United States Environmental Protection Agency
Office of Emergency and Remedial Response Washington, DC 20460
Office of Research and Development Cincinnati, OH 45268
Superfund
EPA/540/S-94/503
April 1994

EPA

# Engineering Bulletin
# Solvent Extraction

## 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. This bulletin replaces the one on solvent extraction issued in September 1990.

## Abstract

Solvent extraction does not destroy hazardous contaminants, but is a means of separating those contaminants from soils, sludges, and sediments, thereby reducing the volume of the hazardous material that must be treated. Generally it is used as one in a series of unit operations and can reduce the overall cost for managing a particular site. It is applicable to organic contaminants and is generally not used for treating inorganic compounds and metals [1, p.64].* The technology generally uses an organic chemical as a solvent [2, p.30], and differs from soil washing, which generally uses water or water with wash improving additives. Commercial-scale units are in operation. There is no clear solvent extraction technology leader because of the solvent employed, type of equipment used, or mode of operation. The final determination of the lowest cost/best performance alternative will be more site specific than process dominated. 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

Solvent extraction has been shown to be effective in treating sediments, sludges, and soils containing primarily organic contaminants such as polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), halogenated solvents, and petroleum wastes. The technology is generally not used for extracting inorganics (i.e., acids, bases, salts, heavy metals). Inorganics usually do not have a detrimental effect on the extraction of the organic components, and sometimes metals that pass through the process experience a beneficial effect by changing to a less toxic or leachable form. The process has been shown to be applicable for the separation of the organic contaminants in paint wastes, synthetic rubber process wastes, coal tar wastes, drilling muds, wood treating wastes, separation sludges, pesticide/insecticide wastes, and petroleum refinery oily wastes [3].

Table 1 lists the codes for the specific Resources Conservation and Recovery Act (RCRA) wastes that have been treated by the technology [3][4, p.11]. The effectiveness of solvent extraction on general contaminant groups for various matrices is shown in Table 2 [5, p.1][1, p.10]. Examples of constituents within contaminant groups are provided in Reference 1 "Technology Screening Guide for Treatment of CERCLA Soils and Sludges." This table is based on the current available information or professional judgment where 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 efficiencies achieved will be acceptable at other sites. For the ratings used for this table, demonstrated effectiveness means that at some scale treatability was tested to show the technology was effective for that particular contaminant

* [reference number, page number]

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**Table 1**
**RCRA Codes for Wastes Treated by Solvent Extraction**

| | |
|---|---|
| Wood Treating Wastes | K001 |
| Water Treatment Sludges | K044 |
| Dissolved Air Flotation (DAF) Float | K048 |
| Slop Oil Emulsion Solids | K049 |
| Heat Exchanger Bundles Cleaning Sludge | K050 |
| American Petroleum Institute (API) Separator Sludge | K051 |
| Tank Bottoms (leaded) | K052 |
| Ammonia Still Sludge | K060 |
| Pharmaceutical Sludge | K084 |
| Decanter Tar Sludge | K089 |
| Distillation Residues | K101 |

and matrix. The ratings of potential effectiveness or no expected effectiveness are both based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminated group in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no expected effectiveness rating is given.

## Limitations

Organically bound metals can co-extract with the target organic pollutants and become a constituent of the concentrated organic waste stream. This is an unfavorable occurrence because the presence of metals can restrict both disposal and recycle options.

The presence of detergents and emulsifiers can unfavorably influence extraction performance and material throughput. Water soluble detergents found in some raw wastes (particularly municipal) will dissolve and retain organic pollutants in competition with the extraction solvent. This can impede a system's ability to achieve low concentration treatment levels. Detergents and emulsifiers can promote the evolution of foam, which hinders separation and settling characteristics and generally decreases materials throughput. Although methods exist to combat these problems, they will add to the process cost.

When treated solids leave the extraction subsystem, traces of extraction solvent are present [6, p.125]. The typical extraction solvents used in currently available systems either volatilize quickly from the treated solids or biodegrade easily. Ambient air monitoring can be employed to determine if the volatilizing solvents present a problem.

The types of organic pollutants that can be extracted successfully depend, in part, on the nature of the extraction solvent. Treatability tests should be conducted to determine which solvent or combination of solvents is best suited

**Table 2**
**Effectiveness of Solvent Extraction on General Contaminant Groups for Soil, Sludges, and Sediments**

| | *Contaminant Groups* | *Effectiveness* Soil | Sludge | Sediments |
|---|---|---|---|---|
| *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

to the site-specific matrix and contaminants. In general, solvent extraction is least effective on very high molecular weight organics and very hydrophilic (having an affinity for water) substances.

Some commercially available extraction systems use solvents that are flammable, toxic, or both [7, p.2]. However, there are standard procedures used by chemical companies, service stations, etc. that can be used to greatly reduce the potential for accidents. The National Fire Protection Association (NFPA) Solvent Extraction Plants Standard (No. 36) has specific guidelines for the use of flammable solvents [8, p. 4-60].

## Technology Description

Some type of pretreatment is necessary. This may involve physical processing and, if needed, chemical conditioning after the contaminated medium has been removed from its original location. Soils and sediments can be removed by excavation or dredging. Liquids and pumpable sludges can be removed and transported using diaphragm or positive displacement pumps.

