United States
Environmental Protection
Agency

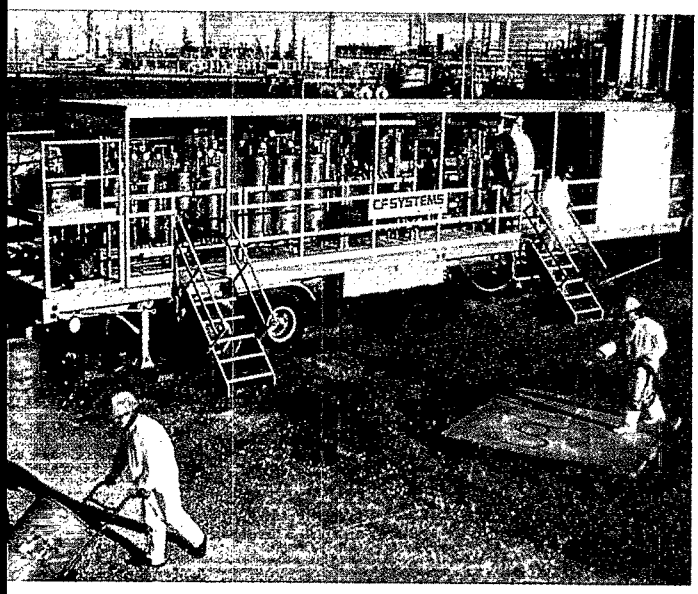
Office of Research
and Development
Washington, D.C. 20460

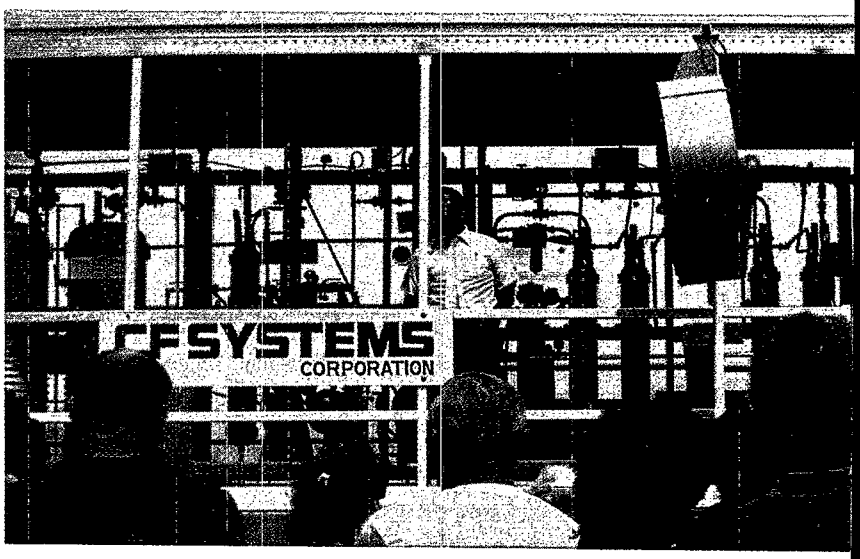
EPA/540/A5-90/002
August 1990

EPA

CF Systems Organics Extraction Process New Bedford Harbor, MA

Applications Analysis Report





SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/A5-90/002
August 1990

CF Systems Organics Extraction Process New Bedford Harbor, Massachusetts Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency under Contract No. 68-03-3485 and the Superfund Innovative Technology Evaluation (SITE) Program. It has been subjected to the Agency's peer review and administrative review and it has been approved for publication as a USEPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The SITE program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards that require greater reliance on permanent remedies. This is accomplished through technology demonstrations that are designed to provide engineering and cost data on selected technologies.

This project consists of an analysis of CF Systems' proprietary organics extraction process. The technology demonstration took place at the New Bedford Harbor Superfund site, where harbor sediments are contaminated with polychlorinated biphenyls and other toxics. The demonstration effort was directed at obtaining information on the performance and cost of the process for use in assessments at other sites. Documentation will consist of two reports. A Technology Evaluation Report described the field activities and laboratory results. The Applications Analysis provides an interpretation of the data and conclusions on the results and potential applicability of the technology including a projection of costs from the demonstrated pilot unit to a full-scale commercial unit.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA 22161, (703) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or 382-3000 in Washington, DC, to inquire about the availability of other reports.

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Demonstration

Abstract

The SITE Program Demonstration of the CF Systems organics extraction technology was conducted to obtain specific operating and cost information that could be used in evaluating the potential applicability of the technology to Superfund sites. The demonstration was conducted concurrently with dredging studies managed by the U.S. Army Corps of Engineers at the New Bedford Harbor Superfund site in Massachusetts. Contaminated sediments were treated by CF Systems' Pit Cleanup Unit (PCU) that used a liquefied propane and butane mixture as the extraction solvent. The PCU was a trailer-mounted system with a design capacity of 1.5 gallons per minute (gpm), or 20 barrels per day (bbl/day). The technology extracts organics from contaminated soils based on solubility of organics in a mixture of liquefied propane and butane.

The objectives included an evaluation of (1) the unit's performance, (2) system operating conditions, (3) health and safety considerations, (4) equipment and system materials handling problems, and (5) projected system economics. The conclusions drawn from the test results and other available data are:

- Polychlorinated biphenyl (PCB) extraction efficiencies of 90 percent were achieved for New Bedford Harbor sediments containing PCBs ranging from 350 to 2,575 parts per million (ppm). Concentrations of PCBs in the clean sediment were as low as 8 ppm.
- Extraction efficiencies of 95 percent are demonstrated in the laboratory for volatile and semivolatile organics contained in aqueous and semisolid waste matrices.
- Some operating problems occurred during the SITE tests, such as intermittant retention of solids in system hardware and foaming in the treated sediment collection tanks. Corrective measures were identified, and will be incorporated in the full-scale commercial unit.
- Operation of the PCU at New Bedford did not present any threats to the health and safety of operators or the local community.
- The projected cost of applying the technology to a full-scale cleanup at New Bedford Harbor ranges from $148 to $447 per ton. These projections include pre- and post-treatment costs, material handling costs, and costs for a specialized process configuration designed to remediate sediments, however the post-treatment cost did not include the final destruction of the concentrated extract.
- Site specific pre- and post-treatment costs account for approximately one-third of the estimated costs.
- The predicted onstream factor for the full-scale commercial unit is the variable that introduces the greatest uncertainty to the cost estimates.

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Acknowledgments

This report was prepared under the direction and coordination of Richard Valentinetti, EPA SITE Program Manager in the Office of Environmental Engineering & Technology Development in Washington, D.C. Contributors and reviewers for this report were Frank Ciavattieri of EPA Region I, Remedial Project Manager for the New Bedford Harbor Superfund Site; Jim Cummings from the Office of Solid Waste and Emergency Response; Paul de Percin, Gordon Evans, Diana Guzman, and Laurel Staley from the Office of Research and Development; Christopher Shallice and Thomas Cody, Jr. from CF Systems Corporation; and Alan Fowler of EBASCO Services, Inc.

This report was prepared for EPA's SITE Program by Science Applications International Corporation (SAIC), McLean, VA, for the U.S. Environmental Protection Agency under Contract No. 68-03-3485, by Don Davidson, John Bonacci, Richard Hergenroeder, and Omer Kitaplioglu. Laboratory analyses were conducted by E.C. Jordan, Inc., Portland, ME, and Radian Corp, Austin, TX.

Abbreviations and Symbols

amps	amperes
ASTM	American Society for Testing and Materials
bbl/day	barrels per day
BDAT	best demonstrated available technology
BNAs	base/neutral and acid extractable compounds
Cd	cadmium
COE	U.S. Army Corps of Engineers
cP	centipoise
Cr	chromium
CR	column reboiler
Cu	copper
CWA	Clean Water Act
dPa.s	decapascal.seconds
ECD	electron capture detector
EPA	Environmental Protection Agency
EPT	extract product tank
EP Tox	Extraction Procedure Toxicity Test - leach test
F	Fahrenheit
FK	feed kettle
g	grams
GC	gas chromotography
gpd	gallons per day
gpm	gallons per minute
kw-hr	kilowatt hours
lbs	pounds
lb/gal	pounds per gallon
lb/min	pounds per minute
max	maximum
MBAS	methylene blue active substances
mg	milligrams
mg/kg	milligrams per kilogram
min	minimum
ms	mass spectrometry
MSA	method of standard additions
MS/MSD	matrix spike/matrix spike duplicate
ND	not detected
NIOSH	National Institute of Occupational Safety and Health
NR	not reported
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
OVA	organic vapor analyzer
oz	ounces
PAHs	polyaromatic hydrocarbons
Pb	lead
PCBs	polychlorinated biphenyls
PCU	Pit Cleanup Unit
PNAs	polynuclear aromatics
ppm	parts per million
psig	pounds per square inch gauge
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act of 1976
RPD	relative percent difference
RREL	Risk Reduction Engineering Laboratory
RSD	relative standard deviation
SARA	Superfund Amendments and Reauthorization Act of 1986
SBT	still bottoms tank
SITE	Superfund Innovative Technology Evaluation Program
SRC	solvent recovery column
TDS	total dissolved solids
TS	total solids
TSD	treatment, storage, and disposal
TSS	total suspended solids
VAC	volts, alternating current
VOAs	volatile organic analytes
Zn	zinc
<	less than

Section 1
Executive Summary

1.1 Summary

The CF Systems Corporation pilot-scale soil treatment technology was tested and evaluated under EPA's Superfund Innovative Technology Evaluation (SITE) Program. The technology uses a mixture of liquefied propane and butane as a solvent to extract organics from harbor sediments. Successful application of the technology depended on the ability of the organic pollutants to be solubilized by the solvent. Mixing solvent with waste seeks to achieve intimate contact between the solvent and the contaminants. Variables include solvent-to-feed ratios, mixing energy, and residence time in the reactor. Following decanting of the solvent-organics mixture from the solids and water, pressure reduction vaporizes the solvent and separates it from the organics. The solvent is recovered and compressed to a liquid for reuse. The separated organics are collected for disposal. Treated soil may require dewatering. Soil that meets cleanup standards can be returned to the site. Water that meets applicable standards can be discharged directly to a stream or to a Publicly Owned Treatment Works.

Solvent extraction technology relies upon the preferential solubility of organics in certain solvents versus the soil and water in which the contaminants are found in environmental matrices. Application of solvent extraction at Superfund sites is essentially a pretreatment step, resulting in significant reductions in the amount of material that must be subjected to further treatment, e.g., incineration. Thus, in soils contaminated with oil and grease at 1,000 ppm (0.1 percent), the amount of material requiring incineration would be reduced by a factor of 1,000 (assuming a removal efficiency of 99 percent).

Removal efficiency depends on a number of factors including the ability of the technology to bring the solvent into proximity with the contaminant(s) and the degree to which the contaminants prefer the solvent to the medium in which they are located.

CF Systems also markets a wastewater treatment system that uses liquefied carbon dioxide as the solvent. This system was not tested under the SITE Program.

1.2 Conclusions

The conclusions drawn from reviewing limited operational data on the CF Systems technology, both from the SITE evaluation tests and from the information supplied by the developer, are:

- The soils treatment system was tested on sediments obtained from New Bedford Harbor in Massachusetts that contained PCBs at 350 and 2,575 ppm concentration levels. A pilot-scale mobile unit was used for this test. This unit required recycle of product to simulate the operation of a full-scale, four-stage unit. This mode of operation caused material handling problems which in turn restricted process throughput. The multiple-pass mode of the demonstration limits our ability to extrapolate to full-scale units intended to be operated in a once-through mode.
- The technology can separate organics from harbor sediments, sludges, and soils. PCB extraction efficiencies greater than 90 percent were achieved for New Bedford Harbor sediments and attained levels as low as 8 ppm for PCBs. CF Systems' pilot-scale unit has also been successfully demonstrated at petroleum refineries, petrochemical plants, and hazardous waste treatment storage and disposal facilities.
- The technology can also separate organics from wastewater; however, the mixing equipment and solvent used are different from that used for sludges and soils. Although the SITE program tests were conducted only on the soils treating unit, some information is presented in this report on the wastewater treatment unit.
- Operational control was difficult to maintain during the New Bedford Harbor tests. Solvent flow fluctuated widely and caused the solvent-to-feed ratio to fall below specifications. Solids were retained in process hardware, solids were observed in organic extracts, and foaming of treated sediments also occurred. The vendor

believes that these problems are correctable by equipment design changes and by operating in a once-through mode instead of a recycle mode.

- Bench-scale test results show the potential for extraction of a broad range of organics from wastewater, groundwater, and semi solids. These tests were useful for determining whether or not organics contained in a waste matrix will be extracted by a liquefied solvent such as carbon dioxide or propane. Laboratory results indicated that equilibrium conditions did not limit reduction of solid PCB content to levels of 10 ppm.
- Pretreatment technology may be necessary to condition feed materials. Coarse solids removal may be required to maintain feed sediment particle sizes below three-sixteenths inch; water must be added to viscous sludges or dry soils and heat must be supplied to feeds less than 60 degrees Fahrenheit. Post-treatment technology also may be necessary such as thermal destruction of the concentrated extract. In some cases, the cleaned material could be subjected to further treatment.
- Water addition during the SITE Demonstration to achieve required viscosities increased the mass of waste by about 33 percent. Such water addition may result in a requirement for post-treatment dewatering.
- Costs for implementing the CF Systems' technology at New Bedford Harbor were projected based on an economic model. Since a full-scale unit has been placed in the field only recently, operating and cost data for a full-scale system were not available. The estimated cost for removing 90 percent of the PCBs from New Bedford Harbor sediments containing 580 ppm is $148 per ton, which includes pre- and post-treatment costs. The cost for removing 99.9 percent of the PCBs from New Bedford Harbor "hot spots" containing 10,000 ppm is $447 per ton including pre- and post-treatment costs. These costs represent a range of costs anticipated for full-scale application of the technology at New Bedford Harbor. Approximately one-third of the estimated costs are pre- and post-treatment costs. These cost estimates did not include the final destruction of the concentrated extract.
- CF Systems has designed and fabricated a 50-ton-per-day (200 barrels/day) soils treatment unit for Star Enterprises, Inc.facility (Texaco) in Port Arthur, Texas, to treat API separator sludge. Oils extracted from the sludge will be recovered for reuse. CF Systems has agreed to allow the SITE program to monitor the operation of this unit to demonstrate that operability parameters associated with materials handling and on-stream factors are within commercial design claims.

1.3 Applications Analysis

Applications of the CF Systems organics extraction technology depend on waste characteristics, waste volume, and degree of pollutant removal required. Waste characteristics determine the type of solvent to be used and the need for pre- and post-treatment. If a waste contains organics, such as PCBs and PAHs, that are not very soluble in water then a hydrocarbon solvent, such as propane or a propane and butane mixture, is used. Less soluble organics are typically sorbed to soil particles found in sludges, therefore propane is commonly used to extract organics from soils and sludges.

Pre- and post-treatment must be considered if feed materials (1) contain gravel or cobbles, (2) are below 60 degrees F, or (3) are not pumpable. For wastewaters and groundwaters that are relatively free of solids, liquefied carbon dioxide is the preferred extraction solvent since this solvent seeks polar materials in water, is nontoxic, and has favorable thermodynamic properties. CF Systems initially assesses feed materials by conducting bench-scale tests in the laboratory. If bench-scale tests are successful, pilot-scale tests are run with either a laboratory-based pilot scale unit or a mobile, trailer-mounted unit. Only the propane-based unit was evaluated during the SITE tests and is therefore the primary subject of this report.

CF Systems offers standard modular systems for different markets and applications. For sludge and solids treatment the capacity range is about 10 to 1,000 tons per day per unit and liquefied propane or a butane and propane mixture is the extraction solvent. The capacity range for wastewater treatment is about 5 to 150 gpm and liquefied carbon dioxide is used as the extraction solvent. Systems of these size ranges, constructed of carbon or stainless steel, can be modularized, shipped, and field assembled economically. As a result of this approach, several unit sizes have been developed and designed. The units can be configured in parallel if high throughput capacities are required. If high extraction efficiencies are necessary, the units can be arranged in series.

The soils treatment unit evaluated during the SITE tests at New Bedford Harbor was the PCU-20, which is rated at a 5-ton-per-day nominal capacity. The unit is often used for pilot-scale tests, but is also used for remediating small volumes of contaminated sludges or soils. The PCU-20 has a 1-1/2 foot diameter, two-stage extractor that used a mixture of propane and butane as the extraction solvent.

During the SITE tests, treated sediments were recycled through the unit to simulate the design and operation of a full-scale, four-stage unit that has 6-foot diameter extractors.

CF Systems has proposed two types of systems for New Bedford. The first system, the base case, applies to the treatment of 880,000 tons (695,000 cubic yards) of harbor sediments containing approximately 580 ppm of PCB. The second system applies to the treatment of 63,000 tons (50,000 cubic yards) of sediments from harbor "hot spots" that contain approximately 10,000 ppm. Each system differs from the PCU-20 tested at New Bedford. For the base case, two PCU-1000s, each rated at 250 tons per day, would be placed in parallel to accommodate the large volume of waste to be treated. For the hot spot, four PCU-500s each rated at 125 tons per day would be used and these would be configured in pairs so that two parallel trains are available with each train providing a total of 8 stages of treatment for the contaminated sediments.

Key extraction system elements of generic, predesigned soils treatment units offered by CF Systems are shown in Table 1-1. These designs apply to the remediation of soils and sludges at any site but do not include any site-specific support facilities or pre- and post-treatment equipment. All components of the various units can be obtained from "off-the-shelf" sources and no custom fabrications are required.

1.4 Results

Performance

The most extensive evaluation of the CF Systems technology was performed as part of the SITE tests at New Bedford. Qualitative results are also reported by CF Systems for three field demonstrations of a pilot-scale unit and for numerous bench-scale laboratory tests. CF Systems achieved an overall PCB concentration reduction of over 90 percent for New Bedford Harbor sediment samples that contained 350 ppm and 2,575 ppm during the SITE tests. The unit generally operated within specified conditions for flowrates, pressure, temperature, pH, and viscosity. Deviations from operating specifications could not be correlated to changes in extraction efficiency. No significant releases of pollutants to the atmosphere or surrounding area soils occurred. Results of the demonstration tests show that the CF Systems technology is capable of reducing the PCB content of contaminated sediment by greater than 90 percent without a risk to operating personnel or the surrounding community.

CF Systems reports the following field demonstration results for its pilot-scale units:

- Texaco: A unit was run September and October of 1987. Different feed types were run through the system including material from a clay pit, ditch skimmer sludge, tank bottoms, and other miscellaneous waste streams found at the Port Arthur refinery site. The system consistently

Table 1-1. CF Systems' Soils Treatment Extraction Unit Designs

Unit Designation	Nominal Throughput (Tons Per Day) (1)	Extractor Diameter (feet)	Number of Stages	Site Preparation (2) Cost (Dollars)
PCU-20	12	1.5	2	N/A
PCU-200	50	4	4	$350,000
PCU-500	125	6	4	$700,000
PCU-1000	250	6.5	4	$2,000,000

NOTES:

(1) 1.26 tons is equivalent to 1 cubic yard of New Bedford Harbor sediments.

(2) Site preparation costs include clearing, grading, constructing a foundation, and providing access for utilities. Costs are applicable to any site.

achieved high removals of total oil and grease to less than 1 percent residual of the dry solids. Levels of individual components, including benzene, ethylbenzene, toluene, xylene, naphthalene, phenanthracene, pyrene, and other polynuclear aromatics (PNAs), met or bettered the existing best demonstrated available technology (BDAT) standards. In many cases, these levels were found to be below detection limits. Following the demonstration, Star (Texaco) awarded CF Systems a contract to provide a 50-ton-per-day commercial unit to remediate 20,000 cubic yards of API separator sludges and ditch skimmer wastes. This unit was fully operational in July 1989.

- Petro-Canada: A unit was operated at the Petro-Canada refinery in Montreal for a six-week period. During this time, the unit successfully processed 14 different feed types, ranging from API separator sludges to contaminated solids. The unit consistently achieved organic removal levels better than existing BDAT standards.
- Tricil: A unit was used to run a series of demonstration tests at Tricil Canada's treatment, storage, and disposal (TSD) facility in the Province of Ontario. The feeds processed included API separator sludge, paint wastes, synthetic rubber process waste, and coal tar wastes. The level of volatile organics was reduced such that disposal of the material in a local Canadian landfill was acceptable and volumes for disposal were significantly reduced.
- BASF: A mobile treatment system was run at the BASF Kearny, New Jersey, plant site. One of the waste streams from this plant is an emulsified stream containing di-octyl phthalate (DOP), water, and other organic materials. The system successfully separated the emulsion into a recoverable DOP stream and a wastewater suitable for discharge to the wastewater treatment facility.
- Unocal: The unit completed a series of demonstrations at Unocal's Parachute Creek, Colorado, facility. Among the wastes successfully run were samples of shale-oil wastes, drilling muds, and other process and refinery wastes. High recovery of good-quality oil was obtained from shale-oil wastes. Drilling mud wastes were treated to the standards required for land disposal.
- United Cresote NPL Site: A field treatability study was completed for the Texas Water Commission, a Superfund Site in Conroe, Texas. The objective of this study was to evaluate the effectiveness of solvent extraction for remediation of soil contaminated with creosote. PAH concentrations in the soil obtained from the capped area were reduced from 2,879 ppm to 122 ppm, demonstrating that 95-percent reductions were possible.

CF Systems has collected bench-scale test data for a wide range of organic pollutants contained in wastewaters, sludges, and soils. Carbon dioxide was used as a solvent to remove volatile and semivolatile organics from wastewaters and groundwaters. Extraction efficiencies ranged from 95 to 99.99 percent for 24 pollutants that ranged in concentrations from 0.4 ppm to 520 ppm, as shown in Table 3-1. Propane was used as a solvent to extract polyaromatic hydrocarbons (PAHs) and benzene, ethylbenzene, toluene, and xylene from refinery sludges, API separator sludges, and contaminated soils. Extraction efficiencies ranged from 80 to 99 percent for concentrations that ranged from 0.3 ppm to 1930 ppm, as shown in Table 3-2.

Economics

The cost of installing and operating a commercial-scale system depends primarily on (1) waste characteristics that affect the need for pre- and post-treatment, (2) the amount of waste to be treated, (3) the degree of treatment required, and (4) the percentage of time that the system is actually operational. Soil pretreatment includes water addition, large solids removal, and possibly heat addition, while post-treatment includes dewatering. The amount of waste at a site affects equipment sizing, the total amount of time required to clean up a site, and life-cycle costs. The degree of treatment required affects operating costs since longer residence times of the waste in the equipment are needed to achieve higher pollutant removals. The percentage of time that the unit is fully operational can have a significant effect on the unit treatment costs, in terms of cost per ton.

CF Systems sized and costed two soil treatment units for PCB removal from New Bedford Harbor sediments. The objective was to estimate cleanup costs at New Bedford using the CF Systems technology and to illustrate the design approach used to scale-up the technology for a commercial application. The estimate was based on data obtained for PCB extraction from New Bedford Harbor sludge using the pilot-scale unit and on a commercial design of the unit at the Texaco, Port Arthur facility. The base case addressed a large mass of sediment (880,000 cubic yards) at a 580 ppm PCB concentration. Treatment would be conducted over an eight-year period to produce sediment concentrations of 50 ppm at a rate of 500 tons/day

raw feed. Pre- and post-treatment are required to reduce viscosity and raw feed solids content. Total treatment cost is estimated at $148/ton (1989 dollars) of which one-third is associated with pre-and post-treatment. The hot spot corresponds to treatment of a small mass (63,000 tons) at 10,000 ppm PCB concentration over a one-year time frame. The treated sediment concentration goal is 10 ppm PCB. Total treatment costs are $447/ton (1989 dollars), of which approximately one-third are pre- and post-treatment costs.

