese oxides and represent soil and water mixtures transported by and deposited in aquatic environments. In most cases, the relative amounts of gravel, sand, silt, clay in sediment and some sediment characteristics such as particle size distribution, pH, organic content, oxidation-reduction conditions, solids content, density and salinity of the waterbody may influence decisively the interaction among sediment particles and contaminants. For example, organic carbon content in sediments may influence the adsorption capacity of some contaminants such as PCBs. Some components of remedial alternative may modify these physical properties, with advantages, as to facilitate handling or treatment of contaminants. However, changes to these properties by a remediation technique may also increase material quantities and costs. Sediment particles may be classified according to their grain sizes (Table 1). In fact, these characteristics alter the association of the contaminants with the sediment and affect the potential for pollutant migration. Sediment contaminants tend to be associated more with silt and clay fractions and less with sand and gravel fractions, because fine-grained sediments have higher affinity for the most of contaminants. In addition, sand and gravel deposits are usually present in areas of high energy (i.e., erosion and scouring) where fine-grained sediments and contaminants have been washed away. The organic matter content increases the affinity of sediments for some metals and nonpolar organic contaminants. The sediment properties are site-specific and may be relatively homogeneous. Nevertheless, the physical and chemical properties of sediment deposits in some waterway areas may vary both laterally and vertically. Some sediment deposits have also layers with distinct physical and chemical properties. Upper layers of sediment deposits usually contain higher concentration of contaminants, which can redissolve and migrate easily into the water column.

Table 1 – Sediment Particle Sizes.

Sediment-Texture Classification	Soil Composition	Particle size Diameter (mm)
Clay	Clay	< 0.004
	Very Fine Silt	0.004 - 0.008
	Fine Silt	0.008 - 0.016
	Medium Silt	0.016 - 0.032
	Coarse Silt	0.032 - 0.064
Sand	Very Fine Sand	0.064 - 0.125
	Fine Sand	0.125 - 0.25
	Medium Sand	0.25 - 0.5
	Coarse Sand	0.5 – 1.0
	Very Coarse Sand	1.0 – 2.0
Gravel	Granule	2.0 – 4.0
	Pebble	4.0 - 64
	Cobble	64 - 255
	Boulder	255 - 1000

(1) http://www.geog.uvic.ca/geog376/docs/376_manual-Ch6%5BS05%5D.pdf 1.3

1.3 Sediment Remediation Techniques

Sediment treatment refers to the use of physical, chemical or biological treatment technologies to reduce contaminant concentrations within the sediment in order to attend environmental cleanup goals. Remediation techniques act separating, destroying or converting the contaminants from the sediment to less toxic forms, or even stabilizing the contaminants so that the contaminants are fixed to the solids and are resistant to losses by environmental pathways. These techniques may be chosen according to sediment textures of coarse sand, very coarse sand and gravel, permeability and particle size diameter. Generally, the site of original contamination has the highest concentration of contaminant and the concentration decreases as it moves further away from the source. However, any remediation technique may remove contaminants from sediment without causes some disturbances and release contaminants.

A common goal of most sediment remedial alternatives is to separate the solids from the water fraction of the sediment (i.e., dewater) to the maximum extent possible. This is done to minimize disposal costs for the solids and is a requirement of some treatment technologies, such as removal and non removal technologies (Table 1). Sediments may be dewatered through a variety of processes to solids content greater than 50 percent. Depending on the process used, there may be little or no volume reduction, because water is replaced by air in the voids between the sediment solids. Otherwise, many of remediation process for sediments are not stand-alone process, but may compose a system that involves a multiple treatment phases to solve multiple contaminant problems.

One of the most important factors to be considered during a sediment remediation process is how the sediments are removed, in order to minimize contaminants release. Some sediment remedial methods (except non removal) involves the excavation of the sediment from the bottom of the waterway and moving excavated sediment to a location where the material may be placed into a holding area, moved into pretreatment units, and then carried into treatment units. In addition to the solids, the residual water from dewatering, effluent, and leachate systems and residues produced by remedial treatments must be also collected and routed.

Sediment management strategies may involve one or more component categories, including non removal options as monitored natural recovery and in-situ capping (in situ), and removal options, such as dredging with containment, and dredging with sediment treatment (Table 2). *In situ* remedial alternatives are somewhat limited, and generally involve a single technology such as capping. *Ex situ* remedial alternatives typically require a number of component technologies to remove, transport, pretreat, treat, and/or dispose sediments and treatment residues.

Table 2 - Descriptions of Sediment Remediation Technologies

<i>In Situ</i> TECHNOLOGIES		
1. Physical/Chemical Treatments		Capping
		Containment Barriers
		Solidification/Stabilization
		Confined Disposal Facility
<i>Ex Situ</i> TECHNOLOGIES		
2. Biological Treatments		Bioslurry
		Containment Land
		Composting
3. Physical/Chemical Treatments		Chelation
		Oxidation
		Dechlorination
		Solidification/Stabilization
		Basic Extractive Sludge
		Solvent Extraction
		Carver-Greenfield Process
		Soil Washing
	Containment Barriers	
4. Thermal Treatments	Thermal Destruction Technologies	Incineration
		Pyrolysis
		High-Pressure Oxidation
		Vitrification
	Thermal Desorption Technologies	X*TRAX System
		Desorption and Vaporization Extraction
		High-Temperature Thermal System
		Low-Temperature Thermal System
		Low-Temperature Thermal Aeration
		Anaerobic Thermal Processor

Some technologies, such as dredging and confined disposal, have been widely used with sediments. Most pretreatment and treatment technologies were developed for use with other media (i.e., sludges, soils, etc.) and have only been demonstrated with contaminated sediments at bench- or pilot-scale applications. Some of the most common strategies include:

- In situ Containment: is an active remediation option in which a layer of clean isolating material is placed in CDF's (Confined disposal facilities), CAD's (Contained Aquatic Disposal) and landfills to contain and stabilize the contaminated sediment in place from target organisms. A variety of capping materials and cap placement techniques are available, and monitoring data collected for a number of projects has indicated capping can be an effective remedy;
- In Situ Treatment: treatment technologies to remediate contaminated sediments are based on biological properties of the contaminants;

- Ex Situ Containment: land disposal technologies to contain or minimize contaminants impacts released around the dredging operation;
- Ex Situ Treatment and Extraction: refers to remediation techniques that are applied off-place, based on chemical and physical properties of the contaminants. The costs of each of these remediation operations may be significant. In some cases, physical properties of contaminated sediments (such as particle size and solids/water composition) may require the application of one or more pretreatment technologies prior to the processing of the sediment through a treatment unit.

Proposed technologies must be feasible for a minimal disturbance on the aquatic environment. The first consideration is certifying if the treatment technique can operate effectively under some physical properties of *in situ* sediments, such as saturated and anaerobic conditions and ambient temperatures. For example, remediation technologies which require greater levels of sediment manipulation are less likely to be feasible for *in situ* applications. On the other side, sites with groundwater movement through the sediment are suitable to be treated by non removal technologies, due to possibly contaminant losses. The concerns about remediation technique to be employed also include the costs of equipment, materials, reagents, and labor necessary to treat the sediments.

In situ treatment has some limitations, such as non homogeneous distribution of contaminants, sediment physical properties, the difficulty in ensuring uniform dosages of chemical reagents or additives throughout the sediments to be treated, the lack of process control due to dependence on monitoring conditions at the site, before and after treatment. In addition, *in situ* treatments can produce negative impacts on the water column, through releasing residues from the own treatment. On the other hand, some *In situ* treatments may be less cost effective than *ex situ* treatment.

1.3.1 IN SITU TECHNOLOGIES

Non removal technologies involves the remediation of contaminated sediments, removing them *in situ* (i.e., in place) from rivers, lakes or harbors. These technologies include *in situ* capping, *in situ* containment, and *in situ* treatment and generally involve addition and mixing of biological organisms or immobilization reagents with contaminated bottom sediment. The primary advantage of such technologies is treating the sediments in place, decreasing the handling and consequently the exposure of contaminants caused by resuspension or even volatilization of toxicants bounded to the particles of sediment and brought to the surface (Table 3). These techniques are also more simple and less expensive, especially because eliminate the need to remove and pretreat contaminated sediments. *In situ* remediation technologies for sediments are more effective to low flow streams where the flow can be diverted while the treatment takes place. However, these methods can be limited by saturated conditions, anaerobic environments, sediment type, contaminant distribution and ambient temperatures.

Table 3 - Main Advantages and Disadvantages of *In Situ* Treatment*

Advantages	Disadvantages
Relatively inexpensive	Lack of process control
Usually results in less resuspension of contaminated sediments than removal technologies	Poor environmental conditions for treatment
Treats, does not contain, contaminants	Lower treatment efficiency than ex situ treatment
Reduces handling and exposure of sediments	Limited experience with in situ treatments

*<http://clu-in.org/products/intern/renhold.htm>

Some descriptions of non removal technologies for sediment remediation, for application *in situ* are presented, in the following:

1. Capping: isolates the contaminated sediments from water column by using a covering or cap over an *in situ* deposit. The cap may be constructed of clean sediments, sand, or gravel, or may involve a more complex design using geotextiles, liners, and multiple layers;

2. Containment: involves the complete isolation of a portion of the waterway. Physical barriers are used to isolate a portion of a waterway, including sheetpile, cofferdams, and stone or earthen dikes. The isolated area can be used for the disposal of other contaminated sediments, treatment residues, or other fills material. The area may have to be modified to prevent contaminant migration (e.g., slurry walls, cap and cover);

3. Biological Treatment: uses natural microbiological processes to promote enzymatic production and microbial growth necessary to degrade or transform contaminants to less toxic or nontoxic forms in the environment. Contaminants in sediments provide nutrients and carbon enough to microorganisms for their development in these media. This remediation treatment is increasingly effective to remediate organic compounds, as following: chlorinated aromatic compounds, chlorinated straight-chain compounds, aromatic compounds and straight-chain hydrocarbon compounds. However, difficulties in adjusting

environmental conditions for various stages of the biodegradation process may limit this technique for *in situ* remediation.

4. Chemical Treatment: chemical reagents are mixed with sediment matrix for the purpose to destroy contaminants completely, to alter the form of the contaminants so that they are amenable to other treatments, or to be used to optimize process conditions for other treatment processes. Some chemical treatment techniques includes the use of aluminum sulfate (alum) to control the release of phosphorus from bottom sediments and limit algal growth, and the injection of calcium nitrate into sediments to promote the oxidation of organic matter. These processes may be even combined to biological treatments, providing oxygen for biological use, oxidation of organopollutants, and alteration of the soil matrix. Chemical treatment technologies include the use of chelation, dechlorination, and oxidation of organic compounds;

5. Thermal Treatment: highly effective processes to destroy contaminants on sediments by heating a wide variety of elements and compounds for several hundreds or thousands of degrees above ambient temperature. Thermal technologies are classified in two groups:

a) Thermal Destructive Technologies: Processes such as incineration, pyrolysis, high-pressure oxidation and vitrification are used to destroy completely PCBs, PAHs, chlorinated dioxins and furans, petroleum hydrocarbons, and pesticides. Some technologies, such as vitrification, may immobilize metals in a glassy matrix. Volatile metals, particularly mercury, must to be removed by equipments for emission control.

b) Thermal Desorption Technologies: sediment are heated to temperatures ranging from 90 to 540°C and contaminants are condensed and collected as liquid, captured on activated carbon, and/or destroyed in an afterburner. Remediation techniques includes X*TRAX System, Desorption and Vaporization Extraction System, High Temperature Thermal System, Low Temperature Thermal System, Low-Temperature Thermal Aeration System and Anaerobic Thermal Processor System. These techniques offer several some advantages over thermal destructive processes, including reduced energy requirements, less potential for formation of toxic emissions, and smaller volumes of gaseous emissions. Disadvantages include the need for a follow-on destruction process for the volatilized organic compounds and reduced effectiveness for less volatile organic compounds.

6. Immobilization: alters the sediment's physical and/or chemical characteristics to reduce the potential for contaminants to be released from the sediment to the surrounding environment (Myers and Zappi 1989). In general, the contaminant is reduced by leaching it from the disposal site to groundwater and/or surface water. The principal environmental pathway affected by *in situ* immobilization for sediments is leaching of contaminants from the treated sediment to groundwater and/or surface water. Solidification/stabilization is a commonly used term that covers the immobilization technologies discussed herein.

1.3.2 EX SITU TECHNOLOGIES

The removal or excavation of sediments from a water body is commonly known as dredging, with the objective of effectively removing contaminated material in a manner that minimizes the release of sediments and contaminants to the aquatic environment. The term environmental dredging involves mechanically penetrating, grabbing, raking, cutting, or hydraulically scouring the bottom of the waterway to dislodge subaqueous sediment. Once dislodged, the sediment is removed from the waterway either mechanically, as with buckets, or hydraulically, through a pipe. In fact, appropriate safety precautions should always be taken in all dredging operations to recover hazardous materials or contaminated mud with regard to the properties of the chemicals involved. Various types of dredgeheads are discussed in the following sections, as showed in Table 4.

Table 4 – Operational Characteristics of Some Types of Dredges*.

DREDGE TYPE	PERCENT SOLIDS BY WEIGHT ^(A)	RANGE OF PRODUCTION RANGES (M ³ /HR)
Clamshell	near in situ	23 - 460
Suction	10 - 15	19 – 3,800
Dustpan	10 - 20	19 – 3,800
Cutterhead	10 - 20	25 – 2,500
Hopper	10 - 20	380 – 1,500
Horizontal Auger	10 - 30	46 - 120
Pneuma®	25 - 40	46 - 300
Oozer	25 - 40	340 - 500
Clean-up	30 - 40	380 – 1,500
Refresher	30 - 40	150 - 990
Backhoe	near in situ	20 - 150

(a) Typical solids concentration under optimal conditions. Percent solids may be lower if operational difficulties (e.g. excess debris) are encountered.

<http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/tab4-6.gif>

On the other hand, a monitoring program for environmental dredging should be designed to provide information quickly so that appropriate changes to dredging operations or equipment can be made to meet project-specific objectives. In general, monitoring are conducted to measure contaminated sediment removal efficiency, to determine dredged volumes, to measure sediment resuspension at dredge, to track contaminant transport and to check performance of barriers and other controls. Simple and instantaneous measurements such as turbidity, conductivity and dissolved oxygen are most useful, acting as indicators to evaluate the performance of the dredging contractor, equipment, and the barriers and environmental controls in use. For example, the quantity of dredged material may be estimated from bathymetric surveys conducted before and after the dredging. Measurements of turbidity or suspended solids at water samples are made to monitor the level of sediment resuspension caused by the dredge. Monitoring may also be integrated into the health and safety plan for the dredging operation to ensure that exposure threshold levels are not exceeded.

1.4 CRITERIA

The basic strategy to the selection of an optimum technique to remediate sediments of a contaminated site includes a site and sediment characterization, availability and feasibility of technical alternatives, contaminant losses and overall environmental impacts, and total project costs. These components represent therefore some criteria to provide information and estimate for most suitable treatment technology for full-scale application in the remediation project, within a risk-based framework.

The following section presents different rating descriptions and some general information cost ranges for such tests. Selection factors for treatment technologies will be discussed in terms some categories such as Remediation Applicability (General Applicability and Site-specific Applicability) and Remediation Performance Assessment (General Assessment and Time-cost Assessment). A shortened list of screening criteria for this framework is listed at Table 5.

Table 5 – Rating Descriptions.

Criteria	Issue
Applicability	
General Applicability	Contaminant Type Sediment Type Depth
Site-specific Applicability	Site Accessibility Contaminant Concentration Levels Water Type Water Mobility Minimum Achievable Concentration Safety
Performance Assessment	
General Assessment	Development Status Short-term/Long-term Effectiveness Reliability and Maintenance Residuals Produced Data Needs Stand Alone Character Public Acceptability
Time-cost Assessment	Clean-up Time Required Overall Cost

1.4.1 REMEDIATION TECHNIQUE APPLICABILITY

A - General Applicability

The analysis is related to important indicators (contaminant type, type of sediment and concentration levels) for sediment remediation, depending on the composition of contaminants and sediment properties, such as density and grain size. This step will prepare a basis for a proper management of site-specific applicability criteria, resulting methodological approaches suitable for strategy implementation of a remediation technique.

Contaminant Type

The contaminants are distributed in two groups and eight categories, taking into account their principal characteristics, formulation and use. The main groups are:

1. Organic Contaminants:

1.1. Nonhalogenated Volatile Organic Compounds (VOCs)

- a. Light Hydrocarbons
- b. BTEX
- c. Oxygenated Hydrocarbons
- d. Other Compounds

1.2. Halogenated VOCs (X-VOCs)

- a. Chlorinated Hydrocarbons
- b. Other Halogenated Compounds

1.3. Nonhalogenated Semi-Volatile Organic Compounds (SVOCs)

- a. Heavy Hydrocarbons
- b. Non-Halogenated Pesticides
- c. Polycyclic Aromatic Hydrocarbons (PAHs)
- d. Nitro Aromatics & Amines
- e. Non-Halogenated Phenols

1.4. Halogenated Semi-Volatile Organic Compounds (X-SVOCs)

- a. Polychlorinated Byphenyls (PCBs)
- b. Halogenated Pesticides
- c. Other Halogenated Compounds

1.5 Dioxins & Furanes

2. Inorganic Contaminants:

2.1. Heavy Metals

- a. Volatile Heavy Metals & Compounds
- b. Non Volatile Heavy Metals & Compounds

2.2. Radionuclides

2.3. Other Inorganic Elements and Compounds

Sediment Type

Refers to sediment texture as process-limiting factor to choose or to eliminate a remediation technology.

1. Silty Sediments

Sediments grouped considering silt as the predominant particle size, with particle size diameter between 0.004 and 0.064mm. Clayey or silty sediments have higher porosity than sandy sediments and are usually compacted at depth, containing less oxygen levels. These sediments may affect treatment system emission controls, increasing particulate generation during thermal drying and handling problems in most processing systems, as dewatering.

2. Sandy Sediments

Sediments grouped considering sand as the predominant particle size, with particle size diameter between 0.064 and 2.0 mm. This group is generally characterized by low organic matter content and high permeability, meaning water flows through them faster. Sandy sediments are composed mainly of fine- to medium-grained quartz, with higher SiO₂ content, and may be easily eroded by tidal currents. Sandy sediments have also a lower capacity to bind heavy metals and organic contaminants, because of smaller specific surface areas.

3. Gravel Sediments

Sediments grouped according to their textures of gravel sediments, with particle size diameter larger than 2.0 mm. Often gravel sediments are more stable (may support faunal communities) and can be found in the center of the stream where the current is faster and the silt and sand particles may be easily carried out.

Depth

Refers to the applicability of a remediation technique in which the depth of the water column is a critical parameter. Sites deeper more than 0.5 m are more preferable because of potential keel clearance of dredging disposal equipment (ex situ).

1. Shallow

Soil surface is less than 0.2 and up to 0.5 m from the plume of contamination;

2. Medium

Soil surface is 0.5 to 1.5 m from the plume of contamination;

3. Deep

Soil surface is 1.5 m or more from the plume of contamination.

B - Site-specific Applicability

Decisions on remediation are based on site-specific aspects. Such indicators must be taken into account when selecting the remediation technique.

Site Accessibility

Refers to the distance and logistics to access the dredging area and disposal site.

Ratings:

+ High = Any logistical problem is encountered to apply the selected remediation technique in the proposed site.

- Medium = The accessibility to contaminated site is considerable short-term.

- Low = The implementation of most suitable remediation project is affected by the highly limited access to remediation site and may be not so cost-effective.

Contaminant Concentration Levels

Refers to the level of contamination before the remediation treatment and its possible effect as limiting-factor to choose or exclude a remediation technology.

Ratings:

+ High = Remediation technique performance is not affected by background contaminant concentration levels.

- Medium = The efficiency of a remediation technique may be affected by concentration levels of some specific contaminants.

- Low = The application of a remediation technique is strongly dependant on constituent concentrations of a contaminated site.

Water Type

Refers to the site water type and its impact in the remediation technique performance. Water types include saline, fresh and brackish.

Ratings:

+ High = Minimal to low requirements.

- Medium = Average requirements (short-term or moderate long-term attention is required).

- Low = High degree of uncertainty associated with control/monitoring, or significant and/or long-term efforts are needed during the remediation.

Water Mobility

Refers to the possibility of sediment dispersion, caused by water diffusion on the contaminated site, including routine currents of waters from lakes, rivers and streams, tides in marine waters (harbors) and estuaries, as well as seasonal waters such as from rainfall or snow-melt induced runoff from land surfaces.

Ratings:

+ High = Low water mobility through sediments, in which contaminated sediment areas are located in sites that are primarily deposited.

- Medium = Average water mobility through sediments, in areas where only a limited surface layer of sediment is immobilized.

- Low = High current velocities through sediments, with risk of exposure of contaminant movement to aquatic environment. Remediation may contribute to sediment dispersion.

Minimum Achievable Concentration

Refers to the minimum pollutant concentration achievable by the technology to achieve the desired remediation effect.

Ratings:

+ High = Less than 5 mg/kg sediment.

● Medium = 5-50 mg/kg sediment.

- Low = More than 50 mg/kg sediment.

Safety

Refers to the measures required to ensure safety to workers, the public and the environment. This also considers the degree of monitoring needed while applying the technology and throughout the remediation.

Ratings:

+ High = Low safety requirements.

● Medium = Average requirements (short-term or moderate long-term attention is required).

- Low = High degree of uncertainty associated with control/monitoring, or significant and/or long-term efforts are needed during the remediation.

1.4.2 REMEDIATION TECHNIQUE PERFORMANCE ASSESSMENT

A - General Assessment

The analysis is based on the latest scientific findings on more innovative and cost-effective remediation techniques and is case by case connected with a range of soil remediation technologies, as in-situ or ex-situ treatments.

Development Status

Refers to the situation of development of the specific technology in terms of the scale of expansion and use.

Ratings:

- + High = Full scale application.
- Medium = Pilot scale.
- Low = Laboratory scale.

Short-term/Long-term Effectiveness

Considers how remediation technologies effectively restore a contaminated site by means monitoring program to attend selected environmental goals.

Ratings:

- + High = The risk for human and ecological receptors after the remediation is not significant, since contaminant levels are lower than limits established by environmental laws.
- Low = The exposure pathway after remediation must be controlled by monitoring programs.

Reliability and Maintenance

Refers to the level of complexity of the system or technology and how easy it is to maintain.

Ratings:

- + High = High reliability and low maintenance.
- Medium = Average reliability and maintenance.
- Low = low reliability and high maintenance.

Residuals Produced

Refers to the production of residuals and resuspension of sediment solids when the remediation treatment technology is applied.

Ratings:

- + High = Does not produce residuals.
- Low = Produces residuals.

Data Needs

Refers to the extent of pre-remediation investigations. These may include site and near-site sampling, sub-surface strata characterization, feasibility studies, pilot testing, environmental impact assessment, modeling etc.

Ratings:

+ High = Some characterization is required, but it should not impact the time to accomplish the remediation nor significantly increase the total remediation costs.

• Medium = Considerable efforts are required to model the site or to determine whether the proposed methods will perform satisfactorily.

- Low = Extensive characterization/investigation required. These will usually impact the remediation schedule and constitute a major expense.

Stand Alone Character

To which extent the technology needs to be complemented by other treatments in order to obtain the desired cleaning level.

Ratings:

+ High = Does not require to be complemented by other treatment technologies.

- Low = Requires to be complemented by other treatment technologies.

Public Acceptability

Refers to the degree to which the technology is acceptable to the public. This category can vary widely depending on the level of community involvement.

Ratings:

+ High = Minimal opposition from the community is likely.

• Medium = Public involvement usually occurs, but the technology is generally accepted.

- Low = Serious public involvement is likely and the outcome is uncertain.

B - Time-cost Assessment

Decisions are based on appropriate indicators (cost-effective and remediation time) to be undertaken at a contaminated site, considering the financial input for execution of interventions, installations, monitoring required measures, etc.

Clean-up Time Required

This refers to a "standard" site of 0.4 hectare and 3 m depth. The soil mass is 18,000 metric tons.

Ratings for ex situ techniques:

High = Less than 6 months.

Medium = 6 months – 1 year.

Low = More than 1 year.

Ratings for in situ techniques:

High = Less than 1 year.

Medium = 1 – 3 year.

Low = More than 3 years.

Overall Cost

Includes design, construction, operations and maintenance costs of the core process that defines each technology. It does not include site preparation or post treatment costs. Excavation costs of 50 Euro/metric tons are assumed for ex situ technologies.

Ratings:

High = Less than 100 Euro/metric ton.

Medium = 100-300 Euro/metric ton.

Low = More than 300 Euro/metric ton.

1.4.3 CONTAMINANTS DESCRIPTION

Understanding of contaminant behaviour is essential to determine likely exposure pathways and the potential risk posed to particular receptors. The environmental fate and transport of a contaminant is governed by its physical and chemical properties, which are determined by specific parameters. The description of the main groups of contaminants in this section is referred to contaminants types as listed at “General Applicability” in 1.3.1 of “Remediation Technique Applicability”.

