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Superfund

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Engineering Bulletin
Slurry Biodegradation

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

In a slurry biodegradation system, an aqueous slurry is created by combining soil or sludge with water. This slurry is then biodegraded aerobically using a self-contained reactor or in a lined lagoon. Thus, slurry biodegradation can be compared to an activated sludge process or an aerated lagoon, depending on the case.

Slurry biodegradation is one of the biodegradation methods for treating high concentrations (up to 250,00 mg/kg) of soluble organic contaminants in soils and sludges. There are two main objectives for using this technology: to destroy the organic contaminant and, equally important, to reduce the volume of contaminated material. Slurry biodegradation is not effective in treating inorganics, including heavy metals. This technology is in developmental stages but appears to be a promising technology for cost-effective treatment of hazardous waste.

Slurry biodegradation can be the sole treatment technology in a complete cleanup system, or it can be used in conjunction with other biological, chemical, and physical treatment. This technology was selected as a component of the remedy for polychlorinated biphenyl (PCB)-contaminated oils at the General Motors Superfund site at Massena, New York, [11, p. 2]* but has not been a preferred alternative in any record of decision [6, p. 6]. It may be demonstrated in the Superfund Innovative Technology Evaluation (SITE) program. Commercial-scale units are in operation. Vendors should be contacted to determine the availability of a unit for a particular site. This bulletin provides information on the technology applicability, the types of residuals produced, the latest performance data, site requirements, the status of the technology, and sources for further information.

Technology Applicability

Biodegradation is a process that is considered to have enormous potential to reduce hazardous contaminants in a cost-effective manner. Biodegradation is not a feasible treatment method for all sites. Each vendor's process may be capable of treating only some contaminants. Treatability tests to determine the biodegradability of the contaminants and the solids/liquid separation that occurs at the end of the process are very important.

Slurry biodegradation has been shown to be effective in treating highly contaminated soils and sludges that have contaminant concentrations ranging from 2,500 mg/kg to 250,000 mg/kg. It has the potential to treat a wide range of organic contaminants such as pesticides, fuels, creosote, pentachlorophenol (PCP), PCBs, and some halogenated volatile organics. It is expected to treat coal tars, refinery wastes, hydrocarbons, wood-preserving wastes, and organic and chlorinated organic sludges. The presence of heavy metals and chlorides may inhibit the microbial metabolism and require pretreatment. Listed Resource Conservation and Recovery Act (RCRA) wastes it has treated are shown in Table 1[10, p. 106].

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*[Reference number, page number]

Table 1
RCRA-Listed Hazardous Wastes

Wood Treating Wastes	K001
Dissolved Air Floatation (DAF) Float	K048
Slop Oil Emulsion Solids	K049
American Petroleum Institute (API) Separator Sludge	K051

The effectiveness of this slurry biodegradation on general contaminant groups for various matrices is shown in Table 2 [12, p. 13]. Examples of constituents within contaminant groups are provided in Reference 12, "Technology Screening Guide for Treatment of CERCLA Soils and Sludges." This table is based on current available information or professional judgment when no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiency achieved will be acceptable at other sites. For the ratings used for this table, demonstrated biodegradability means that, at some scale, treatability was tested to show that, for that particular contaminant and matrix, the technology was effective. The ratings of potential biodegradability and no expected biodegradability are based upon expert judgment. Where potential biodegradability is indicated, the technology is believed capable of successfully treating the contaminant group. When the technology is not applicable or will probably not work for a particular contaminant group, a no-expected-biodegradability rating is given. Another source of general observations and average removal efficiencies for different treatability groups is contained in the Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS [10], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions," (OSWER Directive 9347.3-07FS [9].

Limitations

The various characteristics limiting the process feasibility, the possible reasons for these, and actions to minimize impacts of these limitations are listed in Table 3 [11, p. 2]. Some of these actions could be a part of the pretreatment process. The variation of these characteristics in a particular hardware design, operation, and/or configuration for a specific site will largely determine the viability of the technology and cost-effectiveness of the process as a whole.