The economic analysis addressed costs directly related to the extraction unit as well as site-specific costs. Costs were categorized as fixed facility, extraction unit, pre- and post-treatment, contingency, and project management costs. CF Systems assigned an accuracy of plus or minus 20 percent to their cost estimates. However, industry experience with innovative technologies has shown that costs could range from plus 50 percent to minus 30 percent. The uncertainty associated with the estimated costs is believed to be low since CF Systems incorporates "off-the-shelf" equipment into their designs. CF Systems based their estimates on a unit construction for use at a Texaco refinery and on designs specific to New Bedford.

The greatest source of uncertainty associated with CF Systems' cost estimates is their assumption of the percent of time that the unit will be on-stream. CF Systems assumed an on-stream factor of 85 percent; however, this was not demonstrated by operating the PCU-20 at New Bedford. CF Systems claimed that material-handling problems associated with the operation of a pilot unit would be minimized with a commercial unit. CF Systems must demonstrate that an 85-percent on-stream factor is achievable for a commercial unit. EPA intends to evaluate the vendors' claim for the 85-percent on-stream factor by observing the performance of a commercial unit at a future date. EPA will also observe and evaluate materials handling associated with the operation of a full-scale unit to verify mitigation of the problems experienced with the pilot unit.

CF Systems also offers a wastewater treatment unit that differs from the soils treatment unit in the types of solvent and equipment used. Liquefied carbon dioxide is used instead of propane or butane. CF Systems has delivered a wastewater treatment unit to a Clean Harbors, Inc., facility in Baltimore. Although CF Systems reports typical wastewater treatment costs of 5 to 15 cents per gallon, the cost for treating wastewater at the Baltimore facility is 15 cents per gallon, which is approximately $35 per ton. Costs associated with CF Systems' wastewater treatment unit are lower than those associated with the soils treatment unit for two reasons. First, the equipment used in the design differs. Second, no pre- or post-treatment is required since solids content and viscosity are low and temperatures are moderate.

Section 2
Introduction

2.1 The SITE Program

In 1986, the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the SITE Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its third year, SITE is helping to provide the treatment technologies necessary to implement new Federal and State cleanup standards aimed at permanent remedies. The SITE Program is composed of three major elements: the Demonstration Program, the Emerging Technologies Program, and the Measurement and Monitoring Technologies Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. EPA also will accept proposals at any time when a developer has a treatment project scheduled with Superfund waste. To qualify for the program, a new technology must be at the pilot or full scale and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA regional offices and State agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of waste needed to assess the technology. After the completion of a technology demonstration, EPA prepares two reports, which are explained in more detail below. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of a system ready for field demonstration. The third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative measurement technologies to better characterize Superfund sites.

2.2 SITE Program Reports

The analysis of technologies participating in the Demonstration Program is contained in two documents, the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report contains a comprehensive description of the demonstration sponsored by the SITE program and its results. This report gives a detailed description of the technology, the site and waste used for the demonstration, sampling and analysis during the test, and the data generated.

The purpose of the Applications Analysis Report is to estimate the Superfund applications and costs of a technology based on all available data. This report compiles and summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology. Costs of the technology for different applications are estimated based on available data on pilot- and full-scale applications. The report discusses the factors, such as site and waste characteristics, that have a major impact on costs and performance.

The amount of available data for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic wastes, or may include performance data on actual wastes treated at the pilot or full scale. In addition, there are limits to conclusions regarding

Superfund applications that can be drawn from a single field demonstration. A successful field demonstration does not necessarily ensure that a technology will be widely applicable or fully developed to the commercial scale. The Applications Analysis attempts to synthesize whatever information is available and draw reasonable conclusions. This document will be very useful to those considering the technology for Superfund cleanups and represents a critical step in the development and commercialization of the treatment technology.

2.3 Key Contacts

For more information on the demonstration of the CF Systems technology, please contact:

1. Regional contact concerning the New Bedford Harbor, MA, site:

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Section 3
Technology Applications Analysis

3.1 Overall Technology Approach

CF Systems' organics extraction technology physically separates organic contaminants from the inorganic components of a waste matrix. This separation and volume reduction technology allows the organic contaminants to be ultimately disposed in a more cost-effective manner. For example, the cost of incinerating a large volume of oil-laden soils can be minimized by separating the oils from the soils, then incinerating only the small volume of oils. Any inorganic contaminants, such as heavy metals, that remain in the treated product may require additional treatment. The SITE Program showed, however, that the organics extraction process did not affect the physical or chemical characteristics of the metals contained in the sediments. Metals were not extracted by the solvent and remained with the treated sediments. The presence of metals in the sediments did not affect the extraction of organics. Furthermore, the metal leaching characteristics, as determined by the EP Tox procedure, were not affected by the process. The extraction process is not an ultimate disposal method, but it is a significant organics separation technique that can make ultimate disposal more economic.

Applications of the CF Systems organics extraction technology depend on the physical/chemical characteristics of the waste, its volume, and the degree of pollutant removal required. Waste characteristics determine the type of solvent to be used. For example, liquefied propane, or a mixture of propane and butane, is used to extract organics that are not very soluble in water, such as PCBs and PAHs. These hydrophobic organics tend to sorb to particulate matter present in soils and sludges. CF Systems has shown in the laboratory and in pilot-scale demonstrations that propane and butane are effective extraction solvents for removing these organics from soils and sludges. Carbon dioxide is used by CF Systems to extract water-soluble organics from wastewater and groundwater since carbon dioxide seeks polar materials in water, is nontoxic, and has favorable engineering properties. Carbon dioxide used in the process can be maintained near its thermodynamic critical point, the operating region where the liquid makes a phase transition to a gas. At this point, carbon dioxide has the viscosity of a gas, mixes easily with waste, and has the solvent properties of a liquid. Waste characteristics also determine the nature and extent of pre- and post-treatment that may be required. For example, dry solids require water addition to create a pumpable slurry, and the ultimate disposal of treated wastes with water added may require dewatering.

Waste characteristics, waste volume, and the degree of pollutant removal significantly affect system design. CF Systems has designed standard modular systems for different markets and applications. For sludge treatment units, the capacity range is about 12 to 250 tons per day. For wastewater treatment units, the capacity range is about 5 to 150 gallons per minute. The units are constructed of carbon or stainless steel and can be modularized, shipped, and field assembled. If high throughput capacities are required, the modular units can be placed in parallel. If high extraction efficiencies are necessary, several units can be arranged in series. As a result of this approach, a number of specific units have been developed and designed.

The soils treatment units are designed to process high solids sludge feeds and contaminated soils. They contain extractors and separators designed to facilitate the treatment of oily solids typical of petroleum sludges and waste materials found in refinery impoundments requiring remediation. The systems included in this product series are:

- PCU-50: This system, designed to process a maximum of about 12 tons per day, is a standard product for refinery sludges regulated by EPA's RCRA land disposal ban and sludges found at pit bottoms, as well as oil- and PCB-contaminated soils and silts. The system is modular and will be designed for installation into confined spaces so as to be readily integrated into existing operations.
- PCU-200: This system, designed to process a maximum of about 50 tons per day, is a standard product for refinery sludges regulated by EPA's RCRA land disposal ban and sludges found at pit bottoms, as well as oil- and PCB-contaminated soils and silts. The system is mounted on two flat bed trailers, and can be demobilized-remobilized at a new location in several days.
- PCU-500: The PCU-500 is similar to the PCU-200 design, but with increased extractor capacity

to provide for throughputs up to about 125 tons per day. Although the cost increment over the PCU-200 is relatively small, the PCU-500 requires somewhat longer time for mobilization and demobilization vs. transportable modules. It is designed for remediation of fixed base use where site relocation is infrequent.

- PCU-1000: This system, with a 250-ton-per-day nominal capacity, is intended for large remediation jobs where onsite time is projected to be one year or more at a single location. Modular and transportable, but with multiple modules, this system requires several weeks for mobilization and demobilization.

The LL series is designed for the extraction of dissolved or emulsified organics in water streams. Solids are usually not present at a significant level in these streams. If present, solids must be reduced to the 2 to 3 percent level by pretreatment. Organics content of the feed can range as high as 30 to 50 percent and removal efficiencies can exceed 99.9 percent. Applications for the LL series include a wide range of organic wastewaters.

3.2 Technology Evaluation

The most extensive evaluation of the CF Systems technology was conducted for a soils treatment unit as part of the SITE tests at New Bedford. Qualitative evaluations are also available for similar units tested by CF Systems at other locations. CF Systems has reported the results from extensive bench-scale tests conducted with either propane or carbon dioxide used as the extraction solvent.

CF Systems initially assesses a clients' waste by conducting bench-scale tests in the laboratory to determine if the organic constituents will solubilize in the liquefied solvent. CF Systems is also able to use rules-of- thumb to roughly estimate the number of processing stages that might be required to achieve a desired extraction efficiency. In the laboratory, the waste can be observed to determine if large particles are present that could clog system hardware and to determine if water should be added to make the waste pumpable. If the bench-scale tests show that the organic constituents can be separated from the waste, then pilot-scale tests are run. Wastewaters containing organics that are amenable to extraction by liquefied carbon dioxide are tested with a pilot-scale unit located in CF Systems' Massachusetts laboratory. Soils, sludges, and other semisolids that are effectively treated by liquefied propane or a propane/butane mix are tested in the field with CF Systems' trailer-mounted unit. Based on successful field demonstration results, clients have placed orders for soils and wastewater units.

Bench-Scale Tests

CF Systems has conducted numerous bench-scale tests for contaminated wastewaters, groundwaters, sludges, and soils. Table 3-1 shows extraction efficiencies achieved for removing various pollutants from wastewaters and groundwaters. Liquefied carbon dioxide was used to reduce contaminant concentrations that ranged from 0.4 to 520 ppm by more than 95 percent for 23 volatile and semivolatile organics. Liquefied propane was used to extract organics from samples of refinery sludges, separator sludges, and contaminated soils. Table 3-2 shows extraction efficiencies for the separation of volatile and semivolatile organics that range in concentration from 0.3 to 1,930 ppm. Extraction efficiencies ranged from 80 to 99.9 percent with a median of 97 percent. The bench-scale data demonstrate that a wide range of organics can be separated from aqueous and semisolid wastes; however, the extraction of organics from semisolids is somewhat less efficient than that of aqueous wastes.

Pilot-Scale Tests

The SITE program tests on the soils treatment unit in New Bedford produced analytical and operating data used for the evaluation system performance, operating conditions, and equipment and material handling problems. The performance of the unit was evaluated in terms of extraction efficiency and a mass balance. Extraction efficiency per pass was defined as the input PCB concentration minus the output PCB concentration divided by the input PCB concentration (multiplied by 100 percent). An inventory of system inputs and outputs was established and evaluated for total mass, total solids, and total mass of PCBs. Five tests were run. Test 1 was a shakedown test and Test 5 was a decontamination test. Results of these tests and evaluations are summarized as follows:

- PCB removal efficiencies of 90 percent and greater, were achieved for sediments containing PCBs ranging from 350 to 2,575 ppm. A high removal efficiency was achieved after several passes, or recycles, of treated sediments through the unit. The low concentration for PCBs that was achieved was 8 ppm.
- Extraction efficiencies greater than 60 percent were achieved on the first pass of each test. Later passes of treated sediments through the unit resulted in efficiencies ranging from zero to 84 percent. This wide range was due to solids retention in the system. Solids retained in the system cross-contaminated treated sediments that were recycled. (Recycling was necessary to simulate the performance of a full-scale commercial system. CF Systems' full-scale designs do not include recycling since additional extrac-

Table 3-1. Bench-Scale Test Results For Wastewaters and Groundwaters

Compound	Raw Waste Concentration (parts per million)	Extraction Efficiency (1)
Acetone	82	99.7
Acetonitrile	355	99.0
Acrylonitrile	275	99.9
Benzene	22	99.9
bis (2-ethylhexyl) phthalate	4	97
2-Butanone	520	99.96
Chloroform	180	99.99
1, 2-Dichloroethane	180	99.99
2, 4-Dimethylphenol	0.9	97.7
Dimethyl Phthalate	0.400	95
Isophrone	2.9	99.3
Methylene Chloride	35	99.98
2-Methylphenol	0.4	95
Napthalene	0.400	95
Nitrobenzene	52	99.96
PCB-1242	3.1	95
Phenol	4	95
Tetrachloroethane	20	99.97
Tetrahydro Furan	6	96.1
Trichloroethane	77	99.99
1,1,1-Trichloroethane	22	99.97
Toluene	44	99.98

Notes:
(1) Bench-scale measurements, not necessarily an equilibrium limitation. Extraction efficiency calculated as percent of pollutant removed.

tion stages and longer processing times are involved.) Some solids appear to have been retained in equipment dead spaces and intermittently discharged during subsequent passes.

- A mass balance was not established for PCBs. A total of 157 grams of PCBs were fed to the unit. Of the total, 80 grams were accounted for in system effluents. Decontamination washes produced an additional 169 grams. The sum of effluents and decontamination washes was, therefore, 101 grams greater than that fed to the unit.
  This large difference may be due, in part, to limitations of the analytical method. PCB analytical Method 8080 precision criteria established for this project were plus or minus 20 percent and accuracy criteria were plus or minus 50 percent. In addition the mass balance calculation was dominated by the Test 4 feed concentration. Therefore, error associated with the Test 4 feed sample could also be a source of the PCB mass imbalance. Another possibility is contamination of the PCU from prior use at other sites. However, CF Systems has not previously fed materials to the unit that were known to contain PCBs.
- A good mass balance was established for total mass and solids through the system. A total of 3-1/2 tons of solids and water were fed to the unit during Tests 2, 3, and 4; of the total, 96 percent was accounted for in effluent streams. A total of 789 pounds of solids was processed. Of the total, 93 percent was accounted for in effluent streams. The slight imbalances, 4 and 7 percent, are attributed to the inaccuracy of the weighing device (1 percent), sample error, and accumulation of mass in system hardware.
- Metals were not expected to be removed from the sediments, and were not removed during the extraction. Extraction Procedure Toxicity (EP Tox) test results indicate that metals did not leach from either treated or untreated sediments. Characteristics of the sediments, with respect to the EP Tox test, were not altered by the treatment

Table 3-2. Bench-Scale Test Results for Sludges and Soil

	Average Feed Concentration (PPM)			Typical
	Refinery Sludge	Separator Sludge	Soil	Percent Reduction
Oil and Grease	32.2	5.68	10.5	93 to 98
Volatiles				
Benzene	370	23.8	--	99
Ethyl Benzene	<0.3	25.0	--	80 to 99
Toluene	390	13.4	--	99
Xylenes (Total)	1160	106.3	--	99
Semivolatiles				
Acenophthylene	714	--	95	91 to 99
Acenaphthene	1930	--	32	96 to 99
Anthracene	667	27.7	143	90 to 99
Benzo(A)pyrene	--	1.9	--	82
Bis(2-Ethylhexyl)phthalate	--	4.7	--	85
Chrysene	<35	6.4	--	93 to 97
Fluoranthene	889		34.0	94 to 98
Fluorene	--	13.9	--	97
Naphthalene	<35	41.5	--	97 to 99
Phenanthrene	1360	27.7	56.0	97 to 99
Pyrene	<35	6.9	38.0	90 to 95

process. Copper and zinc concentrations were typically greater than 1,000 ppm, while chromium and lead ranged from 500 to 1,000 ppm.

- The decontamination procedure showed that PCBs were separated from the sediment. Most of the PCBs were contained in extract subsystem hardware. Of the 81 grams of PCB fed to the unit during Tests 2, 3, and 4, only 4 grams remained in the final treated sediments. Subsequent decontamination of the PCU with a toluene wash showed that some PCB had accumulated in system hardware. However, 91 percent of the PCBs contained in decontamination residues were found in extract subsystem hardware.
- A quality assurance/quality control (QA/QC) review showed that analysis data of PCBs in sediments for Tests 1 through 5 were sufficiently accurate and precise for an engineering assessment of the efficiency of this demonstration.

Operating conditions essential to the efficient performance of the PCU were manually controlled and monitored during Tests 2, 3, and 4. The operating conditions included feed temperature, particle size, flow rate, pH, and solids content; solvent flow rate and solvent/feed mass ratio; and extractor pressure and temperature. The unit generally performed as CF Systems predicted, although some deviations from the planned specifications did occur. An evaluation of operating conditions is summarized as follows:

- Feed flow rates and extractor pressures were controlled throughout the tests within specified ranges. Feed flow rates ranged from 0.6 to 1.4 gpm. Extractor pressures ranged between 190 and 290 pounds per square inch guage (psig).
- During Test 2, feed temperatures for the last 4 passes were 10 degrees F lower than the minimum specification, 60 degrees F. Decreased extraction efficiency, which was apparent during this test, could have been related to low feed temperatures. Sustained low temperatures could have the effect of seriously reducing extraction efficiency in a full-scale commercial system.
- Solvent flow fluctuated as much as 75 percent above and below the nominal flow rate, 12 lb/min. In Test 2, Pass 1, this caused the solvent-to-feed ratio to fall below specifications. The solvent flow fluctuations could affect the extraction efficiency in a full-scale system, since less

solvent would be available to extract organic pollutants from the feed soil.

- Specifications for maximum particle size, one-eighth inch, were met by sieving sediments through a screen. This was necessary to prevent damage to system valves. Less than 1 percent of the sediment particles were greater than one-eighth inch.
- Specifications for maximum viscosity, 1,000 centipoise (cP), were met by adding water to form a pumpable feed mixture. Feed viscosities ranged from 25 to 180 cP. However, added water increased the mass of waste by about 33 percent.
- Solids contents ranged from 6 to 23 percent and fell below the minimum specification, 10 percent, after the fourth pass of Tests 2 and 4. A 10-percent minimum specification was set merely to ensure that the technology would be demonstrated for high solids content feeds.
- EPA and the developer will address corrective measures for operational controls and material handling issues. However, these measures are not the subject of this report.

Equipment and system material handling problems occurred, although some problems were anticipated. Problems included the following:

- Internal surfaces of extractor hardware and piping collected PCBs as evidenced by mass balances for PCBs and subsequent washes of the unit with a refined naphtha fuel and later with toluene. The washes recovered accumulated PCBs as well as oil and grease.
  These accumulations of organics are believed to be the result of the short duration of the tests and the small volume of organics contained in the feed sediment, relative to the volume of the extraction system hardware. PCBs are soluble in oil and grease, which is believed to coat the internal surfaces of system hardware. Continuous operation of the unit has resulted in continuous discharge of extracted organics at other demonstrations of the technology.
- The unit intermittently retained and discharged feed material solids. This is the result of the relatively small volumes that were batch fed to the unit. The unit was designed for continuous operation, not short-term tests. In addition, only 50 to 150 gpd were run through the PCU, which was designed to handle up to 2,160 gpd. Therefore, some solids may have been retained in equipment dead spaces and intermittently discharged during subsequent passes.
- Solids were observed in extract samples, which were expected to be solids free. This indicates poor performance or failure of the cartridge filter. An alternative type of filter should be investigated by the developer.
- Extractor and treated sediment hardware contained organic sludge from prior use of the unit at a petroleum refinery. Presence of the petroleum residuals prevented complete interpretation of data collected for oil and grease and semi-volatile organics.
- Low-pressure dissolved propane caused foaming to occur in the treated sediment product tanks. This hindered sample collection and caused frequent overflow of treated sediment to a secondary treated sediment product tank. CF Systems states that design of a commercial-scale unit will allow release of propane entrained in the treated sediment and eliminate the foaming. However, EPA cannot verify the claims on this issue until it evaluates system operability for a full-scale commercial unit.

CF Systems reports successful demonstration of its mobile soils treatment unit at petroleum refineries, petrochemical, and TSD facilities throughout North America, including:

- Texaco,Port Arthur, Texas
- Tricil, Toronto, Canada ,
- Chevron, Salt Lake City, Utah
- Exxon, Baton Rouge, Louisiana
- Chevron, Perth Amboy, New Jersey
- Unocal, Parachute Creek, Colorado
- BASF, Kearny, New Jersey
- United Creosote, Conroe, Texas
- Petro-Canada, Montreal, Canada

The unit had its initial startup at Texaco's Port Arthur refinery in September 1987. Feeds run through the unit included material from a clay pit, ditch skimmer sludge, and tank bottoms. The resulting treated solids product streams were analyzed by Texaco, and representative results are shown in Table 3-3. Levels of individual components, including benzene, ethylbenzene, toluene, xylene, and phenanthracene bettered the existing BDAT standards. In many cases these levels were found to be below detection limits. Following the demonstration, Texaco awarded CF Systems a contract to provide a commercial unit to remediate 20,000 cubic yards of API separator sludges and ditch skimmer wastes.

The unit also operated at the Petro-Canada refinery in Montreal for a six-week period. During this time, the unit successfully processed 14 different feed types, ranging from API separator sludges to contaminated solids. The unit consistently achieved organic removal levels better than existing BDAT standards.

A series of demonstration tests was run at Tricil Canada's TSD facility in the Province of Ontario. The feeds processed included API incinerator sludge, paint wastes, synthetic rubber process waste, and coal tar wastes. The unit affected a large-volume reduction of the material processed and the level of volatile organics was reduced such that disposal of the material in a local Canadian landfill was acceptable.

Generic solvent extraction and incineration technologies were named by EPA as BDAT for listed petroleum refinery hazardous wastes (40 CFR 261.32 K048-K052). CF Systems' and other developer's performance data, from pilot-scale tests, were included in the basis for setting performance specifications for treatment of these wastes.

The MDU completed a treatability study for the Texas Water Commission in conjunction with Roy F. Weston at the United Cresoting Superfund Site in Conroe, Texas. The objective of this study was to evaluate the effectiveness of solvent extraction for remediation of soil contaminated with creosote. PAH concentrations in the soil obtained from the capped area were reduced from 2,879 ppm to 122 ppm, demonstrating that reductions greater than 95 percent were possible. Representative results from this study are shown in Table 3-4.

Full-Scale Applications

Operating, performance, and cost data are not available for a full-scale system. EPA intends to collect these data at a later date. Over the past 18 months, CF Systems' commercial activity has consisted of the following major efforts:

- In March 1989 the first of the Company's 50-tons-per-day unit was shipped to Star's Port Arthur, Texas, refinery (Texaco) for a 14-month full-scale commercial cleanup of oily sludge wastes. Under this contract, the soils treatment unit will treat about 20,000 tons of sludge to produce cleaned solids, treatable water, and oil for recycle. This unit became operational in July 1989.
- A custom-built, 60-tons-per-day soils treatment unit was shipped to ENSCO's El Dorado, Arkansas, incinerator facility in November 1988. Since ENSCO is reorganizing their El Dorado operation the unit has not been placed on line; however, the unit will extract organic liquids from a broad range of hazardous waste feeds sent to the site for incineration. The extracted liquids will be used as incinerator secondary combustion fuel, while the residues, reduced in heat content, will allow higher incinerator throughputs for ENSCO.
- A 20-gpm wastewater treatment unit was sold to Clean Harbor, Inc. It is expected to be installed at a TSD facility in 1989 in Baltimore, MD.
- CF Systems has established performance specifications for the LL-series wastewater treatment unit. A 99-percent extraction efficiency is specified for 2,000 ppm of trichloroethylene in waste waters. A 97-percent extraction efficiency is specified for 12,000 ppm of methyl isobutyl ketone in wastewater.