Any combination of material classifiers, shredders, and crushers can be used to reduce the size of particles being fed into a solvent extraction process. Size reduction of particles increases the exposed surface area, thereby increasing extraction efficiency. Caution must be applied to ensure that an overabundance of fines does not lead to problems with phase separation between the solvent and treated solids. The optimum particle size varies with the type of extraction equipment used.

Moisture content may affect the performance of a solvent extraction process depending on the specific system design. If the system is designed to treat pumpable sludges or slurries, it may be necessary to add water to solids or sediments to form a pumpable slurry. Other systems may require reduction of the moisture content in order to treat contaminated media effectively.

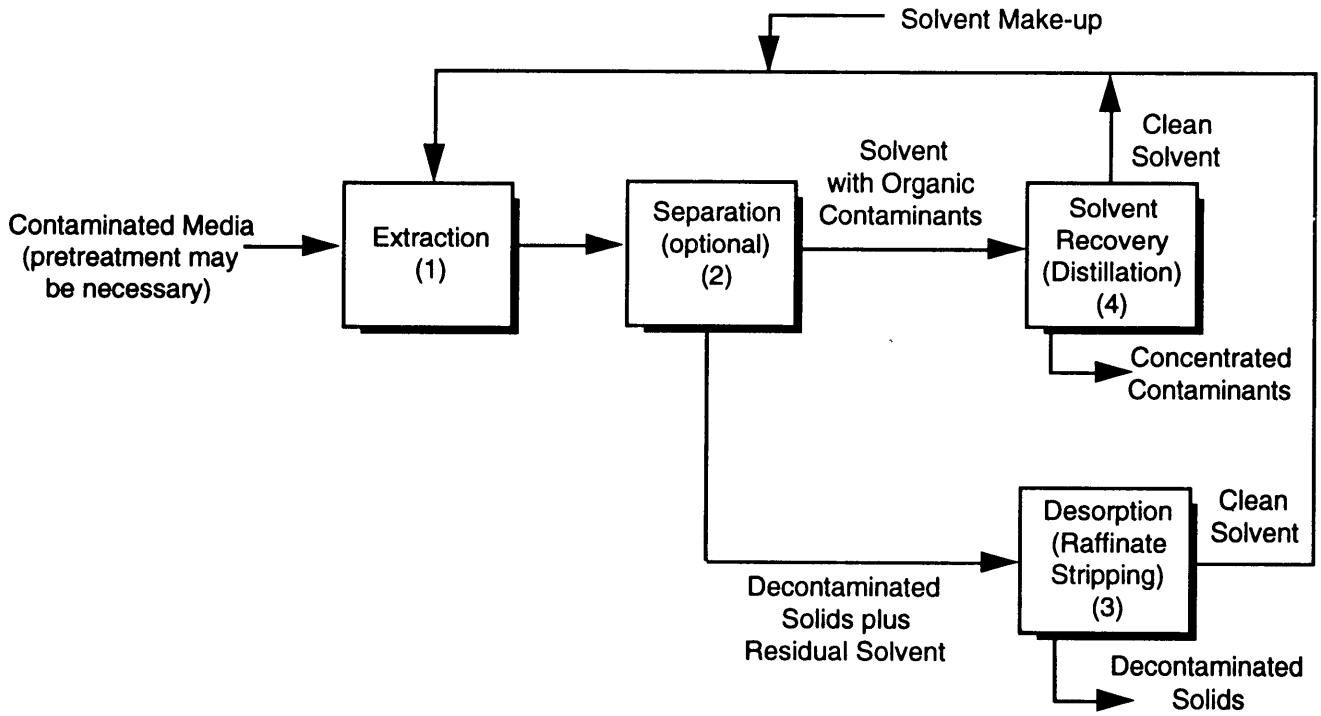
Chemical conditioning may be necessary for some wastes or solvent extraction systems. For example, pH adjustment may be necessary for some systems to ensure solvent stability or to protect process equipment from corrosion.

Depending on the nature of the solvent used, solvent extraction processes may be divided into three general types. These include processes using the following types of solvents: standard, liquefied gas (LG), and critical solution temperature (CST) solvents. Standard solvent processes use alkanes, alcohols, ketones, or similar liquid solvents at or near ambient temperature and pressure. These types of solvents are used to treat contaminated solids in much the same way as they are commonly used by analytical laboratories to extract organic contaminants from environmental samples. LG processes use propane, butane, carbon dioxide, or other gases which have been pressurized at or near ambient temperature. Systems incorporating CST solvents utilize the unique solubility properties of those solvents. Contaminants are extracted at one temperature where the solvent and water are miscible and then the concentrated contaminants are separated from the decanted liquid fraction at another temperature where the solvent has minimal solubility in water. Triethylamine is an example of a CST solvent. Triethylamine is miscible in water at temperatures less than 18°C and only slightly miscible above this temperature.

A general schematic diagram of a standard solvent extraction process is given in Figure 1 [9, p.5]. These systems are operated in either batch or continuous mode and consist of four basic process steps: (1) extraction, (2) separation, (3) desorption, and (4) solvent recovery.