1. Organic Contaminants:

1.1. Nonhalogenated Volatile Organic Compounds (VOCs)

Volatile organic compounds are compounds that have a high vapour pressure and low water solubility. Many VOCs are human-made chemical that are used and produced in the manufacture of paints, pharmaceuticals and refrigerants. According to the WHO definition, a VOC is an organic compound having a boiling point range between 60-250°C. VOCs typically are industrial solvents, such as methyl tert-butyl ether (MTBE) or by-products produced by chlorination in water treatment units, such as chloroform. VOCs are often components of petroleum fuels, hydraulic fluids, paint thinners and dry cleaning agents. VOCs are common ground water contaminants.

Table 6 - Typical VOCs compounds.

Acetone	Ethyl ether	Methyl isobutyl ketone
Acrolein	Ethyl tert butyl ether	Methyl tert butyl ether
Acrylonitrile	Ethylene oxide	N Butanol
Carbon disulfide	Formaldehyde	Naphthalene
Cyclohexanone	Isobutyl alcohol	Tert amyl methyl ether
Diethylene glycol	Methanol	Tetrahydrofuran
Ethanol	Methyl ethyl ketone	Vinyl acetate
Ethyl acetate		

a. Light Hydrocarbons

Considers the series of contaminants considered non-halogenated volatile organic compounds, but greater than C1 and reaching a maximum at C16.

Table 7 - Typical Light Hydrocarbons.

Ethane	Propane	n-butane
i-butane	Ethylene (ethene)	Propylene (propene)
Isoprene(2-methyl-1,3-butadiene)	Benzene	Toluene
1,2,3,4-tetramethylbenzene	2-methylpentane	Cyclohexane
1,2,4,5-tetramethylbenzene	2-methylphenol	Cyclopentane
1,2,4-trimethyl-5-ethylbenzene	3,3,5-trimethylheptane	Dibenzo(a,h)anthracene
1,2,4-trimethylbenzene	3,3-dimethyl-1-butene	n-decane
1,3,5-trimethylbenzene	3-ethylpentane	n-dodecane
3-methyl-1,2-butadiene	1-pentene	n-heptane
2,2,4-trimethylheptane	Benzo(k)fluoranthene	n-hexane
2,2,4-trimethylpentane	Chrysene	n-hexylbenzene
2-methylheptane	Cis-2-butene	n-nonane
2-methylnaphthalene	Creosols	n-octane

Includes alkanes, alkenes, aromatics and biogenically produced compounds including isoprene and terpenes. Light Hydrocarbons include also many fuel contaminants that may occur in aircraft areas, burn pits, chemical disposal areas, contaminated marine sediments, disposal wells and leach fields, fire-fighting training areas, hangars/aircraft maintenance areas, landfills and burial pits, leaking storage tanks, solvent degreasing areas, surface impoundments and vehicle maintenance areas. BTEX compounds are also classified as light hydrocarbons but are presented in a different section by their notorious occurrence as contaminants of soil and groundwater.

b. BTEX

BTEX is an acronym for benzene, toluene, ethylbenzene, and xylene, and reflects that benzene, toluene, ethylbenzene and xylenes are often found together at contaminated sites. This group can be found in petroleum hydrocarbons, such as gasoline, and other common environmental contaminants. They are also used extensively in manufacturing processes:

- a) Benzene is used in the production of synthetic materials and consumer products, such as synthetic rubber, plastics, nylon, insecticides and paints;
- b) Toluene is used as a solvent for paints, coatings, gums, oils, and resins;
- c) Ethylbenzene may be present in paints, inks, plastics, and pesticides;
- d) Xylenes are used as a solvent in printing, rubber, and leather industries;

Table 8 - Typical BTEX compounds.

1,2,3,4 tetramethylbenzene	n-butylbenzene
Benzene	n-propylbenzene
Dimethylbenzene	Sec-butylbenzene
Ethenylbenzene	Tert-butylbenzene
Ethylbenzene	Toluene
Ethyltoluene	Trimetilbenzene
Isopropyltoluene	Xylene

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Table 9 - Physical-chemistry properties.

	Benzene	Toluene	Xylene	Ethylbenzene
Water solubility (mg/l)	1700	550	175-198	170
Boiling points (°C)	80	111	138-144	136
Density (g/cm ³) at 20 °C	0,88	0,87	0,86-0,88	0,87
Viscosity (mPa*s)	0,7	0,6	0,6-0,8	0,7
Koc	~80	~100	~210	~200-1000

The mobility of BTEX in the subsurface is high. Especially benzene and toluene are highly mobile in soil air and water. The mobility of xylene and ethylxylene is much lower. The high vapour pressure of BTEX enhances their migration via soil air. In the liquid phase, their low viscosity favours infiltration. As their density is < 1 g/cm³, they tend to float on the water table. The potential of the BTEX to evaporate is high. Due to their relatively high water solubility, they tend to migrate with the groundwater flow.

Benzene is the most soluble at 1780 mg/l (20 ° C); Toluene has a solubility of 515 mg/l (20° C). The solubility of the isomeric xylene ranges between 175 mg/l o- and m- xylene and 198 mg/l for para- xylene. Sorption to organic matter and clay minerals is moderate.

Degradation

BTEX compounds biodegrade relatively quickly (aerobic - favoured over anaerobic degradation), usually better than cycloalkanes, but worse than isoalkanes. Under aerobic conditions they transform to phenols. Toluene and benzene degrade more easily than xylenes.

Mobility

High to medium, (high when benzene and toluene are dominating compounds, otherwise medium mobility).

c. Oxygenated Hydrocarbons

Oxidation of hydrocarbons produces a variety of volatile oxygenated products including aldehydes, ketones, alcohols and organic acids.

Table 10 – Typical Oxygenated Hydrocarbons.

Aldehydes	Formaldehyde are found with phenols in industrial resin processes; Acrolein is generated as a by-product of acrylonitrile manufacture.
Ketones	Include organic solvents such as acetone as well as more specialized industrial solvents such as methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK).
Alcohols	Methanol and 1-butanol have both human and ecotoxicological risks and are produced by fermentations processes and synthetic routes from natural gas, petroleum, or coal feed stocks.
Organic acids	Organic acids include acetic acid, propionic acid, and formic acid. Occur normally at soil at low concentrations, but environmental contaminations due to presence of higher concentrations of these compounds may causes losses of nutrients on soils.

d. Other Compounds

Includes miscellaneous organic compounds considered Non-Halogenated Volatile Organic Compounds (VOCs), but not previously classified from 1.1 to 1.4.

1.2. Halogenated Volatile Organic Compounds (X-VOCs)

A halogenated volatile organic compound is a chemical compound or mixture, derived from a vegetable or animal source (including certain minerals such as coal or petroleum that originally came from vegetable or animal sources), contained in a solid or liquid that volatilizes or evaporates at room temperature or an elevated temperature. The nature of the halogen bond and the halogen itself can significantly affect performance of a technology or require more extensive treatment than for non halogenated compounds.

Table 11 - Typical halogenated VOCs compounds.

1,1,1,2-Tetrachloroethane	Chlorodibromomethane
1,1,1-Trichloroethane	Chloroethane
1,1,2,2-Tetrachloroethane	Chloroform
1,1,2-Trichloroethane	Glycerol
1,1-Dichloroethane	Hexachlorobutadiene
1,1-Dichloroethylene	Hexachlorocyclopentadiene
Bromoform	Hexachloroethane
Bromomethane	Methylene chloride
Carbon tetrachloride	Trichlorohydrin

a. Chlorinated Hydrocarbons (CHC)

Chlorinated hydrocarbon (CHC) is a generic term given to compounds containing chlorine, carbon and hydrogen. The term can be used to describe organochlorine pesticides such as lindane and DDT, industrial chemicals such as polychlorinated biphenyls (PCB), and chlorine waste products such as dioxins and furans. These compounds are persistent in the environment and most bioaccumulate in the food chain. The human and environmental health risks of chlorinated hydrocarbons depend on the compound in question. As a general statement, exposure to chlorinated hydrocarbon has been associated with suppression of the immune system and cancer. Chlorinated hydrocarbon compounds include chloroform, carbon tetrachloride, ethylene dichloride, methylene chloride, tetrachloroethane and trichloroethylene. They are employed as solvents, plasticizers and monomers for plastic manufacture. Many are prohibited because of their toxicity.

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Table 12 - Physical-chemistry properties.

	¹ TCE	² TRI	^{1,2-cis} ³ DCE	Trichloro methane	Vinyl chloride
Water solubility (mg/l)	~150	~400	3500- 5000	~8000	~2000
Boiling points (°C)	121	81	60	61	-14
Density (g/cm ³) at 20 °C	1.6	1.5	1.3	1.5	0.9
Viscosity (mPa*s)	0.9	0.6	0.5	0.6	-
Koc	~300	~150	~60	~100	~10

¹Tetrachloroethene (TCE), ²Trichloroethene (TRI), ³Dichloroethene (DCE).

CHC are very mobile in soil. Due to their high vapour pressure they readily migrate via soil air. The densities of CHC are greater than water. Low viscosity and low surface tension promote their vertical migration within the subsurface and their potential to exist as NAPL phase within the saturated zone. The sorption capacity onto organic matter is low. As their water solubility is moderate to good, CHC may be transported with the groundwater flow and – due to their high density – may accumulate at the base of the aquifer.

Degradation

Microbial degradation is low; therefore the length of the contaminant plume may be several kilometres. The higher chlorinated compounds are only degradable under anaerobic conditions whereas compounds with lower chlorine numbers are preferably degraded under aerobic conditions. The formation of highly toxic degradation products (e.g. vinyl chloride) is possible.

TCE (anaerobic) → aerobic or anaerobic: TRI → DCE → VC → (Ethene)

Mobility

High

b. Other Halogenated Compounds

Includes Halogenated Volatile Organic Compounds not previously classified at 2.1.

1.3. Non-Halogenated Semi-Volatile Organic Compounds (SVOCs)

Non halogenated semi-volatile organic compounds are a group of synthetic organic compounds that are solvent-extractable and can be determined by gas chromatography/mass spectrometry. SVOCs include phenols, phthalates, higher fatty acids and polycyclic aromatic hydrocarbons (PAH).

SVOCs generally present less vapour pressure and higher boiling point than VOCs. Generally, boiling points are greater than 200°C, but according to WHO definition, compounds considered SVOCs show boiling points around 240-260 °C.

Table 13 - Typical non-halogenated SVOCs compounds.

(1,2,3-cd) pyrene	Benzo(b)fluoranthene
1,2-benzotriacenaphthene	Benzo(k)fluoranthene
1,2-Diphenylhydrazine	Benzoic Acid
1-aminonaphthalene	Ethyl parathion
2,3-phenylenepyrene	Fluorine
2,4,-Dinitrophenol	Indene
2-aminonaphthalene	Isophorone
Benzidine	Malathion
Benzo(a)anthracene	Methylparathion
Benzo(a)pyrene	Pyrene

a. Heavy Hydrocarbons

Includes heavy hydrocarbons (C9 – C23) found at petroleum distillates and products. In general, are ignitable liquids, such as Kerosene, fuel oil, jet fuels and diesel fuel (ASTM Standard Practice E 1387).

b. Non-Halogenated Pesticides

Pesticides and Herbicides are chemical compounds used to control insects, rodents, plants etc. These two classes of organics include organophosphorous pesticides, carbamate pesticides, pyrethroid pesticides and chlorinated pesticides (item 4.3). Another way to think about pesticides is to consider those that are chemical pesticides or are derived from a common source or production method. Other categories include biopesticides, antimicrobials, and pest control devices.

Organophosphate Pesticides affect the nervous system by disrupting the enzyme that regulates acetylcholine, a neurotransmitter. Most organophosphates are insecticides. Some are very poisonous (they were used in World War II as nerve agents). However, they usually are not persistent in the environment.

Table 14 - Typical Organophosphate Pesticides.

Dimethylphosphate (DMP).	Malathion
Dimethyldithiophosphate (DMDTP)	Metasystox
Diethylphosphate (DEP)	Dicapton
Diethylthiophosphate (DEPT)	Disyston
Diethyldithiophosphate (DEDTP)	

Carbamate Pesticides affect the nervous system by disrupting an enzyme that regulates acetylcholine, a neurotransmitter. The enzyme effects are usually reversible. There are several subgroups within the carbamates.

Table 15 - Typical Carbamate Pesticides.

Common name	Chemical name
Aldicarb	2-methyl-2-(methylthio)propionaldehyde O-(methylcarbamoyl)oxine
Carbaryl	1-naphthyl methylcarbamate
Carbofuran	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate
Fenoxycarb	Ethyl [2-(4-phenoxyphenoxy)ethyl] carbamate
Methiocarb	3,5-dimethyl-4-(methylthio)phenyl methylcarbamate
Methomyl	S-methyl N-[(methylcarbamoyl)oxy]thioacetimidate
Oxamyl	S-methyl N,N-dimethyl-N-(methylcarbamoyloxy)-1-thio-oxamimidate
Thiodicarb	Dimethyl N,N-(thiobis(methylimino)carbonyloxy)bis(ethanimidothioate)

Pyrethroid Pesticides were developed as a synthetic version of the naturally occurring pesticide pyrethrin, which is found in chrysanthemums. They have been modified to increase their stability in the environment. Some synthetic pyrethroids are toxic to the nervous system.

Table 16 - Typical Pyrethroid Pesticides.

Allethrin	Bifenthrin
Cyfluthrin	Cyhalothrin
Cypermethrin	Deltamethrin
Esfenvalerate	Fenpropathrin
Fluvalinate	Permethrin
Resmethrin	Tefluthrin
Tetramethrin	Tralomethrin

Pesticide losses from soils and their potential to contaminate ground- or surface water can be estimated considering simultaneously persistence and sorption: sorption is determined by the partition coefficient (Koc) and persistence is determined by degradation measured in half-life $T_{1/2}$ = measure of the amount of time it takes for one-half the original amount of a pesticide in soil to be deactivated.

Table 17 - Qualitative assessment of a pesticide's contamination potential.

Persistence	Sorption	Potential Impact	
		Groundwater	Surface Water
¹⁾ Non-persistent	low-moderate	low	low
Non-persistent	moderate-high	low	moderate
²⁾ Moderately persistent	moderate-high	moderate	moderate
Moderately persistent	low-moderate	high	high
³⁾ Persistent	moderate-high	moderate	high
Moderately persistent & persistent	low-high	Impacts on ground- and surface water is determined by site specific conditions	

¹⁾ Non persistent: $T_{1/2}$ = 30 days or less (e.g. 2, 4, 5 -T, Parathion).

²⁾ Moderately persistent: $T_{1/2}$ = > 30 days and < 100 days (e.g. Atrazine, Diazinon).

³⁾ Persistent: $T_{1/2}$ = > 100 days (e.g. Lindane, Endosulfane).

c. Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a group of compounds formed during the incomplete combustion of coal, oil, gas, wood, garbage or other organic substances. In most cases PAHs occur as a mixture of several compounds, not as a single chemical. Several PAHs are produced commercially to be used in the industrial organic synthesis. Once released into the aquatic environment, degradation by micro-organisms is often slow, leading to their accumulation in exposed sediments, soils, aquatic and terrestrial plants, fish and invertebrates. In terms of human health, prolonged exposure to PAHs can have a deleterious effect.

Table 18 - Typical Polycyclic Aromatic Hydrocarbons (PAHs).

Acenaphthene	Chrysene
Acenaphthylene	Dibenzo(a,h)anthracene
Anthracene	Benzo(a)anthracene
Benzo(a)pyrene	Naphthalene
Benzo(b)fluoranthene	Phenanthrene
Benzo(g,h,i)perylene	Pyrene

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Table 19 - Physical-chemistry properties.

	Naphthalene (2 rings)	Anthracene (3 rings)	Pyrene (4 rings)	Benz(a)pyrene (5 rings)
Water solubility (mg/l)	32	0,07	0,14	0,001
Boiling points (° C)	218	314	393	496
Density (g/cm ³) at 20° C	1,15	1,24	1,27	1,3
Viscosity (mPa*s)	*solid	*solid	*solid	*solid
Koc	1,300	26,000	44,000	4,500,000

* at room temperature

PAH strongly (sometimes irreversibly = bound residues) sorb onto soil particles and humic acids. Their volatility and water solubility (hydrophobic) is low. The mobility of PAH decreases with increasing number of carbon rings. Their water solubility and vapour pressure decrease, the sorption onto organic carbon increases. Sorbed onto colloids, they may get into the groundwater with seepage water.

Their potential to contaminate groundwater is generally little. An exception is naphthalene, having higher water solubility than the other PAH. The mobility of naphthalene is about that of fuel oil. Due to their water solubility usually 2 to 3 ring PAH, as well as Pyrene, are found in the water. PAH are persistent, immobile soil contaminants.

Degradation

PAH are moderately biodegradable under aerobic conditions. The biodegradation decreases with increasing number of carbon rings. The biodegradability of PAH with more than 4 rings is negligible. PAH tend to accumulate in the food chain.

Mobility

Medium mobility: 2 rings (naphthalene), 3 ring PAH

Low mobility: > 3 ring PAH

d. Nitroaromatics & Amines

Nitroaromatics are carcinogenic and mutagenic aromatic substances that are typical contaminants of contaminated military sites, as some pesticides (atrazine), and a number of anilines. The majority of nitroaromatic compounds are industrial chemicals such as explosives, dyes, polyurethane foams, herbicides, insecticides and solvents and have become common contaminants of soil, sediments, and water.

Table 20 - Typical NitroAromatics compounds.

2,4,6-Trinitrotoluene (TNT)
2,4-dinitrotoulene (DNT)
1,3,5-trinitro-1,3,5-triazine (RDX)
cyclotetramethylene tetranitramine (HMX)

Amines are derivatives of ammonia in which one or more hydrogen atoms are replaced by alkyl groups such as alkyl amines, aliphatic diamines, alicyclic amines, heterocyclic amines, propylene amines and aliphatic etheramines. Most of amines, such as phenylamine, are danger to the environment as it is danger of serious damage to human health. Typical amines compounds are:

Table 21 - Typical Nitramines compounds.

Methylamine	CH_3NH_2
Propylamine	$\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$
2-propylamine	$(\text{CH}_3)_2\text{CHNH}_2$
Diethylamine	$(\text{CH}_3)_2\text{NH}_2$
Aniline	$\text{C}_6\text{H}_5\text{NH}_2$
4-methylphenylamine	$4\text{-CH}_3\text{C}_6\text{H}_4\text{NH}_2$

e. Non-Halogenated Phenols

These compounds have widely been used in the production of pesticides, herbicides, and wood preservatives. They can also be generated as byproducts in industrial operations, such as the paper pulp bleaching process and water disinfection with chlorine. Chlorophenols can enter water streams through various transport mechanisms and can also chemisorb onto soil surfaces and aquatic sediments. Due to their toxicity, these xenobiotics are consequently harmful to humans, animals, and fish that are exposed to such contaminated environments.

Table 22 - Typical Non-Chlorinated Phenols.

2,4-dimethylphenol	2,4-dinitrophenol
2-methyl 4,6-dinitrophenol	Nitrophenol (2-, 4-)
Phenol	Cresol

1.4. Halogenated Semi-Volatile Organic Compounds (X-SVOCs)

Halogenated (e.g., fluorine, chlorine, bromine, or iodine) semi-volatile organic compounds are a group of synthetic organic compounds that are solvent-extractable and can be determined by gas chromatography/mass spectrometry, with less vapour pressure and higher boiling point than VOCs. The nature of the halogen bond and the halogen itself can significantly affect performance of a technology or require more extensive treatment than for non-halogenated compounds. Typical X-SVOCs compounds are organochlorines and polychlorinated biphenyls (PCBs).

Table 23 - Typical halogenated SVOCs compounds.

1,2,4-Trichlorobenzene	Bis(2-chloroethoxy) phthalate	Chlordane
1,2-Bis(2-chloroethoxy) ethane	Bis(2-chloroethyl) ether	Quintozene
1,2-Dichlorobenzene	Hexachlorobenzene	Chlorphenothane
1,3-Dichlorobenzene	Hexachlorobutadiene	Ethyl parathion
1,4-Dichlorobenzene	Hexachlorocyclopentadiene	Chlorobenzilate
2,4,5-Trichlorophenol	p-chloro-m-cresol	Chlorobenzene
Bis(2-chloroethoxy) ether	p-dichlorobenzene	Phenylether
Bis(2-chloroethoxy) methane	4-Chlorophenyl phenylether	4-Chloroaniline
2-Chloronaphthalene	Bis(2-chloroethoxy) ether	4-Chlorophenyl
4-Bromophenyl phenyl ether	Bis(2-chloroethoxy) methane	
3,3-Dichlorobenzidine	Bis(2-chloroethoxy) phthalate	
Pentachlorobenzene	Bis(2-chloroethyl) ether	
o-dichlorobenzene	Bis(2-chloroisopropyl) ether	

a. Polychlorinated Biphenyls (PCBs)

PCB (or PCBs) is a category, or family, of chemical compounds formed by the addition of Chlorine (Cl₂) to Biphenyl (C₁₂H₁₀), which means a dual-ring structure comprising two 6-carbon Benzene rings linked by a single carbon-carbon bond. There are 210 different PCB compounds. Commercial mixtures typically have 40%-60% chlorine by weight.

Table 24 - Typical PCBs compounds.

Aceclor	Clophen	Hydol	Pydraul
Adkarel	Clophenharz	Inclor	Pyraclor
ALC	Clorinal	Inerteen	Pyralene
Apiolio	Delor	Kaneclor	Pyranol
Arochlor	Delorene	Leromoll	Pyroclor
Arubren	Diaclor	Magvar	Pyronol
Asbestol	Diconal	Montar	Saf-T-Kuhl
Askarel	Educarel	Nepolin	Santosol
Auxol	Elaol	Non-Flamol	Santotherm
Bakola	Elinol	Orophene	Santovac
Chlophen	Eucarel	Phenoclor	Solvol
Chlorinated biphenyl	Fenclor	Plastivar	Terphenychlore
Chlorinol	Gilotherm	Prodelec	Turbinol
Cloresil			

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Table 25 - Physical-chemistry properties.

	2,4,4-Tricl. biphenyl	2,2,4,5,5- Pentachlor biphenyl	2,2,3,4,4,5,5 Heptachlor biphenyl	PCB range from 19-71% Cl
Water solubility (mg/l)	0.14	0.01	0.004	0.001-6
Viscosity (mPa*s)	viscous	viscous	viscous	viscous
Kow	740,000	2,500,000	5,000,000	20,000-150 x 10 ⁶

PCB have a high viscosity, the water solubility is low for compounds with high chlorine content. The mobility of PCB in soil is very low, decreasing with the number of chlorine atoms. PCB readily sorb to humic acids and iron oxides. The volatility is very low.

Degradation

As PCBs are chemically very stable, the degradation in soil is very slow. The degradability decreases with increasing number of chlorine atoms. Due to their lipophilic properties, PCBs tend to accumulate in the food chain.

Mobility

Low

b. Halogenated Pesticides

Halogenated pesticides derived in whole or in part from benzene or other aromatic hydrocarbons and are composed by elements from the group seven (the halogens Fluorine, Chlorine, Bromine, Iodine, and Astatine) of the periodic table of the elements. Chlorinated hydrocarbons are known as organochlorines, and historically make up a large group of compounds, such as DDT, chlordane, dieldrin, lindane, and heptachlor. Halogenated pesticides are, in general, more fat soluble and more resistant to biodegradation, while methylated pesticides are more water soluble and, therefore, more biodegradable.

Table 26 - Physical-chemistry properties.

Aldrin	4,4'-DDT	Heptachlor
BHC-alpha	Dieldrin	Heptachlor epoxide
BHC-beta	Endosulfan I	Malathion
BHC-delta	Endosulfan II	Methylparathion
BHC-gamma	Endosulfan sulfate	Parathion
Chlordane	Endrin	Toxaphene
4,4'-DDD	Endrin aldehyde	Benzo(b)fluoranthene
4,4'-DDE	Ethion	Benzo(k)fluoranthene
Fluoranthene	Fluorene	

c. Other Halogenated Compounds

Includes some compounds not mentioned at items 4.1 and 4.2. It includes also some halogenated phenols, which have widely been used in the production of pesticides, herbicides, and wood preservatives. They can also be generated as byproducts in industrial operations, such as the paper pulp bleaching process and water disinfection with chlorine. Chlorophenols (Tables 23 and 24) can enter water streams through various transport mechanisms and can also chemisorb onto soil surfaces and aquatic sediments. Due to their toxicity, these xenobiotics are consequently harmful to humans, animals, and fish that are exposed to such contaminated environments.

Table 27 - Other Halogenated X-SVOCs.