3.3 Waste Characteristics and Operating Requirements

The SITE program tests provided waste characterization and system operating data for the propane-based pilot unit, which is designed for the treatment of soils and sludges. CF Systems' wastewater treatment unit was not a subject of the SITE tests; therefore, no discussion of that unit appears in the sections that follow. However, some aspects of system operation and economics for the two technologies are similar. Details on the two technologies are presented in Appendix A - Process Description.

Feed Material Specifications

Physical characteristics of wastes fed to CF Systems' sludge and soils treatment technology must fall within the ranges shown in Table 3-5. Solids greater than 3/16 inch may clog process valves and piping. Feed pH must be maintained between 6 and 10 to protect process equipment from corrosion. The feed must be pumpable in order to flow through the system under pressure; therefore, a maximum viscosity of 5,000 cP is established. Viscous or dry materials are typically slurried with water, although this practice increases the volume of waste and may require dewatering. If the feed is less than 60 degrees F, freezing may occur in the extractor. Conversely, feeds greater than 120 degrees F may cause solvent vaporization. CF Systems' experience has shown that extraction efficiencies are high when feed solids and water contents fall within the wide ranges shown in Table 3-5.

If the technology was considered for a full-scale cleanup at New Bedford Harbor, pretreatment would be required to bring the sediments within the required physi-

Table 3-3. Texaco, Port Arthur Performance Data

Parameter	BDAT Levels (mg/Kg)	CLAY PIT AREA(1) Feed (mg/Kg)	Treated Solids (mg/Kg)	Water (mg/L)	SLUDGE(1) Feed (mg/Kg)	Treated Solids (mg/Kg)	TCLP (mg/L)	SLUDGE(1) Feed (mg/Kg)	Treated Solids (mg/Kg)	DITCH SKIMMER(1) Feed (mg/Kg)	Treated Solids (mg/Kg)	TCLP (mg/L)
Water(1)	--	60.5	--	--	62	--	--	57	--	53	--	--
Solids(1)	--	22.3	--	--	32	--	--	33	--	35	--	--
Oil(1)	--	17.2	--	--	6	--	--	10	--	12	--	
Total Oil & Grease(1)	--	--	1.9	--	--	3.6	--	--	1.0	--	0.7	--
Benzene(3)	9.5	9.6	<0.1(3)	<0.01	<2.0	<2.0	<0.01	13.7	<2.0	5.1	<0.1	<0.01
Ethylenzene	67	13	<0.1	<0.01	<2.0	<0.1	<0.01	20.2	<0.1	13	<0.1	<0.01
Toluene	9.5	16	<0.1	<0.01	<2.0	<0.1	<0.01	54.4	<0.1	52	<0.1	<0.01
Xylenes	63	<0.1	<0.01	<2.0	<2.0	<0.1	<0.01	75.9	<0.1	71	<0.1	<0.01
Fluorene	--	--	--	--	--	--	--	--	--	9.3	<0.20	--
Naphthalene	--	210	<5.3		<50	<3.3		45	<3.3	16.5	<0.20	--
2-Methyl Napthalene	--	300	<5.3	--	--	--	--	--	--	--	--	--
Phenanthrene	7.7	--	--	--	31	<3.3	--	30	<3.3	18.6	<0.20	--

Notes:
(1) Water, solids, oil, and total oil and grease reported as percent by weight.
(2) TCLP is the Toxicity Characteristic Leaching Procedure.
(3) < indicates less than the detection limit shown.

Table 3-4. United Creosote Superfund SITE Performance Data

Compound	Feed Soil (MG/KG)	Treated Soil (MG/KG)
Acenaphthene	360	3.4
Acenaphthylene	15	3.0
Anthracene	330	8.9
Benzo(A)anthracene	100	7.9
Benzo(A)pyrene	48	12
Benzo(B)fluoranthene	51	9.7
Benzo(G,H,I)perylene	20	12
Benzo(K)fluoranthene	50	17
Chrysene	110	9.1
Dibenzo(A,H)anthracene	ND	4.3
Fluoranthene	360	11
Fluorene	380	3.8
Indeno(1,2,3-CD)pyrene	19	11
Naphthalene	140	1.5
Phenanthrene	590	13
Pyrene	360	11
Total (MG/KG)	2879	122.6

Notes: Mg/Kg on a dry weight basis. ND indicates not detected.

Table 3-5. Sludge and Soil Feed Requirements

	Minimum	Nominal	Maximum
Solids Size	—	1/8	3/16 inch
pH	6	--	10
Viscosity (centipoise)	0.5	10	5,000
Feed Temp. (degrees Fahrenheit)	60	70	120
Feed Solids (percent by weight)	0	30	50
Water (percent by weight)	20	40	90
Organics (percent by weight)	1	20	90

cal specifications. Less than one percent of the New Bedford Harbor sediments were greater than 3/16 inch; nonetheless, sieving through screens was required to remove oversize particles. The sediments were also viscous; therefore, water was added to ensure pumpability. On one day during the SITE tests, ambient temperatures fell and caused the feed to drop below 60 degrees F, which may have affected extraction efficiency. A full-scale application would require sieving of untreated sediments, water addition, and heat addition. Cost-effective disposal of treated sediments would require dewatering to minimize disposal volumes. In turn, dewatering effluent would require treatment at a publicly owned treatment works or by an onsite waste water treatment system. CF Systems' experience has shown that oversized solids removal is sometimes required and that water addition is necessary for dry solids.

The technology is capable of treating the wide range of waste matrices found in most waste handling situations. The ranges specified for viscosity, feed solids water content, and organics content are very broad. The ranges specified for solids size, pH, and temperature are also broad but these parameters are more likely to exceed input specifications. However, off-the-shelf technology is available to bring off-spec feeds within CF Systems' required operating ranges.

Utilities and Labor

Utility requirements for the technology include (1) electricity, (2) cooling water maintained at 60 to 80 degrees F, (3) commercial-grade propane and/or butane, and (4) nitrogen to pressure test the equipment during startup. The amounts of electricity, propane, and butane used during the SITE tests were not significant. In addition, the unit was satisfactorily pressure-tested. The amount of noncontact cooling water, 5 gpm, was significant on this site and should be considered in the design of any future application.

All CF Systems' units are mobile and can be transported on public roads. The modular design of the units mitigates the need for field fabrication. The sizes of CF Systems treatment modules are limited by the need for transportability on public roads. A firm, level foundation is needed and the area required for the 200-ton-per-day commercial-sized unit, including ancillary skids, is about 4,000 square feet. An estimated 2,000 hours of labor are required to install the system. A site engineer, a site manager, and additional labor and safety equipment would also be required. Space for safe storage of the liquefied solvent is also necessary. A large commercial-scale unit can be operated continuously by four or five people per shift (two or three unit operators, one supervisor, and a pre-/post-treatment operator). Three such teams, each operating on an 8-hour shift, can be used to operate the unit on a 24-hours-per-day, 7-days-per-week basis.

3.4 Materials Handling Requirements

Pre- and Post-Treatment

Requirements for pre- and post-treatment of wastes are site specific. The SITE program experience, at New Bedford, provided an example of the types of material handling needs that must be addressed. Pretreatment of New Bedford sediments would be required to remove particles greater than 3/16 inch, to decrease viscosity, and to maintain feed temperature. In addition, the feed consistency should be homogeneous to minimize process uncertainty and to improve control of flowrates. Hence, solids removal, water addition, mixing, and storage are important pretreatment steps. The addition of water and heat can be incorporated into either the solids removal or the mixing operations. Sufficient storage capacity is also important for those operating days when treatment goals are not being met because of equipment failure or slug loads of high concentration wastes.

A sieving and screening method is the most appropriate pretreatment method for New Bedford Harbor sediments, based on experience during the demonstration test, and was thus selected for this application. Vibrating screens are more widely used than any other screen types because of their larger capacity per unit screen area and their higher efficiency. However, wet or sticky materials tend to blind the screen; therefore, wet screening with sprays can be used to discourage blinding.

Manual or automated high-pressure water spraying is assumed adequate to treat oversized solids. These coarse solids would be disposed of with fine-grained sediments treated by the CF Systems technology. Spray water would be collected and reused. Common mixing equipment and storage tanks are adequate to provide a homogeneous source of feed for the CF Systems technology. Heat can be provided by steam addition.

Post-treatment must be considered for the two product streams generated by this process. The extract contains the concentrated organics and the treated sediments contain the water and solids. Provisions for extract containment, handling, storage, and transport off site would have to be made. The volume of treated sediments would be greater than that of the untreated if water is added during pretreatment; dewatering could be necessary. However, dewatering effluent could be reused in the pretreatment operation. Thus, wastewater treatment costs would be minimized. Treated sediments would be disposed of in either a Resource Conservation and Recovery Act (RCRA) approved landfill or a confined disposal facility located in the harbor.

Materials handling requirements would be integrated with the CF Systems technology for applying the technology to a New Bedford Harbor cleanup. The overall process would consist of the following steps:

Step 1. Dredging

Step 2. Untreated Sediment Storage

Step 3. Untreated Sediment Handling

Step 4. Coarse Solids Separation, Water, and Heat Addition

Step 5. Extraction

Step 6. Extract Collection

Step 7. Treated Sediment Dewatering

Step 8. Transportation of Treated Sediments

Step 9. Offsite Disposal of Extracted Organics

Step 10. Disposal of Treated Sediments.

Each of these steps is shown in the flow diagram, Figure 3-1.

Process Operability

Foaming in the treated sediments and extract product tanks was evident throughout the SITE tests. This is suspected to be caused by propane entrainment in the treated sediments propane mixture, and has two adverse effects. First, extracted PCBs may be present in the foam. Second, foaming increases the volume of material that must be handled in the product stream, thereby increasing the probability of PCB migration and decreasing the feed throughput. Foaming can be mitigated by using oversized tank volumes, which have lower surface-to-volume ratios; thus, nominal throughputs can be maintained by use of large treated sediment collection tanks. CF Systems has addressed these issues in their scaled-up design and in the latest unit to be built. The commercial designs also contain an additional pressure relief step to more gradually decrease the pressure and thereby decrease foaming.

Solids and oil retention in process hardware also affected interpretation of SITE test data. The pilot-unit was operated in a recycle mode to simulate multiple stages, which caused cross-contamination of the recycled treated sediments. In addition, very small volumes were run through the unit during each day of testing. CF Systems' full-scale units do not incorporate recycling, operate in a once-through mode, and are expected to be on-line 20 hours per day. Therefore, solids and oil retention is not expected to be a significant problem, although some oil will coat internal hardware surfaces and should be removed with an organic solvent if the character of the feed changes substantially, to prevent cross contamination. Solids were observed in extracted oils; however, this minor problem can be corrected by more frequent changes of filter elements or by selection of different filters.

3.5 Health and Safety Issues

The SITE tests indicated that no acute threats to operator health and safety are associated with operation of the unit. Combustible gas meters indicated that the unit did not leak significant amounts of propane. Therefore, operation of the unit does not present an explosion threat much different from that associated with domestic propane usage. Background air sampling and personnel monitoring results indicate that organic vapors and PCB levels were present at levels below the detection limit for the analytical methods. The unit did not cause a sudden release of propane/butane or liquids. Only minor leaks occurred and staging area soils were not affected. Gases vented from the system at the conclusion of the tests were passed through a carbon canister. Analysis results showed that the gases contained minor amounts of PCB. The greatest threat presented by handling of the New Bedford Harbor sediments was dermal exposure. OSHA Level B protection is recommended for personnel who handle treated and untreated New Bedford Harbor sediment. Level C protection is recommended for extraction process operators.

All electrical equipment is explosion proof and all potential sources of ignition are restricted for a 20-foot perimeter around the unit. Spark-proof tools are also used. The solvent recovery hardware, which involves major phase changes for propane, is very similar to commercial refinery depropanizers, used safely throughout the world.

3.6 Testing Procedures

A portable GC and a chemist should be available onsite to allow a rapid response to changes in feed composition or operational control. The Spittler Method was used at New Bedford as a more timely alternative to EPA methods. However, even with this method, 24 hours were required for sample shipment and subsequent analysis.

Reviewers suggested the use of EPA Method 680, since the CF Systems technology could have selectively extracted higher molecular weight PCB congeners as opposed to lower weight PCB congeners. Method 680 would reveal any selective extraction, since Method 680 is used to analyze individual PCB congeners. Method 8080, a less expensive analysis method, would not reveal selective extraction since it is used to analyze mixtures of PCBs called Aroclors, instead of individual congeners. EPA Method 8080 was chosen over Method 680 since selective extraction was minor and since it analyzes for the classes of congeners that compose the majority of PCB

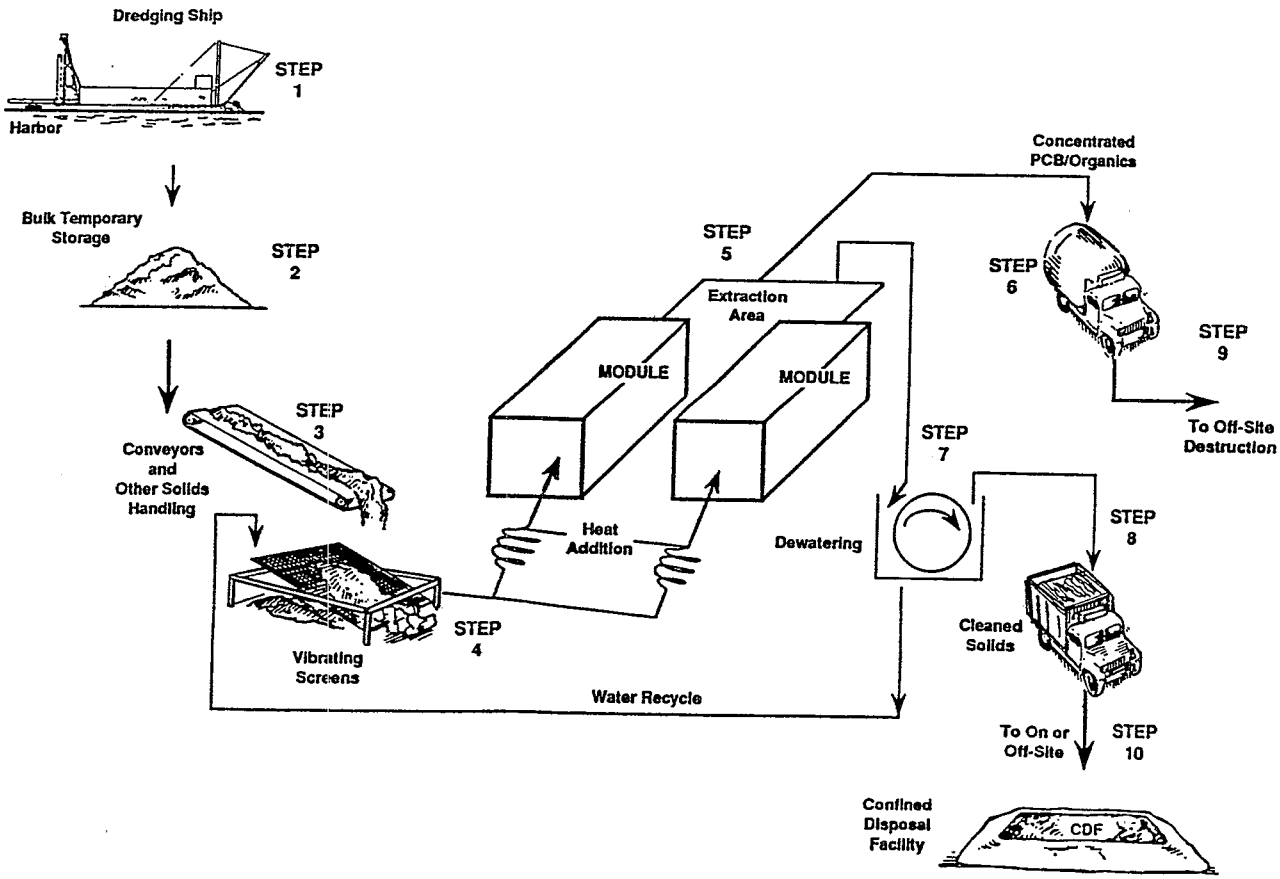


Figure 3-1. New Bedford Harbor Application Flow Diagram.

contaminants (Aroclors 1242 and 1254) in the harbor sediments.

Methods 680 and 8080 produced similar relative results, but very different absolute results. Use of Method 680 in Test 4 showed a PCB extraction efficiency of 96 percent and Method 8080 showed a similar efficiency, 87 percent. However, Method 680 showed an untreated sediment PCB concentration of 8,700 ppm while Method 8080 showed 2,575 ppm. Data quality objectives were met for each measurement. Therefore, regulatory or engineering interpretation of future PCB analyses should include consideration of the analysis methods used. Interpretation of results from any PCB treatability study should include a discussion of the precision of the analysis method as well as the accuracy.

Section 4
Economic Analysis

4.1 Introduction

The objective of the economic analysis was to estimate costs for a commercial-size site remediation using the CF Systems technology. This evaluation illustrates how variations in process conditions, such as volume to be treated, treatment time, water dilution of the raw feed, and reduction in outlet PCB concentration can impact system design and pre- and post-treatment costs. Five treatment cases were evaluated for PCB removal from New Bedford Harbor sediments to illustrate the cost methodology.

CF Systems developed costs for a base case and a hot spot case, then extrapolated the costs to three other cases. The base case refers to the treatment of 880,000 tons (695,000 cubic yards) of sediments containing 580 ppm of PCB. The hot spot case refers to the treatment of 63,000 tons (50,000 cubic yards) of sediments containing 10,000 ppm of PCB. The three additional cases were developed that represent variations of both the base and hot spot cases. These variations include changes of the on-stream factor, elimination of the need for adding water to reduce solids content, and higher PCB removal goals.

Standard process design sizing and costing algorithms were used by CF Systems. This consisted of: using off-the-shelf equipment of standardized size; obtaining total treatment capacity by adding units in parallel; and obtaining increased reduction of PCB outlet concentration by adding units in series. CF Systems assigned an accuracy of plus or minus 20 percent to its cost estimates. This is a reasonable estimate given the fact that off-the-shelf equipment is incorporated into CF Systems' designs. This accuracy goal falls within the order-of-magnitude estimates of plus 50 to minus 30 percent defined by the American Association of Cost Engineers. Results of the analysis and apparent trends are as follows:

- The estimated base case cost, including pre-and post- treatment, is $148/ton of raw solids feed, with an accuracy range of $104/ton to $222/ton. Sediment excavation and pre- and post-treatment costs are 41 percent of the total cost. This post-treatment estimate does not include the final destruction of the concentrated extract.
- The above costs are based on a system design using two PCU-1000 units, each with nominal capacities of 250 tons/day. This design uses two extraction units in parallel with one solvent recovery section in series. One extraction unit consists of two mixer/settler units. A total treatment time of 8.3 years is projected.
- The hot spot cost, including pre- and post- treatment, is $447/ton of raw solids feed, with an accuracy range of $313/ton to $671/ ton, with sediment excavation and pre- and post-treatment costs being 32 percent of the total.
- The design for the hot spot case is based on the PCU-500, with a nominal capacity of 100 tons/ day. This design utilizes two modules in series, with each module consisting of an extraction and a solvent recovery unit in series. A total treatment time of 1 year is projected.
- Key to all designs is the assumption of 85 percent on-stream factor. This was not demonstrated by operating the PCU-20 unit at New Bedford Harbor because of significant materials handling problems associated with recycle of treated solids. This recycle was required to evaluate PCB extraction using more than two extraction stages. Since recycle is not a unit operation for a commercial-size unit, CF Systems claims that material handling problems would be minimized with a commercial unit. CF Systems must demonstrate an 85 percent on-stream factor on commercial unit.
- To attain a total treatment cost less than $100/ ton, the solids feed content to extraction unit must be greater than 26 percent to minimize pre- and post-treatment costs.

4.2 Basis for Process Design, Sizing, and Costing

In general, soil remediation projects encompass excavation, treatment, containment, and/or removal of contaminated soils and sludges. Depending upon the types of contamination and the level of cleanup required, further processing of sediments treated by CF Systems' extraction system may be necessary. This may include fixation for heavy metals and incineration of the extracted organics;

however, these costs are not addressed in this study. A typical remediation project may consist of any combination the following steps, for which equipment sizing and costing is required to meet a specific treatment plan for total tonnage, treatment time, and reduction in contaminant concentration:

1 The excavated material may have to be slurried with water to create a pumpable mixture.
2 The slurry is passed through a shaker screen to remove material larger than 1/8-inch diameter. Oversized material may be crushed and recycled to the screens or separately washed.
3 The pH of the sieved slurry is monitored and, if required, lime is added to the mixture to maintain a pH between 6 and 8.
4 The slurry may require thickening prior to the slurry being pumped to the CF Systems Extraction Unit.
5 The slurry is processed in modular extraction units to reduce the PCB content of the solids.
6 Two product streams exit the extraction unit: a solids/water stream and a liquid organic stream. The organic stream will generally be returned to the client for reuse or disposal.
7 The solids/water stream is dewatered through the use of a gravity thickener, filter press, or centrifuge. The water from the dewatering step may be reused to slurry dry feed solids. Excess dewatering effluent could be discharged to a POTW or treated and discharged onsite.

CF Systems has developed a proprietary model for estimating site remediation costs. Outputs of the model are only intended for use in planning, scoping, and the inviting of firm bids. The Agency based this economic analysis on estimates prepared by the developer. No attempt was made to mirror the developer's work since this would involve a substantial effort to design and cost a facsimile of CF Systems' technology. Some features of the technology are unique to CF Systems' design approach. These features include unit modularity, process component integration, safety instrumentation, relief system backup, and automatic shutdown.

A cost analysis was prepared by breaking the costs into 12 groupings. These will be described in detail as they apply to the CF Systems technology. The categories, some of which do not have costs associated with them for this technology, are as follows:

- Site preparation costs
- Permitting and regulatory costs
- Equipment costs
- Startup and fixed costs
- Labor costs
- Supply costs
- Supplies and consumables costs
- Effluent treatment and disposal costs
- Residuals and waste shipping, handling, and transport costs
- Analytical costs
- Facility modification, repair, and replacement costs
- Site demobilization costs.

The 12 cost factors, along with the assumptions utilized by CF Systems in their proprietary cost model, are described below with respect to the soils treatment technology.

SITE Preparation Costs

Approximately 20 weeks are required to mobilize and demobilize the extraction unit and pre- and post-treatment equipment. The cost of ancillary service, such as construction of concrete pads and rental of construction equipment, increases the site preparation costs by about 50 percent. No land costs are assumed for the New Bedford site.

Permitting and Regulatory Costs

Since New Bedford Harbor is a Superfund site, it is assumed that no permits will be required, neither Federal nor State. The need for developing analytical protocols or monitoring records is assumed not to exist based on SITE program tests.

Equipment Costs

Capital costs include equipment, maintenance and technical service, engineering, procurement, fabrication, permitting, startup and operating assistance, and facility modification, repair, and replacement. Provisions for pre- and post-treatment of New Bedford sediment would involve solids handling and feed treatment equipment. Each cost element is described below.