Table 2
Degradability Using Slurry Biodegradation Treatment on General Contaminant Groups for Soils, Sediments, and Sludges

Contaminant Groups		Biodegradability All Matrices
Organic	Halogenated volatiles	▼
	Halogenated semivolatiles	■
	Nonhalogenated volatiles	▼
	Nonhalogenated semivolatiles	■
	PCBs	▼
	Pesticides	■
	Dioxins/Furans	❑
	Organic cyanides	▼
	Organic corrosives	❑
Inorganic	Volatile metals	❑
	Nonvolatile metals	❑
	Asbestos	❑
	Radioactive materials	❑
	Inorganic corrosives	❑
	Inorganic cyanides	▼
Reactive	Oxidizers	❑
	Reducers	❑

■ Demonstrated Effectiveness: Successful treatability test at some scale completed
▼ Potential Effectiveness: Expert opinion that technology will work
❑ No Expected Effectiveness: Expert opinion that technology will not work

Technology Description

Figure 1 is a schematic of a slurry biodegradation process.

Waste preparation (1) includes excavation and/or moving the waste material to the process where it is normally screened to remove debris and large objects. Particle size reduction, water addition, and pH and temperature adjustment are other important waste preparation steps that may be required to achieve the optimum inlet feed characteristics for maximum contaminant reduction. The desired inlet feed characteristics [6, p. 14] are:

Organics:	.025-25%	by weight	Temperature:15-35°C
Solids:	10-40%	by weight	pH: 4.5-8.8
Water:	60-90%	by weight	
Solids particle size:		Less than 1/4"	

After appropriate pretreatment, the wastes are suspended in a slurry form and mixed in a tank (2) to maximize the mass transfer rates and contact between contaminants and microorganisms capable of degrading those contaminants. Aerobic treatment in batch mode has been the most common mode of operation. This process can be performed in contained reactors (3) or in lined lagoons [7, p. 9]. In the latter case, synthetic liners have to be placed in existing unlined lagoons, complicating the operation and maintenance of the system. In this case, excavation of a new lagoon or above-ground tank reactors should be considered. Aeration is provided by floating or submerged aerators or by compressors and spargers. Mixing is provided by aeration alone or by aeration and mechanical mixing. Nutrients and neutralizing agents are supplied to relieve any chemical limitations to microbial activity. Other materials, such as surfactants, dispersants, and compounds supporting growth and inducing degradation of contaminant compounds, can be used to improve the materials' handling characteristics or increase substrate availability for degradation [8, p. 5]. Microorganisms may be added initially to seed the bioreactor or added continuously to maintain the correct concentration of biomass. The residence time in the bioreactor varies with the soil or sludge matrix; physical/chemical nature of the contaminant, including concentration; and the biodegradability of the contaminants. Once biodegradation of the contaminants is completed, the treated slurry is sent to a separation/dewatering system (4). A clarifier for gravity separation, or any standard dewatering equipment, can be used to separate the solid phase and the aqueous phase of the slurry.

Process Residuals

There are three main waste streams generated in the slurry biodegradation system: the treated solids (sludge or soil), the process water, and possible air emissions. The solids are dewatered and may be further treated if they still contain organic contaminants. If the solids are contaminated with inorganics and/or heavy metals, they can be stabilized before disposal. The process water can be treated in an onsite treatment system prior to discharge, or some of it (as high as 90 percent by weight of solids) is usually recycled to the front end of the system for slurrying. Air emissions are possible during operation of the system (e.g., benzene, toluene, xylene [BTX] compounds); hence, depending on the waste characteristics, air pollution control, such as activated carbon, may be necessary [4, p. 29].

Site Requirements

Slurry biodegradation tank reactors are generally transported by trailer. Therefore, adequate access roads are required to get the unit to the site. Commercial units require a setup area of 0.5-1 acre per million gallons of reactor volume.

Standard 440V three-phase electrical service is required. Compressed air must be available. Water needs at the site can be high if the waste matrix must be made into slurry form. Contaminated soils or other waste materials are hazardous and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures.