1,2,4-Trichlorobenzene	4-Chloroaniline	Hexachlorobenzene
1,2-Bis(2-chloroethoxy) ethane	4-Chlorophenyl phenylether	Hexachlorobutadiene
1,2-Dichlorobenzene	Bis(2-chloroethoxy) ether	Hexachlorocyclopentadiene
1,3-Dichlorobenzene	Bis(2-chloroethoxy) methane	o-dichlorobenzene
1,4-Dichlorobenzene	Bis(2-chloroethoxy) phthalate	p-Chloro-m-cresol
2-Chloronaphthalene	Bis(2-chloroethyl) ether	p-dichlorobenzene
4-Bromophenyl phenyl ether	Bis(2-chloroisopropyl) ether	Pentachlorobenzene
3,3-Dichlorobenzidine	Fluoranthene	Quintozene
Chlorobenzene	Chlorobenzilate	Chlorophenothane
Ethion	Unsym-trichlorobenzene	Ethyl parathion
Methylparathion	Fluorene	Malathion
Benzo(b)fluoranthene	Parathion	Toxaphene
Benzo(k)fluoranthene		

Table 28 – Typical Halogenated Phenols.

Chlorophenol isomers (ortho, meta, para)
Dichlorophenols (2,6-, 2,5-, 2,4-, 3,5-, 2,3-, 3,4-),
Trichlorophenols (2,4,6-, 2,3,6-, 2,4,5-, 2,3,5-, 2,3,4-, 3,4,5-)
Tetrachlorophenols (2,3,5,6-, 2,3,4,5-, 2,3,4,6-)

1.5. DIOXINS & FURANES

The general term "dioxin" collectively refers to a class of structurally and chemically related compounds known as halogenated aromatic hydrocarbons. They include poly-chlorinated dibenzo-p-dioxins (PCDD or Dioxin's), polychlorinated dibenzofurans (PCDF or Furans) and the "dioxin-like" Biphenyls (PCBs). The term dioxin-like refers to compounds having basic similarities in molecular structure, chemical properties, environmental persistence, bioaccumulation potential and mechanisms of toxic actions. In general, the term "dioxin" only includes both PCDD and PCDF. Information presented for X-SVOCs may also be appropriate for many of the contaminants presented in this subsection.

Table 29 - Typical Dioxins and Furanes.

Dibenzo-p-dioxins (PCDD)	2,3,7,8-TCDF
2,3,7,8-TCDD	1,2,3,7,8-PnCDF
1,2,3,7,8-PnCDD	1,2,3,4,7,8,-HxCDD
1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8,-HpCDD
Dibenzofurans (PCDFs)	

2. Inorganic Contaminants

Inorganics are compounds that do not contain carbon in their structure; nevertheless some compounds like carbon dioxide are considered inorganic. Inorganics also involve compounds with bonds with some metals. Metals, heavy metals, non metals etc. are also included in this group. The availability of heavy metals and metalloids in soil is determined by: pH, redox-potential, sorption and chemical speciation. Generally the mobility of heavy metals in soil increases with decreasing pH (exception: Se). Amphoteric metals such as Cr and Zn are also soluble at higher pH.

The valency state of metals and metalloids is influenced by the redox potential and consequently determines their mobility and toxicity. Changing the redox potential may change their mobility. (e.g. heavy metal oxides are stable under oxidising conditions, but will dissolve in a reducing environment with their mobility increasing.). The sorption capacity of soils increases with increasing contents of organic matter, clay and Fe-, Mn- and Al-hydroxides. The water solubility of a metal or metalloid depends on its chemical speciation. In their cationic form: chlorides (CuCl_2 , Hg_2Cl_2), nitrates and sulfates (except: PbSO_4 , BaSO_4) are more water soluble than hydroxides (solubility is strongly pH dependent) or cyanides (difference: free CN \gg CN-complexes). Sulphides, silicates and carbonates are insoluble in water. In their anionic form the water solubility of metals/metalloids is generally high. Increasing metal mobility in soil increases their concentration in soil solution, thus enhances plant uptake and their potential for leaching into the groundwater. Metal mobility decreases as follows: Cd \gg Zn \gg Tl > Ni > Co > Cu > As, Cr \gg Pb \gg Hg.

2.1. Heavy Metals

Heavy metals comprehend elements and some of its compounds with high molecular weights which are generally toxic or poisonous to living things at low concentrations and tend to accumulate in the food chain.

Heavy metals can enter a water supply by industrial and consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater.

a. Volatile Heavy Metals & Compounds

Volatile heavy metals include Mercury (Hg) and non-metallic arsenic (As) and some of their compounds. Mercury sources are especially from mine drainage, leaching and sediment runoff from slag heaps, leakage from old electrical components such as switching gear either still in use or out of commission.

Table 30 - Typical Heavy Metals.

	Name	Symbol	Atomic Number	Boiling Point (°C)
Volatile	Mercury	Hg	80	357 °C
	Arsenic	As	33	subl. 614 °C

b. Non-Volatile Heavy Metals & Compounds

Examples of non-volatile heavy metals include Antimony (Sb), Bismuth (Bi), Cadmium (Cd), Cerium (Ce), Chromium (Cr), Cobalt (Co), Copper (Cu), Gallium (Ga), Gold (Au), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Platinum (Pt), Silver (Ag), Tellurium (Te), Thallium (Tl), Tin (Sn), Uranium (U), Vanadium (V), and Zinc (Zn).

2.2. Radionuclides

Typical radionuclides contaminants encountered include the following: Americium-241; Iodine-129,-131; Ruthenium-103,106; Barium-140; Krypton-85; Silver-110; Carbon-14; Molybdenum-99; Strontium-89,-90; Cerium-144; Neptunium-237; Technetium-99; Cesium-134, -137; Plutonium-238, -239,-241; Tellurium-132; Cobalt-60; Polonium-210; Thorium-228, -230, -232; Curium-242,-244 and Radium-224, -226.

Table 31 - Typical Radionuclides.

Name	Atomic Number	Radiation Type		
		Alpha	Beta	Gamma
<u>Americium-241</u>	95	•		•
<u>Cesium-137</u>	55		•	•
<u>Cobalt-60</u>	27		•	•
<u>Iodine-129 & -131</u>	53		•	•
<u>Plutonium</u>	94	•	•	•
<u>Radium</u>	88	•		•
<u>Radon</u>	86	•		
<u>Strontium-90</u>	38		•	
<u>Technetium-99</u>	43		•	•
<u>Tritium *</u>	1		•	
<u>Thorium</u>	90	•		•
<u>Uranium</u>	92	•		•

*Tritium is a specific isotope, H-3.

A radionuclide is an atom with an unstable nucleus, which is a nucleus characterized of excess energy which is available to be imparted either to a newly-created radiation particle within the nucleus, or else to an atomic electron (see internal conversion). The radionuclide, in this process, undergoes radioactive decay, and emits a gamma ray(s) and/or subatomic particles. These particles constitute ionizing radiation. Radionuclides may occur naturally, but can also be artificially produced. Radionuclides are often referred to by chemists and biologists as radioactive isotopes or radioisotopes, and play an important part in the technologies that provide us with food, water and good health. However, they can also constitute real or perceived dangers.

2.3. Other Elements and Compounds (Inorganics)

Basically inorganics are compounds not having a carbon basis, including metals in the elemental form and their salts. Typical inorganic contaminants are based on the following elements: alumina, cobalt, selenium, aluminum, copper, silver, antimony, iron, sodium, arsenic, lead, thallium, barium, magnesium, tin, beryllium, manganese, titanium, bismuth, mercury, vanadium, boron, zinc, cadmium, molybdenum, zirconium, calcium, nickel, chromium, potassium.

1.5 GLOSSARY

Acid-volatile sulfide (AVS): Reactive solid-phase sulfide fraction that can be extracted by cold hydrochloric acid; appears to control the bioavailability of most divalent metal ions because of the sulfide ions' high affinity for divalent metals, resulting in the formation of insoluble metal sulfides in anaerobic (anoxic) sediments.

Acute toxicity: Immediate or short-term response of an organism to a chemical substance; refers to generalized toxic response with lethality usually being the observed endpoint.

Aerobic: Life or processes that require, or are not destroyed by, the presence of oxygen.

Amphoteric: Having both acidic and basic characteristics.

Anaerobic: Life or processes that require, or are not destroyed by, the absence of oxygen.

Anionic: Having negatively charged surface-active ion.

Apparent Effects Thresholds (AETs): Sediment chemistry screening values based on a biological effects correlation approach. The AET is the highest concentration at which statistically significant differences in observed adverse biological effects from reference conditions do not occur, provided that the concentration also is associated with observance of a statistically significant difference in adverse biological effects. AET is based on empirical data from Puget Sound. EPA defined the AET-low as the lowest AET among applicable biological indicators, and the AET-high as the highest AET among applicable biological indicators.

Aromatic: Pertaining to or characterized by the presence of at least one benzene ring.

Autotrophic organism: An organism capable of synthesizing organic nutrients from inorganic substances.

Benthic abundance: The quantity or relative degree of plentifulness of organisms living in or on the bottom of streams, rivers, or oceans.

Benthic organisms: Species living in or on the bottom of streams, rivers, or oceans.

Bioaccumulation Factor: The ratio of the steady-state toxicant concentration in an organism, generally given on a wet weight basis, accumulated through multiple routes to the toxicant concentration in source compartment. For sediment contamination, sediment concentration on a dry weight basis is often used for the source compartment.

Bioaccumulation: The accumulation of contaminant by organisms from all routes of exposure.

Bioavailability: The fraction of chemical present that is available for uptake by aquatic organisms.

Biodegradable: The ability to break down or decompose rapidly under natural conditions and processes.

Biological community: An assemblage of organisms that are associated in a common environment and interact with each other in a self-sustaining and self-regulating relationship.

Biological effects empirical approach: A method for relating the incidence of adverse biological effects to the dry-weight sediment concentration of a specific chemical at a particular site based on the evaluation of paired field and laboratory data. Exceedance of the identified level of concern concentration is associated with a likelihood of adverse organism response, but does not demonstrate that a particular chemical is responsible.

Bioremediation: The manipulation of living systems to bring about desired chemical and physical changes in a confined and regulated environment.

Biota-Sediment Accumulation Factor: The ratio of the steady state organism toxicant concentration normalized to organism lipid content divided by the sediment toxicant concentration normalized to the amount of organic carbon.

BOD (Biochemical Oxygen Demand): The amount of dissolved oxygen in water consumed in five days by biological processes breaking down organic matter.

Cationic: Having one or more positively charged surface-active ions.

Chelating agent: Organic compound in which atoms form more than one coordinate bond with metals in solution.

Chronic toxicity: Response of an organism to repeated, long-term exposure to a chemical substance. Typical observed endpoints include growth and reproduction.

COD (Chemical Oxygen Demand): A measure of the oxygen required to oxidize all compounds in water, both organic and inorganic.

Cometabolism: Alteration of a non-nutrient material requiring the presence of another readily transformable compound.

Contaminated sediment: Sediment that contains chemical substances at concentrations that pose a known or suspected threat to aquatic life, wildlife, or human health.

Decantation: A method for mechanically dewatering a wet solid by pouring off the liquid without disturbing the underlying sediment.

Dehalogenation: Removal of the halogen atom from a substance by chemically replacing it with hydrogen or hydroxide ions in order to detoxify the substances involved.

Denitrification: The anaerobic biological reduction of nitrate nitrogen to nitrogen gas.

Distillation: The act of purifying liquids through boiling, so that the steam condenses to a pure liquid and the pollutants remain in the concentrated residue.

Divalent metals: Metals those are available for reaction in a valence state of two (i.e., carrying a positive electric charge of two units).

Ecosystem: An ecological unit consisting of both the biotic communities and the nonliving (abiotic) environment, which interact to produce a system which can be defined by its functionality and structure.

Effects range-median (ERM) and effects range-low (ERL) values: Sediment quality guidelines based on a biological effects empirical approach. Represent chemical concentration ranges that are rarely (i.e., below the ERL), sometimes (i.e., between ERL and ERM), and usually (i.e., above the ERM) associated with toxicity for marine and estuarine sediments. Ranges are defined by the tenth percentile and fiftieth percentile of the distribution of contaminant concentrations associated with adverse biological effects.

Elutriate phase toxicity test: Toxicity test in which sediments are mixed with test water for a fixed period of time, the test water is then siphoned off, and test organisms are introduced to the test water in the absence of sediments; useful for representing the exposure to chemicals that can occur after sediments have been resuspended into the water column or after they have passed through the water column as part of dredged material disposal operations.

Emulsification: The process of dispersing one liquid in a second immiscible liquid.

Equilibrium concentration: The thermodynamic state when the fugacity between two phases is equal, or when the free energy of the system is zero; the condition when the concentration in one phase is at the same chemical activity as that in the surrounding phases.

Equilibrium partitioning (EqP) approach: Methodology for developing sediment quality guidelines that assumes that an organism receives an equivalent exposure from water only exposure or from any equilibrated phase (e.g., either from pore water via respiration; or from sediment organic carbon, via ingestion; or from a mixture of the routes). Approach results in guideline values expressed in terms of a sediment phase controlling contaminant bioavailability (e.g., organic carbon for nonionic organic compounds or sulfides for metals).

Equilibrium partitioning sediment guidelines (ESGs): Sediment quality guidelines derived using the EqP approach. When used in conjunction with an appropriately protective water only exposure concentration, a resulting guideline represents the sediment contaminant concentration that protects benthic organisms from the effects of that contaminant. ESGs replace the term "sediment quality criteria" for use by the U.S. EPA.

Fluidized bed: Suspension of finely divided solids by a rising current of air or other fluids.

Halogen: Any of a group of five chemically related nonmetallic elements that include bromine, fluorine, chlorine, iodine, and astatine.

Heterotrophic organism: An organism that obtains nourishment from the breakdown of organic matter.

Hydraulic conductivity: A measure of the rate at which water flows through a unit cross section under unit hydraulic gradient; also known as permeability coefficient.

Hydrophilic: Having an affinity for, or attraction to water.

Incineration: Treatment technology involving destruction of waste by controlled burning at high temperatures.

Inorganic compound: Chemical compounds that do not contain carbon as the principal element (except carbonates, cyanides, and cyanates).

Interstitial water: Water in an opening or space, as between rock, soil, or sediment (i.e., pore water).

Leachate: A liquid that results from water collecting contaminants as it trickles through wastes, agricultural pesticides or fertilizers.

Leaching: The process by which soluble constituents are dissolved and carried down through the soil by a percolating fluid.

Microbial toxicity test: Type of toxicity test in which members of the microbial community (i.e., bacteria) are used as the test organism. Microbial responses in toxicity tests have been recommended as early warning indicators of ecosystem stress. However, questions have been raised concerning the sensitivity of sediment microbial toxicity testing.

Microflora: Microscopic plants.

Molar concentration: The ratio of the number of moles (chemical unit referring to the amount of an element having a mass in grams numerically equal to its atomic weight) of solute (the substance being dissolved or that present in the smaller proportion) in a solution divided by the volume of the solution expressed in liters.

Nonionic organic chemicals: Compounds that do not form ionic bonds (bonds in which the electrical charge between bonded atoms in the compound is unequally shared). Nonionic compounds do not break into ions when dissolved in water and therefore are more likely to remain in contact with and interact with sediment compounds or other compounds in water.

Non-ionic: Having no charge on its surface-active ion.

Nonpolar organic chemicals: Compounds that do not exhibit a strong dipole moment (there is little difference between the electrostatic forces holding the chemical together). Nonpolar compounds tend to be less soluble in water. In aquatic systems, nonpolar chemicals are more likely to be associated with sediments or other nonpolar compounds than with the surrounding water.

Organic compound: Chemical compounds containing carbon as their principal element.

Osmosis (osmotic): The tendency of a fluid to pass through a permeable membrane (such as the wall of a living cell) into a less concentrated solution so as to equalize the concentrations on both sides of the membrane.

Oxidation: 1. The addition of oxygen which breaks down organic waste or chemicals such as cyanides, phenols, and organic sulfur compounds in sewage by bacterial and chemical means. 2. The chemical process whereby electrons are removed from a molecule.

Packed tower: A pollution control device that forces dirty air through a tower packed with crushed rock or wood chips while liquid is sprayed over the packing material. The pollutants in the air stream either dissolve or chemically react with the liquid.

pH: A measure of the acidity or alkalinity of a liquid or solid material.

Polychlorinated Biphenyls (PCBs): A group of toxic, persistent chemicals used in transformers and capacitors for insulation purposes and in gas pipeline systems as lubricants. Its manufacture was stopped in 1976 in the U.S.

Pore water: See Interstitial water.

Probable effects levels (PELS) and threshold effects levels (TELS): Sediment quality guidelines based on a biological effects empirical approach similar to ERMs/ERLs. A generalized approach used to develop effects-based guidelines for the state of Florida and others. The lower of the two guidelines for each chemical (i.e., the TEL) is assumed to represent the concentration below which toxic effects rarely occur. In the range of concentrations between the two guidelines, effects occasionally occur. Toxic effects usually or frequently occur at concentrations above the upper guideline value (i.e., the PEL). Ranges are defined by specific percentiles of both the distribution of contaminant concentrations associated with adverse biological effects and the "no effects" distribution.

Pyrolysis: Decomposition of a chemical by extreme heat.

Reagent: A substance, chemical, or solution used in the laboratory to detect, to measure or otherwise examine other substances, chemicals or solutions.

Reduction: Chemical reaction in which a molecule gains an electron.

Refractory: A material of high melting point.

Sediment quality advisory levels (SQALs): Equilibrium partitioning-based sediment quality guidelines derived for use in evaluating sediment chemistry data in the National Sediment Inventory. Derived for 35 nonionic organic compounds using the same approach used to develop sediment quality criteria; however, SQALs may be based on a limited set of aquatic toxicity data.

Sediment quality criteria (SQC): Draft sediment quality guidelines using the equilibrium partitioning-based approach published by the U.S. EPA for the protection of aquatic life.

Draft SQCs were developed by EPA for five nonionic organic chemicals: acenaphthalene, dieldrin, endrin, fluoranthene, and phenanthrene. This term has been dropped by the U.S. EPA in favor of "equilibrium partitioning sediment guidelines" (ESGs).

Simultaneously extracted metals (SEM): Metal concentrations that are extracted during the same analysis in which the acid-volatile sulfide (AVS) content of the sediment is determined.

Solid-phase toxicity test: A toxicity test in which test organisms are exposed directly to sediments. Sediments are carefully placed in the exposure chamber and the chamber is then filled with clean water. Resuspended particles are allowed to settle before initiation of exposure. Solid-phase toxicity tests integrate multiple exposure routes, including chemical intake from dermal contact with sediment particles as well as ingestion of sediment particles, interstitial water, and food organisms.

Steady-state concentration: Condition where a given system is in balance. The concentration in a particular phase is constant and is maintained through equal input and output from that phase.

Substrate: The material or substance on which the enzyme reacts.

Surfactant: A soluble compound that reduces the surface tension of liquids, or reduces interfacial tension between liquids or a liquid and a solid.

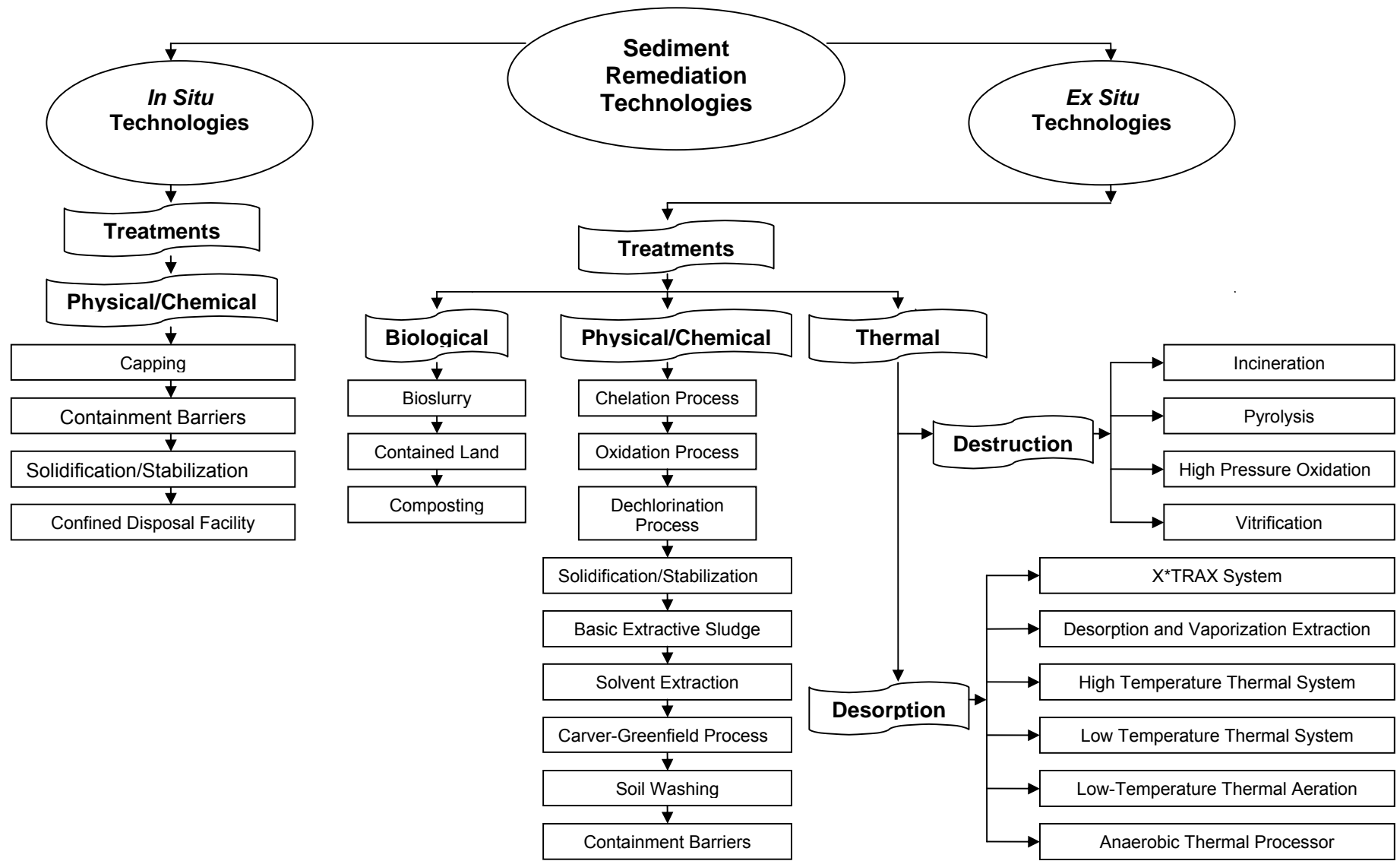
Theoretical bioaccumulation potential (TBP): An estimate of the equilibrium concentration of a contaminant in tissues if the sediment in question were the only source of contamination to the organism. TBP is estimated from the organic carbon content of the sediment, the lipid content of the organism, and the relative affinities of the chemical for sediment organic carbon and animal lipid content (e.g., BSAF).

Total organic carbon (TOC): A measure of the organic carbon content of sediment expressed as a percent; used to normalize the dry-weight sediment concentration of a chemical to the organic carbon content of the sediment.

Vitrification: Thermal treatment in which the chemical and physical characteristics of the waste are transformed such that the treated residues containing hazardous material are immobilized in a glass-like mass.

Volatile Organic Compound (VOC): Any organic compound which participates in atmospheric photochemical reactions except for those designated by the EPA as having negligible photochemical reactivity.

Volatile: Description of any substance that evaporates readily.



2. *IN SITU* PHYSICAL/CHEMICAL TREATMENTS

2.1. CAPPING

Description of the method

In situ Capping refers to the operation of covering or caps the contaminated sediment to maintain it chemically and biologically isolated in place from the aquatic environment. In general, the capping material may be designed with different layers such as granular material (clean sediment, sand or gravel) or also with permeable and impermeable materials. The suitability of *in situ* capping to a contaminated sediment site is less affected by the type or level of contaminants present, because it physically isolates the sediments and their associated contaminants. The determination of the minimum required cap thickness is dependent on the physical and chemical properties of the contaminated sediments, the potential for bioturbation of the cap by aquatic organisms, the potential for consolidation and erosion of the cap material, and the type(s) of cap materials used.

In general, sandy sediments are suitable for use as a cap at sites with relatively low erosive energy, while armoring materials may be required at sites with high erosive energy. A variety of information about the project site and sediments is needed to prepare an *in situ* capping design, especially considering bioturbation baths. Conventional minimum required caps thickness for chemical isolation from the overlaying water column may be highly variable, from the order of 10 cm to minimum cap thicknesses of 50-60 cm. A variation of *in situ* capping would involve the removal of contaminated sediments to some depth, followed by capping the remaining sediments in place.