In the first step, solids are loaded into an extraction vessel and the vessel is purged with an inert gas. Solvent is then added and mixed with the solids. Designs of vessels used for the extraction stage vary from countercurrent, continuous-flow systems to batch mixers. The ratio of solvent-to-solids also varies, but normally remains within a range from 2:1 to 5:1. Solvent selection may also be a

**Figure 1**
**General Schematic of a Standard Solvent Extraction Process**



consideration. Ideally, a hydrophilic (having an affinity for water) solvent or mixture of hydrophilic/hydrophobic (lacking an affinity for water) solvents is mixed with the solids. This hydrophilic solvent or solvent mixture will dewater the solids and solubilize organic materials. Subsequent extractions may use only hydrophobic solvents. The contact time and type of solvent used are contaminant-specific and are usually selected during treatability studies.

Depending on the type of contaminated medium being treated, three phases may exist in the extractor: solid, liquid, and vapor. Separation of solids from liquids can be achieved by allowing solids to settle and pumping the contaminant-containing solvent to the solvent recovery system. If gravity separation is not sufficient, filtration or centrifugation may be necessary. Residual solids will normally go through additional solvent washes within the same vessel (for batch systems) or in duplicate reaction vessels until cleanup goals are achieved. The settled solids retain some solvent which must be removed. This is often accomplished by thermal desorption.

Solvent recovery occurs in the final process step. Contaminant-laden solvent, along with the solvent vapors removed during the desorption or raffinate stripping stage, are transferred to a distillation system. To facilitate separation through volatilization and condensation, low boiling point solvents are used for extraction. Condensed solvents are normally recycled to the extractor; this conserves solvent and reduces costs. Water may be evaporated or discharged from the system, and still bottoms, which contain high boiling point contaminants, are recovered for future treatment.

In Figure 2, a general schematic diagram of an LG extraction process is shown [9, p.7]. The same basic steps associated with standard solvent processes are used with LG systems; however, operating conditions are different. Increased pressure and temperature are required in order for the solvent to take on LG characteristics.

Pumps or screw augers move the contaminated feed through the process. In the extractor, the slurry is vigorously mixed with the hydrophobic solvent. The extraction step can involve multiple stages, with feed and solvent moving in countercurrent directions.

The solvent/solids slurry is pumped to a decanting tank where phase separation occurs. Solids settle to the bottom of the decanter and are pumped to a desorber. Here, a reduction in pressure vaporizes the solvent, which is recycled, and the decontaminated slurry is discharged.

Contaminated solvent is removed from the top of the decanter and is directed to a solvent recovery unit. A reduction of pressure results in separating organic contaminants from the solvent. The organic contaminants remain in the liquid phase and the solvent is vaporized and removed. The solvent is then compressed and recycled to the extractor. Concentrated contaminants are removed for future treatment.

CST processes use extraction solvents for which solubility characteristics can be manipulated by changing the temperature of the fluid. Such solvents include those binary (liquid-liquid) systems that exhibit an upper CST (sometimes referred to as upper consolute temperature), a