Climate can influence site requirements by necessitating covers over tanks to protect against heavy rainfall or cold for long residence times.

Large quantities of wastewater that results from dewatering the slurried soil or that is released from a sludge may need to be stored prior to discharge to allow time for analytical tests to verify that the standard for the site has been met. A place to discharge this wastewater must be available.

Onsite analytical equipment for conducting dissolved oxygen, ammonia, phosphorus, pH, and microbial activity are needed for process control. High-performance liquid chromatographic and/or gas chromatographic equipment is desirable for monitoring organic biodegradation.

Performance Data

Performance results on slurry biodegradation systems are provided based on the information supplied by various vendors. The quality assurance for these results has not been evaluated. In most of the performances, the cleanup criteria were based on the requirements of the client; therefore, the data do not necessarily reflect the maximum degree of treatment possible.

Remediation Technologies, Inc.'s (ReTeC) full-scale slurry biodegradation system (using a lined lagoon) was used to treat wood preserving sludges (K0001) at a site in Sweetwater, Tennessee, and met the closure criteria for treatment of these sludges. The system achieved greater than 99 percent removal efficiency and over 99 percent reduction in volume attained for PCP and polynuclear aromatic hydrocarbons (PAHs) (Table 4 and Table 5).

Figure 1
Slurry Biodegradation Process

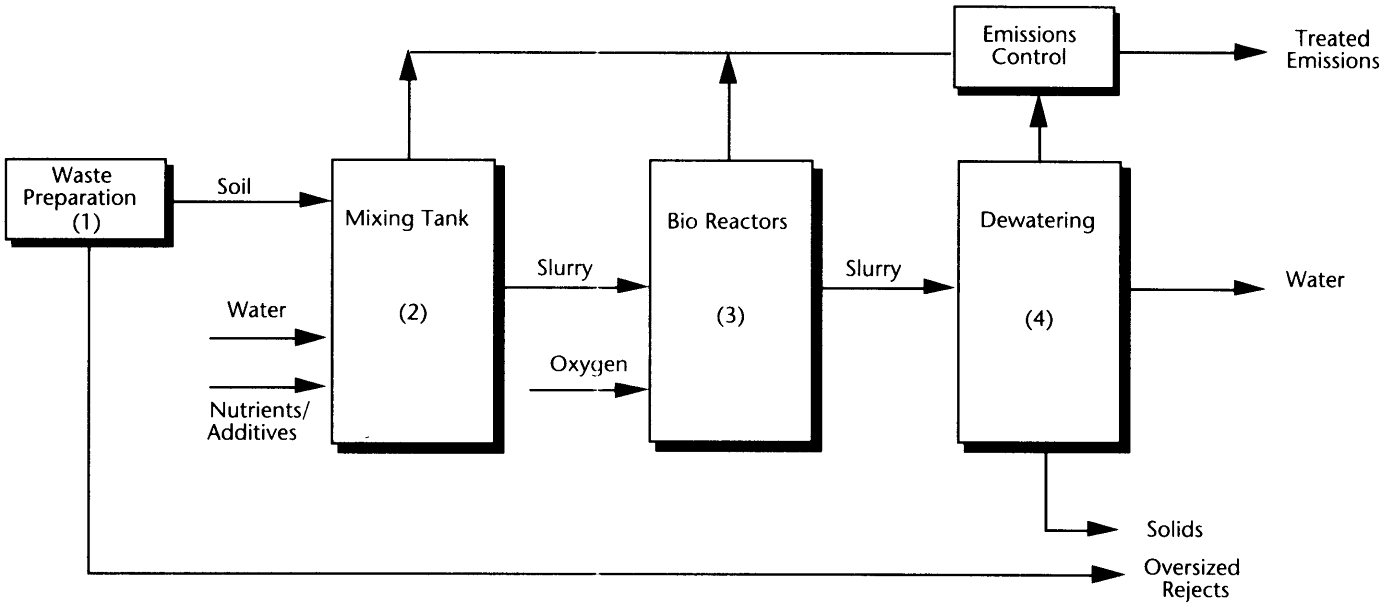


Table 3
Characteristics Limiting the Slurry Biodegradation Process

CHARACTERISTICS LIMITING THE PROCESS FEASIBILITY	REASONS FOR POTENTIAL IMPACT	ACTIONS TO MINIMIZE IMPACTS
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity	Dilution of waste stream. Increase mixing
Nonuniform particle size	Minimize the contact with microorganisms	Physical separation
Water solubility	Contaminants with low solubility are harder to biodegrade	Addition of surfactants or other emulsifiers
Biodegradability	Low rate of destruction inhibits process	Addition of microbial culture capable of degrading particularly difficult compounds or longer residence time