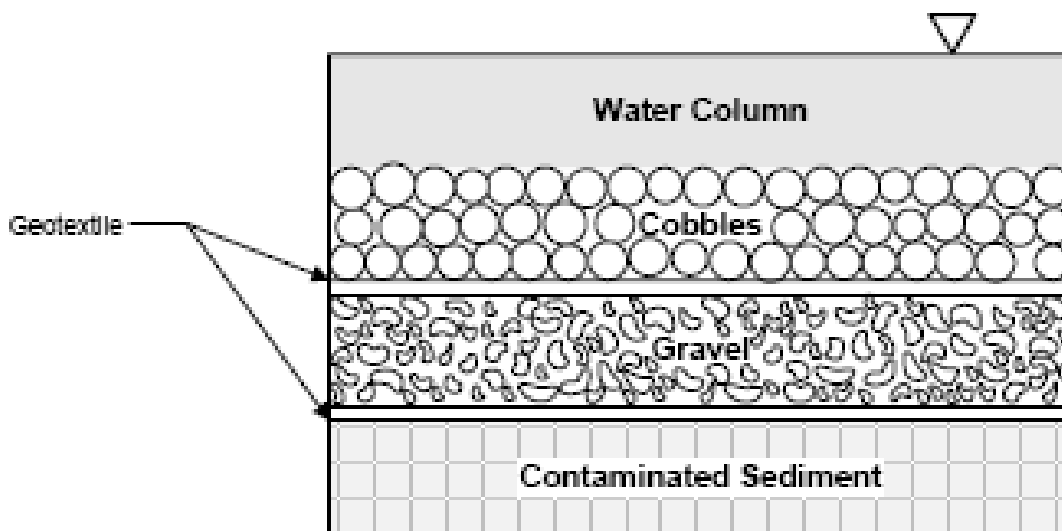


Figure 1: Generalized Capping System Design*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
	Dioxins & Furanes		●
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	+	
Radionuclides		●	
Other Inorganics		●	
Sediment Type	a. Silty	+	
	b. Sandy	●	
	c. Gravel	-	
Depth of Contamination	a. Shallow	-	
	b. Medium	●	
	c. Deep	+	
2. Site-specific Applicability			
Site Accessibility		-	
Contaminant Concentration Levels		●	
Water Type		+	
Water Mobility		-	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		+	

+ High ● Medium - Low *Not Defined

Applicability

Capping is a viable alternative for disposal of contaminated sediments that have been dredged and placed in another aquatic location. *In situ* capping has been applied in riverine, nearshore and estuarine settings and must not be exposed to high erosive forces, such as currents, waves, or navigation propeller wash, or to upwelling from groundwater.

Capital costs for *in situ* capping include the complexity of the cap design, accessibility of the capping site, water depth, capping materials, construction equipment, and labor. This technology is best used to contain volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), pesticides, and metals.

Advantages

- ❖ Can reduce exposure of aquatic environment to contaminants in a short time
- ❖ Requires less infrastructure of material handling
- ❖ May be an effective technique for long-term containment of contaminants
- ❖ Dispersion and volatilization of contaminants are minimal

Limitations

- ❖ Contaminated material remains in the aquatic environment
- ❖ Intensive monitoring is necessary at capping sites during and immediately after construction, followed by long-term monitoring at less frequent intervals
- ❖ Pipeline and barge placement of dredged material for *in situ* capping projects is appropriate in more open areas such as harbors or wide rivers
- ❖ The use of cap materials different from native self bottom materials may alter the biological community
- ❖ Strong currents can displace capping materials
- ❖ Future uses of the waterway may be limited if a river with contaminated sediment deposits is already shallow, in order to avoid cap from disturbances

Development status

The technology has only been applied at a small scale at a limited number of sites. As a result, guidance on their feasibility, design, and implementation is very limited.

References

- <http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/EPA-905-B94-003.html>
- <http://www.em.doe.gov/define/techs/remdes2.html#372>
- [*http://www.epa.gov/superfund/resources/sediment/pdfs/guidance.pdf](http://www.epa.gov/superfund/resources/sediment/pdfs/guidance.pdf)

2.2 CONTAINMENT BARRIERS

Description of the method

In situ containment remediation technology involves the complete isolation of a portion of the waterway by physical barriers in order to render the impact of contamination environmentally negligible. It includes sheetpile, cofferdams, and stone or earthen dikes. In some cases, the isolated area can be used for the disposal of other contaminated sediments, treatment residues, or other fill material, but it may also be modified to prevent contaminant migration (e.g., slurry walls, cap and cover). Landfill, Confined Disposal Facilities (CDFs) and Contained Aquatic Disposal (CAD) represent some containment techniques for the permanent disposal of dredged sediments. CDFs are diked upland or nearshore areas covered with a low-permeability cap. These facilities are constructed for storage and rehandling contaminated sediment, not only before treatment, but also for a final disposal. CAD refers to a submerged capped disposal system with lateral confinement. Contaminated sediments are placed within natural or excavated pit.

In general, *in situ* containment technique requires structural measures and environmental controls to isolate the containment area from the adjacent waterway and prevent unacceptable contaminant migration. The actions involve multiple treatment steps such as placement of impermeable cover, constructions of a blanket composed of graded material and construction of a curtain to prevent groundwater infiltration. It may also be possible to completely reroute waterways with contaminated sediments. The waterway can then be dewatered, and the sediments removed, treated in place, or confined in place. This is an extreme measure and is only likely to be feasible for small waterways with limited flows.

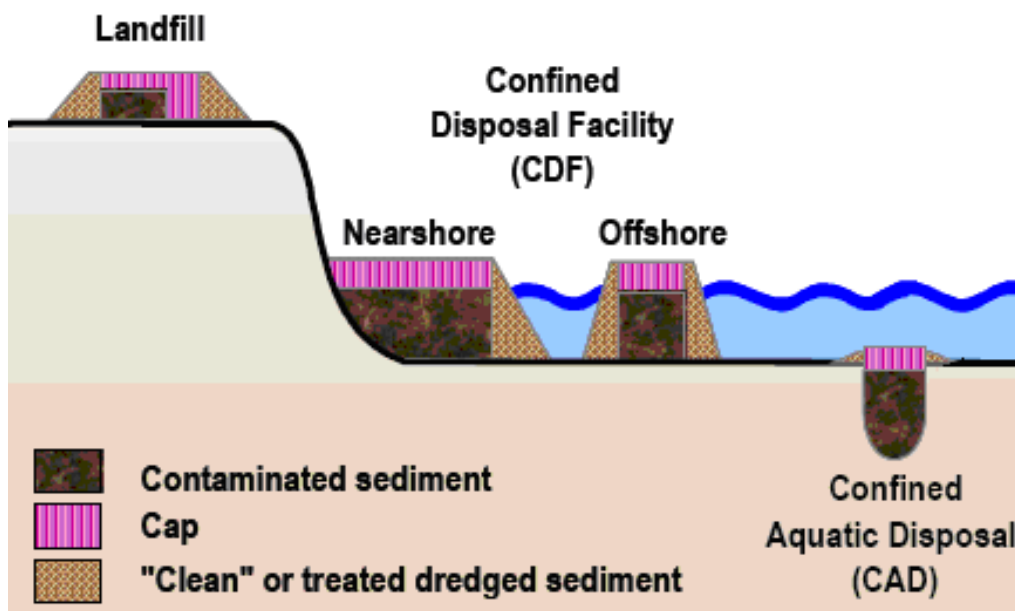


Figure 2: Generalized Containment Systems*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	●
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	+	
	b. Sandy	●	
	c. Gravel	-	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		-	
Contaminant Concentration Levels		+	
Water Type		-	
Water Mobility		-	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		+	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		+	

+ High ● Medium - Low *Not Defined

Applicability

The technical feasibility of using *in situ* containment is determined primarily by the physical conditions of the site. Areas that may be suitable for *in situ* containment include backwater areas, slips, turning basins, and some wide areas of rivers. Areas within active navigation channels are generally not suitable. The primary factors limiting the feasibility of *in situ* containment are the potential impacts of the new fill on flow patterns, flooding, navigation, and habitat.

Advantages

- ❖ Engineered landfills reduce the potential for contaminant migration and can be cost-effective.
- ❖ Proximity to the site limits transportation costs of CDFs
- ❖ CDFs also can provide beneficial future use as wetlands or brownfields
- ❖ CDFs permits treatment of sediments within storage cells
- ❖ Capping of storage systems minimize future releases of contaminants.

Limitations

- ❖ Containment system do not destroy contaminants
- ❖ Potential for contaminant leaching into the aquatic environment
- ❖ Operation, monitoring and routine maintenance costs may not be cost-effective
- ❖ Long-term monitoring is required
- ❖ Sediments my require pre-treatment before disposal

Development status

Containment is considered a commercial technology.

References

- http://www.geosynthetica.net/tech_docs/NAGS_GRI19/HarneyHoltz.pdf
- [**https://portal.navfac.navy.mil/pls/portal/docs/PAGE/NAVFAC/NAVFAC_WW_PP/NAVFAC_NFESC_PP/ENVIRONMENTAL/ERB/DOCUMENTS-R/TDS-2092-SED.PDF](https://portal.navfac.navy.mil/pls/portal/docs/PAGE/NAVFAC/NAVFAC_WW_PP/NAVFAC_NFESC_PP/ENVIRONMENTAL/ERB/DOCUMENTS-R/TDS-2092-SED.PDF)

2.3 SOLIDIFICATION/STABILIZATION

Description of the method

Chemical stabilization treatments mix the contaminants with reactive reagents to solidify or fix them into a chemically unavailable form. These processes produce blocks of waste with high structural integrity to make contaminants resistant to aqueous leaching, reducing contaminant mobility, in order to permit them to be left in place or disposed safely. Some of these techniques include cement-based solidification, silicate-based solidification and microencapsulation. Reagents for the solidification process can be injected into the sediment in a liquid or slurry form. Porous tubes are sometimes used to distribute the reagents to the required depth. Available commercial equipment includes a hollow drill with an injection point at the bottom of the shaft. The drill is advanced into the sediment to the desired depth.

The chemical additive is then injected at low pressure to prevent excessive spreading and is blended with the sediment as the drill rotates. The treated sediment forms a solid vertical column. These solidified columns are overlapped by subsequent borings to ensure sufficient coverage of the area (USEPA 1990e).

In many commercially available processes, proprietary reagents are added during the basic solidification process to improve the effectiveness of the overall process or to target specific contaminants. The effectiveness of an immobilization process for a particular sediment is difficult to predict, and can only be evaluated using laboratory leaching tests. *In situ* solidification may be limited by difficulties to control the mixing process and the temperature *in situ*.

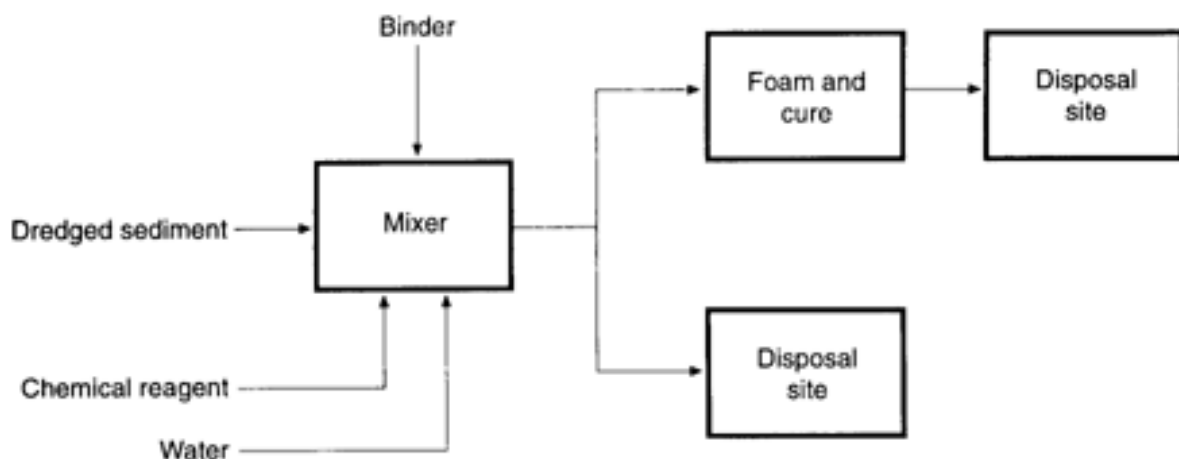


Figure 3: Diagram of a Solidification/Stabilization Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	-
		b. BTEX	-
		c. Oxygenated Hydrocarbons	-
		d. Other Compounds	-
	X-VOCs	a. Chlorinated Hydrocarbons	-
		b. Other Halogenated Compounds	-
	SVOCs	a. Heavy Hydrocarbons	-
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	-
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	-
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	-
Dioxins & Furanes		-	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	+	
Radionuclides		+	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	+	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		●	
Water Mobility		●	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		●	
Residuals Produced		●	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		+	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

While it is one of the few techniques available to treat metals in situ, it is generally not used to treat organics due to their tendency to be more unstable and capable of degradation.

Advantages

- ❖ Anions may also be immobilized by entrapment or microencapsulation.

Limitations

- ❖ This technology does not change the toxicity of contaminants in the sediment
- ❖ Erosion and diffusion may eventually release contaminants
- ❖ May not be particularly effective for organic contaminants, particularly VOCs
- ❖ Fine particles may bind to larger particles preventing effective bonding of the binder material
- ❖ Inorganic salts may affect curing rates and reduce strength of stabilized product
- ❖ Organic contaminants may volatilize due to heat generated during the reaction (possibly prompting the need for air emission permits)
- ❖ High moisture content requires increased amounts of reagent
- ❖ Long-term monitoring requirement

Development status

Solidification/Stabilization is a full scale commercial technology.

References

- <http://www.mass.gov/czm/section45.pdf>
- <http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-3.gif>

2.4 CONTAINED DISPOSAL FACILITY

Description of the method

A confined disposal facility is defined as a confined area with confinement walls, used to keep dredged material in-water or upland from being released to the environment. The contaminated sediment may be covered with a suitable material, commonly referred to as a cap, generally using dredged silt or sand. This technique provides long-term to permanent storage and is favorable to be applied for bioremediation of sediments.

However, the depth of sediments may limit the capability to control conditions compared to other bioremediation systems. These limitations are similar to those for *in situ* bioremediation processes for contaminated soil sites. Bioremediation applied with this technique may offer an economical process for reducing sediment organic contamination, but more research is needed to develop techniques for implementation.

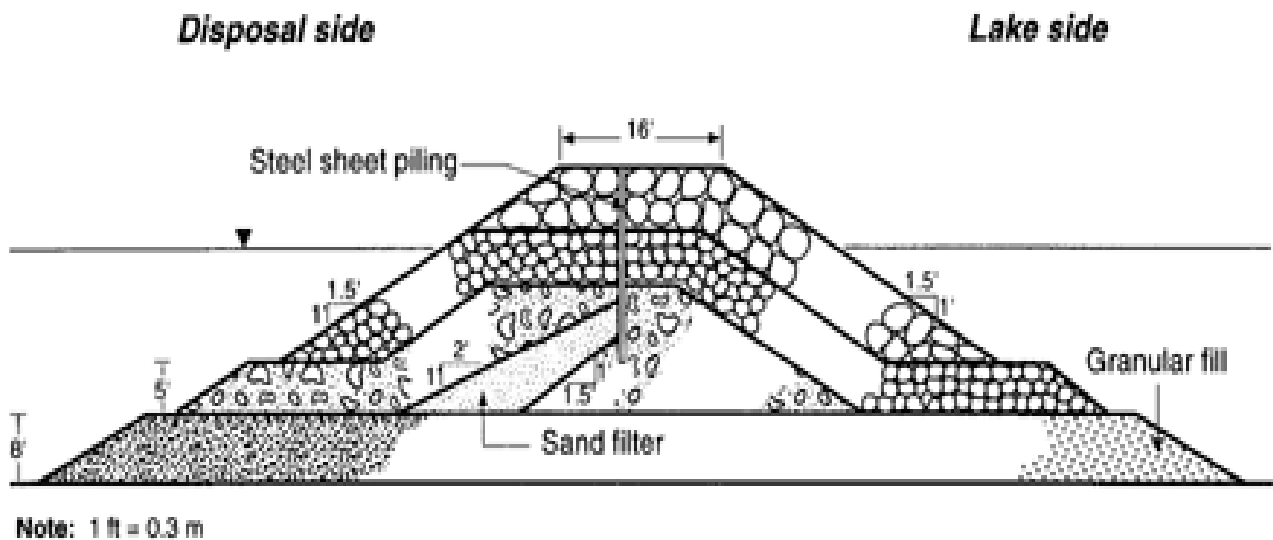


Figure 4: Diagram of a Contained Disposal Facility*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	-
	Dioxins & Furanes		●
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	+	
	b. Sandy	●	
	c. Gravel	-	
Depth of Contamination	a. Shallow	+	
	b. Medium	●	
	c. Deep	-	
2. Site-specific Applicability			
Site Accessibility		-	
Contaminant Concentration Levels		+	
Water Type		-	
Water Mobility		-	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		-	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		+	

+ High ● Medium - Low *Not Defined

Applicability

CDFs have been routinely used for dredged materials, but may be used as contained treatment facilities for bioremediation of organic compounds on sediments.

Advantages

- ❖ May offer lowest cost under favorable conditions
- ❖ A large volume of sediment may be treated
- ❖ Favors anaerobic processes
- ❖ Materials handling of sediment and rehandling of treatment material is easy

Limitations

- ❖ Applicable to coarse sediments, with high permeability
- ❖ Extensive treatability studies
- ❖ May be necessary to control leaching activities
- ❖ Not easy to monitor cleanup efficiency
- ❖ Large space required
- ❖ Requires months of remediation time
- ❖ May generate odors
- ❖ Collection of off-gas is difficult

Development status

The CDFs represent a technology for sediments on undergoing development stage.

References

- [*http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/gifs/fig9-2.gif](http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/gifs/fig9-2.gif)
- <http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch7.html#RTFToC132>

3. *EX SITU* BIOLOGICAL TREATMENTS

3.1 BIOSLURRY

Description of the method

Bioslurry is a biological technology that uses a bioreactor to treat fine-grained sediments. In a bioslurry system, sediment-water slurry is maintained in suspension and continuously mixed with appropriate microorganisms under controlled conditions in an open or closed reactor. Aerobic treatment, which involves adding air or another oxygen source, is the most common mode of operation. However, conditions suitable for anaerobic microorganisms can also be maintained in the reactor where this state is an essential step in the biodegradation process. Bioslurry also permits sequential anaerobic/aerobic treatments and combined treatment with soil washing, by coupling two separate slurry-phase reactors in series and using weak acids and chelating agents.

Contaminants with potential for volatilization during the mixing and/or aeration process can be controlled using emission control equipment. Systems for treating soils or sediments are often operated in batch mode, because typical retention times are on the order of 2-12 weeks. Once the treatment period is completed, the solids may be separated from the water and disposed of separately. This technique may also be combined with soil washing, using weak acids and chelating agents.

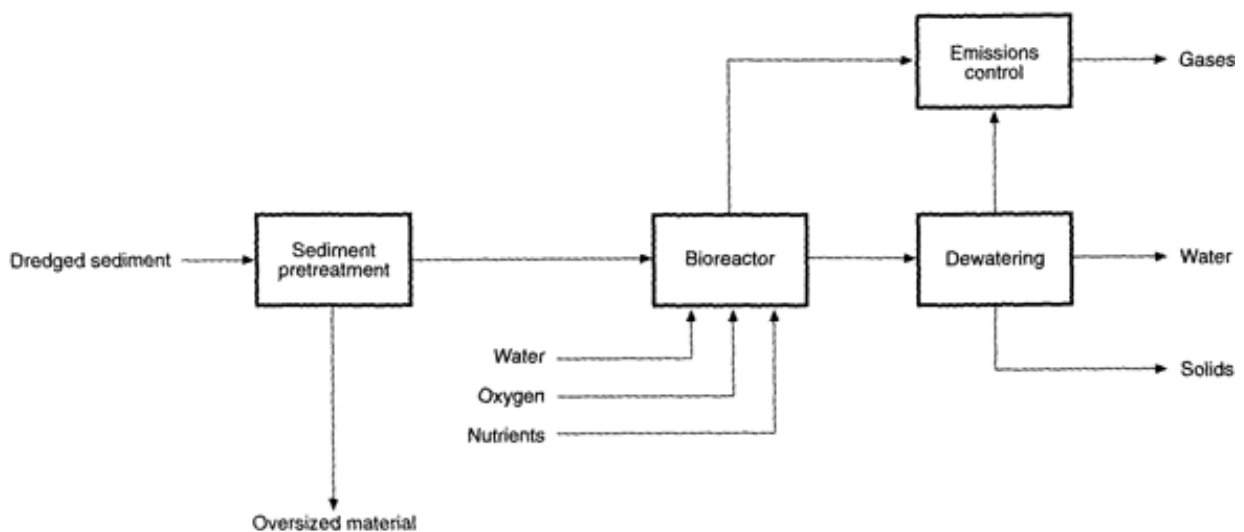


Figure 5: Generalized Aerobic Bioslurry System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	*	
	b. Sandy	*	
	c. Gravel	*	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		+	
Contaminant Concentration Levels		-	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		●	
Safety		+	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		●	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

Bioslurry has been applied to contaminated sediments to treat a wide range of contaminants such as pesticides, fuels, creosote, PCBs and some halogenated volatile organics. On the other hand, the presence of heavy metals may inhibit metabolism of microorganisms. Slurry-phase bioreactors are used to treat halogenated and nonhalogenated VOCs and SVOCs, pesticides and PCBs in excavated soils and dredged sediments.

Advantages

- ❖ Effective for treating metals and organics
- ❖ Treatment residuals include processed soils
- ❖ Sidestream wastes include wastewater from dewatering the treated slurry and off-gas from the treatment vessel

Limitations

- ❖ Toxicity of heavy metals and chlorines at high concentrations can inhibit microbial degradation
- ❖ Treatment and disposal of wastewater may be required
- ❖ Dewatering is required after treatment
- ❖ Equipment operation and maintenance is intensive
- ❖ Higher energy costs than solid-phase bioremediation
- ❖ Organic destruction efficiencies are generally low at low concentrations
- ❖ Low cleanup standards may be difficult to meet for recalcitrant organics

Development status

Bioslurry is a relatively new technology, with a number of pilot-scale applications, but few full-scale installations.

References

- <http://www.mass.gov/czm/section45.pdf>
- [*http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-6.gif](http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-6.gif)

3.2 CONTAINED LAND

Description of the method

Contained land treatment systems require mixing of appropriate amendments with the sediments, followed by placement of the material in an enclosure such as a building or tank and on a pad or prepared surface (USEPA 1991d). A schematic diagram of a contained land treatment system is shown in the figure bellow. Leachate from the sediment is collected by underdrains for further treatment as necessary. The excess water associated with the sediment as it is placed in the treatment bed may create operational problems for startup and will likely require that the system be designed for lateral confinement of the material.

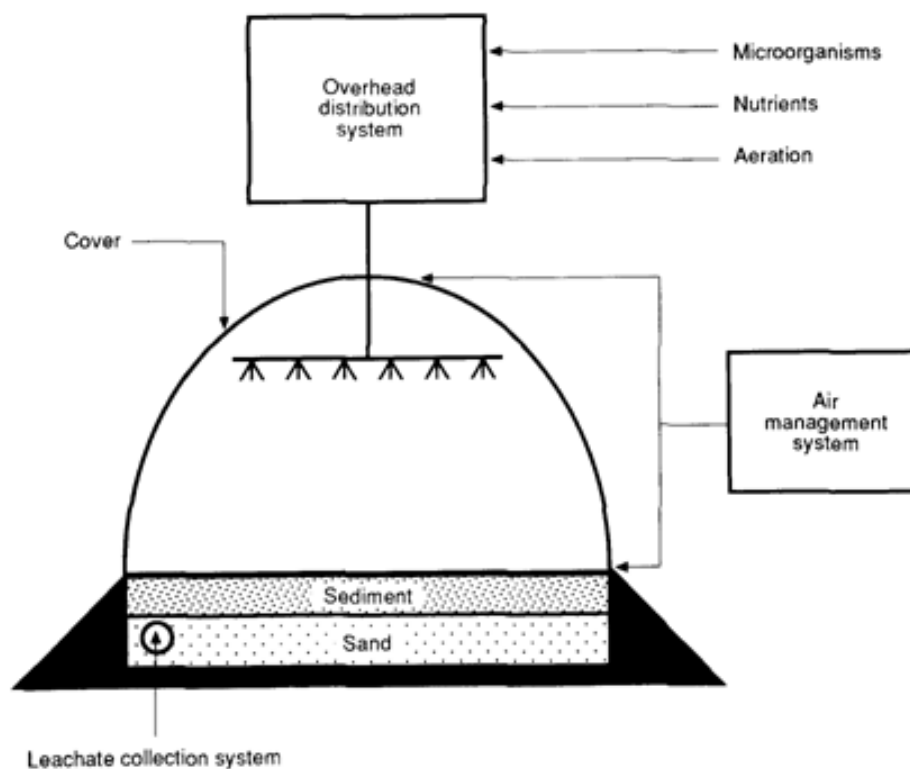


Figure 6: Diagram of a Generalized Contained Land System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	*	
	b. Sandy	*	
	c. Gravel	*	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		+	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		●	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

Contained land process has been applied on sediments to transform some organic compounds, such as petroleum hydrocarbons, VOCs, SVOCs and pesticides, to less toxic or nontoxic forms.