The solids handling equipment is provided to move New Bedford Harbor sediments from the stockpile to the CF Systems treatment site. Contaminated dry soils will be excavated through the use of equipment such as frontend loaders, backhoes, or bulldozers. These soils will then be fed into a preliminary screening device to remove any materials larger than four-inches in diameter. Solids captured in the screens will be collected, washed, and disposed of in an appropriate manner. Screened material will be transported on a conveyer belt to a pug mill where size reduction is effected. The pug mill will combine the dry

solids with water to produce a solids/water extrudate. This paste will then travel via a second conveyer belt to a tank or pump where additional water will be added to produce slurried solids. Solids handling equipment costs are based on 10 hours of daily operation for the duration of the remediation.

Feed pretreatment equipment is provided to screen and slurry the feed prior to the solvent extraction system. Slurried solids from either the pug mill or the dredge will pass through a multilayered shaker screen similar to those used in the oil drilling industry. The objective will be to screen out solids larger than 3/16 inch in diameter. Solids captured by the screen will be collected, washed, and recycled to the pug mill or crusher/grinder for size reduction. Sludge passing through the screen will be collected in a storage tank equipped with mixers. If required, lime will be added at this point to maintain a pH between 6 and 8. The slurry will then be pumped from this tank either to the extraction unit or to a thickener. If pumped to a thickener, the slurry will be thickened to approximately 50-percent solids. This is accomplished through the use of either a moving screen or a decantation system, depending on the water solubility of the waste. Water extracted by the thickener will be returned to the dredge area or to another approved discharge point. The thickened solids slurry will be pumped to another holding tank and then fed to the Extraction Unit.

The product handling equipment is provided to receive the product streams from the extraction system and to deliver these product(s) to the client for disposal. The de-oiled solids and water produced from the extraction process will be dewatered. This stream will be run through a belt filter press, where a combination of pressure and conditioning flocculents, if required, will remove excess water, leaving a cake with approximately 40- to 45-percent solids. Water separated from the slurry will be returned to the dredge area or to the water treatment system. De-oiled solids in the form of a cake will move via conveyer from the belt filter press to a small blending mill.

Startup and Fixed Costs

Various facilities would be required to support the operation and maintenance of the CF Systems technology or any other onsite remediation technology. Those facilities would include office, laboratories, laboratory analyses, security, sanitary facilities, power generation, and a cooling water supply. Most of these facility costs are fixed for a given site. However, some costs, such as power generation and cooling water supply, vary in proportion to the capacity of the extraction unit.

Labor Costs

The extraction unit would operate 24 hours a day, 7 days a week. Fulltime operating staff would include 2 operators and a shift supervisor. A site engineer and a site manager would be onsite 8 hours per day. Pre- and post-treatment would require 2 operators 24 hours a day, 7 days a week. Safety equipment for all site personnel is estimated to cost $40 a day per man, which includes disposal of contaminated gear.

Supplies and Consumable Costs

No supply costs are incurred.

Utilities Cost

Actual equipment to generate and deliver utilities is accounted for in the Startup and Fixed Cost Group. Utilities include electrical power and propane. Unit costs used in the cost estimates for electricity were 6 cents per kilowatt hour and 20 cents per pound of propane.

Effluent Treatment and Disposal Costs

The only continuous wastewater effluent associated with this technology is once-through, noncontact cooling water. If no closed loop system is available, water from the post-treatment solids dewatering step would beused to slurry dry feed solids. Excess dewatering effluent would bereturned to the dredge area or intermittently discharged to the harbor.The cost for monitoring these discharges is included in the Analytical Cost Group.

Residual and Waste Shipping, Handling, and Treatment Costs

No costs are estimated here for residuals shipping. The costs associated with treated solids dewatering and storage and extract storage are estimated under the Site Preparation, Equipment, Labor, and Supplies Cost Catgeories. Solids would be returned to the harbor or would be treated by fixation for metals. Extracted oils would be transported and incinerated at minimal cost since the extract could serve as a fuel supplement.

Analytical Costs

In the absence of a site sampling and analysis plan, analytical costs are estimated at $500 per day and are included in the Startup and Fixed Cost Group.

Facility Modification, Repair, and Replacement Costs

These costs are borne by the developer since the equipment is marketed though lease agreements. Therefore, the developer has included these costs in the Equipment Cost Group.

SITE Demobilization Costs

Demobilization costs are included in the Site Preparation Cost Group.

4.3 Developer's Estimate for a New Bedford Harbor Cleanup

CF Systems prepared cost estimates using their proprietary model for two cases: a large mass (695,000 cubic yards of sediment) of low PCB concentration (580 ppm) referred to as the "base case;" and a small mass (50,000 cubic yards) of high PCB concentration (10,000 ppm) referred to as "hot spot." Each is described below:

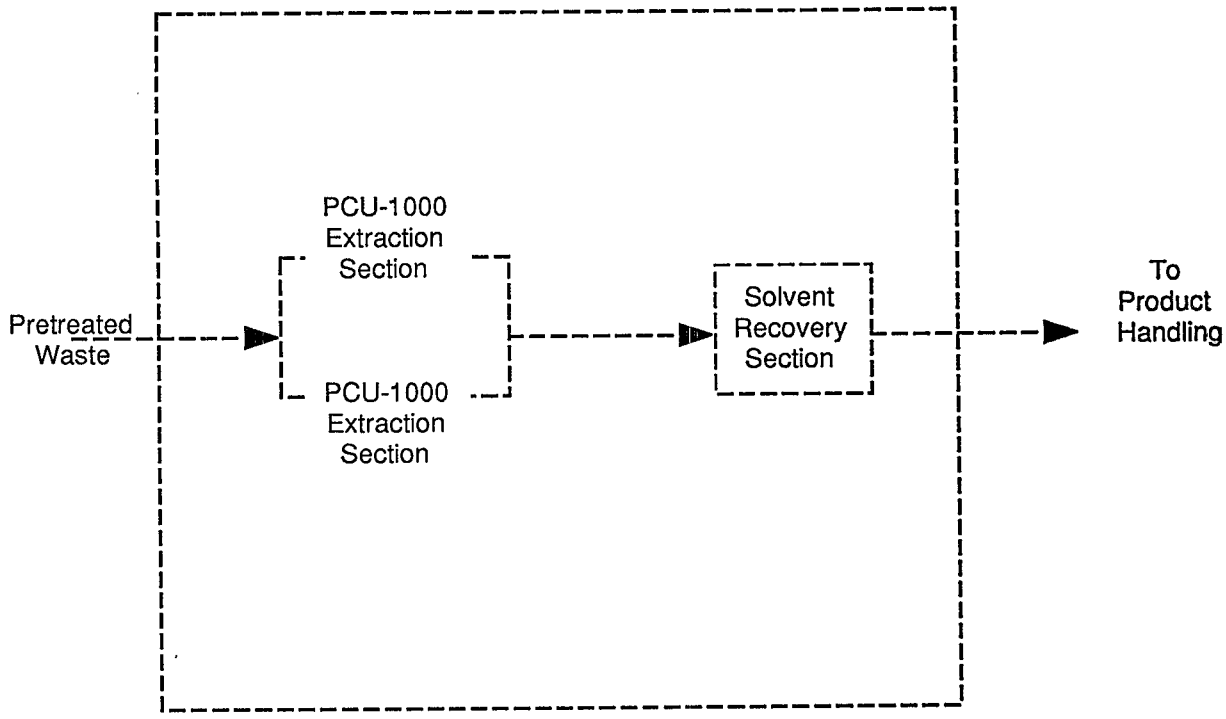
Base Case: The quantity of material to be treated, for the base case, is 695,000 cubic yards of PCB-contaminated soil. This quantity of material represents removal and treatment of all the contaminated soil in the New Bedford Harbor estuary. The level of PCBs in this material is assumed to average 580 ppm on a dry solids weight basis. The PCBs in this material will be reduced to a 50-ppm level via solvent extraction. The time schedule for processing this material is about eight years.

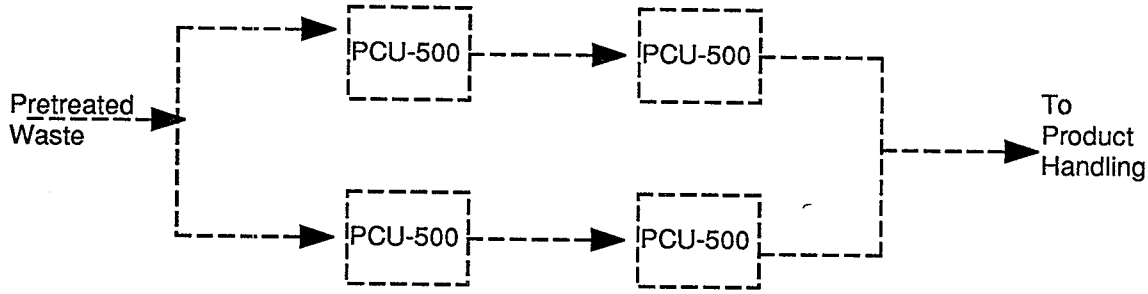
For this case, which involves a large tonnage removal for multiple years on site, CF Systems recommends the use of two PCU-1000s but only one solvent recovery section. This system will process about 500 tons/day in the following configuration:

Hot Spot Case: The quantity of material to be cleaned, for the hot spot case, is 50,000 cubic yards of PCB-contaminated soil. This quantity of material represents removal and treatment of the high concentration spots in New Bedford Harbor. The level of PCBs in this material is assumed to be 10,000 ppm on a dry solids weight basis. The PCBs in this material will be reduced to 10 ppm on a dry solids weight basis via solvent extraction technology. This represents a 99.9-percent removal of PCBs. The time schedule for processing this quantity of material is approximately one year.

For this case, CF Systems recommends the use of four PCU-500s, which would complete the remediation in about 1.2 years. These are 100 ton/day units, each having its own extraction and solvent recovery sections. The configuration of these units is shown below.

The selection of this size unit and the paired configuration is made to reduce onsite time and the units can be deployed to other customers at the end of the job. Two units in series are required to achieve an extraction efficiency of





99.9 percent. The parallel configuration is required to handle the total volumetric throughput.

Process conditions and costs developed by CF Systems are summarized for each case in Table 4-1. The base case involved removing 91 percent of the PCB from a large volume of sediment. The total average cost over the 8-year duration of the project is $148 per ton treated. Pre- and post-treatment costs represent about 41 percent of the total cost. The hot spot case involves removing 99.9 of the PCB from a somewhat smaller volume of sediment. The total average cost for treating hot spot sediments is $497 per ton over a project life of approximately one year. The pre- and post-treatment costs account for 32 percent of the total cost. Cost differences between base and hot spot cases are due to the significantly different PCB removals required, as well as the different project lives.

Variations of the base and hot spot cases were evaluated to determine the cost impacts of different removal efficiencies, pretreatment requirements, and on-stream factors. These various cases are listed below and are compared to the base and hot spot cases:

Case 1A The base case: The base case involves the exraction of 91 percent PCBs contained in 695,000 cubic yards of harbor sediments. An 8-year project life, and an 85-percent on-stream factor were assumed. The base case includes pre-treatment for the reduction of the solids content.

Case 1B The base with a 70-percent on-stream factor: This case is similar to the base case except that an on-stream factor of 70 percent is assumed instead of 85 percent. A less optimistic on-stream factor would result if material-handling problems or equipment breakdowns ocurred. A lower on-stream factor would require equipment with higher capacities in order to keep the project within an 8-year project life.

Case 1C The base case without solids content reduction: This case is similar to the base case except that no solids content reduction would be required. Harbor sediments contain approximately 40 percent solids; however, the SITE program tests showed that solids concent reduction was necessary to improve pumpability. This involved adding water to the sediment to reduce the solids content to 17 percent. The consequences of water addition include increased throughput and increased equipment sizes. With more experience at the New Bedford site, CF Systems may be able to modify their equipment and operating procedures to accommodate sediments with 40 percent solids. Thus the need for water addition would be eliminated, throughput would be decreased, and equipment sizes would also be decreased.

Case 1D The base case with increased extraction efficiency: This case is similar to the base case except that an extraction efficiency of 98 percent, instead of 91 percent, is assumed. This change would result in a PCB outlet concentration of 50 ppm instead of 100 ppm. Increased extraction efficiency requires an increased number of extraction units that would be aligned in a series flow configuration.

Case 2 The hot spot case: The hot spot case involves treating 50,000 cubic yards of sediments containing 10,000 ppm of PCB. An extraction efficiency of 99.9 percent, an on-stream factor of 85 percent, and a 1-year project life are assumed. The hot spot case includes pretreatment for the reduction of the solids content.

Table 4-1. Base Case and Hot Spot Case Summary

Capacity	Base Case	Hot Spot Case
Raw sludge (40% solids): cubic yards	695,000	50,000
tons	880,000	63,000
Processing Time: years	8.35	1.19
Operating Days	2,591	369
Raw sludge feed rate (at 40% solids) tons/operating day	339.5	171.5
Extractor Feed: % Solids	26.7	26.7
total tons processed	1,319,414	94,922
nominal system size (tons/day)	500	250
feed rate (tons/operating day)	509.2	257
Inlet PCB Concentration: ppm	580	10,000
Outlet PCB Concentration: ppm	50	10
PCB Reduction: percent	91	99.9
Configuration*	(1)	(2)
Processing Fee (1989 $)		
Facilities	$ 5,170,676	$ 762,496
Extraction	$ 62,109,781	$15,857,695
Pre-/Post-Treatment	$ 46,172,028	$ 7,993,608
Contingency	$ 11,345,248	$ 2,461,380
Project Management	$ 5,672,624	$ 1,230,690
TOTAL	$130,470,358	$28,305,869
Total Life Cycle Unit Cost ($/ton):		
Extraction only	$ 71	$251
Total	$148	$447

NOTES:

*Configuration: 1 - Two extraction sections connected in parallel feeding one solvent recovery section connected in series.

2 - An extraction and solvent recovery section in series connected parallel with a second identical extraction and solvent recovery section.

Costs for all of the cases were developed by CF Systems and are shown in Table 4-2. Process differences among the cases are also shown, as are costs for each cost category. The differences among the cases provide the following conclusions:

- A decrease in the on-stream factor from 85 to 70 percent increases all costs by approximately 20 percent. This is the result of increased equipment capacities and sizes required.
- Elimination of the pretreatment step to decrease the solids content can result in a 30-percent cost savings. This savings occurs as a result of reduced volumetric throughputs, reduced equipment sizes, and elimination of some pre- and post-treatment steps.
- Changing the base case PCB removal goal from 91 to 98 percent increases total costs by approximately one-fifth. Although not shown in Table 4-2, an additional case was evaluated to observe the effect of reducing the PCB removal efficiency from 99.9 to 99 percent for the hot spot case. This resulted in a cost decrease of approximately one-quarter. Therefore, increasing or decreasing the removal efficiency by an order of magnitude results in corresponding increase of decrease of approximately 25 percent.
- Startup and fixed and analytical costs account for 4 to 6 percent of remediation costs.
- Costs specific to the extraction unit account for 53 to 68 percent of remediation costs.
- Sediment excavation and pre- and post-treatment costs account for 28 to 41 percent of remediation costs.
- Eliminating the need for decreased solids content in the feed affects costs more than any other variable. However, the greatest uncertainty lies with the assumptions for the on-stream factor since EPA has not evaluated this variable and CF Systems has no long-term operational data available.

4.4 Evaluation of the Developer's Estimate

CF Systems has designed and built a 50-ton/day single train system, which was shipped to a customer in the first half of 1989 and was scheduled for startup in 1989. They have also designed larger systems of 100- and 200-tons/day throughput, but have not built these to date. The system designed for the base case is called a PCU-2000 and is configured as two 200 ton/day extraction sections connected in parallel and one propane solvent recovery section connected in series. The complete extraction system provides a total capacity of about 500 tons/day, which, in combination with an 85-percent on-stream factor, results in an 8-year treatment time for 695,000 cubic yards of sediment. The 92-percent reduction in solids PCB concentration and 26-percent solids feed to the extraction unit are based on data obtained from testing the PCU-20 at New Bedford Harbor.

The total life-cycle cost for the extraction unit was not developed from an explicit capital cost investment (equipment list) or specific operating and maintenance cost assessments. The developer's proprietary estimates were used in combinations with cost-capacity curves and ratios based on literature values and general experience. The greatest uncertainty associated with this estimate is related to the assumption of an 85-percent on-stream factor. The reasons for this are:

- Sizing and costing equipment to handle five times the capacity of a first commercial unit is not expected to involve major uncertainties because CF Systems utilizes industrial standardized off-the-shelf equipment.
- An on-stream factor could not be measured during the demonstration test at New Bedford with the PCU-20 due to materials handling problems associated with recycling processed feed. Recycling is not a commercial design operation.
- Commercial operating data are not currently available for the PCU-200, which has been installed and is in a startup phase at a refinery in Texas.
- If a commercial on-stream factor lower than 85-percent results, then a larger system design for tons/day would be required for the base case to maintain the 8-year treatment time.

As a means of accounting for the uncertainty in the on-stream factor it is recommended that the cost range of plus or minus 20 percent for a budget estimate be downgraded to an order-of-magnitude estimate of plus 50 percent and minus 30 percent as defined by the American Association of Cost Engineers. This level of estimate is associated with no preliminary design work using cost-capacity curves and ratios. This results in an accuracy range of $104/ton to $222/ton for the base case, and $317/ton to $671/ton for the hot spot.

The developer's extraction unit design and capital costs cannot be verified without a significant effort. Any attempt to duplicate the proprietary design must include provisions for the unit's modularity, the integration of process components, safety-related instrumentation, pressure relief system backups, and automatic shutdown. However, some elements of the remedial design and esti-

Table 4-2. Estimated Cost

Case Description(1)	1A Base Case Factor	1B Base Case With Reduced On-Stream Reduction	1C Base Case Without Solids Content	1D Base Case With Increased PCB Removal Efficiency	2 Hot Spot
Total Waste Volume (Tons)	880,000	880,000	880,000	880,000	63,000
PCB Reduction (Percent)	91	91	91	98	99.9
Solids Content (Percent)	27	27	40	27	27
On-Stream Factor (Percent)	85	70	85	85	85
Remediation Duration (Weeks)	434	527	280	347	64
			Estimated Cost, $/ton		
Site Preparation					
Extraction Unit	3.02	2.96	3.02	5.86	47.53
Pre/Post Treatment	1.95	1.95	1.95	1.58	23.57
Excavation	21.44	26.03	13.97	17.14	
43.94					
Permitting and Regulatory	---	---	---	---	---
Equipment					
Extraction Unit	48.39	58.52	31.53	77.81	173.57
Pre/Post Treatment	23.86	28.98	15.50	19.08	
48.91					
Startup and Fixed Costs	6.76	8.21	4.39	5.40	13.73
Labor					
Extraction Unit	10.72	13.02	6.97	10.86	33.68
Pre/Post Treatment	10.80	13.11	7.01	9.01	24.09
Supply	---	---	---	---	---
Supplies and Consumables					
Extraction Unit Utilities	17.06	19.51	11.08	23.91	29.20
Pre/Post Treatment Utilities	2.29	2.78	1.48	1.83	4.68
Effluent Treatment	---	---	---	---	---
Residual Transport	---	---	---	---	---
Analytical	1.98	2.41	1.29	1.59	4.07
Facility Modifications	---	---	---	---	---
Site Demobilization	---	---	---	---	---
TOTALS, $/ton	148.27	177.48	98.19	174.09	446.97

Notes:
1) A narrative description of the cases appears in the text.
2) These estimates are only intended for use in plannning, scoping, and the inviting of firm bids. The American Association of Cost Engineers has established an accuracy goal of plus 50 to minus 30 percent for preliminary estimates such as these.
3) The costs shown are based on a proprietary model developed by CF Systems, Inc. Cost model outputs are presented in Appendix B for the Base Case and the Hotspot Case.

mated costs, which are not directly related to the extraction unit design, can be checked against available construction cost data. Excavation, pre- and post-treatment equipment, and labor costs are the most significant cost elements aside from the extraction unit. Each of these elements is compared below to costs reported in the literature:

- Excavation--The base case excavation cost is $21.44/ton, which compares well with a $19.60/ton cost reported for bulk excavation in a coffer dam with a clamshell (Means, 1986).
- Pre- and Post-treatment--The base case cost is $23.86/ton, and is composed primarily of unit costs for leased equipment services. The unit costs compare with costs reported in the literature (Means, 1986).
- Labor--The base case labor cost is $21.52/ton or $43,635/week for 952 labor hours/week. These costs are equivalent to an average labor rate of $46/hour. This hourly rate is not unreasonable since it is a composite rate that includes engineering and management, costs for safety gear, and employee benefits and overhead.

4.5 Extrapolation of CF Systems' Sludge Treatment Costs to Other Sites

A generic cost model was developed to provide a method for end users to estimate the remediation costs at a specific site for the CF Systems sludge treatment technology. A total system cost consists of an extraction system cost(E) and a pre- and post-treatment cost(P). A procedure has been developed to estimate E as a function of: total mass of sediments to be treated; total treatment time; percent reduction in PCB solids content; and level of dilution of raw feed by water prior to extraction. A generic method of estimating P is not provided because this cost is highly site-specific.

Development of the extraction system cost involves three steps:

- Defining the following elements: the basic PCU processing unit to be used (PCU-50, PCU-200, PCU-500, PCU-1000); the number of units in parallel (NP); and the number of units in series (NS).
- Estimating unit capital and operating costs for one processing unit and then multiplying these unit costs by NP plus NS to obtain the total extraction cost.
  - Select the total mass of solids to be treated (T) and total treatment time (t).
- Calculating the total system throughput of raw feed by dividing T by t.
  - Calculate the total extration feed rate by adjusting the raw feed rate to account for water dilution to condition the solids to the required solids content required by the extraction system.
  - Select a PCU series module of given capacity.
  - The number of parallel units is obtained by dividing the total extraction feed rate by the capacity of the PCU module selected.
  - Select the fractional reduction in inlet PCB concentration that is required.
  - Some of the significant variables that affect extractability performance are: size and nature of solids; source and nature of organic contamination; relative concentrations of volatiles and semivolatiles; age of feedstock; and initial concentration. For purposes of scoping costs, the reduction in concentration that can be projected per module is a function of the organic content of the feed: inlet concentration in excess of 10 percent, 99.5-percent reduction; for inlet concentration of 1 percent, 95-percent to 99-percent reduction; and for inlet concentration less than 500 ppm, 95-percent reduction. If greater percentage removal of organics is required at corresponding inlet concentrations, then additional modules can be added in series or extra stages can be added per module.

4.6 Conclusions and Recommendation

The cost estimates developed by CF Systems for the base case (estuary) and hot spot case involve two key assumptions: that capital and operating costs can be scaled up to a commercial capacity based on pilot-scale testing of the PCU-20; and that an 85-percent on-stream factor applies to a commercial unit. Assumptions regarding scale-up of equipment costs are considered to be less critical because CF Systems designs are based on purchase of off-the-shelf equipment, and field tests at New Bedford demonstrated that outlet PCB concentrations of 50 ppm and 20 ppm were obtained using mixer/settler equipment. However, the number of modules required to meet a total throughput capacity is dependent on the value of the on-stream factor. CF Systems must demonstrate an on-stream factor of 85 percent for a commercial operation in order to reduce the uncertainty associated with projecting a cost of $148/ton for treating a large mass of New Bedford Harbor sediments using CF Systems technology. This will also increase the confidence in using the generic model to estimate costs for waste treatment at other sites. Based on this discussion it is recommended that EPA verify the credibility of the use of the 85-percent on-stream factor.