Temperature outside 15-35°C range	Less microbial activity outside this range	Temperature monitoring and adjustments
Nutrient deficiency	Lack of adequate nutrients for biological activity	Nutrient monitoring; adjustment of the carbon/nitrogen/phosphorus ratio
Oxygen deficiency	Lack of oxygen is rate limiting	Oxygen monitoring and adjustments
Insufficient Mixing	Inadequate microbes/solids/organics contact	Optimize mixing characteristics
pH outside 4.5 - 8.8 range	Inhibition of biological activity	Sludge pH monitoring. Addition of acidic or alkaline compounds
Microbial population	Insufficient population results in low biodegradation rates	Culture test, addition of culture strains
Water and air emissions discharges	Potential environmental and/or health impacts	Post-treatment processes (e.g., air scrubbing, carbon filtration)
Presence of elevated, dissolved levels of: • Heavy metals • Highly chlorinated organics • Some pesticides, herbicides • Inorganic salts	Can be highly toxic to microorganisms	Pretreatment processes to reduce the concentration of toxic compounds in the constituents in the reactor to nontoxic range

Table 4
Results Showing Reduction in Concentration for Wood Preserving Wastes

Compounds	Initital Concentration Solids (mg/kg)	Initital Concentration Slurry (mg/kg)	Final Concentration Solids (mg/kg)	Final Concentration Slurry (mg/kg)	Percent Removal Solids (mg/kg)	Percent Removal Slurry (mg/kg)
Phenol	14.6	1.4	0.7	<0.1	95.2*	92.8
Pentachlorophenol	687	64	12.3	0.8	98.2	92.8
Naphthalene	3,670	343	23	1.6	99.3*	99.5*
Phenanthrene & Anthracene	30,700	2,870	200	13.7	99.3	99.5
Fluoranthene	5,470	511	67	4.6	98.8	99.1
Carbazole	1,490	139	4.9	0.3	99.7	99.8

*May be due to combined effect of Volatilization and Biodegradation. [Source: ReTec, 50,000 gal. reactor]

Table 5
Results Showing Reduction in Volume For Wood Preserving Wastes

Compounds	Before Treatment (Total pounds)	After Treatment (Total pounds)	Percent Volume Reduction
Phenol	368	41.4	88.8*
Pentachlorophenol	141,650	193.0	99.9
Naphthalene	179,830	36.6	99.9*
Phenanthrene & Anthracene	2,018,060	303.1	99.9
Fluoranthene	190,440	341.7	99.8
Carbazole	114,260	93.7	99.9

*May be due to combined effect of Volatilization and Biodegradation. [Source: ReTec, 50,000 gal. reactor]