**Figure 2**
**General Schematic of an LG Solvent Extraction Process**

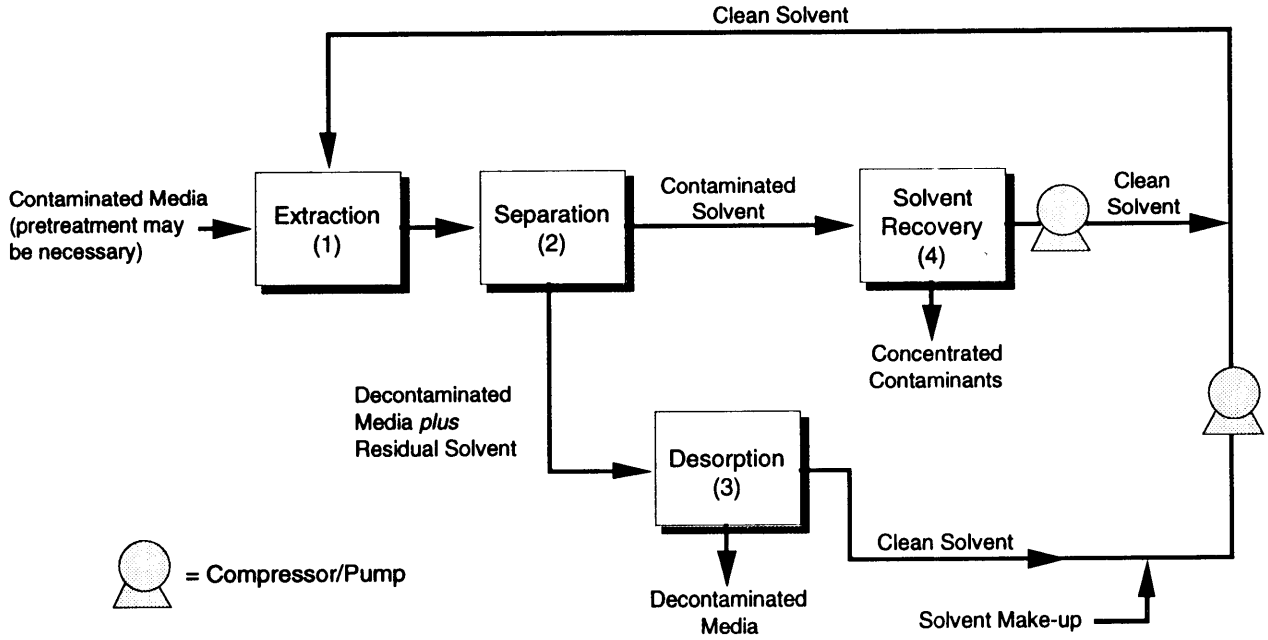
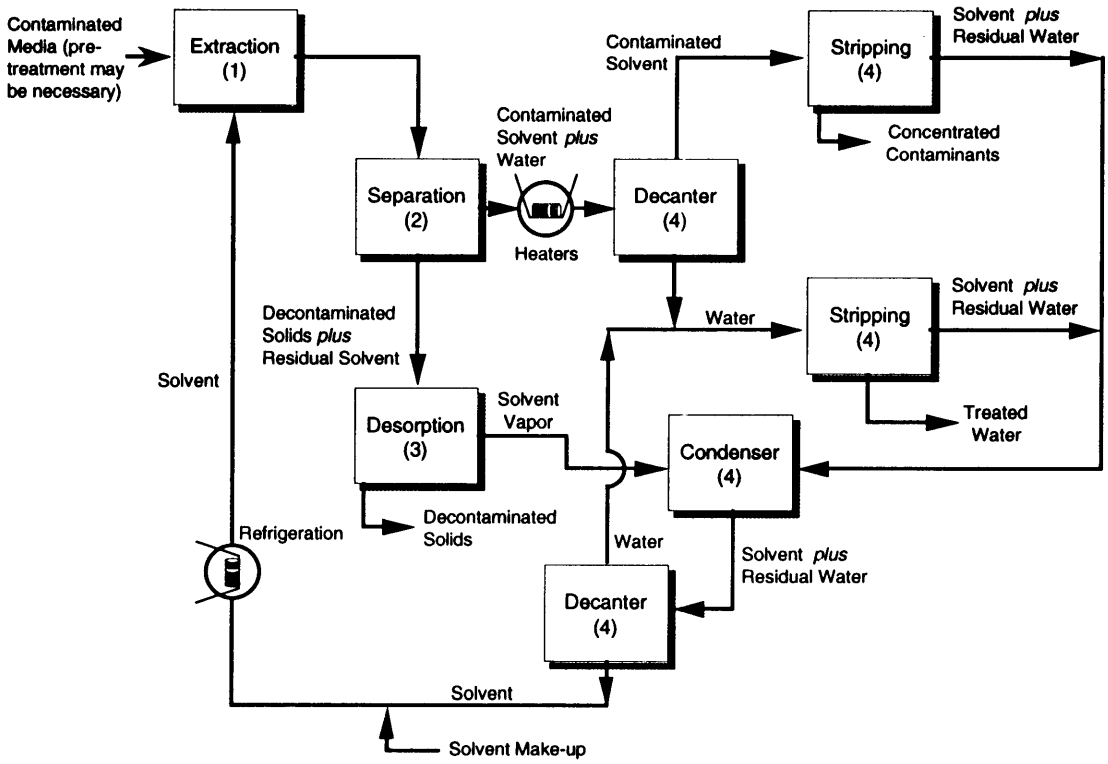


**Figure 3**
**General Schematic of a CST Solvent Extraction Process**




lower CST (sometimes referred to as lower consolute temperature), or both. For such systems, mutual solubilities of the two liquids increase while approaching the CST. At or beyond the CST, the two liquids are completely miscible in each other. Figure 3 is a general schematic of a typical lower CST solvent extraction process. Again, the same four basic process steps are used; however, the solvent recovery step consists of numerous unit operations [9, p.8].

## Process Residuals

Three main product streams are produced from solvent extraction processes. These include treated solids, concentrated contaminants (usually the oil fraction), and separated water. Each of these streams should be analyzed to determine its suitability for recycle, reuse, or further treatment before disposal. Treatment options include: incineration, dehalogenation, pyrolysis, etc.

Depending on the system used, the treated solids may need to be dewatered, forming a dry solid and a separate water stream. The volume of product water depends on the inherent dewatering capability of the individual process, as well as the process-specific requirements for feed slurrying. Some residual solvent may remain in the soil matrix. This can be mitigated by solvent selection, and if necessary, an additional separation stage. Depending on the types and concentrations of metal or other inorganic contaminants present, post-treatment of the treated solids by some other technique (e.g., solidification/stabilization) may be necessary. Since the organic component has been separated, additional solids treatment should be simplified.

The organic solvents used for extraction of contaminants normally will have a limited effect on mobilizing and removing inorganic contaminants such as metals. In most cases, inorganic constituents will be concentrated and remain with the treated solids. If these remain below cleanup levels, no further treatment may be required. Alternatively, if high levels of leachable inorganic contaminants are present in the product solids, further treatment such as solidification/stabilization, soil washing, or disposal in a secured landfill may be required. The exception here is organically bound metals. Such metals can be extracted and recovered with the concentrated contaminant (oil) fraction. High concentrations of specific metals, such as lead, arsenic, and mercury, within the oil fraction can restrict disposal and recycle options.

Concentrated contaminants normally include organic contaminants, oils and grease (O&G), naturally occurring organic substances found in the feed solids, and some extraction fluid. Concentration factors may reduce the

overall volume of contaminated material to 1/10,000 of the original waste volume depending on the volume of the total extractable fraction. The highly-concentrated waste stream which results is either destroyed or collected for reuse. Incineration has been used for destruction of this fraction. Dechlorination of contaminants such as PCBs remains untried, but is a possible treatment. Resource recovery may also be a possibility for waste streams which contain useful organic compounds.