Advantages

- ❖ Permits the recovery of the dredged sediments, after settlement and dewatering, for re-use
- ❖ Prevents material from precipitation and moderates temperature changes
- ❖ Permits moisture control
- ❖ Permits to control volatile organic compound emissions.

Limitations

- ❖ The layer of sediment treated for each lift is generally no deeper than 6-8 in. (15-20 cm)
- ❖ Regular cultivation of the sediments and the addition of nutrients are typically required to optimize environmental conditions for rapid bioremediation.

Development status

The Contained Land Treatment System is at the field demonstration stage.

References

- [*http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-7.gif](http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-7.gif)
- <http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch7.html#RTFToC132>

3.3 COMPOSTING

Description of the method

Composting is a biological treatment process used to degrade contaminated solid materials to innocuous compounds such as carbon dioxide and water. Bulking agents (e.g., wood chips, bark, sawdust, straw) are added to the solid material to absorb moisture, increase porosity, and provide a source of degradable carbon. Water, oxygen, and nutrients are needed to facilitate bacterial growth. Sediment solids contents will likely be sufficient for composting operations and in some cases dewatering of the sediment may be necessary as a pretreatment step. Available composting techniques include aerated static pile, windrowing, and closed reactor designs (USEPA 1991d). Volatilization of contaminants may be a concern during composting and may require controls such as enclosures or pulling air through the compost pile rather than pushing air into and out of the pile. Use of composting to treat sediments may also increase permeability of the sediment, allowing for more effective transfer of oxygen or nutrients to the microorganisms.

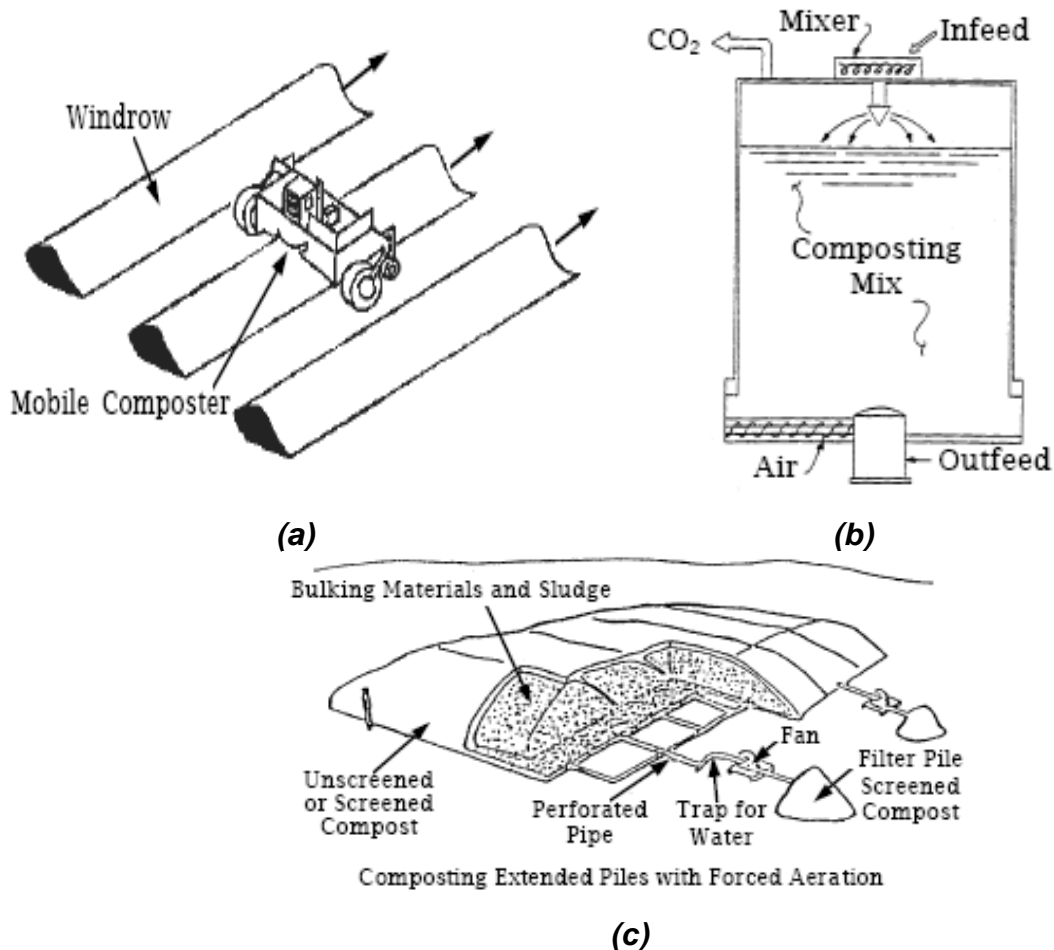


Figure 7: Generalized Composting Operation*: (a) Windrow, (b) Closed reactor and (c) Aerated Static Pile*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	●
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		●	
Sediment Type	a. Silty	*	
	b. Sandy	*	
	c. Gravel	*	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		●	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		+	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		-	
Overall Cost		+	

+ High ● Medium - Low *Not Defined

Applicability

The composting process may be applied to soils and lagoon sediments contaminated with biodegradable organic compounds. Pilot and full-scale projects have demonstrated that aerobic, thermophilic composting is able to reduce the concentration of explosives (TNT, RDX, and HMX), ammonium picrate (or yellow-D), and associated toxicity to acceptable levels. Aerobic, thermophilic composting is also applicable to PAH-contaminated soil. All materials and equipment used for composting are commercially available.

Advantages

- ❖ Is a demonstrated, efficient technology to treat explosives
- ❖ It is a commercially available, technically attractive technology
- ❖ Relatively low cost and low technology
- ❖ Adds organic bulk and humus to regenerate poor soils
- ❖ Less costly alternative to conventional bioremediation techniques

Limitations

- ❖ Slow process
- ❖ Large land area required
- ❖ Substantial space and labor costs are required for composting
- ❖ Excavation of contaminated soils is required and may cause the uncontrolled release of VOCs and dust
- ❖ Low effectiveness for PAHs
- ❖ If VOC contaminants are present in soils, off-gas control may be required
- ❖ Results in an increase in material because of the addition of amendment material
- ❖ Although levels of metals may be reduced via dilution, heavy metals are not treated by this method

Development status

The composting treatment is considered a commercial technology, although its use for sediments is on undergoing development stage.

References

- www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/c-12.pdf
- [*http://waterresourcescience.com/Documents/esm223_11_Reading_Bioremediation_implementation_seminar.pdf](http://waterresourcescience.com/Documents/esm223_11_Reading_Bioremediation_implementation_seminar.pdf)
- <http://www.mass.gov/czm/section45.pdf>
- The Composting Alternative to Incineration of Explosives Contaminated Soils
www.clu-in.org/products/newsletters/TTREND/ttcmpost.htm

4. *EX SITU* PHYSICAL/CHEMICAL TREATMENTS

4.1 CHELATION

Description of the method

Chelation is the process of stable complex formation (a chelate) between a metal cation and a ligand (chelating agent). Complexes with multidentate ligands are usually more stable than those with monodentate ligands. Those chelators with many coordinating sites can penetrate into soil matrix to hold metals and form stable complexes. The best known chelating agents are synthetic amino acid EDTA (Ethylene Diamine Tetracetic Acid), Diethylenetrinitrilopentaacetic Acid (DTPA), Nitrilotris(methylene)triphosphonic Acid (NTTA), Thiobis(ethylenenitrilo) tetraacetic acid (TEDTA), N-2-acetamidoimino-diacetic acid (ADA), 2-Aminoethanethiol Iminodiacetic acid (IDA), Nitrilotriacetic acid (NTA) and Ethylenediiminodiacetic acid (EDDA).

This process could also be considered an immobilization process, and some extraction processes also use chelating agents. Binding of the metal cation in a stable complex renders it unavailable for further reaction with other reagents in chemical or biological systems. The complex formed by a chelating agent and a metal ion is known as a chelate. Chelating agents may be either organic or inorganic compounds, but the number of inorganic agents is very small. The stability of a complex generally increases as the number of bonds increases between the ligand and the metal cation (Snoeyink and Jenkins 1980). A ligand forming a single bond is known as monodentate, a ligand forming two bonds is known as bidentate, while a ligand forming more than two bonds is known as polydentate. Ethylenediaminetetraacetic acid (EDTA) is a well-known example of a polydentate ligand (Brady and Humiston 1986). pH is one of the most important parameters that affects the treatment process. Efficiency varies with the chelating agent and dosage used (Averett et al., in prep.).

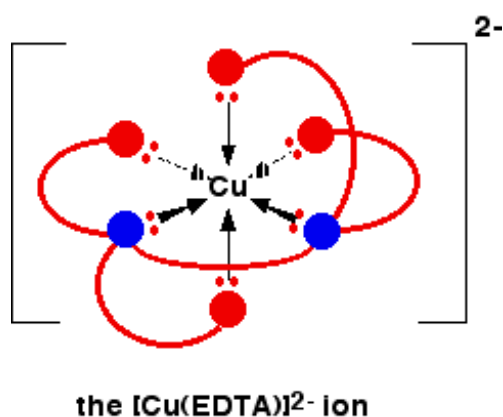


Figure 8: Typical Chelation Operation*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	-
		b. BTEX	-
		c. Oxygenated Hydrocarbons	-
		d. Other Compounds	-
	X-VOCs	a. Chlorinated Hydrocarbons	-
		b. Other Halogenated Compounds	-
	SVOCs	a. Heavy Hydrocarbons	-
		b. Non-Halogenated Pesticides	-
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	-
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	-
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	-
		b. Halogenated Pesticides	-
c. Other Halogenated Compounds		-	
Dioxins & Furanes		-	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	+	
Radionuclides		●	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		+	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		+	
Residuals Produced		+	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		+	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

Targeted contaminants for chelation processes are metals in soils and dewatered sediments. Chelating extraction is a potential technology of remediation for heavy metals-contaminated soils.

Advantages

- ❖ Relatively moderate cost
- ❖ The chelation process for metal immobilization may reduce the leachable metal concentrations adequately to meet the Toxicity Characteristic Leaching Procedure (TCLP) requirements
- ❖ Treated sediments are the only residuals generated by the chelation treatment process

Limitations

- ❖ Not effective for organics

Development status

The process is available at the full-scale commercial level.

References

- <http://www.mass.gov/czm/section45.pdf>
- [*http://www.uvm.edu/~gdrusche/Classes/GEOL%20195%20-%20Geochemistry/Fall%202005%20Lectures/Lecture17.ppt](http://www.uvm.edu/~gdrusche/Classes/GEOL%20195%20-%20Geochemistry/Fall%202005%20Lectures/Lecture17.ppt)

4.2 OXIDATION

Description of the method

Chemical oxidation involves the use of chemical additives to transform, degrade, or immobilize organic wastes. Oxidizing agents most commonly used (singly or in combination with ultraviolet [UV] light) are ozone, hydrogen peroxide, peroxone (combination of ozone and hydrogen peroxide), potassium permanganate, calcium nitrate, and oxygen. The use of ozone, peroxide, and peroxone has come to be known as advanced oxidation processes. Strictly defined, oxidation is the addition of oxygen to a compound (creation of carbon to oxygen bonds) or the loss of electrons from a compound (increase in the positive valence).

Oxidation is used to transform or break down compounds into less toxic, mobile, or biologically available forms. Theoretically, compounds can be decomposed completely to carbon dioxide and water. Adequate process control of pH, temperature, and contact time is important to prevent the formation of hazardous intermediate compounds, such as trihalomethanes, epoxides, and nitrosamines, from incomplete oxidation.

Oxidation is nonselective, and all chemically oxidizable material (including detritus and other naturally occurring organic material) will compete for the oxidizing agent. It is not applicable to highly halogenated organic compounds (Averett et al., in prep.). Certain contaminants, such as PCBs and dioxins that will not react with ozone alone require the use of UV light with the oxidizing agent. This limits the effectiveness of the process with slurries because the UV light cannot penetrate the mixture.

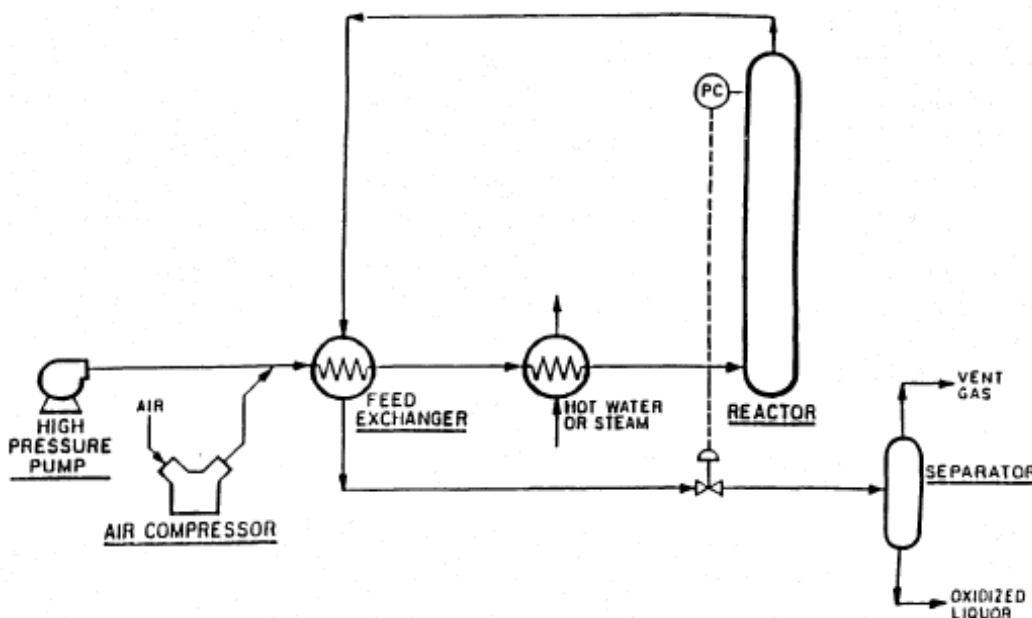


Figure 9: Generalized Oxidation Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	●
		c. Oxygenated Hydrocarbons	●
		d. Other Compounds	●
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	●
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		+	
Sediment Type	a. Silty	●	
	b. Sandy	+	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		●	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

The technology is applicable to halogenated and semi-halogenated organic compounds (PCBs, pesticides, dioxins and furans), hydrocarbons, volatile and semi-volatile organic compounds in soils and dewatered sediments. The effectiveness of oxidation depends on the organic compound. Oxidation is specifically used to treat amines, phenols, chlorophenols, cyanides, halogenated aliphatic compounds, mercaptans, and certain pesticides in liquid waste streams (USEPA 1991b). It can also be used on soil slurries and sludge.

Advantages

- ❖ Effective for most organics and inorganics
- ❖ Combines biological and physical-chemistry techniques
- ❖ Compared to other in-situ technologies, it has shown greater accessibility in low permeability soils such as clays, silts and fine sands

Limitations

- ❖ High clay, low solids and high organic content may increase treatment costs
- ❖ Not applicable for some PAHs
- ❖ Volume of residuals produced may exceed that of contaminations
- ❖ May require post treatment processes or other disposals of residuals

Development status

The technology is full scale commercial.

References

- [*http://www.epa.gov/glnpo/arcs/EPA-905-R94-007/EPA%20905-R94-007.pdf](http://www.epa.gov/glnpo/arcs/EPA-905-R94-007/EPA%20905-R94-007.pdf)
- <http://www.mass.gov/czm/section45.pdf>

4.3 DECHLORINATION

Description of the method

The dechlorination processes involve the destruction or transformation of aromatic organic contaminants by the addition of a chemical reagent under alkaline conditions at increased temperatures. Typically, chemical reagents are mixed with the contaminated sediments and heated to temperatures of 110-340°C for several hours, forming homogeneous slurry from the chemical reaction and releasing steam and volatile organic vapors. The vapors are removed from the processor, collected in a condenser, and further treated using activated carbon. The treated residue is rinsed to remove reactor by-products and reagent and is then dewatered prior to disposal. The resulting products, generally glycol-ethers and water-soluble chloride compounds are much less toxic than the original contaminants. Field-scale demonstrations have used alkali metal polyethylene glycolate (APEG) or base-catalyzed dechlorination (BCD).

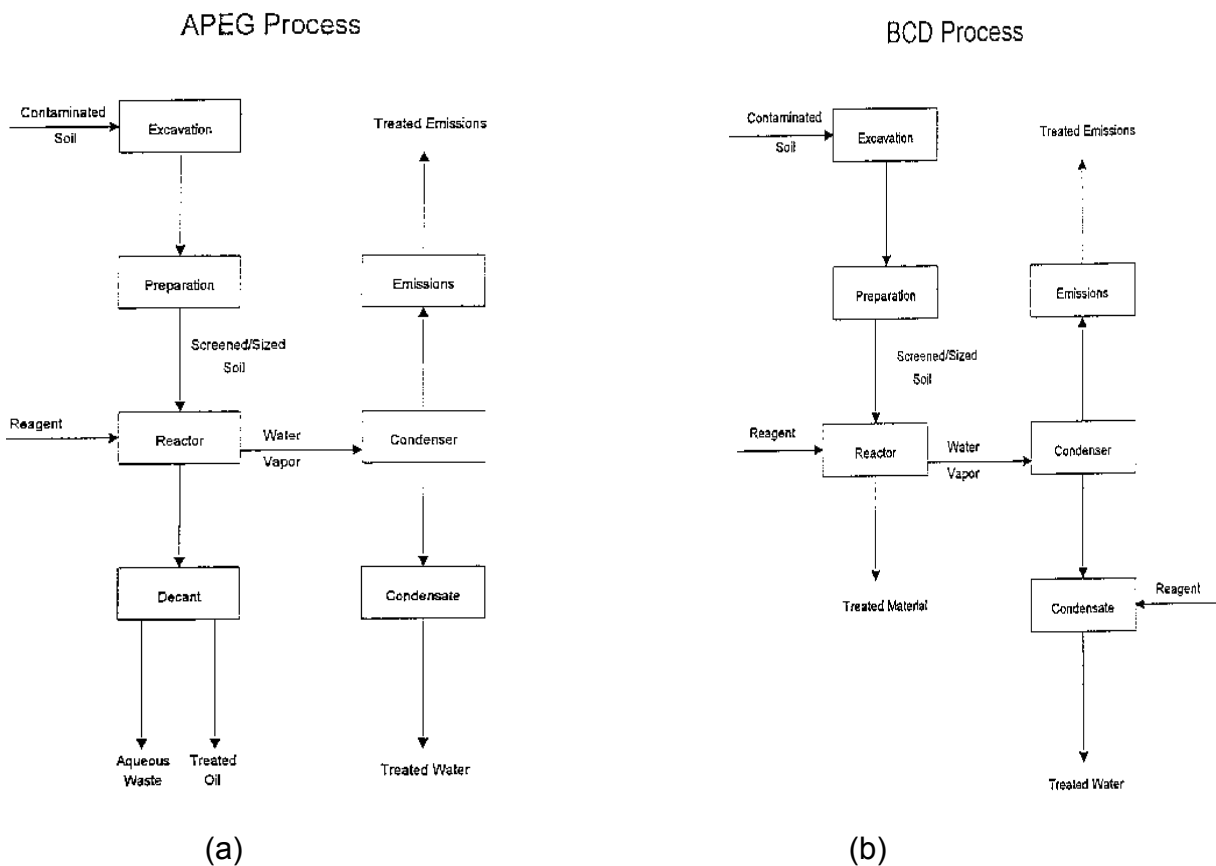


Figure 10: Schematic Dechlorination Technologies*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	-
		b. BTEX	-
		c. Oxygenated Hydrocarbons	-
		d. Other Compounds	-
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	-
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	-
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	-
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		+	
Sediment Type	a. Silty	●	
	b. Sandy	+	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		-	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

The technology is typically applicable to sediments containing PCBs, Dioxins, Furans and some halogenated pesticides.

Advantages

- ❖ High efficiency to reduce PCBs, dioxins and furans to non detectable concentrations.

Limitations

- ❖ Ineffective for metals and PAHs and high concentrated contaminants
- ❖ Sediments with high water content and low pH may limit process
- ❖ Post-treatment wastewater may be required to remove residuals reagents and by-products such as chloride salts, polymers and heavy metals.
- ❖ Incomplete or ineffective dehalogenation can produce intermediate toxic daughters which can be more persistent than the original contaminant.
- ❖ May not be suitable when others contaminants than halogenated compounds are present.
- ❖ Degradation may proceed slowly at ambient temperatures

Development status

The dechlorination processes used to treat PCB-contaminated oils represent a proven and commercial technology. In addition, a few dechlorination processes for treating contaminated soils and sludges have been developed to the stage of "applied technology."

References

- [*http://www.atsdr.cdc.gov/HAC/PCB/b_pcb_c4.html#iidechlorination](http://www.atsdr.cdc.gov/HAC/PCB/b_pcb_c4.html#iidechlorination)
- <http://www.mass.gov/czm/section45.pdf>

4.4 SOLIDIFICATION/STABILIZATION

Description of the method

Chemical stabilization treatments mix the contaminants with reactive reagents to solidify or fix them into a chemically unavailable form. These processes produce blocks of waste with high structural integrity to make contaminants resistant to aqueous leaching, reducing contaminant mobility, in order to permit them to be left in place or disposed safely. Some of these techniques include cement-based solidification, silicate-based solidification and microencapsulation. *Ex situ* solidification/stabilization processes are readily implemented using conventional mixing equipment. Reagents for the solidification process can be injected into the sediment in a liquid or slurry form. Porous tubes are sometimes used to distribute the reagents to the required depth. Available commercial equipment includes a hollow drill with an injection point at the bottom of the shaft. The drill is advanced into the sediment to the desired depth.

The chemical additive is then injected at low pressure to prevent excessive spreading and is blended with the sediment as the drill rotates. The treated sediment forms a solid vertical column. These solidified columns are overlapped by subsequent borings to ensure sufficient coverage of the area (USEPA 1990e).

In many commercially available processes, proprietary reagents are added during the basic solidification process to improve the effectiveness of the overall process or to target specific contaminants. The effectiveness of an immobilization process for a particular sediment is difficult to predict, and can only be evaluated using laboratory leaching tests. *In situ* solidification may be limited by difficulties to control the mixing process and the temperature *in situ*.

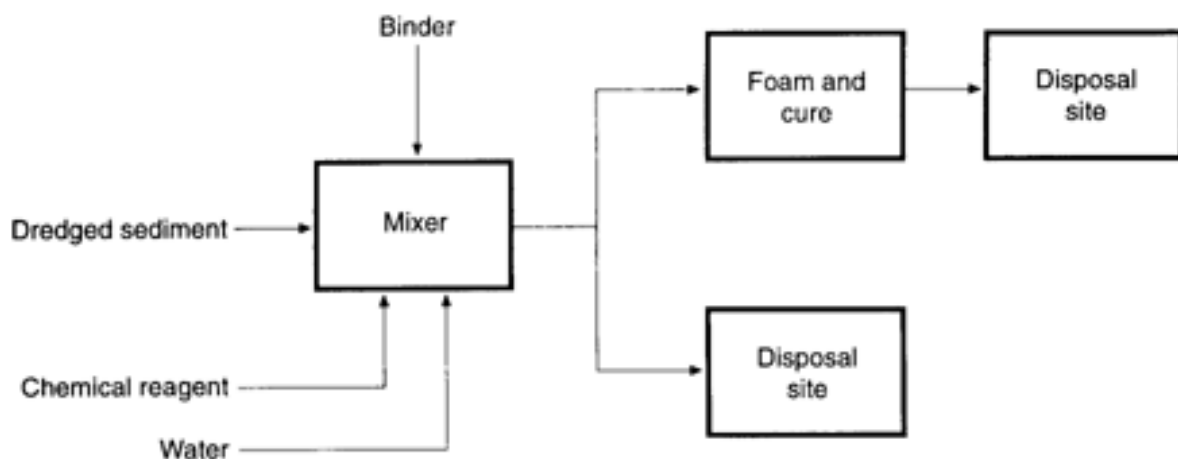


Figure 11: Diagram of a Solidification/Stabilization Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	-
		b. BTEX	-
		c. Oxygenated Hydrocarbons	-
		d. Other Compounds	-
	X-VOCs	a. Chlorinated Hydrocarbons	-
		b. Other Halogenated Compounds	-
	SVOCs	a. Heavy Hydrocarbons	-
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	-
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	-
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	-
Dioxins & Furanes		-	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	+	
Radionuclides		+	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	+	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		●	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		+	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

While it is one of the few techniques available to treat metals in situ, it is generally not used to treat organics due to their tendency to be more unstable and capable of degradation.