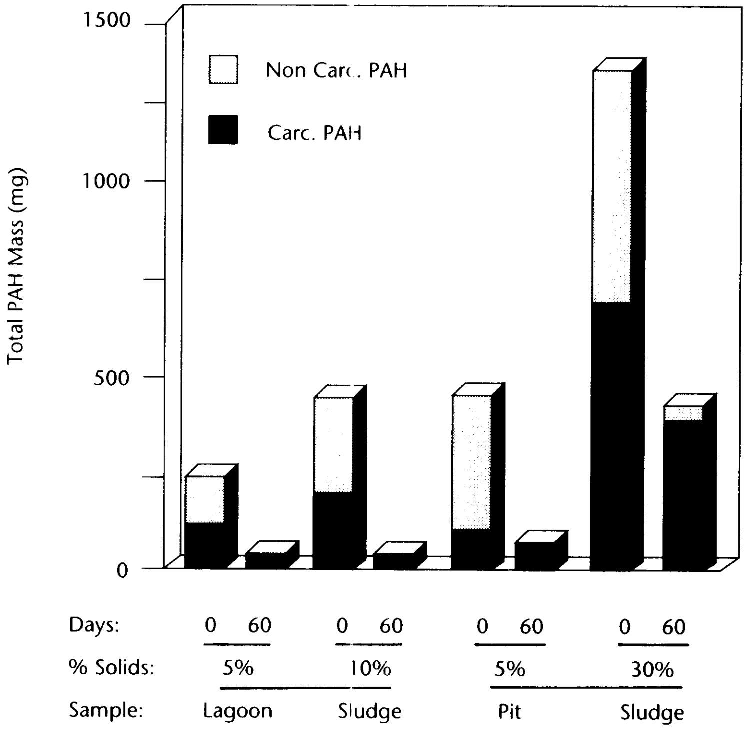
Data for one of these pilot-scale field demonstrations, which treated 72,000 gallons of oil refinery sludges, are shown in Figure 2 [8, p. 24]. In this study, the degradation of PAHs was relatively rapid and varied depending on the nature of the waste and loading rate. The losses of carcinogenic PAHs (principally the 5- and 6-ring PAHs) ranged from 30 to 80 percent over 2 months while virtually all of the noncarcinogenic PAHs were degraded. The total PAH reduction ranged from 70 to 95 percent with a reactor residence time of 60 days.

ECOVA's full-scale, mobile slurry biodegradation unit was used to treat more than 750 cubic yards of soil contaminated with 2,4-Dichlorophenoxy acetic acid (2,4-D) and 4-chloro-2-methyl-phenoxyacetic acid (MCPA) and other pesticides such as alachlor, trifluralin, and carbofuran. To reduce 2,4-D and MCPA levels from 800 ppm in soil and 400 ppm in slurry to less than 20 ppm for both in 13 days, 26,000-gallon bioreactors capable of handling approximately 60 cubic yards of soil were used. The residuals of the process were further treated through land application [3, p. 4]. Field application of the slurry biodegradation system designed by ECOVA to treat PCP-contaminated wastes has resulted in a 99-percent decrease in PCP concentrations (both in solid and aqueous phase) over a period of 24 days [3, p. 5].

Performance data for Environmental Remediation, Inc. (ERI) is available for the treatment of American Petroleum Institute (API) separator sludge and wood-processing wastes. Two lagoons containing an olefin sludge from an API separator were treated. In one lagoon, containing, 4,000 cubic yards of sludge, a degradation time of 21 days was required to achieve 68 percent volume reduction and 62 percent mass oil and grease reduction at an operating temperature of 18°C. In the second lagoon, containing 2,590 cubic yards of sludge, a treatment time of 61 days was required to achieve 61 percent sludge reduction and 87.3 percent mass oil and grease reduction at an operating temperature of 14°C [1, p. 367].

At another site, the total wood-preserving constituents were reduced to less than 50 ppm. Each batch process was

Figure 2
Pilot Scale Results on Oil Refinery Sludges



[Source: ReTeC]

carried out with a residence time of 28 days in 24-foot-diameter, 20-foot-height tank reactors handling 40 cubic yards per batch [6]. The mean concentrations of K001 constituents before treatment and the corresponding concentrations after treatment, for both settled solids and supernatant, are provided in Table 6 [2, p. 11]. The supernatant was discharged to a local, publicly owned wastewater treatment works.

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements (ARARs) for CERCLA response actions. Slurry biodegradation can produce a treated waste that meets treatment levels set by BDAT, but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where slurry biodegradaton does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS) [10] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [9]. Another approach could be to use other treatment techniques in series with slurry biodegradation to obtain desired treatment levels.