Use of hydrophilic solvents with moisture-containing solids produces a solvent/water mixture and clean solids. The solvent and water mixture are separated from the solids by physical means such as decanting. Some fine solids may be carried into the liquid stream. The solvent is normally separated from the water by distillation [10]. The water produced via distillation will contain water-soluble contaminants from the feed solids, as well as trace amounts of residual solvent and fines which passed through the separation stage. If the feed solids were contaminated with emulsifying agents, some organic contaminants may also remain with the water fraction. Furthermore, the volume of the water fraction can vary significantly from one site to another, and with the use of dewatering as a pretreatment. Hence, treatment of this fraction is dependent upon the concentration of contaminants present in the water and the flowrate and volume of residual water. In some cases, direct discharge to a publicly owned treatment works (POTW) or stream may be acceptable; alternatively, onsite aqueous treatment systems may be used to treat this fraction prior to discharge.

Solvent extraction units are designed to operate without air emissions. Nevertheless, during a recent SITE Demonstration Test, solvent concentrations were detected in 2 of 23 samples taken from the offgas vent system [11]. Corrective measures were taken to remedy this. In addition, emissions of dust and fugitive contaminants could occur during excavation and materials handling operations.

## Site Requirements

Solvent extraction units are transported by trailers. Therefore, adequate access roads are required to get the units to the site. Typical commercial-scale units of 25 to 125 tons per day (tpd) require a setup area of 1,500 to 10,000 square feet [12]. NFPA recommends an exclusion zone of 50 feet around solvent extraction systems operating with flammable solvents [8, p. 4-61].

Standard 440V three-phase electrical service is needed. Depending on the type of system used, between 50 and 10,000 gallons per day (gpd) of water must be available at the site [12]. The quantity of water needed is vendor and site specific.

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. Storage should be provided to hold the process product streams until they have been tested to determine their acceptability for disposal or release. Depending upon the site, a method to store waste that has been prepared for treatment may be necessary. Storage capacity requirements will depend on waste volume.

Onsite analytical equipment for conducting O&G analyses and a gas chromatograph capable of determining site-specific organic compounds for performance assessment will shorten analytical turnaround time and provide better information for process control.

## Performance Data

Full-scale and pilot-scale performance data are currently available from only a few vendors: CF Systems, Resources Conservation Company (RCC), Terra-Kleen Corporation, and Dehydro-Tech Corporation. Lab-scale performance data are also available from these and other vendors. Data from Superfund Innovative Technology Evaluation (SITE) demonstrations are peer-reviewed and have been acquired in independently verified tests with stringent quality standards. Likewise, performance data

**Table 3**
**Contaminant Concentrations in Typical Solids Treated by CF Systems' Process at Port Arthur, Texas Refinery**

| *Compound* | *mg/kg (ppm)* | *BDAT* |
|---|---|---|
| Benzene | BDL | 14 |
| Ethylbenzene | BDL | 14 |
| Toluene | BDL | 14 |
| Xylenes | 1.5 | 22 |
| Naphthalene | 2.2 | 42 |
| Phenanthrene | 3.4 | 34 |
| 2-Methylphenol | BDL | 6.2 |
| Anthracene | BDL | 28 |
| Benzo(a)anthracene | BDL | 28 |
| Pyrene | 1.6 | 36 |
| Chrysene | BDL | 15 |
| Benzo(a)pyrene | BDL | 12 |
| Phenol | BDL | 3.6 |
| 4-Methylphenol | BDL | 6.2 |
| Bis(2-E.H.)phthalate | BDL | 7.3 |
| Di-n-butyl phthalate | BDL | 3.6 |

BDL below detection limits.

from remedial actions at Superfund sites or EPA sponsored treatability tests are assumed to be valid. The quality of other data has not been determined.

The CF Systems' 25-tpd commercial unit treated refinery sludge at Port Arthur, Texas, and operated with an on-line availability of greater than 90 percent. Extraction efficiencies for BTX and polynuclear aromatic hydrocarbon (PAH) compounds were greater than 99 percent. As demonstrated by Table 3, the typical level of organics in the treated solids met or exceeded the EPA Best Demonstrated Available Technology (BDAT) standards required for these listed refinery wastes [13].

Pilot-scale activities include the United Creosoting Superfund Site treatability study and the SITE demonstration at New Bedford Harbor, Massachusetts. During the spring of 1989, CF Systems conducted a pilot-scale treatability study for EPA Region VI and the Texas Water Commission at the United Creosoting Superfund Site in Conroe, Texas. The treatability study's objective was to evaluate the effectiveness of the CF Systems process for treating soils contaminated with pentachlorophenol (PCP), dioxins, and creosote-derived organic contaminants, such as PAHs. Treatment data from the field demonstration (Table 4) show that the total PAH concentration in the soil was reduced by more than 95 percent. Untreated soil had total PAH concentrations ranging from 2,879 to 2,124 mg/kg [13].

The SITE demonstration was conducted during the fall of 1988 to obtain specific operating and cost information for making technology evaluations for use at other Superfund sites. Under the SITE Program, CF Systems demonstrated an overall PCB reduction of more than 90 percent (see Table 5) for harbor sediments with inlet concentrations up to 2,575 ppm [14, p.6]. An extraction solvent blend of propane and butane was used in this demonstration.