Appendix A
Process Description

A.1 Introduction

CF Systems technology uses a liquefied gas, such as propane or carbon dioxide, as a solvent to extract organics from soils, sludges, and waste waters. The solvent is mixed with the waste, then the solvent-organics mixture, (after extraction) which is not soluble in the solids and water, is separated from the solids and water. The pressure of the separated solvent-organics mixture is then reduced to vaporize the solvent and separate it from the organics. The solvent is then recovered and compressed to a liquid for reuse. Separated organics are collected for disposal or use in fuel blends.

CF Systems currently offers two treatment systems.

- The soils and sludge system uses liquefied propane to extract organics contained in a solid waste using a series of mixer/settler units operated at pressures below the critical point of propane.
- The wastewater system uses liquefied carbon dioxide to extract organics from a water stream using a series of sieve extraction trays contained in vertical column which is operated at a pressure at or near the critical point of carbon dioxide.

Combinations of the above systems could be used to remove organics contained in both water and solids after segregating the water and solids phases.

A.2 Process Design Sludge Extraction System

Process Description

CF Systems Pit Cleanup Unit (PCU), shown in Figure A-1, is a continuous processing unit that used a liquified propane/butane mix as the extraction solvent. The solvent mix was 70 percent propane and 30 percent butane. For each of the 3 demonstration tests, a batch of approximately 50 gallons of sediments was fed to the unit at a nominal rate of 0.9 gpm. Feed viscosity was maintained below 1,000 cP, by adding water in order to produce a pumpable slurry. Particles greater than one-eighth inch were screened from the feed to prevent damage to valves. Sediments were pumped to the extractors, which were typically operated at 240 psig and 70 degrees F. Liquified solvent was also pumped to the extractors at a rate of 2.3 gpm (10 lb/min) and mixed with the sediments. Organics, such as PCBs that are soluble in the liquified solvent were extracted. After extraction, treated sediments were decanted and separated from the liquified solvent and organics mixture. The mixture flowed from the extractor and passed to a separator through a valve that partially reduced the pressure. The pressure reduction caused the solvent to vaporize and separate from the extracted organics. The solvent was recycled and compressed to a liquid for reuse in the system.

The PCU-20 was not designed for large-scale remedial actions. Therefore, treated sediments were recycled, or passed through the unit to simulate operation of a commercial-scale unit. CF Systems' commercial-scale designs do not include recycling. These designs feature 60 gpm flowrates, several extraction stages, and longer processing times.

Equipment Specifications

The major pieces of equipment and their function are described in Table A-1. Process equipment that contacted the solvent or feed materials were constructed of 316 stainless steel. All process pumps were constructed of stainless steel, and both compressors were made of carbon steel. All of the process equipment was designed to withstand temperatures and pressures that exceed normal operating conditions. To guard against sudden overpressure, each vessel had a relief valve that vented to a header system that discharged to the pollution control system. Table A-1 outlines the major equipment items and the function of each piece of equipment in the process.

The utility and process materials requirements that were necessary to operate the PCU at New Bedford Harbor were:

- Electricity--480 VAC 3 Phase, 100 amps
- Process Water--5 GPM, 60-80 degrees F inlet, 30-90 psi
- Potable Water--Available
- Propane--four, 100 gallon bullets, 95-97 percent purity
- Butane--As needed, for Propane/Butane (70/30) solvent mix

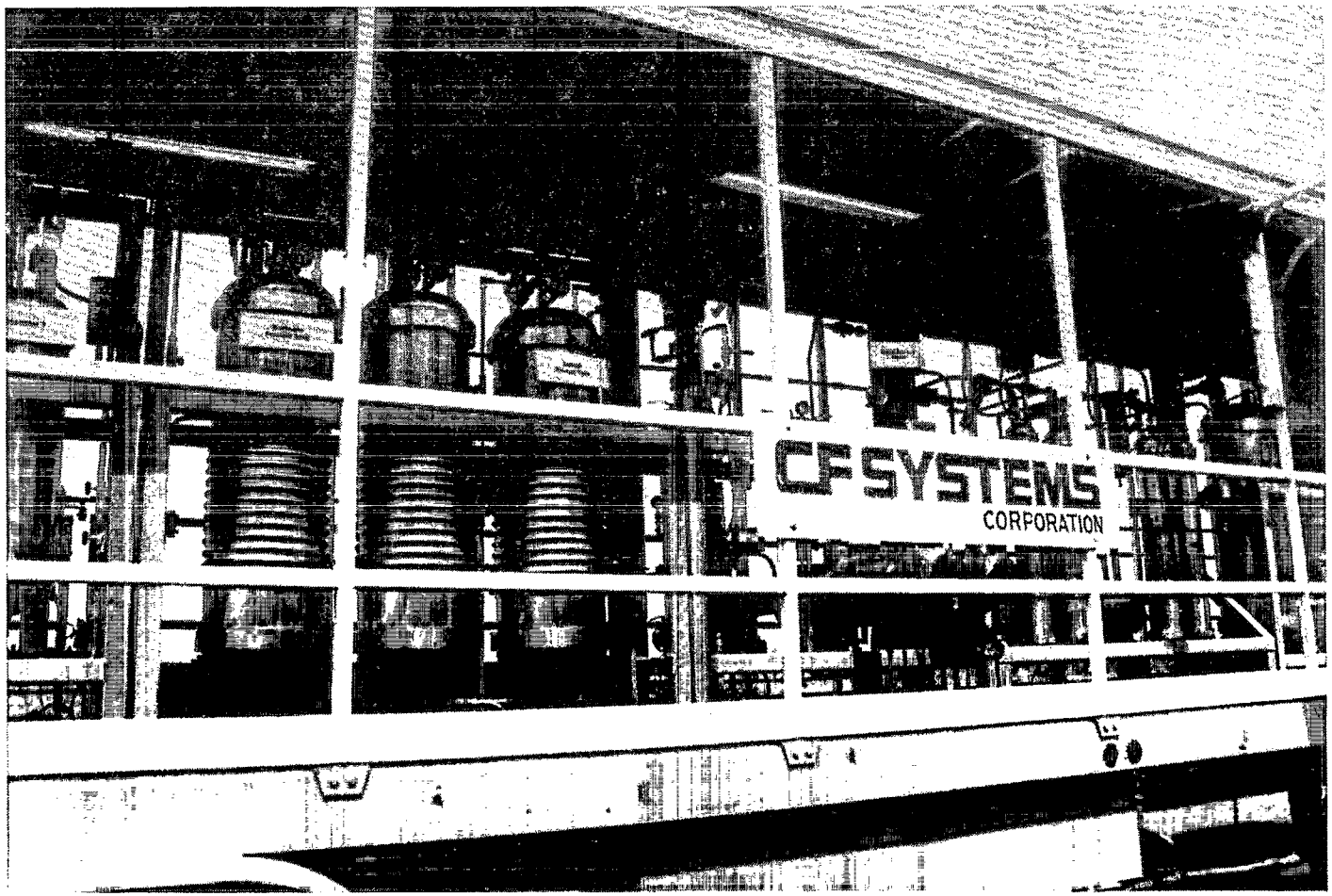


Figure A-1. Pit Cleanup Unit.

Table A-1. Process Equipment Description

Process Equipment	Designation	Function in System
Feed Kettle	FK	Holds approximately 100 gallons of strained, slurried feed. Counter-rotating agitators homogenize feed.
Basket Strainer	S-1	Prevents oversized (>1/8 inch) feed material from entering the system.
Extractor 1	E-1	Extracts organics from water-solids feed mixture with solvent from D-2.
Decanter 1	D-1	Allows separation of solvent-organic mixture from water-solids layer. Sends water-solids layer to Extractor 2 (E-2) and solvent-organics layer to the solvent recovery system.
Extractor 2	E-2	Extracts organics from water-solids mixture with fresh propane from the solvent recovery process.
Decanter 2	D-2	Allows separation of solvent-organics layer from water-solids mixture.
Cartridge Filter	F-2	Filters residual solid fines from solvent-organics stream leaving Decanter 1 (D-1).
Solvent Recovery Column	SRC	Separates propane solvent from organics via pressure reduction and heat from the Column Reboiler (CR). Solvent vapor flows out the overhead while organics are deposited in the CR.
Column Reboiler	CR	Provides both holdup for the recovered organics and heat for the Solvent Recovery Column (SRC) via a tube bundle heat exchanger.
Treated Sediment (Raffinate) Product Tank	RPT-1 RPT-2	Receives treated sediments (raffinate) from Decanter 2 (D-2). Recovers residual propane via flash pressure reduction and heat from water jacket. RPT-2 receives RPT-1 overflow.
Extract Product Tank	EPT	Receives extracted organics effluent from the Column Reboiler (CR). Recovers residual propane via flash pressure reduction and heat from the water jacket.
Main Compressor	C-1	Compresses both Low Pressure Solvent Compressor (C-2) outlet solvent and Solvent Recovery Column (SRC) overhead solvent. Outlet sent to Column Reboiler (CR) for heat exchange before returning to Extractor 2 (E-2).
Low Pressure Solvent Compressor	C-2	Compresses scavenged propane from Extract and Raffinate Product Tanks (EPT, RPT-1, and RPT-2). Sends compressed solvent to Main Compressor (C-1).

Table A-2. Range of Operating Conditions for Testing

	Minimum	Nominal	Maximum
Extractor Pressure (PSIG)	180	240	300
Extractor Temp. (degrees F)	60	100-110	120
Feed Temp. (degrees F)	60	70	100
Solvent Flow (lb/min)	8	12	15
Feed Flowrate (GPM)	0.2	0.2-0.5	1.5
Solvent/Feed Ratio	1	1.5	2
Feed Solids (percent by weight)	10	30	60
Solids Size (maximum)	--	--	1/8 inch
pH (standard units)	6	7	12
Viscosity (cP)	0.5	10	1,000

- Nitrogen (for pressure testing during shakedown period)--(2) 1A size cylinders.

Utility usage for a commercial-scale unit cannot be easily compared with the PCU because pilot-scale equipment consumed much more energy per gallon of throughput.

The operating conditions listed in Table A-2 are essential to the efficient operation of CF Systems' pilot-scale unit. Failure to operate the unit within the specified operating ranges can result in decreased extraction performance. The operating parameters were set during the shakedown portion of the demonstration. CF Systems claimed that minor fluctuations would not affect performance.

The feed temperature is that of the material piped into the feed kettle. The feed must be maintained above 60 degrees F to avoid freezing, which could interfere with the extraction process. The feed must be maintained below 120 degrees F to prevent vaporization of the solvent.

The extractor pressure, measured at the gauges on extractors 1 and 2, is controlled by the main compressor and at the extract discharge from the extraction segment of the unit.

The viscosity and solids content must be such that the feed material is pumpable. Pretest sampling determines the viscosity of the potential feed. Any potential feed with a viscosity above the listed range is slurried with water to yield a pumpable mixture.

In order to prevent damage to the process equipment, the pilot-scale unit has a maximum limit for solids size. Basket strainers, located between the feed pump and the first extractor, prevent larger-than-allowable size solids from entering the system. Oversized solids removed from the feed were hauled to an RCRA-approved facility.

The feed flow rate represents the rate at which material is pumped from the feed kettle into the extraction system. Operational flow rates above the listed maximum can force segments of the system, such as decanters and control valves, beyond their effective hydraulic capacity. The feed flow rate is manually controlled through the feed pump controller located beneath the feed kettle. Average detention time of throughput is about one hour.

Process Flow Diagram

The PCU process flow diagram is shown in Figure A-2. The extraction portion of this unit consisted of two stages of counter-current extraction with solid-liquid separation between the extractors. The feed was transferred from a feed preparation drum to the feed kettle with a pump. In the feed kettle, slurry solids were kept suspended while in the feed kettle by two counter-rotating agitators. During this process, feed was pumped from the feed kettle through a basket strainer, which removed any particles greater than 1/8 inch in diameter. Then feed flowed to the first extractor, where feed was mixed with the liquid propane/butane solvent. An agitator (not shown in the figure) provided mixing action before the solvent-organics mixture flowed to decanter 1. At decanter 1, the mixture separated into two immiscible layers. The solids and water settled into the underflow to the second extractor. The decanter overflow, which contained extracted organics, propane/butane, and fine solids, flowed through a filter and then to a solvent recovery column.

The pressure difference between the first decanter and the second extractor moved the solid-liquid stream into the

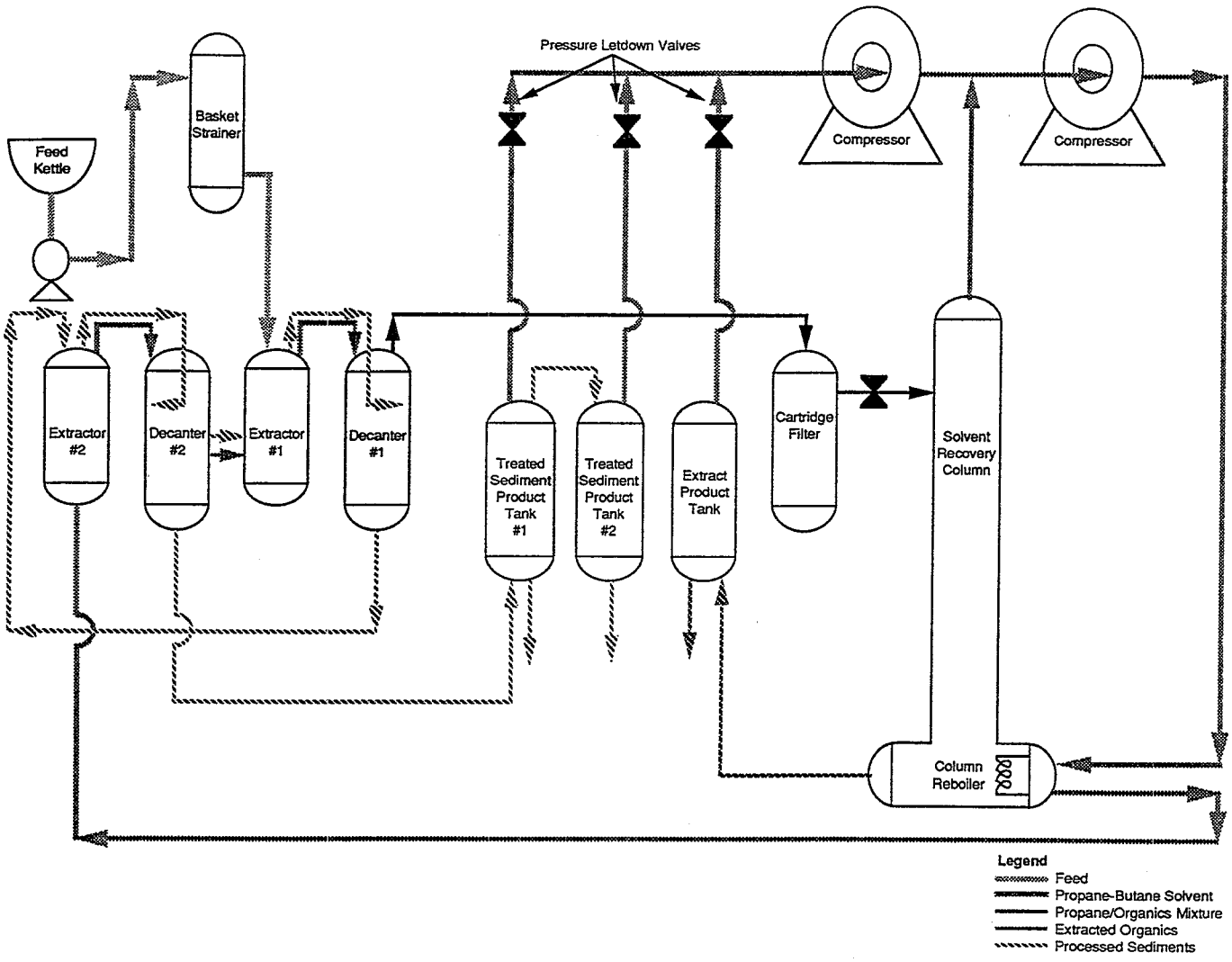


Figure A-2. *CF Systems Process Schematic.*

second extractor for second-stage extraction. Fresh liquified solvent (propane/butane mixture) from the solvent recovery process then mixed with the solids/water stream and further extracted the organic components. An agitator (not shown in the figure), which was located above the second extractor, provided mixing action before the solvent-organics mixture flowed to decanter 2. At decanter 2, two immiscible layers were formed. The organics-solvent layer floated to the top while the solids sank into the underlying water layer. The lower water-solids layer flowed from the bottom of the decanter to the treated sediment product tanks, while the upper organics-solvent layer recycled to the first extractor for final stage extraction.

The organic-solvent stream from the first stage extractor passed through a filter cartridge that collected fine solids and went to the solvent recovery column. In the solvent recovery column, the solvent vaporized and was removed from the column overhead, while the organics remained as a separate liquid. The mixture of organics containing dissolved propane gathered in the column reboiler and subsequently passed to the extract product tank. Solvent from the column overhead flowed to the main compressor. The compressed solvent passed through the column reboiler heat exchanger to provide the heat necessary to boil off residual solvent remaining in the organic mixture. The condensed solvent left the reboiler and reentered the extraction system via the second extractor.

The residual solvent that vaporized off the system products in the extract or the treated sediment tanks flowed to the low-pressure solvent compressor. The outlet stream of the low-pressure solvent compressor fed to the main compressor, where it was compressed along with vapors from the column overhead.

During system shutdown or if overpressure within a vessel opens a relief valve, material is vented to a relief header, which directs the material to a blowdown tank where solids and liquids are removed from the vented stream. The gases from the blowdown tank pass through a 42-gallon activated carbon filter to remove contaminants in the propane gas. The gas then passes through a flame arrestor and is vented to the atmosphere. This system was used only once during the demonstration, at the conclusion of PCU decontamination.

A.3 Process Design Waste Water Extraction System

Process Description

The CF Systems wastewater extraction process is a solvent extraction technique which, instead of using a typical solvent such as methylene chloride, toluene or hexane, uses liquefied carbon dioxide (CO_2) gas. This solvent has high solubilities for most hazardous organic compounds. In addition, CO_2 is inexpensive, non-toxic, and can be easily separated from the extracted compounds. In contrast to the sludge unit the wastewater unit uses a sieve tray extraction instead of mixer/settler extraction units.

Figure A-3 provides a simplified flow diagram of the CF Systems extraction process using liquid CO_2 as a solvent to extract organics from wastewater. As shown in the figure, organic-bearing wastewater is continuously fed into the top of the extractor and flows down the column through a series of sieve tray downspouts. Simultaneously, liquid CO_2 is fed into the bottom of the extractor, and jets upward through perforations in the sieve trays because liquid CO_2 has a lower density than water. During this countercurrent contact between CO_2 and wastewater, organics are dissolved out of the water phase to form a CO_2/organics phase, or extract, which continuously exits from the top of the extractor. As the extract stream flows from the extractor to the separator vessel, it passes through a pressure reducing valve that allows some of the CO_2 to vaporize and exit from the top of the separator. The CO_2 vapor leaving the top of the separator vessel is continuously fed to a compressor, recompressed, liquefied and then reused as fresh solvent, resulting in a totally enclosed recycle system. In the separator vessel, as CO_2 changes phase from liquid to vapor, the liquid organics are released and flow to the bottom of the separator, where they are collected and removed as a concentrated stream usually containing less than five percent water. Both the concentrated organic stream and the water effluent from the bottom of the extractor vessel are reduced in pressure prior to being pumped off-skid.

- Equipment Specification
  CF Systems Organics Extraction Unit Model LL20CO-1 is designed such that the extraction process will not be interrupted by component failure. To accomplish this, each component has design parameters appropriate to its function in the process. Most components are designed for use in environments with temperatures and pressures of 350°F and 150 psig, respectively. Table A-3 lists all major components and their functions. Utility and process water requirements are given in Table A-4.
- Process Flow Diagram
  This section describes the functioning of the major operating units shown in a process flow diagram; Figure A-4.
- Extraction
  In the extraction process, the wastewater feed is pumped from a storage tank through a strainer, a heat exchanger, and then to a surge drum. The

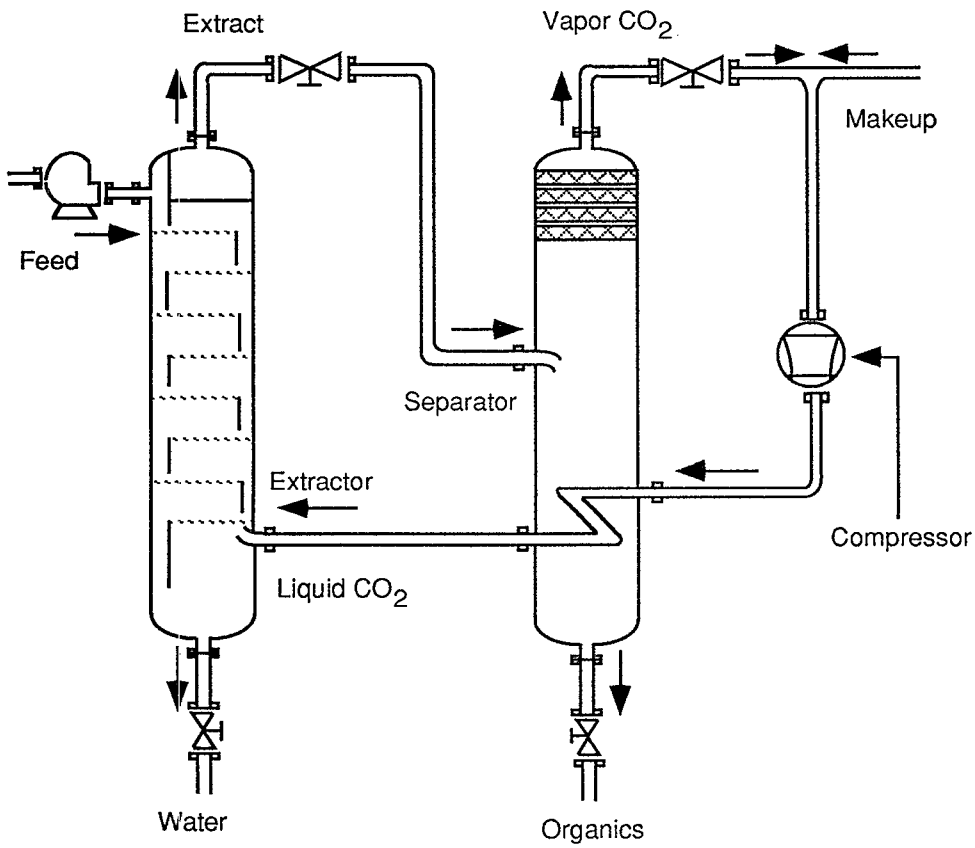


Figure A-3. *Simplified Flow Diagram.*

Table A-3. Major Components and Functions

Component #	Name	Function
T-1	Extractor	Provides contact between the water-organics feed stream and the liquid CO_2 solvent.
T-2	Solvent Recovery Column	Separates most of the CO_2 solvent from the organics in the extract stream.
D-1	Feed Drum	Intermediate surge for the wastewa ter feed between the low pressure pump (GP-102) and the high pres sure feed pump (P-1).
D-2	Medium Pressure Extract Flash Drum	Provides intermediate pressure separation of CO_2 solvent from ex tracted organics and cooling of CO_2 vapor discharged from the second stage of the Low Pressure Compres sor (C-3).
D-3	Low Pressure Extract Flash Drum	Provides low pressure separation of CO_2 from the organics.
D-4	Medium Pressure Raffinate Flash Drum water.	Provides initial separation of CO_2 fromextracted water.
D-5	Low Pressure Raffinate Flash Drum	Provides final separation of the CO_2 from extracted water.
D-6	C-2 Interstage Knockout Drum	Provides removal of any organics condensed from the CO_2 vapor going to the second stage of the Medium Pressure Compressor (C-2).
D-7	C-3 Interstage Knockout Drum	Provides removal of organics con densed from CO_2 vapor before en tering the second stage of the Low Pressure Compressor (C-3).
D-9	C-1 Suction Knockout Drum	Provides removal of any liquid con densed from the CO_2 vapor from the Solvent Recovery Column (T-2) and the C-1 Recycle Cooler (E-5) before the vapor enters the Main Compres-sor (C-1).
D-11	CO_2 Storage Drum	Provides location for CO2 storage.
E-1	Column Reboiler	Heat exchanger used to transfer the heat of vaporization to the liquid CO_2 in the Solvent Recovery Col-umn (T-2).
E-2	After condenser	Heat exchanger used to condense the CO_2 vapor/liquid mixture coming from the Column Reboiler (E-1).
E-3	Solvent Subcooler	Cools the liquid CO_2 from the Aftercondenser (E-2)