Technology Status

Biotrol, Inc. has a pilot-scale slurry bioreactor that consists of a feed storage tank, a reactor tank, and a dewatering system for the treated slurry. It was designed to treat the fine-particle slurry from its soil-washing system. Biotrol's process was included in the SITE program demonstration of its soil-washing system at the MacGillis and Gibbs wood-preserving site in New Brighton, Minnesota, during September and October of 1989. Performance data from the SITE demonstration are not currently available; the Demonstration and Applications Analysis Report is scheduled to be published in late1990.

Table 6
Results of Wood Preserving Waste Treatment

Wood Preserving Waste Constituents	Before treatment	After Treatment	
	In Soil (mg/kg)	In Settled Soil (mg/kg)	In Supernatant (mg/L)
2-Chlorophenol	1.89	<0.01	<0.01
Phenol	3.91	<0.01	<0.01
2,4-Dimethylphenol	7.73	<0.01	<0.01
2,4,6-Trichlorophenol	6.99	<0.01	<0.01
p-Chloro-m-cresol	118.62	<0.01	<0.01
Tetrachlorophenol	11.07	<0.02	<0.02
2,4-Dinitrophenol	4.77	<0.03	<0.03
Pentachlorophenol	420.59	3.1	<0.01
Naphthalene	1078.55	<0.01	0.04
Acenaphthylene	998.80	1.4	1.60
Phenanthrene + Anthracene	6832.07	3.8	3.00
Fluoranthene	1543.06	4.9	16.00
Chrysene + Benz(a)anthracene	519.32	1.4	8.20
Benzo(b)fluoranthene	519.32	<0.03	4.50
Benzo(a)pyrene	82.96	0.1	2.50
Indeno(1,2,3-cd)pyrene + Dibenz(a,h)anthracene	84.88	0.5	1.70
Carbazole	135.40	<0.05	1.70

[Source: Environmental Solutions, Inc.]

ECOVA Corporation has a full-scale mobile slurry biodegradation system. This system was demonstrated in the field on soils contaminated with pesticides and PCP. ECOVA has developed an innovative treatment approach that utilizes contaminated ground water on site as the make up water to prepare the slurry for the bioreactor.

ERI has developed a full-scale slurry biodegradation system. ERI's slurry biodegradation system was used to reduce sludge volumes and oil and grease content in two wastewater treatment lagoons at a major refinery outside of Houston, Texas, and to treat 3,000 cubic yards of wood-preserving waste (creosote-K001) over a total cleanup time of 18 months.

Environmental Solutions, Inc. reportedly has a full-scale slurry biodegradation system, with a treatment capacity of up to 100,000 cubic yards, that has been used to treat petroleum and hydrocarbon sludges.

Groundwater Technology, Inc. reportedly has a full-scale slurry biodegradation system, which employs flotation, reactor, and clarifier/sedimentation tanks in series, that has been used to treat soils contaminated with heavy oils, PAHs, and light organics.

ReTeC's full-scale slurry biodegradation system was used in two major projects: Valdosta, Georgia, and Sweetwater, Tennessee. Both projects involved closure of RCRA-regulated surface impoundments containing soils and sludges contaminated with creosote constituents and PCP. Each project used in-ground, lined slurry-phase bioreactor cells operating at 100 cubic yards per week. Residues were chemically stabilized and further treated by tillage. For final closure, the impoundment areas and slurry-phase cells were capped with clay and a heavy-duty asphalt paving [5]. ReTeC has also performed several pilot-scale field demonstrations with their system on oil refinery sludges (RCRA K048-51).

One vendor estimates the cost of full-scale operation to be $80 to $150 per cubic yard of soil or sludge, depending on the initial concentration and treatment volume. The cost to use slurry biodegradation will vary depending upon the need for additional pre- and post-treatment and the addition of air emission control equipment.

EPA Contact

Technology-specific questions regarding slurry biodegradation may be directed to:

Dr. Ronald Lewis
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