**Table 4**
**CF Systems' Performance Data at United Creosote Superfund Site**

| *Compound* | *Feed Soil (mg/kg)* | *Treated Soil (mg/kg)* | *Reduction (percent)* |
|---|---|---|---|
| PAHs | | | |
| Acenaphthene | 360 | 3.4 | 99 |
| Acenaphthylene | 15 | 3.0 | 80 |
| Anthracene | 330 | 8.9 | 97 |
| Benzo(a)anthracene | 100 | 7.9 | 92 |
| Benzo(a)pyrene | 48 | 12 | 75 |
| Benzo(b)fluoranthene | 51 | 9.7 | 81 |
| Benzo(g,h,i)perylene | 20 | 12 | 40 |
| Benzo(k)fluoranthene | 50 | 17 | 66 |
| Chrysene | 110 | 9.1 | 92 |
| Dibenzo(a,h)anthracene | ND | 4.3 | NA |
| Fluoranthene | 360 | 11 | 97 |
| Fluorene | 380 | 3.8 | 99 |
| Indeno(1,2,3-cd)pyrene | 19 | 11 | 58 |
| Naphthalene | 140 | 1.5 | 99 |
| Phenanthrene | 590 | 13 | 98 |
| Pyrene | 360 | 11 | 97 |
| Total PAH concentration | 2879 | 122.6 | 96 |

Notes: mg/kg on a dry weight basis. ND indicates not detected. NA indicates not applicable.

**Table 5**
**Extraction of New Bedford Harbor Sediments Using CF Systems' Process**

| *Test #* | *Initial PCB Concentration (ppm)* | *Final PCB Concentration (ppm)* | *Reduction (Percent)* | *Number of Passes Through Extractor* |
|---|---|---|---|---|
| 1 | 350 | 8 | 98 | 9 |
| 2 | 288 | 47 | 84 | 1 |
| 3 | 2,575 | 200 | 92 | 6 |

**Table 6**
**B.E.S.T.® Process Data from the General Refining Superfund Site**

| *Metals* | *Initial Concentration (mg/kg)* | *Product Solids Metal (ppm)* | *TCLP Levels (ppm)* |
|---|---|---|---|
| As | <0.6 | <0.5 | <0.0 |
| Ba | 239 | 410 | <0.03 |
| Cr | 6.2 | 21 | <0.05 |
| Pb | 3,200 | 23,000 | 5.2 |
| Se | <4.0 | <5.0 | 0.008 |

The ability of the RCC full-scale B.E.S.T.® process to separate oil feedstock into product fractions was evaluated by the EPA at the General Refining Superfund Site near Savannah, Georgia, in February 1987. The test was conducted with the assistance of EPA's Region X Environmental Services Division in cooperation with EPA's Region IV Emergency Response and Control Branch [15, p.1]. The site was operated as a waste oil reclamation and re-refining facility from the early 1950s until 1975. As a result of those activities, four acidic oily sludge ponds with high levels of heavy metals (Pb= 200 to 10,000 ppm, Cu= 83 to 190 ppm) and detectable levels of PCBs (2.9 to 5 ppm) were produced. The average composition of the sludge from the four lagoons was 10 percent oil, 20 percent solids, and 70 percent water by weight [15, p.13]. The transportable 70-tpd B.E.S.T.® unit processed approximately 3,700 tons of sludge at the General Refining Site. The treated solids from this unit were backfilled to the site, product oil was recycled as a fuel oil blend, and the recovered water was pH adjusted

**Table 7**
**Summary of Results from the SITE Demonstraton of the RCC B.E.S.T.® Process**
**(Averages from Three Runs)**

| | *Transect 28 Sediment* | | | *Transect 6 Sediment* | | |
|---|---|---|---|---|---|---|
| *Parameter* | *PCBs* | *PAHs* | *Triethylamine* | *PCBs* | *PAHs* | *Triethylamine* |
| Concentration in Untreated Sediment, mg/kg | 12.1 | 550 | NA | 425 | 70,900 | NA |
| Concentration in Treated Solids, mg/kg | 0.04 | 22 | 45.1 | 1.8 | 510 | 103 |
| Removal from Sediment, percent | 99.7 | 96.0 | NA | 99.6 | 99.3 | NA |
| Concentration in Oil Product, mg/kg | NA[1] | NA[1] | NA[1] | 2,030 | 390,000 | 733[2] |
| Concentration in Water Product, mg/L | <0.003 | <0.01 | 1.0 | <0.001 | <0.01 | 2.2 |

NA Not applicable.

[1] The Transect 28 oil product was sampled at the end of the last run conducted on Transect 28 material. When the oil was sampled, there was not sufficient oil present for oil polishing (using the solvent evaporator to remove virtually all of the triethylamine for the oil). Excess triethylamine was therefore left in the oil.

[2] This oil product was sampled following oil polishing.

and transported to a local industrial wastewater treatment facility. Test results (Table 6) showed that the heavy metals were mostly concentrated in the solids product fraction. Toxicity Characteristic Leaching Procedure (TCLP) test results showed heavy metals to be in stable forms that resisted leaching, illustrating a potential beneficial side effect when metals are treated by the process [4, p.13].