Advantages

- ❖ Anions may also be immobilized by entrapment or microencapsulation.

Limitations

- ❖ This technology does not change the toxicity of contaminants in the sediment
- ❖ Erosion and diffusion may eventually release contaminants
- ❖ May not be particularly effective for organic contaminants, particularly VOCs
- ❖ Fine particles may bind to larger particles preventing effective bonding of the binder material
- ❖ Inorganic salts may affect curing rates and reduce strength of stabilized product
- ❖ Organic contaminants may volatilize due to heat generated during the reaction (possibly prompting the need for air emission permits)
- ❖ High moisture content requires increased amounts of reagent
- ❖ Long-term monitoring requirement

Development status

Solidification/Stabilization is a full scale commercial technology.

References

- <http://www.mass.gov/czm/section45.pdf>
- <http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-3.gif>

4.5 BASIC EXTRACTIVE SLUDGE

Description of the method

The Basic Extractive Sludge process is a solvent extraction technology that uses a combination of tertiary amines, usually triethylamine (TEA), as solvent to extract contaminants from wastes. Triethylamine has a characteristic to be miscible with water and oils below 65°F, what can be used to treat materials containing both contaminated oil and water.

The first extraction is conducted at temperatures below 40°F where TEA is miscible with water and at a pH greater than 10. Hydrocarbons, water and sediment contaminants simultaneously solubilize with the TEA, producing a homogenous extraction solution. Solids present are separated from the liquid mixture by gravity and decanted. The remaining solvent is removed from the solids fraction by indirect steam heating. Water is separated from the water-organic compound-TEA mixture by heating the solution to temperatures above the miscibility point (about 130°F). Organic compounds and TEA are separated by distillation, and the TEA is recycled to the extraction step.

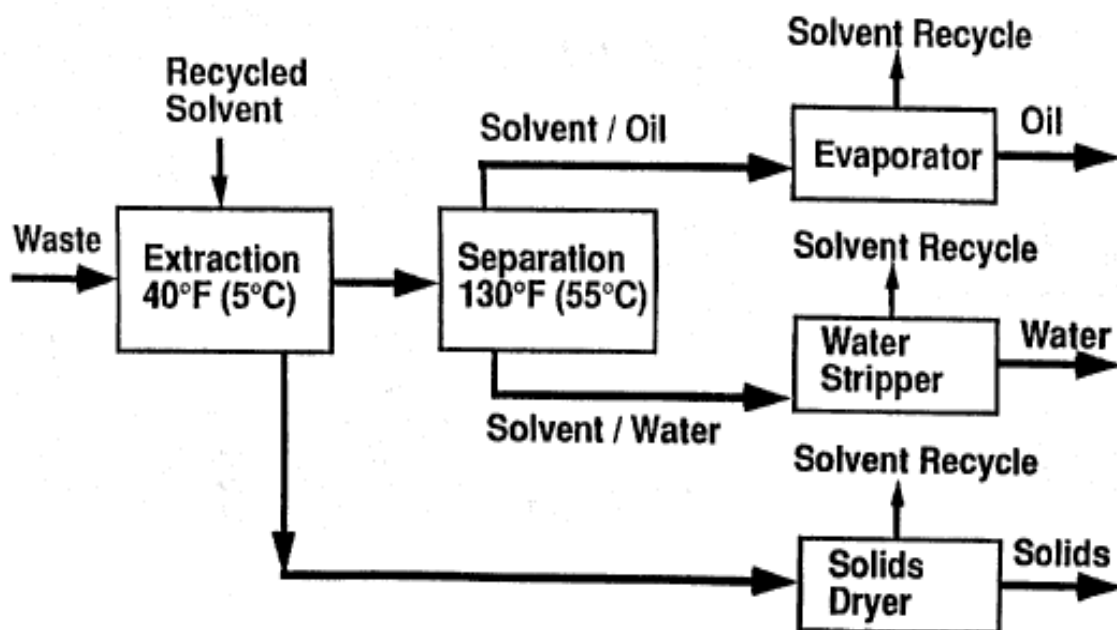


Figure 12: Diagram of Basic Extractive Sludge Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	●
		c. Oxygenated Hydrocarbons	●
		d. Other Compounds	●
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
	Dioxins & Furanes		+
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		-	
B. Performance Assessment			
1. General Assessment			
Development Status		-	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

The process is applicable for the separation of organic contaminants such as PCBs, PAHs and volatile organics.

Advantages

- ❖ Solvent can be easily recovered because its high vapor pressure and the formation of low-boiling azeotrope with water
- ❖ Alkaline pH of solvent (pH=10) convert metals to insoluble form and removed them as treated solids
- ❖ Solvent is moderately toxic and easily biodegrades
- ❖ System operates near ambient pressure and temperatures

Limitations

- ❖ TEA can be ionized at some pH conditions
- ❖ TEA can reacts with some types of contaminants
- ❖ Safety precautions must be conducted due to unknown reactivity among contaminants and TEA

Development status

The technology is emerging and is in the pilot test stage.

References

- <http://www.epa.gov/glnpo/arcs/EPA-905-R94-010/EPA%20905-R94-010.pdf>

4.6 SOLVENT EXTRACTION

Description of the method

Solvent extraction systems do not destroy or detoxify contaminants, but reduce the volume of the contaminated material that must be treated or disposed. These processes leach contaminants from sediments with organic solvents and separate them into three fractions: particulate solids, water, and concentrated organic compounds. These processes are different from soil washing processes that use water or water with additives.

Sediments and solvents are mixed together in an extractor and contaminants are separated by changes in temperature or pressure, or differences in density, and transferred from the separator for post-treatment. Extraction processes can operate in a batch mode or continuous mode and generally uses some organic chemicals such as methanol, ethanol, isopropanol, hexane and ethylene diamine.

The solvent is recycled to the extractor to remove additional contaminants. This cycle is repeated several times before the treated solids are finally removed from the extractor. When treated solids are removed from the extractor, traces of solvent will be present. The solvents selected for these processes generally vaporize or are biodegradable. Some processes include an additional separation step designed to further remove, by distillation or other means, most of the solvent from the product solids. Solvent extraction may be used as a pre-treatment technique for using with other process.

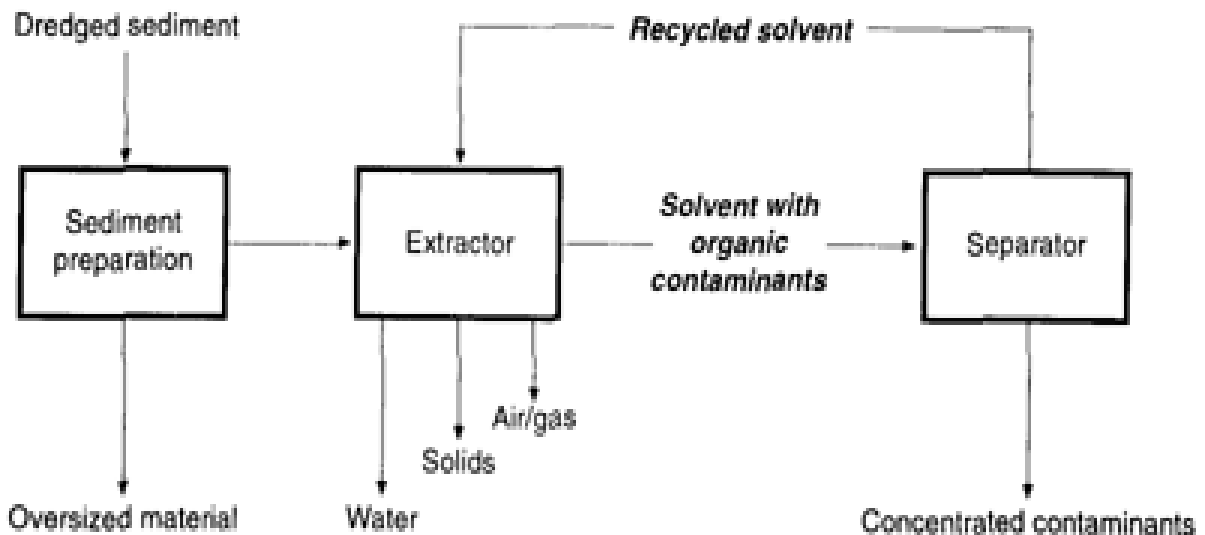


Figure 13: Generalized Solvent Extraction Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	+	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		+	

+ High ● Medium - Low *Not Defined

Applicability

Solvent extraction is suitable for treatment of semi-volatile organic contaminants including PCBs and PAHs, VOCs, petroleum hydrocarbons, and chlorinated solvents such as trichloroethane. This technology is not particularly applicable to inorganics, with the exception of organically-bound metals, which can be extracted.

Advantages

- ❖ Effective to treat organics
- ❖ Recovery and reuse of solvent

Limitations

- ❖ Not effective for metals
- ❖ Low effectiveness for sediments composed primarily of clays and silts
- ❖ Removal of fines from wastewater may require the addition of polymer flocculent
- ❖ Treatment and disposal of water from pre-treatment dewatering
- ❖ Treatment and disposal of amended washwater
- ❖ Dewatering after treatment required
- ❖ Residuals disposal must be addressed for those processes (i.e., thermal desorption, extraction, soil washing) that generate a contaminated, potentially hazardous, waste stream

Development status

Solvent Extraction System is found at various stages of development.

References

- <http://www.mass.gov/czm/section45.pdf>

4.7 CARVER-GREENFIELD PROCESS

Description of the method

The Carver-Greenfield process (Dehydro -Tech Corp.) is a staged physical process that combines dehydration/solvent extraction treatment systems to extract oil-soluble organic compounds from contaminated sediments.

In a mixing tank, the contaminated sediment is combined with food-grade oil with a boiling point of approximately 204°C. The extraction of contaminants takes place and the slurry is transferred to a high-efficiency evaporator where the water is removed. The oil is extracted from the dewatered sediments initially by centrifugation and then by a hydrocarbon solvent that uses hot nitrogen gas or steam to strip the remaining oil from the solids. After separating the contaminants from the oil by distillation, the oil is recycled to the extraction step. The final product is a dried sludge with low percentages of water (<5%) and solvent (<1%) and contains concentrated contaminants that is treated with further precautions (due its flammability) or convenient disposed.

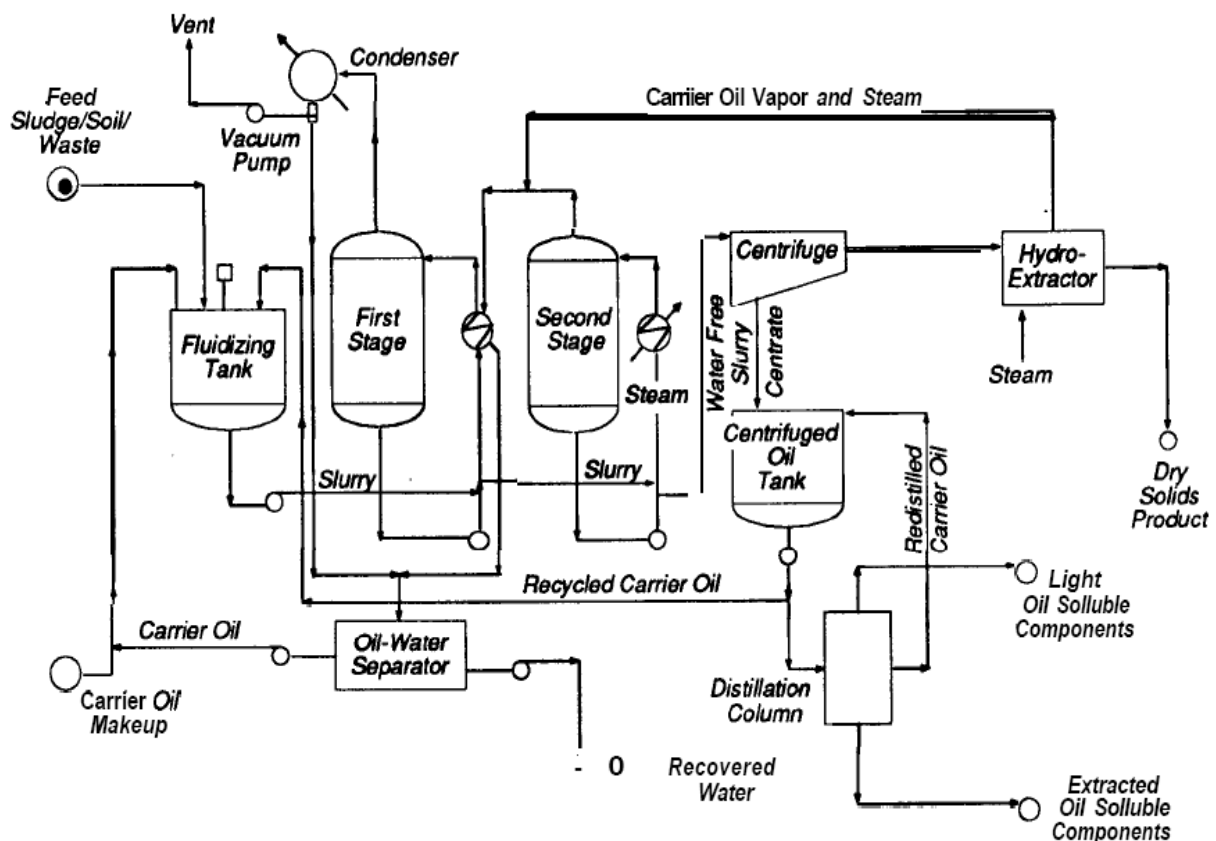


Figure 14: Generalized Carver-Greenfield Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	●
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

The Carver-Greenfield process separates hazardous solvent-soluble organic contaminants (indigenous oil) from, sludges, soils, and industrial wastes. The requirements of this process for fine particle sizes and wet feed material favor applications to contaminated sediments.

Advantages

- ❖ Energy efficiency
- ❖ Low solids content is not a problem for this process, but particle size must be reduced to less than 0.5 cm in diameter
- ❖ Dry produced solids may be suitable for fixation of nonhazardous landfilling
- ❖ water resulted from the process is virtually free of solids and oils and may be processed in an industrial or public wastewater treatment facility

Limitations

- ❖ Not suitable for abrasive materials
- ❖ Plant design not allow easy repairs and maintenance
- ❖ Pipes may erode quickly, requiring early replacement

Development status

The Carver-Greenfield process is considered a commercial technology. Demonstration projects have been conducted on drilling mud wastes, a relatively fine-grain material.

References

- [http://www.epa.gov/ordntrnt/ORD/SITE/reports/540ar92002/540ar92002.pdf*](http://www.epa.gov/ordntrnt/ORD/SITE/reports/540ar92002/540ar92002.pdf)
- <http://www.epa.gov/owm/pipes/npdesgui/eti.pdf>

4.8 SOIL WASHING

Description of the method

Soil washing is an effective technique to remove a wide range of organic and inorganic contaminants from sediments by dissolving or suspending them in a water-based solution. The process utilizes the difference in grain-size and density of the sediment particles to separate the contaminants adhered to sandy and sewer contaminated sediments in different fractions. Soil washing processes also minimize the volume of contaminated material. Typical solvents are composed by water, water combined with organic solvents, chelating compounds, surfactants, acids and bases.

The process involves some steps, as preliminary treatment (separation of metal parts by magnetic overhead belts), sand decontamination (separation of the fine clay and silt particles from the coarser sand fraction using hydrocyclones and upstream classification), gravel washing unit (the stone and gravel-fraction is cleaned in the gravel-washer module by scrubbing and counterflow washing), sludge treatment (the sludge-fraction is further dewatered in a filter press and disposal to landfill) and process water treatment (the mobile plant incorporates on-site water treatment and recirculation). Because most sediment contaminants are tightly bound to particulate matter, water alone is not a suitable extraction fluid. Surfactants, acids, or chelating agents may be used with water to effect separation of some contaminants. The use of surfactants may be successful for removing organic compounds from sandy sediments.

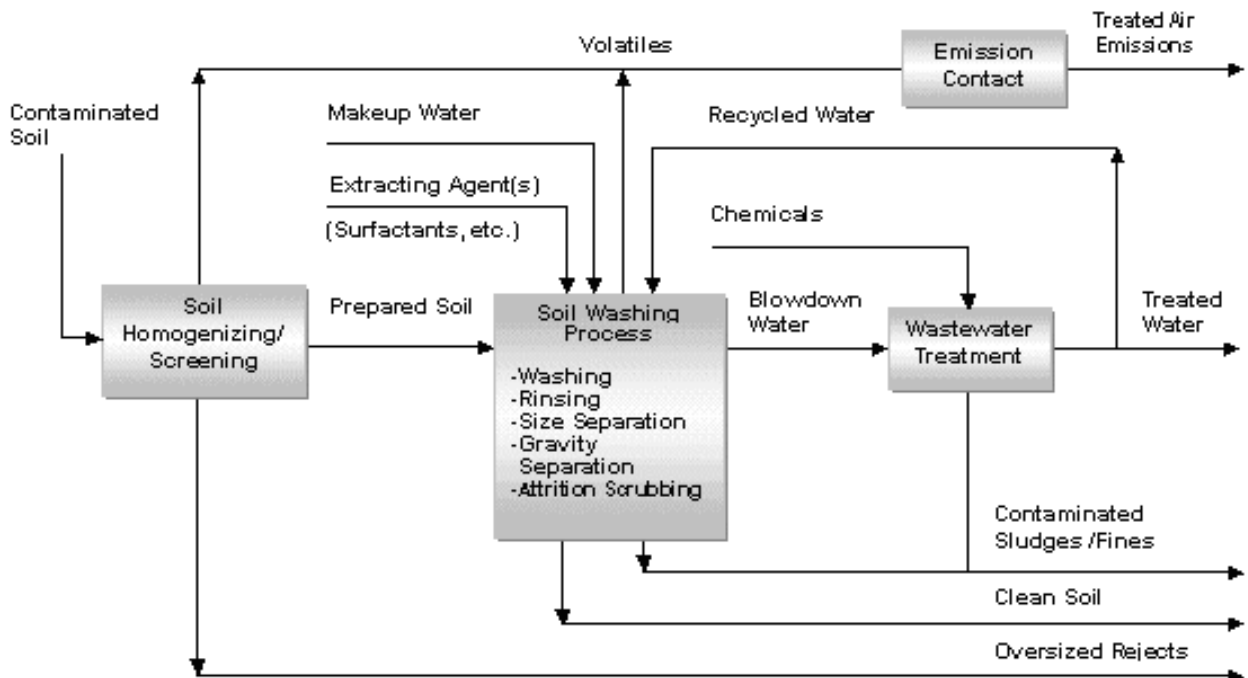


Figure 15: Diagram of Soil Washing System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	●
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	+	
Radionuclides		+	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		●	
Safety		+	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		●	
Residuals Produced		●	
Data Needs		●	
Stand Alone Character		●	
Public Acceptability		+	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

Soil washing can remove a wide range of chemical contaminants including most organic contaminants such as TPH, PAH's and PCB's, halogenated solvents, chlorinated phenols and inorganic contaminants such as heavy metals and cyanides. It's effective with coarse sand and gravel sediments and is only marginally applicable for clays and silts.

Advantages

- ❖ Relatively low technology
- ❖ Cost effective alternative to disposal at landfill
- ❖ Treats a wide range of contaminants, compared to bioremediation
- ❖ Cost effective on relatively small sites and for small volumes of materials in areas with high disposal costs
- ❖ Can be undertaken with reasonably strict programme schedules, irrespective of weather conditions, thus reducing potential delay to site redevelopment.

Limitations

- ❖ Residuals disposal must be addressed for those processes (i.e., thermal desorption, extraction, soil washing) that generate a contaminated, potentially hazardous, waste stream
- ❖ Soil washing may be not effective for sediments composed of clays and silts
- ❖ Maximum particle size typically 0.5 cm
- ❖ Removal of fines from wastewater may require polymer flocculent
- ❖ Dewatering after treatment required
- ❖ Treatment and disposal of washwater and post-treatment dewatering
- ❖ Sequential washing steps may be necessary for high removal efficiencies

Development status

Soil washing technologies are on development.

References

- [*http://www.frtr.gov/matrix2/section4/D01-4-19.html](http://www.frtr.gov/matrix2/section4/D01-4-19.html)
- <http://www.mass.gov/czm/section45.pdf>

4.9 CONTAINMENT BARRIERS

Description of the method

Containment Barriers are generally used during dredging contaminated sediments, in order to contain or minimize contaminants impacts released around the dredging operation. The determination of whether these types of barriers are necessary, aside from regulatory requirements, should be made based on a thorough evaluation of the relative risks posed by the anticipated release of contaminants from the dredging operation, the predicted extent and duration of such releases, and the long-term benefits gained by the overall remediation project. More commonly, nonstructural and flexible barriers, such as oil booms, silt curtains, and silt screens, have been used to reduce the spread of contaminants during dredging. Both systems use a series of floats on the surface, and a ballast chain or anchors along the bottom. Oil booms are appropriate for sediments that are likely to release oils when disturbed. Such booms typically consist of a series of synthetic foam floats encased in fabric and connected with a cable or chains. Oil booms may be supplemented with oil absorbent materials (e.g., polypropylene mats). The effectiveness of nonstructural containment barriers at a sediment remediation site is primarily determined by the hydrodynamic conditions at the site. Conditions that will reduce the effectiveness of barriers including strong currents, high winds, changing water levels, excessive wave height (including ship wakes) and drifting ice and debris.

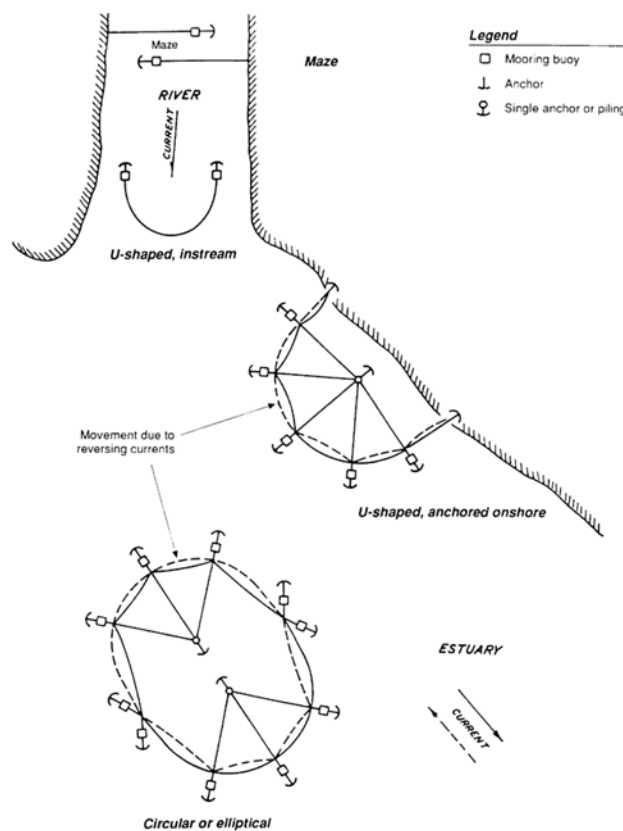


Figure 16: Containment Barriers Configuration (Silt Curtains and Screens)*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	-
		b. Other Halogenated Compounds	-
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	●
		d. Nitro Aromatics & Amines	-
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	-
		b. Halogenated Pesticides	-
		c. Other Halogenated Compounds	-
Dioxins & Furanes		-	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	+	
	b. Sandy	●	
	c. Gravel	-	
Depth of Contamination	a. Shallow	+	
	b. Medium	●	
	c. Deep	-	
2. Site-specific Applicability			
Site Accessibility		-	
Contaminant Concentration Levels		+	
Water Type		+	
Water Mobility		-	
Minimum Achievable Concentration		+	
Safety		+	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		+	

+ High ● Medium - Low *Not Defined

Applicability

Containment barriers are used to prevent sediment contamination during dredging and dragline operations in lakes, ponds, and rivers. Some barriers allow passage of water, but retain contaminated sediment and silt.

Advantages

- ❖ Containment barriers may also be used to protect specific areas (e.g., valuable habitat, water intakes, or recreational areas) from suspended sediment contamination.
- ❖ Silt screens are made from synthetic geotextile fabrics, which allow water to flow through but retain a fraction of the suspended solids.
- ❖ Silt curtains minimized flow through the dredging area, although there were problems in the installation and removal.

Limitations

- ❖ Silt curtains and screens are most effective in relatively shallow water.
- ❖ As water depth increases, and turbulence caused by currents and waves increases, it becomes increasingly difficult to effectively isolate the dredging operation from the ambient water.
- ❖ To be effective, barriers are deployed around the dredging operation and must remain in place until the operation is completed at that site.
- ❖ Care must be taken that the barriers do not impede navigation traffic.
- ❖ The effectiveness of containment barriers is also influenced by the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier.