(continued)

Table A-3. (Continued)

Component #	Name	Function
E-4	Feed Precooler	Cools the incoming wastewater feed from storage.
E-5	C-1 Recycle Cooler	Cools the CO_2 vapor recycled through the Main Compressor (C-1).
E-6	C-2 Intercooler	Cools the hot compressed CO_2 vapor from the first stage of the Medium Pressure Compressor (C-2) before it enters the second stage of C-2.
E-7	C-3 Intercooler	Cools the hot compressed CO_2 vapor from the first stage of the Low Pressure Compressor (C-3) before it enters the second stage of C-3.
E-8	C-1 Lube Oil Cooler	Cools the lube oil for the Main Compressor (C-1).
E-10	Reflux Cooler	Cools the liquid CO_2 from the Solvent Subcooler (E-3) before it enters the Solvent Recovery Column (T-2) to aid in CO_2 vapor and organics separation.
E-12	C-2 Recycle Cooler	Cools the CO_2 vapor recycled from the Medium Pressure Compressor (C-2) back into the Medium Pressure Extract Flash Drum (D-2).
E-13	C-3 Recycle Cooler	Cools the CO_2 vapor recycled from the Low Pressure Compressor (C-3), back to the Low Pressure Extract Flash Drum (D-3).
E-14	D-2 Reboiler	Supplies heat to the liquid in the bottom of the Medium Pressure Extract Flash Drum (D-2).
C-1	Main Compressor	Compresses the CO_2 vapor from the Solvent Recovery Column (T-2).
C-2	Medium Pressure Compressor Extract Flash Drum (D-2).	Compresses the CO_2 vapor collected in the Medium Pressure
C-3	Low Pressure	Compresses the CO_2 vapor collected in Compressor the Low Pressure Extract Flash Drum (D-3).
P-1	Feed Pump	High pressure pump taking wastewa ter from the Feed Drum (D-1) and the Extractor (T-1).
P-2	Solvent Charge Pump	Pumps CO_2 makeup into the Solvent Recovery Column (T-2).
P-3	Extract Pump	Takes suction on the Low Pressure Extract Flash Drum (D-3) discharging to storage.
P-4	Raffinate Pump	Takes suction on the Low Pressure Raffinate Flash Drum (D-5) discharging extracted water to storage.
P-5	C-1 Auxiliary Lube Oil Pump	Provides initial lube oil pressure to start Main Compressor (C-1).

Table A-4. Utility and Process Water Requirements

Electric Power Criteria

460V, 3 phase, 60 Hz AC electric power is distributed to the following loads:

Component (item no.)	Motor HP
Main Compressor (C-1)	125
Medium Pressure Compressor (C-2)	60
Low Pressure Compressor (C-3)	25
Feed Pump (P-1)	20
Extract Pump (P-3)	5
Raffinate Pump (P-4)	5
C-1 Auxiliary Lube Oil Pump (P-5)	1
Feed Mixer (MX-1)	0.5
Total Connected	241.5

Hot Water Criteria

Requirement	Design Value
Supply Temperature	180° F
Supply Pressure	By Client
Design Flow Rate	25 GPM
Return Temperature	150° F
Design Pressure Drop Across Skids	20 psi
Thermal Relief Valve Setpoint	100 psig

Individual component hot water requirements are listed below:

Individual Component	Flow Rate (GPM)
Feed Drum (D-1)	13.3
Medium Pressure Extract Flash Drum (D-2)	9.1
Low Pressure Extract Flash Drum (D-3)	1.5
Total Hot Water	23.9

Refrigerated Water Criteria

Refrigerated water is supplied at the following conditions:

	Design Value
Supply Temperature	55 °F
Supply Pressure	By Client
Design Flow Rate	110 GPM
Return Temperature	70 °F
Pressure Drop Across Skid	30 psi
Thermal Relief Valve Setpoint	100 psig

Individual component refrigerated water requirements are as follows:

Refrigerated Water Requirements Component	Design Value Flow Rate (GPM)
Aftercondenser (E-2)	30
Solvent Subcooler ((E-3)	30
Feed Precooler (E-4)	30
C-1 Recycle Cooler (E-5)	5
C-2 Inter and Recycle Coolers (E-6/E-12)	6
C-3 Inter and Recycle Coolers (E-7/E-13)	4
C-1 Lube Oil Cooler (E-8)	1
Reflux Cooler (E-10)	3
Total Refrigeration Requirement	109

strainer removes any solid particles larger than 60 mesh to prevent these solids from entering the high pressure feed pump and the extractor. The resulting strained feed stream has no more than two percent suspended solids. The Feed Precooler (E-4) cools the wastewater feed to a temperature below 70°F. The jacket on the feed drum heats the wastewater to above 65 °F. The Feed Drum (D-1) provides five minutes of reserve feed for the system process.

From the feed drum, wastewater is pumped by the Feed Pump (P-1) to the Extractor (T-1) at about 950 psig. Wastewater enters at the top of the extractor and flows downward countercurrent to the CO_2 solvent stream. The CO_2 solvent enters at the bottom of the extractor and flows up through the column as the dispersed phase. The column internals consist of sieve trays and downcomers. CO_2 passes through the sieve tray holes as it flows upward from stage to stage. The aqueous solution, coming from the top, flows across a sieve tray before passing through a downcomer to the stage below. The arrangement allows for optimum mixing and contact between the fluids to accomplish extraction of the organics into the CO_2 solvent.

The extract stream from the top of the extractor consists of liquid CO_2, organics extracted from the feed stream, and a small quantity of dissolved water. The organics concentration in the extract stream is over 98 weight percent on a CO_2-free basis. The CO_2-organics extract stream flows through a pressure-reducing valve and is partially flashed. By reducing the stream pressure from 935 psia to 750 psia, about 15 percent of the CO_2 vaporizes. During the flash evaporation process, the liquid loses sensible heat to vaporize the CO_2 and is cooled from 70 °F to 60 ° F. At the lower temperature, the solubility of water in CO_2 decreases and a water phase is formed.

- Pressure Letdown and Carbon Dioxide Distillation

  An important feature of the CO_2 distillation and stripping is that the bulk of the CO_2 in the extract stream is separated from the product organics at a pressure that is very near the extractor pressure. This minimizes the compression work needed to recycle the CO_2 back to the extractor.

  The CO_2 separation is performed in the Solvent Recovery Column (T-2).

  Vaporization heat is supplied from two sources. First, the hot compressed CO_2 vapor discharged from the Main Compressor (C-1) gives up its sensible heat of cooling and latent heat of condensation as it cools from the vapor phase and condenses into the liquid phase. A kettle type heat exchanger, Column Reboiler, (E-1) is provided perform the heat exchange. Second, superheated CO_2 from the second stage discharge of the Medium Pressure Compressor (C-2) is injected into T-2 for direct heat exchange.

  The column reboiler kettle is equipped with a boot for collecting the water layer formed in the pressure letdown and CO_2 distillation. The water layer, which will contain some organics, collects in the boot and is recycled back to the feed drum for organics recovery.

- Extract Stream Flash Evaporation

  The overhead CO_2 vapor from T-2 is fed to the suction of compressor C-1. The still bottoms stream contains about fifty percent of the CO_2 originally present in the extract stream, is fed into a cascaded flash evaporation stage for further CO_2 removal.

  This organics-rich bottoms stream is first flashed across a control valve to about 125 psia. This stream flows into the Medium Pressure Extract Flash Drum (D-2) where the vaporized CO_2 is vented to compressor C-2 for recompression. The liquid is removed from D-2 on level control and flashed to a final pressure of 20 psia in D-3, the Low Pressure Extract Flash Drum, for nearly complete removal of CO_2. The CO_2 vapor from D-3 goes to the first stage of the Low Pressure Compressor (C-3). The organics extract stream is withdrawn from D-3 on level control and is pumped to storage by the Extract Pump (P-3).

  Some of the heat required to vaporize the CO_2 in drum D-2 is supplied by the superheated CO_2 coming from the second stage of C-3, which is injected directly into D-2. D-2 is equipped with a heating coil, and D-3 with a heating jacket, to heat the organics and to help remove the CO_2. CO_2 vapor from the Raffinate Flash Drums (D-4 and D-5) is also injected directly into the extract flash drums.

- Raffinate Stream Flash Evaporation

  The vapors from the Low Pressure Raffinate Flash Drum (D-5) are combined with the vapors from D-3 before recompression by C-3 and injection into D-2. Similarly, the vapors from the Medium Pressure Raffinate Flash Drum (D-4)

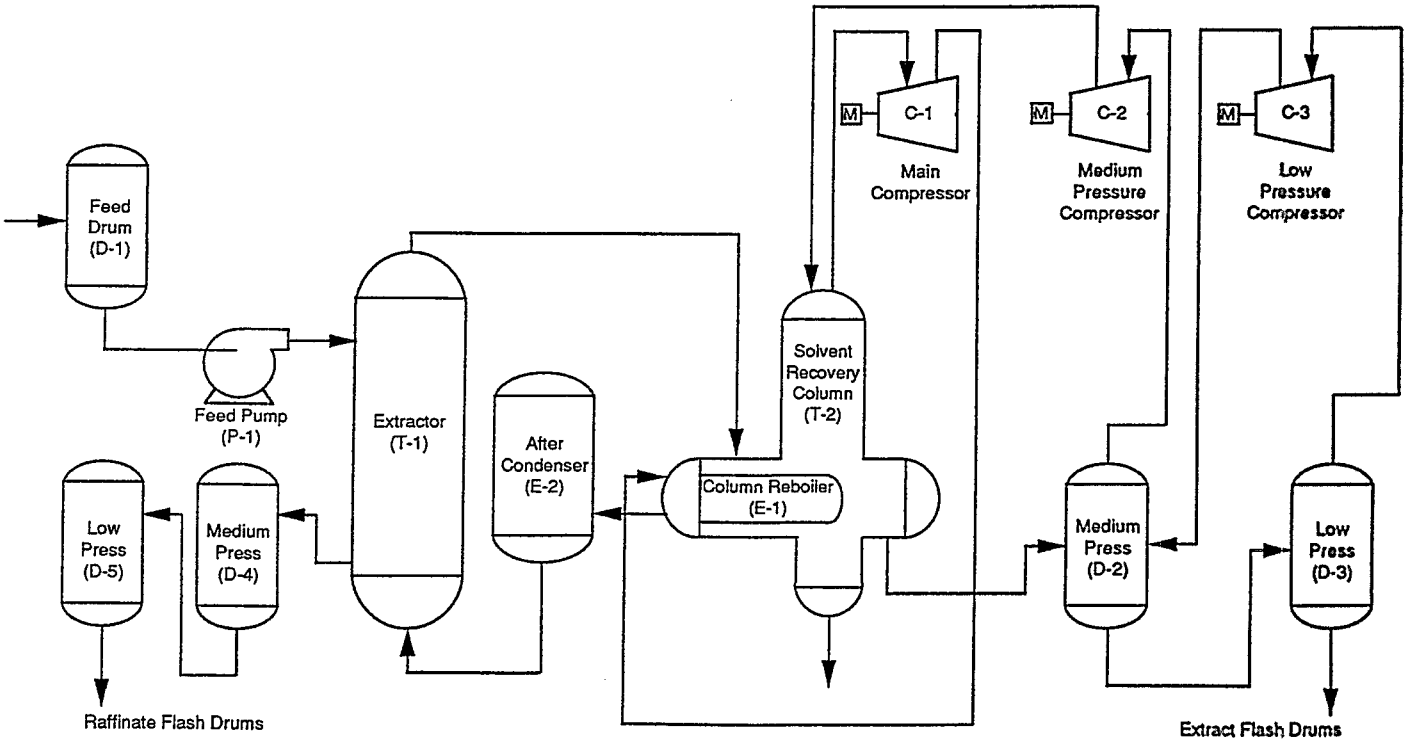


Figure A-4. *CF Systems Organics Extraction Unit Simplified One-Line Diagram.*

are combined with the vapors from D-2 before recompression by C-2 and injection into T-2. The pressure in the raffinate flash drums is controlled by back pressure controllers located in the vapor outlet lines on the two extract flash drums. Both D-4 and D-5 are equipped with level controllers for maintaining proper liquid flow from the drums. From D-5, the raffinate stream is pumped to a storage tank by Raffinate Pump (P-4).

- Carbon Dioxide Recompression, Condensing and Recycling

  The last process involves recompressing, condensing, and recycling the CO_2. The CO_2 vapor coming from D-3 is compressed from 18 psia to 128 psia by compressor, C-3. The CO_2 vapor discharged from C-3 is injected into drum D-2 for direct heat exchange with the liquid in this drum. The CO_2 vapor coming from D-2 is compressed from 124 psia to 753 psia by compressor, C-2. The CO_2 vapor discharged from the second stage of C-2 is injected into the Solvent Recovery Column (T-2) for direct heat exchange to help vaporize CO_2 and to cool the hot compressed CO_2 stream. The overhead vapor from T-2 is fed to compressor C-1 for final recompression from 745 psia to a final pressure of 980 psia. Both two stage compressors, C-2 and C-3, are equipped with intercoolers and knockout (KO) drums. The vapor flowing to the first stage of the compressors contains a small amount of organic vapor. When the hot stream from the first stage is cooled, the organics condense. This liquid has to be removed in a knockout drum before the vapor goes to the compressor second stage. Liquid organics are removed from the knockout drums on level control and are drained to their respective extract flash drums.

  From the main compressor (C-1) discharge, the CO_2 flows through three heat exchangers in series. In the heat exchangers, the CO_2 is cooled, condensed, and subcooled to 70 °F so that it can be recycled to the extractor tower. The CO_2 is cooled and partially condensed by supplying the heat of vaporization of CO_2 in the kettle. The subcooled liquid CO_2 from the last exchanger then flows to the Extractor (T-1).

Appendix B
Developer (Vendor) Comments

1. Introduction

CF Systems Corporation (CF Systems) is a technology-based company in the hazardous-waste-treatment and resource-recovery business, offering services and equipment based on a proprietary extraction technology. CF Systems' solvent-extraction units are designed for removal of organics from soils, sludges, and aqueous streams, concentrating the extracted organics for recovery or final disposal. The result is the minimization of waste volumes, reduction of treatment and disposal costs, and recovery of materials such as oil products, solvents, and chemicals.

In August 1988, the U.S. EPA designated solvent extraction as Best Demonstrated Available Technology (BDAT) for petroleum refinery wastes (K048-K052). Performance data from CF Systems were incorporated in the evaluation used to set these standards for RCRA refinery waste treatment.

CF Systems has demonstrated the effectiveness of its extraction technology through the operation of its Mobile Demonstration Unit (MDU) for nearly two years. To date, the MDU has operated at eleven locations, including refineries, chemical plants, and treatment, storage and disposal (TSD) facilities in the United States and Canada.

In general terms, use of CF Systems' extraction technology provides important benefits for remediation and treatment for land disposal:

- By-product credits for the recovered organics;
- Significant volume reduction of the treated solids;
- Effluent water acceptable for conventional wastewater treatment;
- An environmentally acceptable extraction solvent with low residues.

2. Commercial Activity

CF Systems' major commercial activity has consisted of the following:

- Texaco awarded CF Systems a 14 month remediation contract to clean-up 20,000 cubic yards of First-Third refinery wastes at its Port Arthur Refinery in Texas. This is the first commercial application of any type of solvent extraction technology to treat hazardous waste in the petroleum industry. The Texaco project includes feed pretreatment and material handling services, as well as the solvent extraction system. CFS has installed a full-scale PCU-200 solvent extraction unit at the site and start-up of the system is scheduled for mid-June, 1989.
- In November, 1988, Clean Harbors Inc. purchased a commercial-scale LL-20 system to process 20 gallons per minute (GPM) of organic wastewaters at their Baltimore facility. The unit will be shipped for start-up in July, 1989. Clean Harbors is a rapidly-growing company in the commercial waste treatment, storage, and disposal (TSD) business, with multiple locations nationally. The LL-20 unit will treat a wide range of organic wastewaters to produce disposable water and an organics fraction generally suitable for fuel use.
- A custom 60 ton-per-day system was purchased by ENSCO's El Dorado, Arkansas incinerator facility. The unit is designed to extract organic liquids from a broad range of hazardous-waste feeds sent to the site for incineration. The treated solids produced by the system will be processed by the incinerator at a much faster rate than untreated solids due to their reduced fuel value and the extracted liquids can be used as incinerator secondary combustion fuel.
- The 20 barrel-per-day mobile unit (MDU) has been in operation for test and demonstration purposes under client funding since September, 1987. Operating experience includes six petroleum refineries, U.S. and Canadian; a U.S. chemical plant; a Canadian TSD site; two Superfund sites, a PCB clean-up under this EPA SITE program sponsorship, and the other a woodtreating waste impoundment. In April, 1988, a commercial clean-up job was performed at a major chemical company in New Jersey.

3. The Technology

Critical-fluid solvents, the basis for the CF Systems' technology, are condensed gases or supercritical fluids, such as carbon dioxide, freon, propane, ethylene, ammonia and others, in the vicinity of their critical points. Above the critical point, the transition from gas to liquid is continuous rather than abrupt. At or near such conditions, fluids have very favorable solvent properties. They behave like liquids in that they are capable of dissolving significant amounts of oil or other substances. They behave like gases in that the rates of extraction are extraordinarily high compared to liquid solvents.

In the CF Systems process, a liquid feed such as an organic-containing hazardous waste is admitted to an extractor, along with the solvent. At or near the solvent critical point (usually ambient temperature and several hundred psi), the organics in the waste dissolve into the solvent. The two phases are separated, extracted organics are removed with the solvent, while clean water and solids are removed through an underflow. The extract then goes to a second vessel, where the temperature and pressure are decreased, causing the organics to separate from the solvent. Clean solvent is recycled to the extractor, and concentrated organics are recovered and removed.

Examples of organic pollutants that can be extracted economically using the CF Systems unit include a wide range of aromatic and aliphatic hydrocarbons, chlorinated hydrocarbons, phenols, alcohols, ketones, ethers, and organic acids. The CF Systems technology can be applied to sludges and solids as well as liquid wastes.

4. CF Systems Equipment Systems

CF Systems has developed a series of standard modular equipment systems. For sludge and solids treatment, the capacity range is about 10-500 tons per day; for liquids, about 5-30 gallons per minute (GPM). Treatment systems are assembled as skid-mounted modules to facilitate shipping and field assembly. Production of standard modules also allows high quality, low-cost fabrication.

4.1 The PCU-Series

The PCU-series systems are designed to process high-solids sludge feeds and contaminated solids such as soils. They contain specially-designed extractors and separators to facilitate the treatment of oily solids typical of petroleum sludges and waste materials found in refinery impoundments requiring remediation. Organics removal can be as high as 99.9% or better. At this time the PCU series design has been economically optimized to meet the projected requirements for remediation of both refinery and Superfund applications. Where high levels of clean up are required the economics of the technology will favor operation of the systems at higher temperature and pressures.

The systems included in this product series are:

- PCU-50 - This system, designed to process a maximum of about 12 tons per day, is a standard product for refinery sludges regulated by EPA's RCRA land-disposal ban, impoundment sludges, and oil- and PCB-contaminated soils and silts. The system is skid-mounted and designed for installation into confined spaces and ready integration into existing operations.
- PCU-200 - This system, designed to process a maximum of about 50 tons per day, is a larger-scale product for oily sludges and contaminated soils. The system is mounted on two trailers, and can be mobilized and demobilized in 10-15 days.
- PCU-500 - The PCU-500 is a modified PCU-200 design, with the same solvent-recovery subsystem, but increased extractor capacity to provide for throughputs up to about 100 tons per day. Depending on location and cleanout requirement, mobilization-demobilization may require 4-8 weeks.
- PCU-1000 - This system, with a 200 ton-per-day nominal capacity, is intended for large remediation jobs and relatively long terms (one year or more) at a single location. It is skid-mounted and transportable, but with multiple modules, requiring 2-3 months for mobilization and demobilization.

4.2 The LL-Series

The LL-series systems are designed for the extraction of dissolved or emulsified organics in water streams. Solids are usually not present at a significant level in these streams, or must be removed to the 2-3% level as a pretreatment. Organics content of the feed can range as high as 30-50% and removal efficiencies can exceed 99.9%. The market for the LL-series includes a wide range of organics wastewaters.

The systems are skid-mounted and transportable; however, the extractor is a column which is field-erected. In contrast to carbon steel in the PCU systems, stainless steel is required for this series because of the corrosion potential of the feeds.

5. The Product and the Application

5.1 Applications

The technology is applicable to any solid or liquid feedstock which contains organics water. Depending on the feedstock type and organics various solvent systems are available to meet the product specifications.

For organics contaminated waste water the solvent of choice is carbon dioxide which enables most semi soluble organics to be extracted from the water. Even highly soluble organics such as alcohols may be extracted by correct design of the extraction system.

For sludges where petroleum hydrocarbons or chlorinated hydrocarbons are present together with solids plus water, propane is the solvent of choice.

Finally in these circumstances where non-flammable solvents are required to be used for extraction of organics from sludges environmentally safe chloro-floro-carbons may be used.

6. Application/Market Characteristics

The Company is positioned in the segments of the hazardous waste treatment market where removal of organic material from liquids, soils, and sludges is required. Among the benefits to the user are:

- reduction of wastes to small residual volumes suitable for land disposal;
- elimination of the legal and financial liability of off-site disposal in many cases;
- recovery of organic material with value as a product or fuel; and
- a cost-effective alternative to the next best technical option, incineration.

A major additional advantage is the absence of RCRA permitting requirements in most markets. Under RCRA, treatment systems usually operate under permits to ensure that the treatment itself will not represent a hazard. Incineration, for example, requires permitting and the concomitant requirement for public hearings is delaying incineration capacity by 3-5 years.

CF Systems' permit exemptions fall under three categories:

- the recycling exclusion, where a useful by-product is produced (e.g., petroleum refineries);
- wastewater pretreatment exemption, where the CF Systems unit is a pretreater to final wastewater treatment, as in chemical plants;
- the "totally enclosed" treatment system exclusion, for contained units such as the Company's products.