During the summer of 1992 a SITE demonstration was conducted to test the ability of the B.E.S.T.® system to remove PAHs and PCBs from contaminated sediments obtained from the Grand Calumet River. The pilot-scale B.E.S.T.® system was primarily contained on two skids and had an average daily capacity of 90 pounds of contaminated sediments. As Table 7 demonstrates, more than 96 percent of the PAHs and greater than 99 percent of the PCBs initially present in the sediments collected from Transect 6 and Transect 28 of the Grand Calumet River were removed [16].

Terra-Kleen Corporation has compiled remedial results for its solvent extraction system at three sites; Treband Superfund site, in Tulsa, Oklahoma; Sand Springs Substation site; Sand Springs, Oklahoma; and Pinette's Salvage Yard Superfund site, Washburn, Maine. PCBs were the primary contaminant at each of these sites. Table 8 summarizes the performance at the Treband site. Preliminary results from the Pinette's Salvage Yard site are given in Table 9 [17].

The Carver-Greenfield (C-G) Process®, developed by Dehydro-Tech Corporation, was evaluated during a SITE demonstration at an EPA research facility in Edison, New Jersey. During the August 1991 test, about 640 pounds of drilling mud contaminated with indigenous oil and elevated levels of heavy metals were shipped to EPA in Edison, New Jersey from the PAB Oil Site in Abbeville, Louisiana. The pilot-scale unit was trailer-mounted and capable of treating about 100 lbs/hr of contaminated drilling mud. The process removed about 90 percent of the indigenous oil (as measured by solids/oil/water analysis). The indigenous total petroleum hydrocarbon (TPH) removals were essentially 100 percent for both runs [18, p. 1].

E. S. Fox Limited has determined performance data for the Extraksol® Process developed by Sanivan Group of Montreal, Quebec, Canada. Performance data on contaminated soils and refinery wastes for the 1 ton per hour (tph) mobile unit are shown in Table 10 [19]. The process uses a proprietary solvent that reportedly achieved removal efficiencies up to 99 percent (depending on the number of extraction cycles and the type of soil) on solids with contaminants such as PCBs, O&G, PAHs, and PCP.

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to BDAT levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements (ARARs) for CERCLA response actions. The solvent extraction technology 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 solvent extraction 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, September 1990) [20], and Superfund LDR Guide #6B, "Obtaining a

**Table 8**
**Terra-Kleen Soil Restoration Unit PCB Removal at Treband Superfund Site[1]**

| *Initial Level (ppm)* | *Final Level (ppm)* | *Site Goal (ppm)* | *Reduction (percent)* |
|---|---|---|---|
| 740 | 77 | <100 | 89.6 |
| 810 | 3 | <100 | 99.6 |
| 2,500 | 93 | <100 | 96.3 |

[1] Soil type: sand and concrete dust.

**Table 9**
**Terra-Kleen Soil Restoration Unit PCB Removal at Pinette's Salvage Yard NPL Site[1]**

| *Initial Level (ppm)* | *Final Level (ppm)* | *Site Goal (ppm)* | *Reduction (percent)* |
|---|---|---|---|
| 41.8 | 2.7 | <5.0 | 93.5 |
| 76.9 | 4.31 | <5.0 | 94.4 |
| 381 | 3.59 | <5.0 | 99.1 |

[1] Full scale data. Soil type: glacial till (gravel, sand, silt, and grey marine clay).

Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-06BFS, September 1990) [21]. Another approach would be to use other treatment techniques in series with solvent extraction to obtain desired treatment levels.

## Technology Status

As of October 1992, solvent extraction has been chosen as the selected remedy at eight Superfund sites. Two of these, General Refining,Georgia and Treband Warehouse, Oklahoma were emergency responses that have been completed. The other sites include Norwood PCBs, Massachusetts; O'Conner, Maine; Pinette's Salvage Yard, Maine; Ewan Property, New Jersey; Carolina Transformer, North Carolina; United Creosoting, Texas [22, p. 51].

Solvent extraction systems are at various stages of development. The following is a brief discussion of several systems that have been identified.

CF Systems uses liquefied hydrocarbon gases such as propane and butane as solvents for separating organic contaminants from soils, sludges, and sediments. To date, the CF Systems process has been used in the field at three Superfund sites; nine petrochemical facilities and remediation sites; and a centralized treatment, storage, and disposal (TSD) facility. The CF Systems solvent extraction technology is available in several commercial sizes and the Mobile Demonstration Unit is available for onsite treatability studies. CF Systems has supplied three commercial-scale extraction units for the treatment of a variety of wastes [23, p.3-12]. A 60-tpd treatment system was designed to extract organic liquids from a broad range of hazardous waste feeds at ENSCO's El Dorado, Arkansas, incinerator facility. A commercial-scale extraction unit is installed at a facility in Baltimore, Maryland, to remove organic contaminants from a 20 gallons- per-minute (gpm) wastewater stream. A PCU-200 extraction unit was installed and successfully operated at the Star Enterprise (Texaco) refinery in Port Arthur, Texas. This unit was designed to treat listed refinery wastes to meet or exceed the EPA's BDAT standards. A 220 tpd extraction unit is currently being designed for use at the United Creosoting Superfund site in Conroe, Texas.