Development status

Containment barriers have been selected at numerous sites and are now considered a "commercially available" technology.

References

- <http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig4-4.gif>

5. *EX SITU* THERMAL TREATMENTS

5.1 THERMAL DESTRUCTION TREATMENTS

5.1.1 INCINERATION

Description of the method

Incineration represents one of the most commonly used processes for destroying organic compounds in industrial wastes. This technique involves heating the sediments in the presence of oxygen to burn or oxidize organic materials, including organic compounds. A critical component of the overall treatment process is the emission control system for the gases produced by the process. A diagram of an incineration process is shown in the figure below.

Incineration technologies can be subdivided into two categories: conventional and innovative. Because gaseous emissions from incinerators present a potentially large contaminant loss pathway, the emission control system is a critical component for both categories. Conventional technologies include rotary kiln, fluidized bed, multiple hearth, and infrared incineration that typically heat the feed materials to between 650 and 980deg.C. An afterburner, or secondary combustion chamber, is generally required to achieve complete destruction of the volatilized organic compounds. All of these processes produce a dry ash residue. In contrast, there are a number of innovative processes that are designed specifically for hazardous and toxic wastes, which operate at higher temperatures and generally achieve greater destruction and removal efficiencies compared with conventional incineration. Most of these technologies produce a dense slag or vitrified (glass-like) solid instead of a free-flowing ash. These technologies tend to be very expensive, but offer the advantage of producing a non leachable end product.

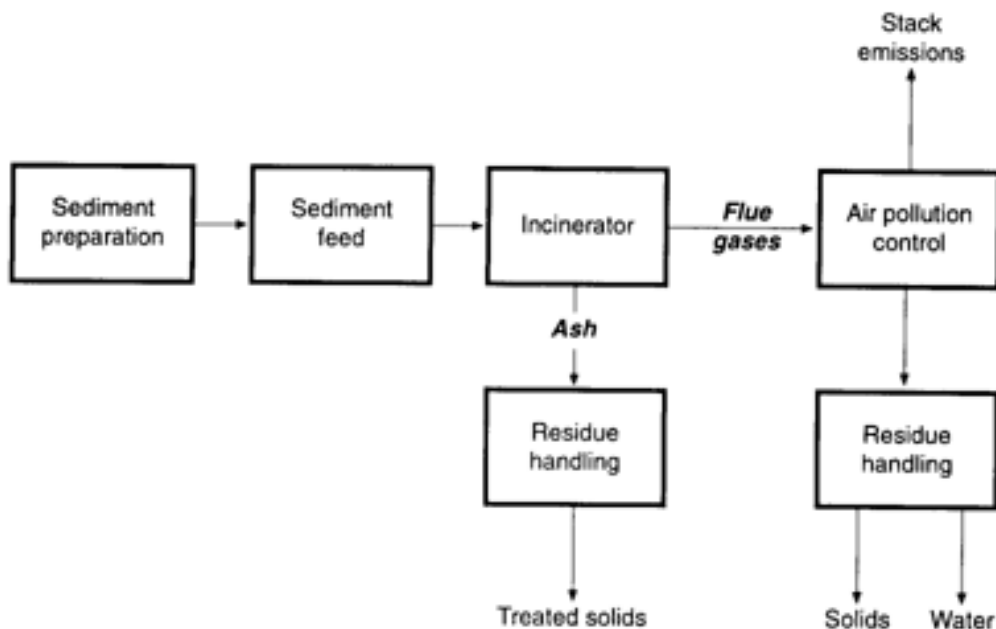


Figure 17: Typical Diagram of an Incinerator*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	+
	Dioxins & Furanes		+
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	●	
	b. Sandy	+	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		●	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

Incineration is applicable to a wide variety of organic contaminants. Not Recommended for PCBs, because may produce dioxins.

Advantages

- ❖ High treatment efficiency, especially for PCBs and dioxins
- ❖ Process large volumes of waste
- ❖ Widely available
- ❖ May produce a slag that is resistant for leaching

Limitations

- ❖ Incineration does not remove heavy metal contamination
- ❖ Wet solids contents increase energy consumption.
- ❖ Increase the leachability of metals through the process of oxidation
- ❖ May produce chlorinated dioxins and furans
- ❖ Community opposition may be expected
- ❖ May volatilize some heavy metals such as mercury
- ❖ Gaseous discharges must be treated
- ❖ Residual material may contain high heavy metals

Development status

Incineration is a full scale commercial technology.

References

- <http://www.mass.gov/czm/section45.pdf>
- *<http://www.epa.gov/grtlakes/arcs/EPA-905-B94-003/gifs/fig7-1.gif>

5.1.2 PYROLYSIS

Description of the method

In contrast to incineration, pyrolysis involves the heating of solids in the absence of oxygen. A pyrolysis system consists of a primary combustion chamber, a secondary combustion chamber, and pollution control devices. High temperatures, ranging from 540 to 760°C, cause large, complex molecules to decompose into simpler ones. The resulting gaseous products can then be collected (e.g., on a carbon bed) or destroyed in an afterburner at 1,200°C.

Different processes are available, such as using hydrogen gas to remove chlorine atoms from PCBs or dioxins. Pyrometallurgy is a nonproprietary form of pyrolysis. This commercial technology is commonly used to treat metal-bearing ores. High levels of metals or metal oxides can be recovered from waste materials of similar metal content because the effectiveness of recovery is directly proportional to the metal content of the waste. However, this process has the potential for forming toxic sludges and has high process costs (Averett et al., in prep.).

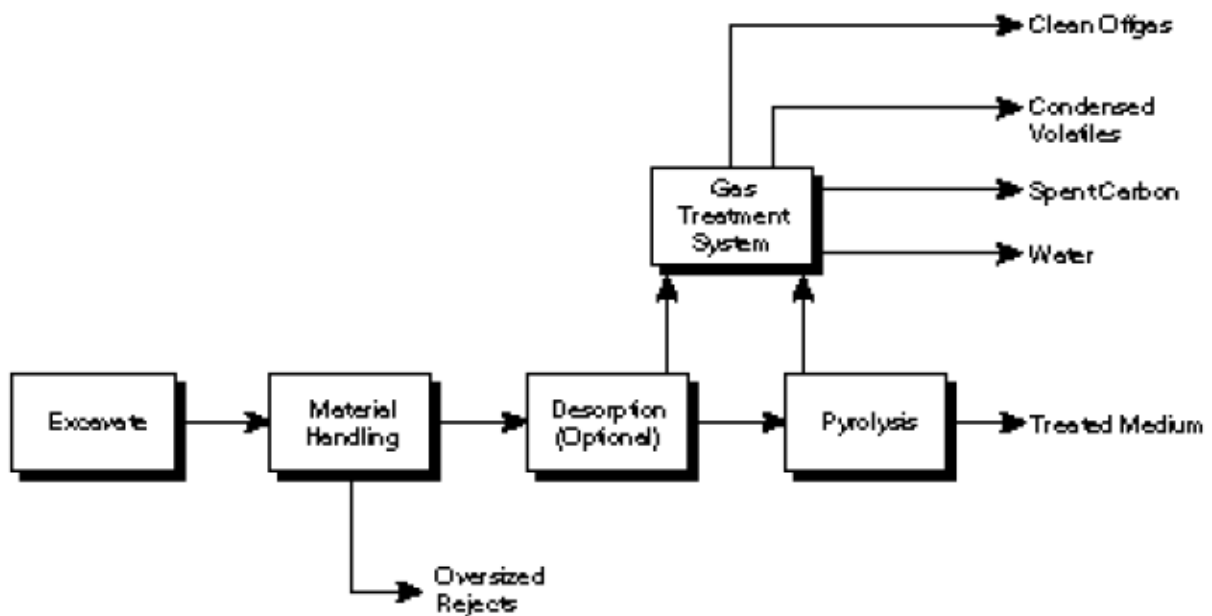


Figure 18: Flow-sheet of Pyrolysis Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	●
		c. Oxygenated Hydrocarbons	●
		d. Other Compounds	●
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
	Dioxins & Furanes		●
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

The target contaminant groups for pyrolysis technology are SVOCs and pesticides, with high concentration of organics and that are not treated by conventional incineration. The process is applicable for the separation of organics from refinery wastes, coal tar wastes, wood-treating wastes, creosote-contaminated soils, hydrocarbon contaminated soils, mixed (radioactive and hazardous) wastes, synthetic rubber processing wastes, and paint waste.

Advantages

- ❖ Efficient destruction of contaminants
- ❖ Produces inert slag
- ❖ More efficient than conventional incineration

Limitations

- ❖ Extensive pretreatment may be required
- ❖ Expensive, when compared to incineration
- ❖ High moisture increase treatment costs
- ❖ Gaseous emissions
- ❖ Public opposition
- ❖ Site space limitations

Development status

The technology is emerging and is in the development stage.

References

- <http://www.mass.gov/czm/section45.pdf>
- <http://www2.bren.ucsb.edu/~keller/courses/esm223/TechSCREEN.pdf>

5.1.3 HIGH PRESSURE OXIDATION

Description of the method

High Pressure Oxidation includes two technologies for sediment remediation: wet air oxidation and supercritical water oxidation. Both processes use the combination of high temperature and pressure to break down organic compounds. The supercritical water oxidation process decomposes completely organic substances by heating and pressurizing water above a critical point, where the solubility of organic substances and oxygen into water increases greatly. This characteristic of the supercritical water is called "supercritical water oxidation technology". PCBs and other stable compounds are destructed at operating temperatures around 400-600 degrees C and pressures near 22,300MPa. In addition, many types of difficult-to-decompose compounds may be decomposed in a short time, resulting in the conversion of these compounds into carbon dioxide, water, and inorganic salts. Wet air oxidation is an oxidation process using molecular oxygen contained in air (or any other oxygen containing gas) as an oxidant. The process is categorized as a low-temperature thermal treatment. The process pumps waste into the system, mixes it with compressed air and breaks down oxidizable inorganic and organic waste at a temperature of 150-300 degrees C and a pressure of 2,000-20,000 MPa.

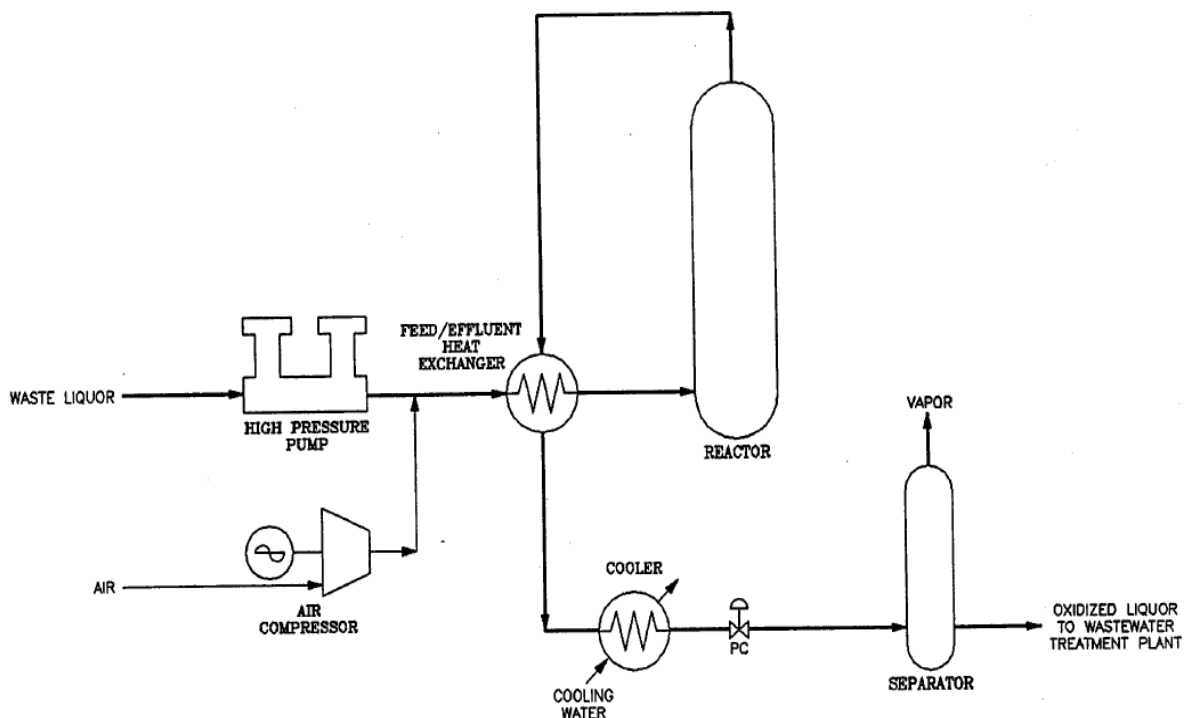


Figure 19: Generalized Wet Air Oxidation Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	*	
	b. Sandy	*	
	c. Gravel	*	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment		+	
Development Status		+	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		+	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		+	
2. Time-cost Assessment			
Clean-up Time Required		●	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

This technology can degrade hydrocarbons (including PAHs), some pesticides, phenolic compounds, cyanides, and other organic compounds (USEPA 1987a).

Advantages

- ❖ Effective for many organic compounds, including PCBs
- ❖ Does not requiring dewatering and drying of sediments
- ❖ Less expensive than incineration
- ❖ Well-developed and proven, extensive operating experience

Limitations

- ❖ Wet Air Oxidation may be not effective to polychlorinated biphenyls and other halogenated compounds
- ❖ Volatile metals can cause stack emission problems.
- ❖ The process has long setup time and requires large gas volume.

Development status

The High-Pressure Oxidation process is a commercially proven technology, although its use has generally been limited to conditioning of municipal wastewater sludges.

References

- [*http://www.water.siemens.com/NR/rdonlyres/6AA2C724-1D1B-4C65-8D3F-E44665CE0104/0/TechnicalReport420.pdf](http://www.water.siemens.com/NR/rdonlyres/6AA2C724-1D1B-4C65-8D3F-E44665CE0104/0/TechnicalReport420.pdf)

5.1.4 VITRIFICATION

Description of the method

Vitrification is an emerging technology that uses electricity to heat and destroy organic compounds and immobilize inert contaminants on soils, sludges and sediments. A typical unit consists of a reaction chamber divided into two sections: the upper section introduces the feed material containing gases and pyrolysis products, while the lower section contains a two-layer molten zone for the metal and siliceous components of the waste. Wastes are vitrified by passing high electrical currents through the material. Electrodes are inserted into the waste solids, and graphite is applied to the surface to enhance its electrical conductivity. A large current is applied, resulting in rapid heating of the solids and causing the siliceous components of the material to melt. The end product is a solid, glass-like material that is very resistant to leaching. Temperatures of about 1,600deg.C are typically achieved. In general, salts must be removed from the sediment prior to vitrification, since some of them are volatilized during the melting process and provide some problems such as the potential corrosion of the system and solid salt deposits in the off gas system. Thus, the pretreatment process of sediment remediation includes washing the sediment with fresh water, which removes large debris and ensures that no particles pass through which could clog the sediment injection nozzle into the plasma melter. The next step is partially dewatered the sediment to remove as much water as possible prior to injection into the melter, avoiding increasing costs with electrical power. On the other hand, if dewatering process of contaminated sediment is too much, the sediment may becomes dry and clay-like, and is very difficult to pump into the melter.

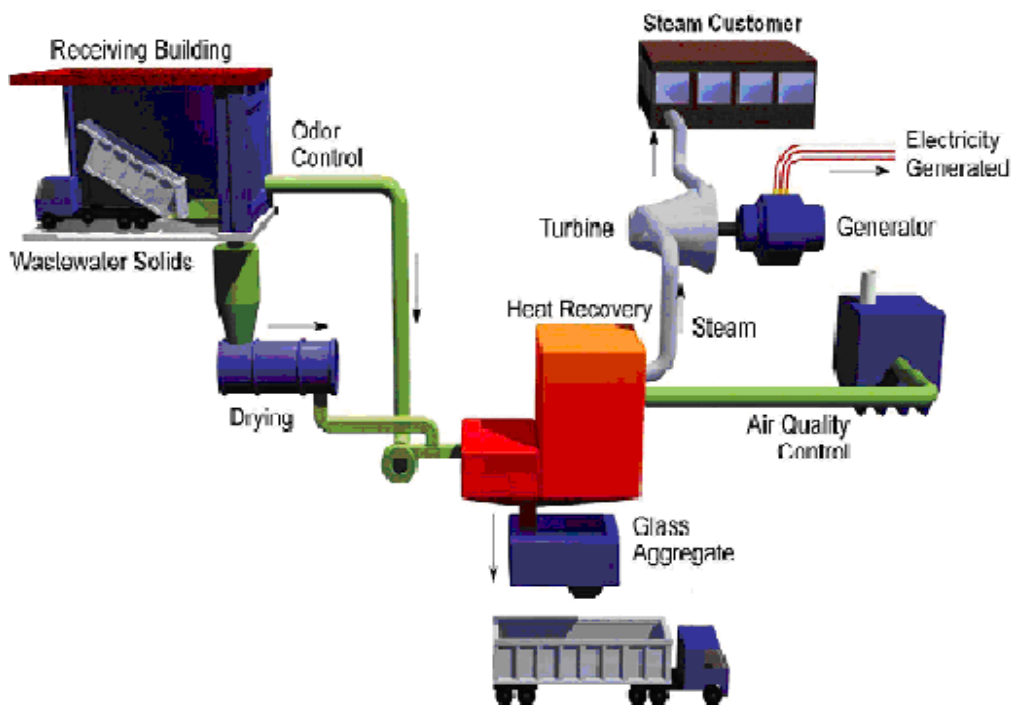


Figure 20: Generalized Vitrification Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	+	
Radionuclides		+	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		-	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		-	
Stand Alone Character		-	
Public Acceptability		-	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

The combination of permanent and complete destruction of organic contaminants with immobilization of heavy metals makes this remediation technique an attractive option to treat highly contaminated sediments or sludges.

Advantages

- ❖ Effective technology to immobilize inorganics (including heavy metals and radionuclides) by producing an inert glass that is resistant to leaching
- ❖ Reduction of Volume/mass of contaminants
- ❖ Eliminates disposal through beneficial reuse
- ❖ Multiple beneficial reuse applications

Limitations

- ❖ Vitrification has only been used for relatively small projects and would be very difficult to implement for full-scale sediment projects.
- ❖ More expensive than conventional incineration
- ❖ Not applicable for high levels of electrically conducting elements
- ❖ Some molten products may take months to cool
- ❖ Permitability
- ❖ Air emissions

Development status

The vitrification process is commercially available at large and small scale.

References

- <http://www.bnl.gov/wrdadcon/publications/articles/westinghouse-weda.PDF>
- <http://www.mass.gov/czm/section45.pdf>
- http://www.wef.org/NR/rdonlyres/55979D60-6B49-4352-9DC7-CDA5F95E45FE/0/Paulson_Power_Point2005.pdf

5.2 THERMAL DESORPTION TREATMENTS

5.2.1 X*TRAX SYSTEM

Description of the method

The X*TRAX system is a physical separation process that uses an externally fired rotary kiln to heat contaminated solid or sludges to low-temperatures thermal desorption processes ranging from 90 to 480°C. This remediation technique is not designed to destroy contaminants, but to remove water and organic contaminants from solid media by the application of heat to the waste in the presence of water. The organics and the water are volatilized and leave behind a dry solid with little or no organic content. The resulting volatilized water and organic mixture is directed from the dryer to the gas treatment system by a nitrogen carrier gas and removed in a stepwise fashion through cooling and condensing stages. Initially, a high-energy scrubber removes dust particles and 10-30 percent of the organic compounds. The gases are then cooled to condense most of the remaining vapors. About 90-95 percent of the cleaned gas is reheated and recycled to the kiln. The remaining 5-10 percent is passed through a particulate filter and activated carbon and is then released to the atmosphere (USEPA 1992g). In the process, the following three factors are adjusted to control the removal of contaminants: the feed rate, the dryer temperature, and the residence time in the dryer.

- Pretreatment requirements include screening or grinding to reduce the particle size to less than 5 cm.
- Post-treatment includes treatment or disposal of the condensates and spent carbon.

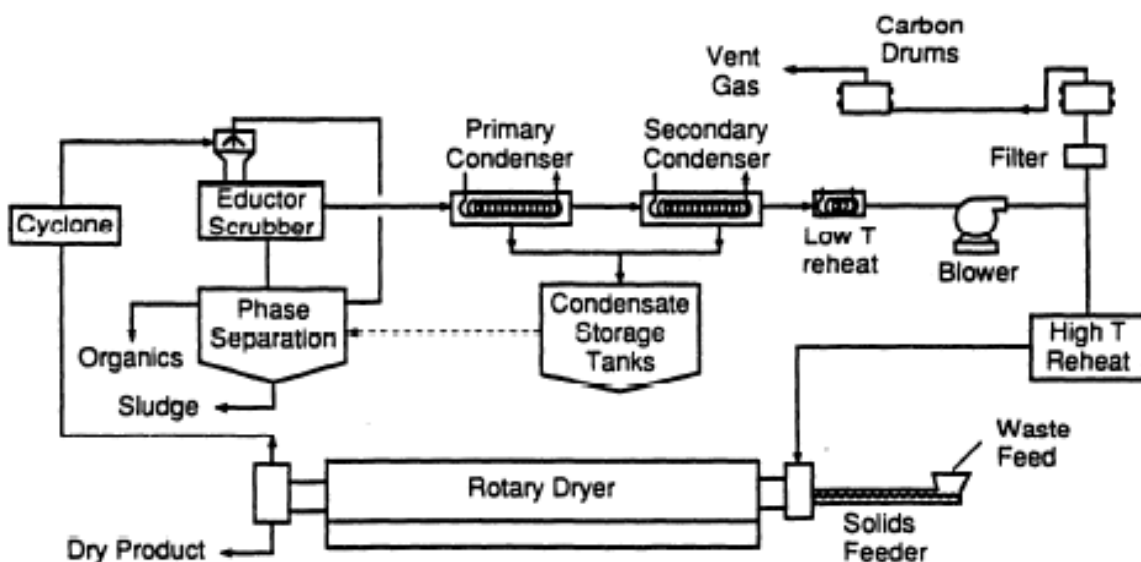


Figure 21: Flow-sheet of X*TRAX System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	●
		c. Oxygenated Hydrocarbons	●
		d. Other Compounds	●
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	●
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		-	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		-	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

The system is applicable to oil, grease, and halogenated/non-halogenated VOCs/SVOCs such as PCBs, pesticides, mixed wastes (organic/radioactive) and mercury. However, the technique requires wastes with some specific conditions such as the presence of organics with boiling points less than 800 degrees F, less than 10% total organics, and less than 60% moisture. The system is not applicable for the removal of heavy metals.

Advantages

- ❖ Large applicability for soils, sediments and other solids

Limitations

- ❖ Maximum organic concentrations of 20%
- ❖ Pretreatment to < 2" particle size.
- ❖ Maximum soil moisture content of 50%, with < 25% moisture preferable
- ❖ Acceptable results may not be achievable for some sediments with high clay

Development status

The X*Trax System is a full-scale commercial technology.

References

- <http://www.ncseonline.org/nle/crsreports/waste/waste-9.cfm>
- <http://aec.army.mil/prod/usaec/et/restor/hotgas.htm>
- <http://www.osti.gov/bridge/servlets/purl/10111505-4fzgTe/native/10111505.PDF>

5.2.2 DESORPTION AND VAPORIZATION SYSTEM

Description of the method

The Desorption and Vaporization Extraction System (DAVES) removes contaminants from sediments by contact with the hot air. The technique submits contaminated sediment to a fluidized bed with temperature about 160°C and a concurrent flow of 540-760 °C air from a gas-fired heater to remove water and contaminants from the particle solids. Vaporized water and organics are removed with the gas treatment and particulates are separated by using cyclone separators and bag houses. Venturi scrubber and counter-current washer are followed used for cooling the vapors before treat them in a carbon adsorption system. Utility requirements for the DAVES include electricity, fuel, and water for cooling, quenching treated soil, and fire protection.

The DAVES is a modular and transportable process and consists of the following four smaller systems:

- Waste feed system
- Vapor extraction system
- Gas treatment system
- Liquid treatment system

Onsite treatment of liquid residues is available as a part of the process. The system requires waste pre-treatment, emissions control, and residuals handling activities as other HTTD systems.