6.1 Superfund Sites

The EPA's inventory of potentially hazardous sites throughout the United States has been stated as greater than 25,000 [2] in number. By the spring of 1989, about 900 of these sites had progressed through the evaluation stage to the point where they were on the National Priorities List (NPL) and subject to enforcement action under CERCLA. In another report, the General Accounting Office estimated the universe of potential hazardous waste sites at somewhere between 130,000 and 425,000 [3]. Whichever figure is used, it is clear that substantial resources will be dedicated to the clean up of old hazardous waste disposal sites for some time to come.

Using refinery experience as a reference, it is estimated that the average Superfund site might contain 50,000-100,000 tons of material and that about 150 applicable sites will be remediated by 1993. On this basis, the Superfund tonnage treated in the period 1989-1993 might be 7.5 to 15 million tons of material.

6.2 Petroleum Refining Wastes

Of the approximately 180 petroleum refinery sites in the United States, about 100 are active and 80 have shut down. Canada has about 50 refineries (active plus inactive).

Refineries have two primary categories of waste treatable by this technology:

- oily sludges produced from current operation, (ongoing wastes) such as API separator sludges (40 CFR 261.32 K048-K052).
- oily sludges and solids from past operations stored in pits, ponds, and lagoons (surface impoundments).

Ongoing wastes are subject to the RCRA land ban in August, 1990. While some refineries may gain further delays, current environmental control activity clearly indicates that many refineries are preparing to have treatment capacity in place by that time.

The average active refinery in the U.S. is estimated to produce 3-5,000 tons per year of listed hazardous wastes (predominantly API separator sludge) subject to the 1990 land ban; as well as additional wastes listed by states such as California, and contaminated soils, which will total 2.5 million tons over five years.

Closure plans for impoundments will be implemented in the refining industry over the next 10 years at active as well as inactive sites. Most refineries have pits or surface impoundments containing waste sludges generated in the past. In the U.S. and Canada, it is estimated that the total of these impoundments exceed 10 million tons.

6.3 Incinerator Pretreatment

Less than 10 RCRA-permitted incinerators for destruction of solid hazardous wastes presently exist in the United States. The demand for such incinerators far outstrips the supply, but are slim because of public opposition to permitting, the prospects for closure of that gap soon. Thus, any means for increasing the throughput of existing incinerators is of obvious value.

A significant fraction of solid hazardous wastes contains organic liquids that can be extracted with a CF Systems unit. This extraction, as a pretreatment, produces an incinerator feed with reduced heat content (BTU per pound of feed). Incinerator capacity is limited by the heat that can be removed (BTU), not the pounds of feed flowing through. Thus, a controlled evolution of the heat content allows more pounds of hazardous waste to be destroyed. Moreover, the extracted liquid fraction can be used as fuel in the so-called secondary burn, which would otherwise require purchased fuel. As a result, the incinerator operator gets a double benefit from CF Systems' pretreatment.

7. Remediation Experience Histories

CF Systems has generated process and equipment design information for applications in the hazardous waste treatment and remediation industry. A substantial database has evolved for a wide range of extractions from sponsored research conducted at our bench-scale and pilot-plant facilities. Continued growth of that database and process correlations is on-going in our research facilities.

As noted earlier, CF Systems' extraction technology has been successfully demonstrated in the field. The 20 barrel-per-day MDU successfully started-up in 1987 at the Texaco refinery in Port Arthur, Texas. Since then, the unit has processed a wide variety of wastes at several refineries, chemical plants, and TSD facilities in North America. These include:

Texaco, Port Arthur, Texas
Chevron, Salt Lake City, Utah
Chevron, Perth Amboy, New Jersey
BASF, Kearny, New Jersey
Petro-Canada, Montreal, Canada
Tricil, Toronto, Canada
New Bedford Harbor Superfund NPL Site, New Bedford, Massachusetts
Exxon, Baton Rouge, Louisiana
Unocal, Parachute Creek, Colorado
United Creosote Superfund NPL Site, Conroe, Texas

1. Texaco, Port Arthur, October, 1987-January, 1988
The MDU had its initial operation at Texaco's Port Arthur refinery in late 1987. A range of different feed types were run through the system, including spent oily clay, primary separator sludge, and tank bottoms. The resulting treated solids product streams were analyzed by Texaco, and representative results are shown in Table 7-1. Performance consistently met what later became BDAT standards for RCRA first- third (K048-K052) refinery wastes. The results of this demonstration led Texaco to award CF Systems a contract to provide a commercial unit to remediate 20,000 cubic yards of primary separator sludges.

2. BASF, Kearny, New Jersey
A mobile treatment system was run at the BASF Kearny, New Jersey, plant site. One of the waste streams from this plant is an emulsified stream containing di-octyl phthalate (DOP), water, and other organic materials. The system successfully separated the emulsion into a recoverable DOP stream and a wastewater suitable for discharge to the wastewater treatment facility.

3. Petro-Canada, Montreal
The MDU operated at Petro- Canada's Montreal refinery for a six-week period. During this time, the unit successfully processed 14 different feed types ranging from API separator sludges to contaminated soils. The unit achieved organic removal levels better than existing BDAT standards. In some cases, the levels of residual organics, both volatile and semivolatile, were better than those obtained with incineration.

4. Tricil, Toronto, Canada
A series of demonstration tests were run at Tricil Canada's TSD facility in Missasauga, Ontario. The system de-oiled a majority of the organic feed materials arriving at this facility. The wastes processed included API separator sludge, paint wastes, synthetic rubber process waste, and coal tar wastes.

Table 7.1. Texaco Port Arthur Performance Data.

		Ditch Skimmer(LAB)			Clay Pit Area (MDU)			SITE 127 Sludge (MDU)			SITE 143 Sludge (MDU)		Ditch Skimmer (MDU)		
	Boat Levels (mg/Kg)	Feed (mG/Kg)	Treated Solids (mg/Kg)	TCLP (mg/L)	Feed (mg/Kg)	Treated Solids (mg/Kg)	Water (mg/L)	Feed (mg/Kg)	Treated Solids (mg/Kg)	TCLP (mg/L)	Feed (mg/Kg)	Treated Solids (mg/Kg)	Feed (mg/Kg)	Treated Solids (mg/Kg)	TCLP (mg/L)
Water (WT. %)					60.5			62			57		53		
Solids (WT. %)					22.3			32			33		35		
Oil (WT. %)		3.1			17.2			6			10		12		
Total Oil & Grease (WT. %, Dry)			0.052			1.9			3.6			1.0		0.7	
Benzene	9.5	5.1	0.06	<0.0005	9.6	<0.1	<0.01	<2.0	<2.0	<0.01	13.7	<2.0	5.1	<0.1	<0.01
Ethylbenzene	67	13	0.13	<0.001	13	<0.1	<0.01	<2.0	<0.1	<0.01	20.2	<0.1	13	<0.1	<0.01
Toluene	9.5	52	0.44	0.0027	16	<0.1	<0.01	<2.0	<0.1	<0.01	54.4	<0.1	52	<0.1	<0.01
Xylenes	Reserved	71	0.59	<0.003	63	<0.1	<0.01	<2.0	< 0.1	<0.01	75.9	<0.1	71	<0.1	<0.01
Fluorene													9.3	<0.20	
Naphthalene	Reserved	50	0.1	0.0005	210	<5.3		<50	<3.3		45	<3.3	16.5	<0.20	
2-Methyl Naphthalene					300	<5.3									
Phenanthrene	7.7	20	0.16	0.0015				31	<3.3		30	<3.3	18.6	<0.20	
Ohromium		400	560	0.02									400	560	0.02
Lead		1100	1300	31									1100	1300	31

Two specific Tricil requirements were achieved:

- a large volume reduction of the wastes processed;
- reduction of the level of volatile organics such that land disposal of the residual solids was acceptable.

5. New Bedford Harbor Superfund NPL Site, New Bedford, Massachusetts
CF Systems participated in the EPA Superfund Innovative Technology Evaluation (SITE) program at New Bedford Harbor in Massachusetts, a location which is heavily contaminated with PCB's. Data obtained during the program indicated that it is feasible to obtain PCB removal to levels in excess of 99.9% at economic costs.

6. Unocal, Parachute Creek, Colorado
The MDU completed a series of demonstrations at Unocal's Parachute Creek, Colorado facility. Among the wastes successfully run were samples of shale-oil wastes, drilling muds, and other process and refinery wastes.
High recovery of good-quality oil was obtained from shale-oil wastes. Drilling mud wastes were treated to the standards required for land disposal.

7. United Creosote Superfund NPL Site, Conroe, Texas
The MDU completed a treatability study for the Texas Water Commission in conjunction with Roy F. Weston at a Superfund Site in Conroe, Texas. The objective of this study was to evaluate the effectiveness of solvent extraction for remediation of soil contaminated with creosote. PAH concentractions in the soil obtained from the capped area were reduced from 2879 ppm to 122 ppm, demonstrating 95+% reductions were possible. Representative results from this study are shown in Table 7-2.

Table 7.2. Conroe Performance Data

COMPOUND	FEED DRY SOIL (MG/KG)	RAFFINATE DRY SOIL (MG/KG)
Acenapthene	360	3.4
Acenaphthylene	15	3.0
Anthracene	330	8.9
Benzo(A)anthracene	100	7.9
Benzo(A)pyrene	48	12
Benzo(B)fluoranthene	51	9.7
Benzo(GHI)perylene	20	12
Benzo(K)fluoranthene	50	17
Chrysene	110	9.1
Dibenzo(A,H)anthracene	ND	4.3
Fluoranthene	360	11
Fluorene	380	3.8
Indeno(1,2,3-CD)pyrene	19	11
Naphthalene	140	1.5
Phenanthrene	590	13
Pyrene	360	11
Total Pah Conc. (MG/KG)	2879	122.6

8. Remediation Services

In general, remediation projects encompass excavation, treatment, and removal of contaminated soils and sludges (Figure B-3). Depending upon the types of contamination and the level of cleanup required, further processing downstream of CF Systems' extraction system may be necessary. This further processing may include fixation for heavy metals and incineration of the extracted organics.

A typical remediation project may consist of the following steps or any combination of these steps:

1. The soil is excavated and/or the slurry is dredged.
2. If necessary, the excavated material is slurried with water to create a pumpable mixture.
3. The slurry is passed through a multilayered shaker screen to remove material larger than 1/8-inch diameter. Oversized material may be crushed and recycled to the screens.
4. The pH of the screened slurry is monitored and, if required, lime is added to the mixture to maintain a pH between 6 and 8.
5. The slurry may require thickening prior to the slurry being pumped to the CF Systems Extraction Unit.
6. Two product streams exit the Extraction Unit; a solids/water stream and a liquid organic stream. The organic stream will generally be returned to the Client for reuse or disposal.
7. The solids/water stream is dewatered through the use of a belt filter press or a centrifuge. The water from the dewatering step may be used to slurry dry feed solids. Any excess water is clean enough to be disposed of in domestic sewers or in a waste water treatment plant.
8. The dewatered solids may require chemical fixation, if there are significant quantities of leachable solids, such as heavy metals, so that the treated solids may be disposed of in a non-hazardous landfill.
9. The treated solids must then be transported to and disposed of in a landfill or other suitable site.

8.1 Excavation and Feed Pretreatment

8.1.1 Dry Soils

Contaminated dry soils will be excavated through the use of equipment such as front end loaders, backhoes, or bulldozers. These soils will then be fed into a preliminary screening device to remove any materials larger than 4 inches in diameter. Solids captured in the screens will be collected, washed, and disposed of in an appropriate manner.

Screened material will be transported on a conveyor belt to a pug mill where size reduction is effected. The pug mill will combine the dry solids with water to produce a solids/water extricate. This paste will then travel via a second conveyor belt to a tank or pump where additional water will be added to produce slurried solids.

8.1.2 Sludges

A diesel engine powered, auger head dredge will slurry the waste sludges for pumping with water either present or added. Water addition is required in areas where the waste is partially solidified. If water addition is necessary, enough water will be added to float the dredge, creating a pond area that the dredging operation will expand.

8.1.3 Solids Screening and Thickening

Slurried solids from either the pug mill or the dredge will pass through a multilayered shaker screen similar to those used in the oil drilling industry. The objective will be to screen out solids larger than 1/8 inch in diameter. Solids captured by the screen will be collected, washed, and recycled to the pug mill or crusher/grinder for size reduction.

Sludge passing through the screen will be collected in a storage tank equipped with mixers. If required, lime will be added at this point to maintain a pH between 6 and 8. The slurry will then be pumped from this tank to either the extraction unit or to a thickener.

If pumped to a thickener, the slurry will be thickened to approximately 50-percent solids. This is accomplished through the use of either a moving screen or a decantation system depending on the water solubility of the waste.

Water extracted by the thickener will be returned to the dredge area or to another approved discharge point. The thickened solids slurry will be pumped to another holding tank and then fed to the Extraction Unit.

8.2 Product Disposal

The de-oiled solids and water produced from the extraction process will be dewatered. This stream will be run through a belt filter press where a combination of pressure and conditioning flocculents, if required, will remove excess water, leaving a cake with approximately 40- to 45-percent solids. Water separated from the slurry will be returned to the dredge area or to the water treatment system. De-oiled solids in the form of a cake will move via conveyer from the belt filter press to a small blending mill.

9. Cost Estimate for a Specific Superfund Application

Cost estimates provided here are CF Systems' standard budget estimates quoted to commercial customers for use in planning, scoping, and inviting of firm bids. The

estimates' accuracy basis is +/- 20% of the expected final quotations given the same basis and assumptions. Cf Systems would utilize subcontractors to do portions of the described work, specifically solids handling before and after the key extraction step. However, CF Systems is willing to provide the services under a user/project manager or under a prime contractor/project manager.

9.1 New Bedford Harbor, Massachusetts Clean Up Case Study

CF Systems has prepared cost estimates for two cases to provide solvent extraction technology to cleanup PCB-contaminated silt at New Bedford Harbor, Massachusetts. The following comprises the Scope of Work and the basis for the cost estimate for the two cases.

9.1. 1 Estuary Case Description

The quantity of material to be cleaned in Case 2 is 695,000 cubic yeards of PCB-contaminated soil. This quantity of material represents removal and treatment of all contaminated soil in the New Bedford Harbor estuary. The level of PCBs in this material is assumed to average 580 ppm on a dry solids weight basis. The PCBs in this material will be reduced to 50 ppm via solvent extraction. The time schedule for processing this material is about five years.

9.1.2 Case 1: Hot Spot Case Description

The quantity of material to be cleaned in Case 1 is 50,000 cubic yards of PCB-contaminated soil. This quantity of material represents removal and treatment of the hot spots in New Bedford Harbor. The level of PCBs in this material is assumed to be 10,000 ppm on a dry solids weight basis. The PCBs in this material will be reduced to 10 ppm on a dry solids weight basis via solvent extraction technology. This represents a 99.9% removal of PCBs. The time schedule for processing this quantity of material is approximately one year.

9.2 Scope of Work

The scope of work for both cases described above is as follows:

1. The PCB-contaminated material has been removed from New Bedford Harbor and stockpiled, by others, at an appropriate site on land.
2. CF Systems will move the contaminated soils from the stockpile to its processing site, using typical heavy-duty earth moving equipment such as backhoes and bulldozers.
3. CF systems will screen the material to remove oversize particles. Solids larger than 1/8" will be retained on the shaker screens, then be sent to a crusher/grinder for size reduction. Solids that cannot be reduced in size will be rejected and returned to the client, who will be responsible for their disposal.
4. CF Systems will slurry and pretreat the screened material before it is processed in the solvent extraction system.
5. CF System will process the pretreated feed in its solvent extraction units to remove the PCBs from the material.
6. Exiting the extraction system will be two product streams: a PCB-rich extracted organics stream and a PCB-free solids/water stream. The PCB stream will be returned to the client for disposal. CF Systems will dewater the solids/water stream and stockpile the solids for disposal by the client.

9.3 Basis for Costing

CF Systems will provide the solvent extraction system for the cleanup of New Bedford Harbor. All auxiliary and support equipment required will be supplied by CF Systems through subcontractors. It should be noted that the pre and post treatment equipment will be assumed to operate only 10 hours per day. Sufficient storage capacity both in the front and back will be assumed so that the extraction system can operate uninterrupted, 24 hours per day. The current cost estimate for the two cases assumed 1989 costs for the subcontracted services. A breakdown of the subcontracted items and the cost basis for these items are as follows:

Solids Handling Equipment:

The solids handling equipment is provided to move the PCB contaminated material from the stockpile to the CF Systems treatment site. Equipment required for this operation is assumed to include:

One(1)Frontend Loader .....$ 500/day

One(1)D6 Bulldozer. $1,100/day

Two(2)25Ton Trucks.....$2,000/day

Safety equipment for the operators is included in the above costs. The above equipment is required for the duration of the job and is assumed to be operating 10 hours per day.

Solids/Sludge Delivery Equipment:

The solids/sludge delivery equipment is provided for size reduction and delivery of the solids to the feed pretreatment system. Equipment required for this operation is assumed to include:

One (1) Frontend Loader.....$ 500/day

Two (2) Pug Mills.....$1,000/day

One (1) Crusher/Grinder..... ..$ 750/day

Four (4) Conveyors.....$ 200/day

Safety Equipment..... ..$ 80/day

The above equipment is required for the duration of the job and is assumed to be operating 10 hours per day.

Feed Pretreatment Equipment:

The feed pretreatment equipment is provided to screen and slurry the feed prior to the solvent extraction system. Equipment required for this operation is assumed to include:

Two (2) Shaker Screens ..... .$ 40/day

Two(2) Clarifiers.....$ 74/day

Two (2) Feed Pumps.....$ 52/day

Two (2) Mud Tanks.....$ 90/day

Two (2) Fractionating Tanks.....$ 200/day

The above equipment is required for the duration of the job.

Product Handling Equipment:

The product handling equipment is provided to receive the product streams from the extraction system and deliver these product(s) to the client for disposal. Equipment required for this operation is assumed to include:

Two (2) Filter Systems. .....$ 800/day

Two (2) Liquid PCB Storage
& Transfer System .....$ 410/day

Two (2) Solids/Water Storage
& Transfer Systems.. .....$ 160/day

Two (2) Conveyors.....$ 30/day

One (1) Front-End Load..... .....$ 500/day

One (1) D6 Bulldozer. $1,100/day

The above equipment is required for the duration of the job.

Facilities:

The following site facilities are provided to support the site personnel and equipment.

One (1) Sanitary/Office Trailer.. .....$ 80/day

One (1) Laboratory Trailer.....$ 50/day

Site Security.....$ 300/day

Analytical Services..... .....$ 500/day

Two (2) Electrical Generator Sets.... .....$ 600/day

Two (2) Packaged Cooling Towers..... .....$ 200/day

Safety Clothing for Personnel
(per man cost)... .....$ 40/day

Utilities:

It is estimated that all the equipment on-site (extraction systems and auxiliaries) will consume approximately 2750 kwh/hr giving a cost of $3,960 per day for electrical consumption at $0.06 per kwh for the estuary base case.

Labor:

The following labor and current (1989) rates for supervising and operating the various operations have been included in the cost estimate:

Supervisors for CF Systems
Extraction System.....$ 720/day

CF Systems' Extraction
System Operators.....$1,800/day

Pre/Post Treatment Operators .....$ 600/day

Site Engineer.....$ 300/day

Site Manager.....$ 400/day

Other Labor.....$ 200/day

Safety Equipment for Above Personnel .....$ 720/day

9.4 Actual Cost Estimates

The specific costs for the two cases are tabulated in Table B-1. CF Systems utilized its proprietary in-house cost model and generated costs for each of the steps listed in the scope of work. The extraction only related costs were broken out and tabulated according to the 12 cost elements defined by the EPA. Pre- and post-treatment costs involving most of the rental equipment for solids handling were lumped together and some details provided on a confidential basis to allow total system analysis. The contingency and project management fees are self-explanatory.

Table B-1. CF Systems Budget Cost Estimates

Facilities (including utilities)	Base Case Estuary	Hot Spot
Facilities	$ 5,170,676	$ 762,496
CFS Extraction Costs		
Site Preparation (1)	$ 2,307,849	$ 2,616,261
PCU Capital Charges	$ 37,027,058	$ 9,555,141
Labor	$ 8,202,600	$ 1,854,720
Utilities	$ 13,053,273	$ 1,607,573
Analytical	$ 1,519,000	$ 224,000
Total Extraction Costs	$ 62,109,781	$15,587,695
Pre/Post Treatment		
Site Preparation (1)	$ 1,495,200	$ 1,297,800
Excavation/Solids Handling	$ 16,405,200	$ 2,419,200
Solids Delivery	$ 9,326,660	$ 1,375,360
Feed Pretreatment	$ 1,974,700	$ 291,200
Product Handling/Post Treatment	$ 6,957,020	$ 1,025,920
Utilities	$ 1,749,888	$ 258,048
Labor	$ 8,263,360	$ 1,326,080
Total Other Costs	$ 46,172,028	$ 7,993,608
Total Job Costs	$113,452,485	$24,613,799
Contingency (10%)	$ 11,345,248	$ 2,461,380
Project Management (5%)	$ 5,672,624	$ 1,230,690
Overall Budget Cost of Remediation	$130,470,358	$28,305,869

(1) Includes mobilization, startup and demobilization

9.5 Description of Extraction System as Costed

9.5.1 Estuary Case 2

For this case, which involves a large tonnage removal for multiple years on-site, CF Systems recommends the use of a custom made PCU-2000 system which will process about 500 tons/day.

The total time on-site will be 8.35 years to remove the PCBs in 695,000 cubic yards of waste from 580 ppm to the 50 ppm level (91.4% removal efficiency).

9.5.2 Hot Spot Case 1

For this case, CF Systems recommends the use of 4 identical modular systems called PCU-500s which would complete the remediation in about 1.2 years. These are approximately 125 ton/day units each having its own set of extraction stages and a solvent recovery section.

The selection of this size unit and system configuration is to minimize total time on-site and total job cost. Two units in series are required to meet the required efficiency (99.9%) i.e., PCB removal from 10,000 ppm to 10 ppm. Two sets in parallel are required to handle the total volumetric throughput.

Appendix C
SITE Demonstration Results

Introduction

Sediments were dredged from five New Bedford Harbor locations and stored in 55-gallon drums for processing by the PCU-20. Drummed sediments were sieved to remove particles greater than one-eighth inch that could damage system valves. Water was also added to produce a pumpable slurry. The drummed sediments were blended to provide feedstocks for four tests.

Test 1 was a system shakedown run to set flow rates and operating pressures and to provide samples for laboratory evaluation of sample matrices. Samples were collected during Tests 2, 3, and 4 to provide data for evaluating the system's performance. A fifth test was run with toluene used as a feedstock for decontaminating the PCU. About 1 to 2 hours were required to run a feedstock through the PCU. Test 2 involved passing, or recycling, the feedstock 10 times. Test 3 involved 3 passes and Test 4 involved 6 passes. Recycling was conducted to simulate the design operation of a full-scale commercial system. The PCU is only a two-stage system, whereas commercial designs include four or more stages, longer extractor residence times, and longer phase separation times. Conditions that varied for each test were:

1. Test 1 was run as a shakedown test to set pressure and flowrates in the PCU. The feed was a 50-gallon composite of sediments taken from drum numbers H-20, H-21, and H-23. The feed had a PCB concentration of 360 ppm. Three passes were run to gain experience with materials handling.
2. Test 2 was a 10 pass test. The feed was a 350 ppm, 511 pound composite of sediments taken from drum numbers H-20, H-21, and H-23. Ten passes were run to simulate a high-efficiency process and to achieve treated sediment levels less than 10 ppm. A 350 ppm concentration was chosen for this test since this represents an average, or typical, PCB concentration in the harbor.
3. Test 3 was a 3 pass test. The feed was a 288 ppm, 508-pound composite of sediments taken from drum numbers H-20, H-21, and H-23. The purpose of this test was to reproduce the results of the first three passes of Test 2.
4. Test 4 was a 6 pass test. The feed was a 2,575 ppm, 299-pound composite of sediments taken from drum numbers I-11 and H-22. The purpose of this test was to reduce a high-level waste to a lower level waste such as that used in Tests 1, 2, and 3. High-level wastes are found at several "hot spots" in the harbor.