**Table 10**
**Summary of 1-tph Extrasol® Process Performance Data**

| *Contaminant* | *Matrix* | *In (ppm)* | *Out (ppm)* | *Reduction (percent)* |
|---|---|---|---|---|
| O&G | Clayey Soil | 1,800 | 182 | 89.9 |
| O&G | Oily Sludge | 72,000 | 2,000 | 97.2 |
| O&G | Fuller's Earth | 313,000 | 3,700 | 98.8 |
| PAH | Clayey Soil | 332 | 55 | 83.4 |
| PAH | Oily Sludge | 240 | 10 | 95.8 |
| PCB | Clayey Soil | 150 | 14 | 90.7 |
| PCB | Clayey Soil | 54 | 4.4 | 91.8 |
| PCP | Porous Gravel | 81.4 | <0.21 | 99.7 |
| PCP | Activated Carbon | 744 | 83 | 88.8 |

Note: Treated concentrations are based on criteria to be met and not process efficiency

RCC's B.E.S.T.® system uses aliphatic amines (typically triethylamine) as the solvent to separate and recover contaminants in either batch or continuous operation [4, p.2]. It can extract contaminants from soils, sludges, and sediments. In batch mode of operation, a pumpable waste is not required. RCC has a transportable B.E.S.T.® pilot-scale unit available to treat soils and sludges. This pilot-scale equipment was used at a Gulf Coast refinery treating various refinery waste streams and treated PCB-contaminated soils at an industrial site in Ohio during November of 1989. A full-scale unit with a nominal capacity of 70 tpd was used to clean 3,700 tons of PCB-contaminated petroleum sludge at the General Refining Superfund Site in Savannah, Georgia, in 1987 [16].

Terra-Kleen Corporation's Soil Restoration Unit was developed for remedial actions involving soil, debris, and sediments contaminated with organic compounds. The

Soil Restoration Unit is a mobile system which uses various combinations of up to 14 patented solvents, depending upon target contaminants present. These solvents are non-toxic and not listed hazardous wastes [17].

Dehydro-Tech Corporation's C-G Process is designed for the cleanup of Superfund sites with sludges, soils, or other water-bearing wastes containing hazardous compounds, including PCBs, polycyclic aromatics, and dioxins. A transportable pilot-scale system capable of treating 30 to 50 lbs/hr of solids is available. Over 80 commercial C-G Process facilities have been licensed in the past 30 years to solve industrial waste disposal problems. More than half of these plants were designed to dry and remove oil from slaughterhouse waste (rendering plants) [12].

NuKEM Development Company/ENSR developed a technique to remove PCBs from soils and mud several years ago. Their solvent extraction method involves acidic conditions, commercially available reagents to prepare the soil matrix for exposure to the solvent, and ambient temperatures and pressures [24]. NuKEM Development Company/ENSR is not currently marketing this technology for the treatment of contaminated soils and sludges. Another application being reviewed is the treatment of refinery sludges (K wastes and F wastes). The Solvent Extraction Process (SXP) system developed for treating these wastes has six steps; acidification, dispersion, extraction, raffinate solvent recovery, stabilization/filtration, and distillation. A pilot-scale SXP system has performed tests on over 20 different sludges. According to the vendor, preliminary cost estimates for treating 5,000 tons per year of a feed with 10 percent solids and 10 percent oil appear to be less than $300 per ton [25].

The Extraksol® process was developed in 1984 by Sanivan Group, Montreal, Quebec, Canada [26, p.35]. It is applicable to treatment of contaminated soils, sludges, and sediments [26, p.45]. The 1-tph unit is suitable for small projects with a maximum of 300 tons of material to be treated. A transportable commercial scale unit, capable of processing up to 8 tph, was constructed by E.S. Fox Ltd. At present, the assembled unit is available for inspection at the fabricator's facility in Welland, Ontario, Canada. [19].

The Low Energy Extraction Process (LEEP), developed by ART International, Inc., is a patented solvent extraction process that can be used on-site for decontaminating soils, sludges and sediments. LEEP uses common organic solvents to extract and concentrate organic pollutants such as PCB, PAH, PCP, creosotes, and tar derived chemicals [27, p.250]. Bench-scale studies were conducted on PCB contaminated soils and sediments, base neutral contaminated soils and oil refinery sludges. ART has designed and constructed a LEEP Pilot Plant with a nominal solids throughput of 200 lbs/hr [12]. The pilot plant has been operational since March 1992. Recently, a 13 tph (dry basis) commercial facility capable of treating soil contaminated with up to 5 percent tar was completed for a former manufactured gas plant site.

Phønix Miljø, Denmark has developed the Soil Regeneration Plant, a 10 tph transportable solvent extraction process. This process consists of a combined liquid extraction and steam stripping process operating in a closed loop. A series of screw conveyors is used to transfer the contaminated soil through the process. Contaminants are removed from soil in a countercurrent extraction process. A drainage screw separates the soil from the extraction liquid. The extraction liquid is distilled to remove contaminants and is then recycled. The soil is steam heated to remove residual contaminants before exiting the process [28].

Cost estimates for solvent extraction range from $50 to $900 per ton [12]. The most significant factors influencing costs are the waste volume, the number of extraction stages, and operating parameters such as labor, maintenance, setup, decontamination, demobilization, and lost time resulting from equipment operating delays. Extraction efficiency can be influenced by process parameters such as solvent used, solvent/waste ratio, throughput rate, extractor residence time, and number of extraction stages. Thus, variation of these parameters, in particular hardware design and/or configuration, will influence the treatment unit cost component but should not be a significant contributor to the overall site costs.

## EPA Contact

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