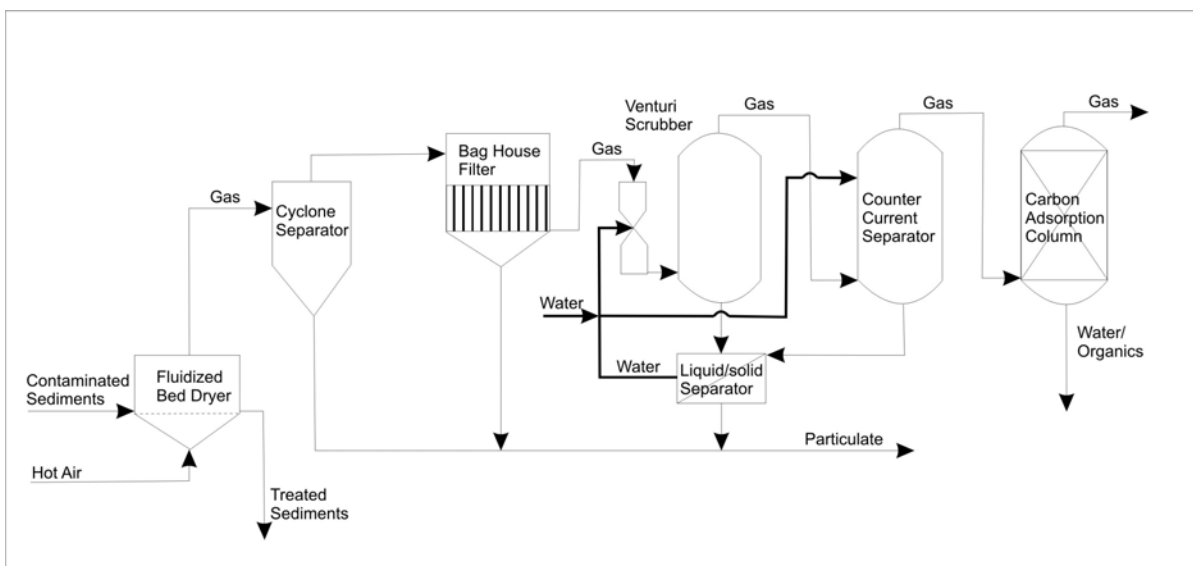


Figure 22: Typical Desorption and Vaporization Extraction System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	●
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	●
Dioxins & Furanes	●		
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	*	
	b. Sandy	*	
	c. Gravel	*	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	

2. Time-cost Assessment	
Clean-up Time Required	+
Overall Cost	-

+ High • Medium - Low *Not Defined

Applicability

This technology is used to separate and dispose as a nonhazardous material, contaminants such as PCBs, PAHs, VOCs, SVOCs, and some volatile inorganic compounds from contaminated soil, sludge, and sediment.

Advantages

- ❖ Site access requirements for the DAVES process are minimal

Limitations

- ❖ The DAVES process requires a gravel or concrete pad area and steel plate supports to support trailers and to prevent equipment from leaning or sliding in soft soil
- ❖ The roadbed to the remediation site must be able to support vehicles that may deliver the vapor extractor, tanks and other equipment required for system operation.
- ❖ Extreme care must be taken when screening contaminated materials to ensure that VOCs, asbestos, and metals are not emitted during screening operations.
- ❖ The DAVES process generates treatment residuals that require off-site treatment
- ❖ Residuals disposal must be addressed for those processes (i.e., thermal desorption, extraction, soil washing) that generate a contaminated, potentially hazardous, waste stream.

Development status

The Desorption and Vaporization Extraction System (DAVES) is an emerging technology which process has been tested in some applications.

Reference

- <http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch7.html#RTFToC132>

5.2.3 HIGH TEMPERATURE THERMAL SYSTEM

Description of the method

The High Temperature Thermal System (HTTD) uses a dryer to heat the sediments (320 to 560°C) and drive off water vapors, organic compounds, and other volatile compounds. The screws for the dryer are heated by a hot molten salt that circulates through the stems and blades of the augers, as well as through the trough that houses the augers. The molten salt is a mixture of salts, primarily potassium nitrate. The motion of the screws mixes the sediment to improve heat transfer and conveys the sediment through the dryer.

HTTD is frequently used in combination with some other techniques such as incineration, solidification/stabilization, or dechlorination, depending upon site-specific conditions. Off-gases are controlled by cyclones, condensers, and activated carbon. Pretreatment should include sorting, screening, and crushing of larger-sized material and dewatering. Gaseous emissions must be treated to recover desorbed organics and to control particulates and other potential air contaminants. Treated material requires quenching and may contain high levels of metals and asbestos; therefore, immobilization of inorganics may be warranted. Condensed organics and oils would be collected for off-site disposal.

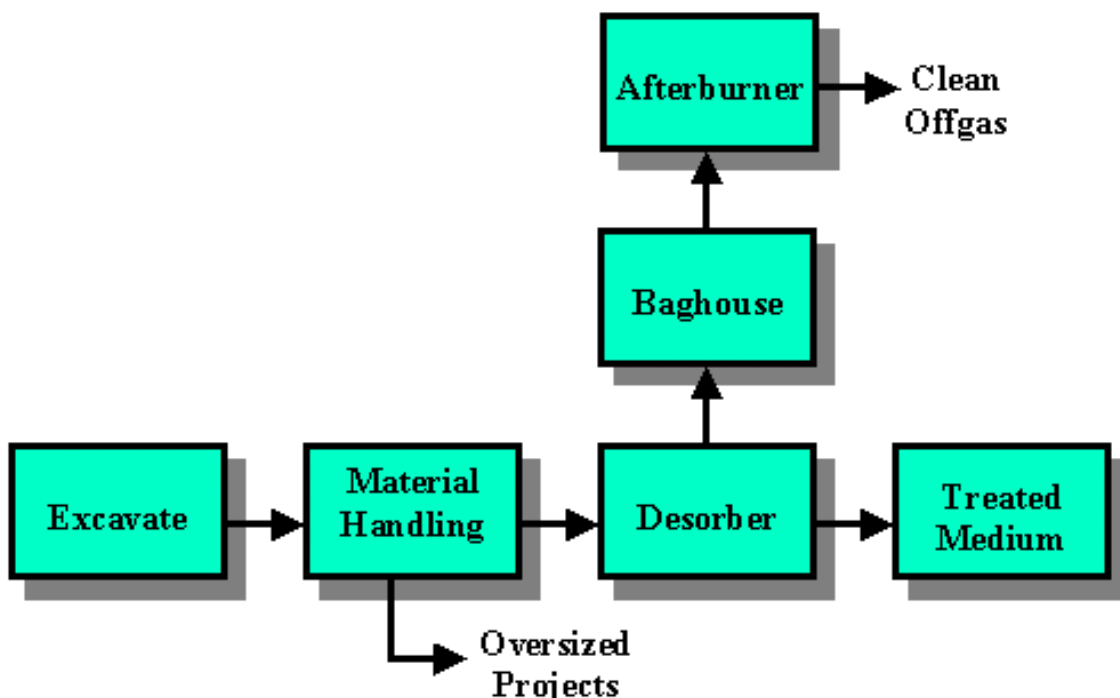


Figure 23: Schematic of High Temperature Thermal System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	●
		b. BTEX	●
		c. Oxygenated Hydrocarbons	●
		d. Other Compounds	●
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
	Dioxins & Furanes		+
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

Contaminants treated in HTTD systems are SVOCs (including dioxins and furans), PAHs, PCBs and pesticides. VOCs and fuels may be treated but treatment may be less cost-effective. Volatile metals may be removed by HTTD, although this technique is not effective for removing or treating some inorganic contaminants.

Advantages

- ❖ The cost is typically less than for incineration
- ❖ High temperature process volatilize a wide range of contaminants

Limitations

- ❖ Has some limitations with heavy metals; these remain in the solid residue and may form toxic by-products during treatment
- ❖ Highly abrasive feed potentially can damage the processor unit
- ❖ Heavy metals in the feed may produce a treated solid residue that requires stabilization
- ❖ Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants
- ❖ There are specific particle size and materials handling requirements that can impact applicability or cost at specific sites
- ❖ Dewatering may be necessary to achieve acceptable soil moisture content levels

Development status

HTTD is a full-scale technology.

References

- <http://www.frtr.gov/matrix2/section4/4-26.html>
- * <http://www.frtr.gov/matrix2/section4/D01-4-26a.html>
- <http://www.mass.gov/czm/section45.pdf>

5.2.4 LOW TEMPERATURE THERMAL SYSTEM

Description of the method

The low-temperature thermal treatment system (LTTD) also uses a dryer, and sediments are heated to between 90 and 320 °C (200 to 600 °F). This range of temperature for the heating fluid is a limiting factor for this process, even though higher temperatures would likely be required to effectively remove PCBs from sediments.

Vapors from the contaminated material are passed through a particulate filter, scrubbers or condensers, and carbon adsorption columns, and may require additional post-treatment. Removal efficiencies >99 percent have been reported for volatile organic compounds; removal efficiencies of about 90 percent have been reported for PAHs (USEPA 1991c).

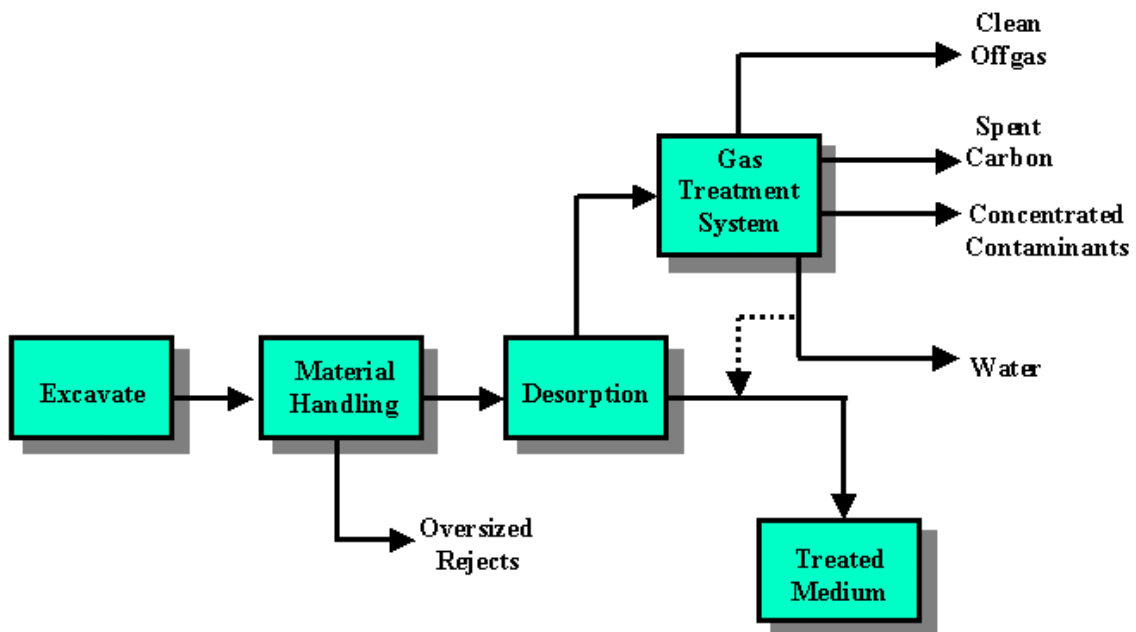


Figure 24: Schematic of Low Temperature Thermal System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	●
		b. Other Halogenated Compounds	●
	SVOCs	a. Heavy Hydrocarbons	●
		b. Non-Halogenated Pesticides	●
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	●
		e. Non-Halogenated Phenols	●
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	●
		b. Halogenated Pesticides	●
		c. Other Halogenated Compounds	●
Dioxins & Furanes		●	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		-	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		-	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		●	

+ High ● Medium - Low *Not Defined

Applicability

Contaminants treated in LTTD systems are non-halogenated VOCs and fuels, with efficiency greater than 95%.

Advantages

- ❖ Technology with high efficiency for removal volatile organic compounds and PAHs

Limitations

- ❖ Has some limitations with heavy metals; these remain in the solid residue and may form toxic by-products during treatment
- ❖ Highly abrasive feed potentially can damage the processor unit
- ❖ Heavy metals in the feed may produce a treated solid residue that requires stabilization
- ❖ Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants
- ❖ There are specific particle size and materials handling requirements that can impact applicability or cost at specific sites
- ❖ Dewatering may be necessary to achieve acceptable soil moisture content levels

Development status

LTTD is a full-scale technology.

References

- * <http://www.frtr.gov/matrix2/section4/D01-4-26b.html>
- <http://www.mass.gov/czm/section45.pdf>
- <http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch7.html#RTFToC132>

5.2.5 LOW-TEMPERATURE THERMAL AERATION

Description of the method

The low-temperature thermal aeration is a thermal treatment system that utilizes hot air to desorb organic contaminants from the contaminated media. The separation is processed into a contained air stream and then treats the air stream extensively before discharging it to the atmosphere. It uses a direct-fired rotary dryer that can heat soil to temperatures of 430°C. The gas stream from the dryer is treated for particulate removal in cyclones and/or baghouses. Organic compounds may be destroyed in an afterburner or scrubbed and adsorbed onto activated carbon. Effective separation of volatile organic compounds and PAHs from contaminated soils has been demonstrated (USEPA 1992g).

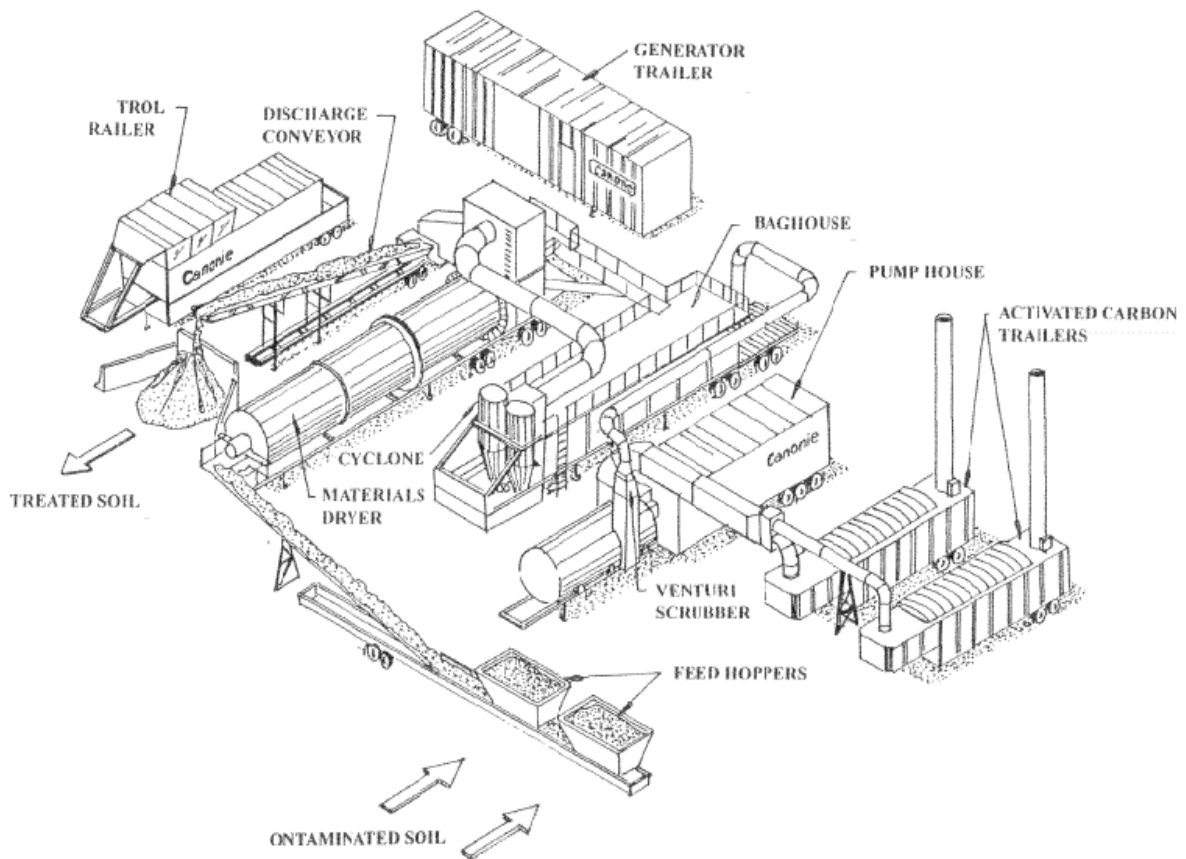


Figure 25: Generalized Low-Temperature Thermal Aeration Process*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	-	
	b. Non Volatile Heavy Metals & Compounds	-	
Radionuclides		-	
Other Inorganics		-	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		-	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		+	
Short-term/Long-term Effectiveness		-	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		-	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

It is initially applicable for the treatment of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), organochlorine pesticides (OCPs), organophosphorous pesticides (OPPs), and other extractable organic compounds and PAHs in contaminated soils.

Advantages

- ❖ Unlike incineration systems, the process does not generate dioxins or dibenzofurans during treatment of OCPs
- ❖ Provides a very cost effective solution for remediation of soils impacted with chlorinated VOCs OCPs, and OPPs
- ❖ No wastewater or waste streams are generated
- ❖ Can remediate a site in a much shorter time than those technologies which utilize indirect heat transfer mechanism, for example a thermal screw system
- ❖ Can be transported from site-to-site
- ❖ Has a flexible system configuration and can utilize a thermal oxidizer in lieu of the carbon adsorption system.

Limitations

- ❖ High moisture content increases cost because require dewatering
- ❖ High concentrations of petroleum hydrocarbons requires a thermal oxidizer or afterburner in the air pollution control system to destroy organic compounds
- ❖ Dioxins and furans may be formed within the system as products of incomplete combustion (PICs) of pesticides.

Development status

The low-temperature thermal aeration system is a full-scale, proven technology and demonstrations indicate that this technology can be implemented for sediments without significant difficulties.

References

- <http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch7.html#RTFToC132>
- [*http://www.epa.gov/ORD/SITE/reports/540ar93504/540ar93504.pdf](http://www.epa.gov/ORD/SITE/reports/540ar93504/540ar93504.pdf)

5.2.6 ANAEROBIC THERMAL PROCESSOR

Description of the method

The Anaerobic Thermal Processor (ATP^[reg.]) system is a physical separation process which consists of a rotary kiln to desorb, collect, and recondense organic contaminants from soil. The process contains four separate internal thermal zones:

1. Preheat: contaminated material is fed into a preheat zone maintained at temperatures of 200-340°C where steam and light organic compounds are vaporized and separated from the solids;
2. Retort: hot solids then move into a 480-620°C retort zone, which vaporizes the heavier organic compounds and thermally cracks hydrocarbons, forming coke and low molecular weight gases;
3. Combustion: coked solids are combusted at 650-790°C;
4. Cooling: the final zone is a cooling zone for the flue gases.

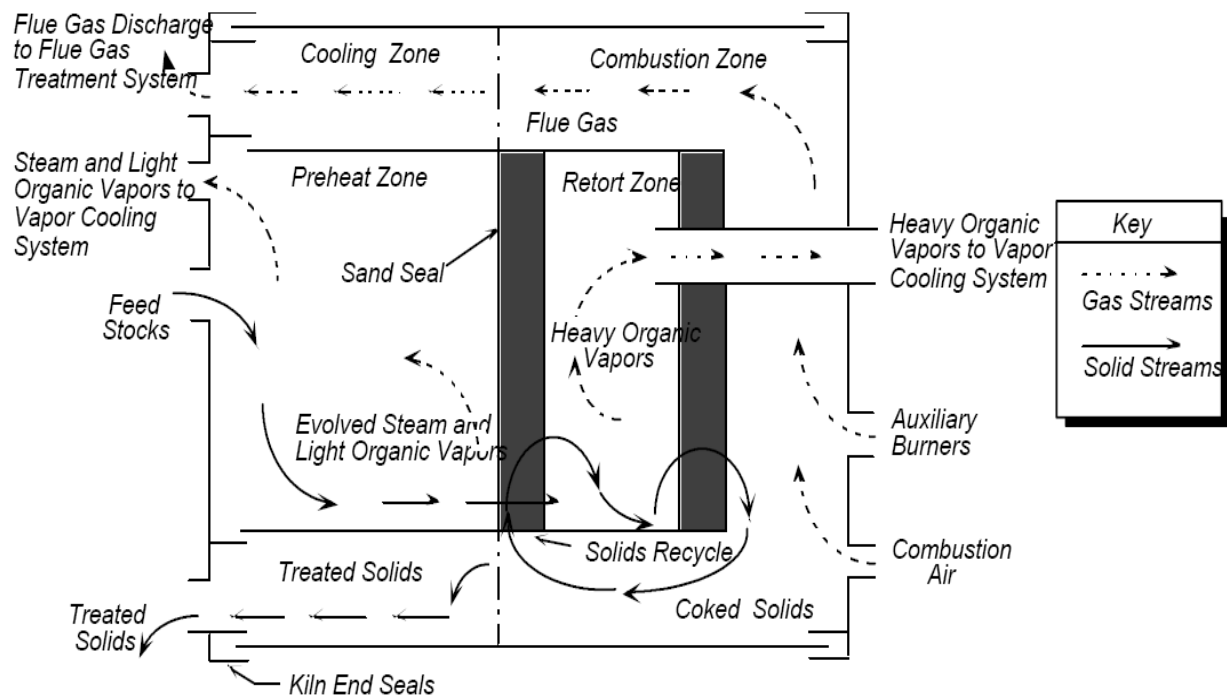


Figure 26: Generalized Anaerobic Thermal Processor System*.

Criteria		Rating	
A. Applicability			
1. General Applicability			
Contaminant Type	Organic Contaminants		
	VOCs	a. Light Hydrocarbons	+
		b. BTEX	+
		c. Oxygenated Hydrocarbons	+
		d. Other Compounds	+
	X-VOCs	a. Chlorinated Hydrocarbons	+
		b. Other Halogenated Compounds	+
	SVOCs	a. Heavy Hydrocarbons	+
		b. Non-Halogenated Pesticides	+
		c. Polycyclic Aromatic Hydrocarbons (PAHs)	+
		d. Nitro Aromatics & Amines	+
		e. Non-Halogenated Phenols	+
	X-SVOCs	a. Polychlorinated Byphenyls (PCBs)	+
		b. Halogenated Pesticides	+
		c. Other Halogenated Compounds	+
Dioxins & Furanes		+	
Inorganic Contaminants			
Heavy Metals	a. Volatile Heavy Metals & Compounds	+	
	b. Non Volatile Heavy Metals & Compounds	●	
Radionuclides		●	
Other Inorganics		●	
Sediment Type	a. Silty	-	
	b. Sandy	●	
	c. Gravel	+	
Depth of Contamination	a. Shallow	*	
	b. Medium	*	
	c. Deep	*	
2. Site-specific Applicability			
Site Accessibility		●	
Contaminant Concentration Levels		+	
Water Type		*	
Water Mobility		*	
Minimum Achievable Concentration		+	
Safety		●	
B. Performance Assessment			
1. General Assessment			
Development Status		●	
Short-term/Long-term Effectiveness		+	
Reliability and Maintenance		-	
Residuals Produced		-	
Data Needs		+	
Stand Alone Character		+	
Public Acceptability		●	
2. Time-cost Assessment			
Clean-up Time Required		+	
Overall Cost		-	

+ High ● Medium - Low *Not Defined

Applicability

It is applicable to contaminants including petroleum hydrocarbons (fuel, oil, lube oil, SVOCs and VOCs), halogenated hydrocarbons (polychlorinated biphenyls (PCB), dioxins, furans, pesticides and herbicides), aromatic hydrocarbons (coal tar residues and polynuclear aromatic hydrocarbons - PAH) and volatile metals (mercury).

Advantages

- ❖ Treats contaminants with a wide range of boiling points
- ❖ High efficiency for PCBs
- ❖ No leachable products are produced
- ❖ Dioxin and furan stack gas emissions are below site-specific standards

Limitations

- ❖ Pretreatment is necessary to reduce the feed materials to less than 5 cm. in diameter.

Development status

The Anaerobic Thermal Processor (ATP^[reg.]) System is an emerging technology which process has been tested in some applications.

References

- <http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch7.html#RTFToC132>
- <http://www.p2pays.org/ref/21/20687.htm>
- * <http://www.epa.gov/ordntrnt/ORD/SITE/reports/540mr92078/540mr92078.pdf>

6. REFERENCE WEB SITES

In addition to the references provided at the end of each technology sub-section, a list of some “top” web sites, where information about conventional and innovative remediation technologies can be found, has been included.

Top-twenty (20) Websites

- (1) <http://clu-in.org> (or <http://www.epa.gov/tio>)
- (2) <http://www.epareachit.org>
- (3) <http://www.frtr.gov>
- (4) <http://www.gwrtac.org>
- (5) <http://www.rtdf.org>
- (6) <http://www.cpeo.org>
- (7) <http://www.epa.gov/ORD/SITE>
- (8) <http://www.epa.gov/superfund>
- (9) <http://em-50.em.doe.gov>
- (10) <http://www.itrcweb.org>
- (11) <http://www.serdp.org/research/research.html>
- (12) <http://www.epa.gov/etv/>
- (13) <http://www.caracas.at>
- (14) <http://www.clarinet.at>
- (15) <http://www.nicole.org>
- (16) <http://www.eea.eu.int>
- (17) <http://race.katowice.pl>
- (18) <http://www.gnet.org>
- (19) <http://www.rec.org>
- (20) <http://nato.int/ccms>