Decontamination of the system involved running toluene through the PCU as a solvent wash. Samples were taken of the feed at the commencement of each test. Treated sediment products and extracts were planned for sampling at each pass. Additional samples were taken of system filters and strainers, although the amount of PCB contained in these miscellaneous samples later proved to be small. PCU operating pressures, temperatures, and flow-rates were monitored throughout the tests. Field tests were conducted for feed viscosity, pH, and temperature.

Results

A large amount of analytical and operating data was obtained, and it was sufficient to meet the program objectives. The detailed results and operating summaries are in the Technology Evaluation Report. The objectives indicated an evaluation of (1) the unit's performance, (2) system operating conditions, (3) health and safety considerations, and (4) equipment and system material handling problems.

System Performance

The evaluation criteria established for system performance were:

- PCB concentration in sediments before and after treatment
- PCB extraction efficiency with each pass of sediments through the PCU
- Mass balances established for total mass, solids, and PCBs.

These criteria are discussed with respect to analytical results below.

PCB Concentration Reductions

PCB analyses for feed sediments and treated sediment, conducted for samples collected at each pass, are shown in Table C-1. The data are displayed graphically in Figures C.1, C.2, and C.3. The data show that treated sediment concentrations of 8 ppm are achievable and that as much as 84 percent of the PCB contained in sediment can be removed in a single pass. In Test 2, feed containing 350 ppm of PCB was reduced to 8 ppm after 9 passes through the PCU. In Test 3, a 288 ppm feed was reduced to 47 ppm after just one pass. In Test 4, a 2,575 ppm feed was reduced to 200 ppm after 6 passes. The percent reductions in PCB concentration, based on a comparison of untreated feed to the final pass, for each test were:

Test	Percent Reduction in PCB Concentration	Number of Passes
2	89%	10
3	72%	3
4	92%	6

The data for each test show general reduction trends based on differences between initial feed and final treated sediment concentrations. However, these trends are not consistent on a pass-by-pass basis. For example, PCB concentrations in treated sediments increase at Test 2, passes 4 and 10, and at Test 3, passes 2 and 3. These anomolies are not related to the extraction process. Instead, they reflect cross contamination within system hardware or limited analytical precision and accuracy. Since the treated sediment collection tanks were under pressure, it was not possible to clean out collection hardware and piping. Therefore, a pass-by-pass mass balance could not be established.

Data for each test can be used to construct a curve that shows the potential number of passes required to reduce PCBs in harbor sediments to specific concentrations using the Pit Cleanup Unit (PCU). If data from Test 2, 3, and 4 are displayed side-by-side, such that similar concentrations coincide, then a PCB reduction curve can be plotted. Data are displayed below, side-by-side, so thatsimilar concentrations overlap.

Table C-1. Pass-by-Pass PCB Concentrations and Reduction Efficiencies

Test Number	Pass Number	PCB Concentration* (ppm)	Pass-by-Pass Concentration Reduction Efficiency (percent)
2	Feed	350	Not Applicable
2	1	77	78
2	2	52	32
2	3	20	62
2	4	66	No Reduction
2	5	59	11
2	6	41	31
2	7	36	12
2	8	29	19
2	9	8	72
2	10	40	No Reduction
3	Feed	288	Not Applicable
3	1	47	84
3	2	72	No Reduction
3	3	82	No Reduction
4	Feed	2,575	Not Applicable
4	1	1000	61
4	2	990	1
4	3	670	32
4	4	325	52
4	5	240	26
4	6	200	17

*PCB data represent feed and treated sediment concentrations.

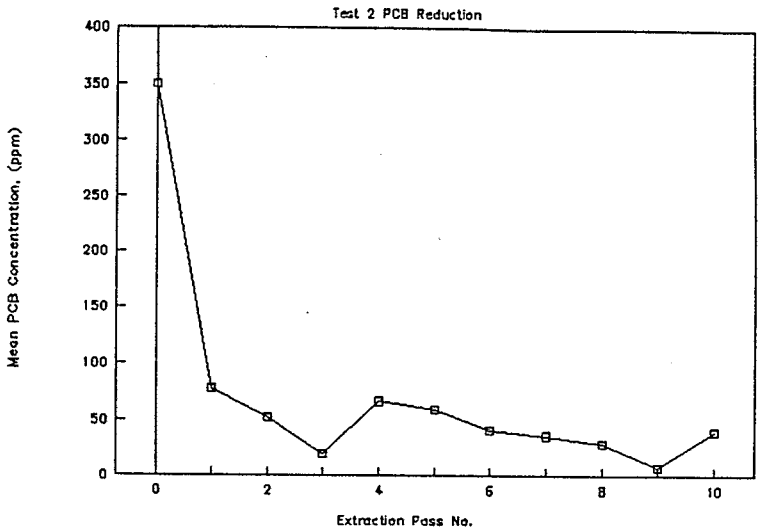


Figure C-1.

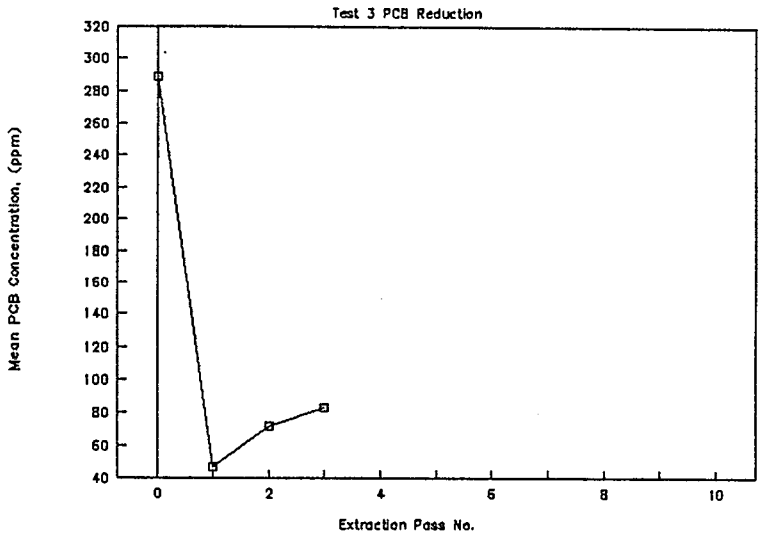


Figure C-2.

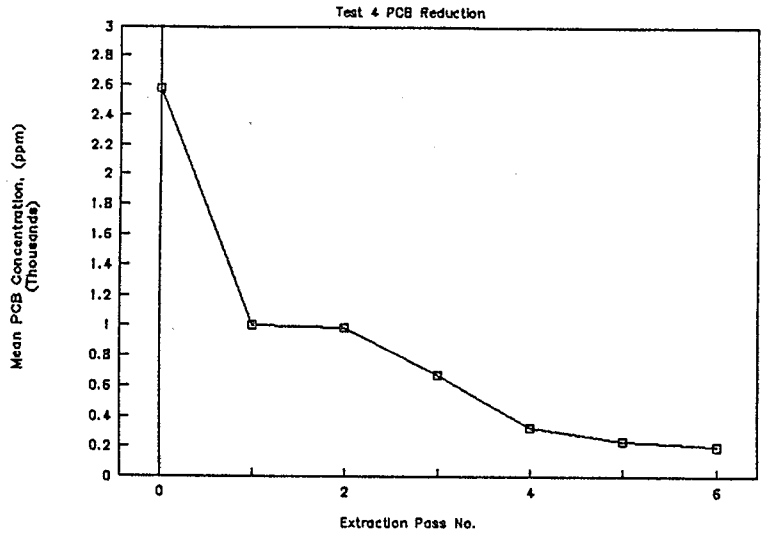


Figure C-3.

Pass-by-Pass PCB Concentrations

Test 4	Test 3	Test 2
2,575	-	-
1,000	-	-
990	-	-
670	-	-
325	288	350
240	47	77
200	72	52
-	82	20
-	-	66
-	-	59
-	-	41
-	-	36
-	-	29
-	-	8
-	-	40

Based on the presentation of the data in Figure C.4, it can be construed that harbor sediments containing 2,500 ppm of PCB could be reduced to 100 ppm after 6 passes through the PCU. A level less than 10 ppm may be achievable after 13 passes.

Extraction Efficiency

Pass-by-pass PCB concentration extraction efficiencies are shown in Table C-1 and are calculated as PCB extracted divided by concentration at the beginning of the pass (multiplied by 100 percent). For each test, the first pass results in efficiencies greater than 60 percent. However, at later passes efficiencies range from negative values to 72 percent. This wide range is the result of cross-contamination of solids retained in the treated sediment subsystem.

Data show that the system irregularly retained and discharged treated sediments. For some passes, as much as 50 percent of the feed was retained in the system. That feed was treated sediment that clung to internal piping and tank surfaces. If discharged with a later pass, the combined discharge could have a higher concentration than feed for the later pass. For example, assume an extraction efficiency of 60 percent, a feed concentration of 350 ppm, and a carry-over of solids from the first pass to the second pass of 25 percent. Then, the treated sediment would contain 77 ppm, instead of 56 ppm if no cross contamination occurred.

The occurrence of cross contamination affects interpretation of each test, but it does not invalidate the fact that treated sediment concentrations as low as 8 ppm were produced. Furthermore, the decontamination procedure, showed that PCB, which accumulated in system hardware, was contained in the extract subsystem, not the treated sediment subsystem.

Mass Balances

Total mass, total solids, and total mass of PCBs were determined for various system inputs and outputs for the purpose of establishing a mass balance. Figure C.5 depicts the inventory sheet used to account for system input and output. Input included feed material and water, although some feed was lost to sampling, sieving, spills, and residuals remaining on the surface of the feed drums. Outputs from the system included samples, spills, container residuals, treated sediment, and residue collected on the basket strainer and cartridge filter. The difference between input and output resulted in either accumulations within the system or unaccounted-for discharges of accumulated material from the system. Mass inventories were developed for each test.

PCB Balance

Table C-2 illustrates the fate of PCB on a pass-by-pass inventory basis. The system accumulated 15.15 grams during Test 2, 6.71 grams during Test 3, and 42.11 grams during Test 4. Only an approximate PCB balance is possible for Test 1, since Test 1 was a shakedown test only. Approximately 21 grams of PCB accumulated within the system during Test 1. Thus, total accumulation within the system from Test 1 through Test 4 was about 85 grams (where 84.96 = 15.14 + 6.71 + 42.11 + 21).

The fuel wash, which occurred immediately after the first pass of Test 3, flushed 35 grams of PCB from the extract subsystem. Final system decontamination with toluene wash delivered an additional 151 grams. Total wash output was 35 plus 151, or 186 grams. Ideally, the amount of PCB washed from the system should equal amount accumulated, or

Accumulation - Wash = 0

However, in this case,

85 grams - 186 grams = 101 grams

The amount of PCB washed from the system is shown above to be greater than the amount fed, which raises the possibility that (1) sampling and analytical errors occurred, or (2) the system was contaminated from a previous CF Systems demonstration.

Quality control samples collected during the demonstration indicate the possibility of sampling and analytical error. For example, laboratory precision and accuracy criteria were 20 and 50 relative percent difference, respectively. In addition, quadruplicate grab samples were collected of the Test 3 feed, the Test 4 feed, and the Test 3

Table C-2. Mass Accumulation and Loss in the System

		Accumulation (Loss) in the System		
Test	Pass	Total Mass (Pounds)	Total Solids (Pounds)	Total PCBs (Grams)
2	1	122	39	14.21
2	2	55	6	0.70
2	3	(25)	(16)	0.50
2	4	78	32	(0.22)
2	5	22	(6)	(0.07)
2	6	68	3	0.3
2	7	(51)	(1)	0.04
2	8	(7)	(11)	(0.07)
2	9	(16)	(3)	0.29
2	10	9	(3)	(0.54)
	Subtotal	254	40	15.14
3	1	24	(13)	6.28
3	2	58	6	1.42
3	3	29	6	(0.99)
	Subtotal	111	1	6.71
4	1	5	10	37.79
4	2	(83)	(12)	(5.25)
4	3	74	9	8.72
4	4	(80)	4	2.55
4	5	106	6	1.63
4	6	(53)	(3)	(3.33)
	Subtotal	(31)	14	42.11
	TOTAL			

Note: Parentheses indicate a loss or discharge from the system.

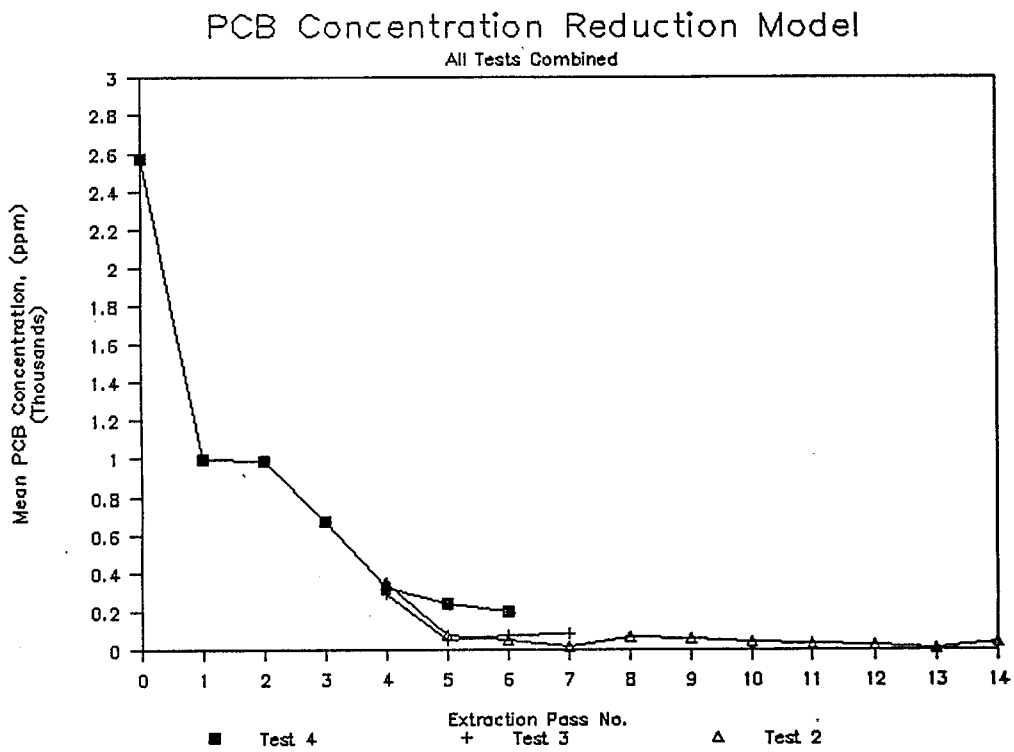


Figure C-4. *Potential Pit Cleanup Unit PCB Reduction.*

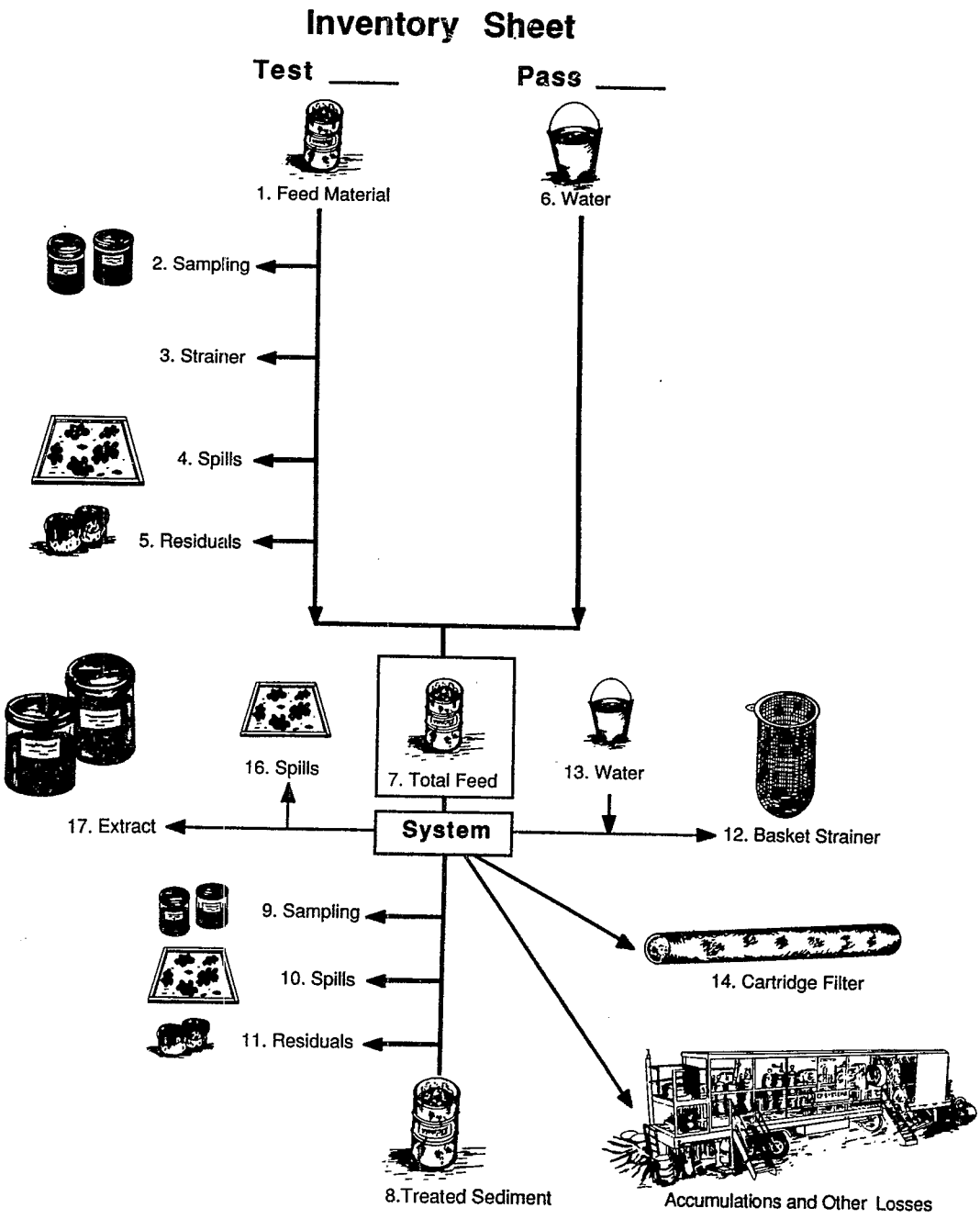


Figure C-5. Illustrative Inventory Sheet.

treated sediment and the RPD calculated for each set ranged from 12 to 47 percent. In particular, the Test 4 feed had a mean concentration of 2,575 ppm, which dominates all other measurements used in the balance, and it had an RPD of 22. Another possible source of the PCB imbalance was contamination of the PCU from prior use at another site. CF Systems did not decontaminate the unit with toluene prior to this demonstration. CF Systems' standard operating procedures now incorporate decontamination with toluene.

In spite of the calculated PCB imbalance, a positive separation of PCB from the harbor sediments was accomplished. The mass balances that 81 grams of PCB were contained in sediments fed to the PCU in Tests 2, 3, and 4. Resulting treated sediments contained 4 grams of PCB, which indicates a mass removal efficiency of 95 percent. Decontamination residue data show that some PCB accumulated in system hardware. However, 91 percent of the PCBs contained in decontamination residues were contained in the extract subsystem. The remaining 9 percent was contained in the treated sediment subsystem hardware.

Basket Strainer, Cartridge Filter, and Carbon Canister

The basket strainer and cartridge filter, which generate residuals that are normally discarded as a waste stream separate from extract and raffinate, did not accumulate a significant PCB mass. The mass balances, shown in Appendix A, show that the accumulation was approximately 2 percent of the PCB mass fed to the system. When compared to PCB removals of 90 percent, this indicates that PCB removal by the basket strainer was not significant. In addition, chemical analysis of the PCB content of filtered solids indicate that the concentration of filtered solids associated with each pass roughly correlated with the treated sediments from the previous pass.

Low pressure propane/butane was vented through the PCU carbon canister at the conclusion of the decontamination procedures. The 285 pounds of activated carbon contained in the canister collected less than 1 gram of PCB. This indicates that air emissions are not significant and PCBs are separated from the solvent when expanded in the PCU.

Total Mass of Solids

The PCU retained and discharged feed material intermittantly throughout the tests. This behavior is demonstrated by tracking the sediment solids. The mass of solids accumulated on a pass-by-pass basis is significant. The flow of solids per pass ranges from 55 percent accumulated to 150 percent discharged. There is no consistent correlation between solids retention and PCB concentration reduction.

During Tests 2, 3, 4, and 5 the system accumulated 302 pounds total mass and 53 pounds total solids. Total mass accumulation represents approximately 4 percent of total mass fed to system during Tests 2 through 5, and total solids accumulation represents about 7 percent of total solids fed to the system.

A total of 3-1/2 tons of solids and water were fed to the unit over the course of 19 passes throughout Test 2, 3, and 4. Of the total, 96 percent was accounted for in the system outputs. Of 789 pounds of solids fed to the system, 93 percent was accounted for in system outputs.

Other Data

Semivolatile Organics

System feed, final treated sediment, and final extract were sampled for base/neutral and acid extractable organics (semivolatiles) during each test for the purpose of (1) characterizing materials for disposal and (2) observing any extraction of semivolatiles. Interpretation of the semivolatiles data, shown in Volume II, is limited for two reasons: (1) the unit contained sludges from a previous demonstration at a petroleum refinery, and (2) a naphtha-based fuel product was added to the unit during Test 3 to clean out the still, extract product tank and related hardware. The following conclusions can be drawn:

- Semivolatiles detected in the toluene wash were also detected in the feed drums, the source being New Bedford Harbor sludge.
- Phenol and 2-methylphenol were found in treated sediments and extracts but were not measured in feed drums, the feed kettle, or toluene washes.
- Test 4 resulted in a reduction of 1,4-dichlorobenzene and pyrene, but chrysene and bis(2-ethylhexyl phthalate) were increased. Similar inconsistencies occur for Test 2 and 3.
- 2-Chlorophenol, 1,3-dichlorobenzene, and benzo(k)fluoranthene were fed to the unit but not detected in any system effluents.

Fate of Metals

A firm conclusion cannot be drawn concerning the fate of metals after each test, since the unit tends to accumulate solids. However, the data in Table C-3 show that treated sediments metals concentrations generally equal or exceed feed metals concentrations. The data also show that metals were not extracted and discharged in the organics effluent. Metals concentrations in organic extracts were one to two orders of magnitude less than treated sediments.

Table C-3. Metals Content of Feed, Treated Sediment, and Extract

Parameter Units	Test 2 Feed	Test 2 Pass 3 Treated Sediment	Test 2 Pass 4 Feed	Test 2 Pass 10 Treated Sediment	Test 2 Pass 10 Extract	Test 3 Feed	Test 3 Pass 3 Treated Sediment	Test 3 Pass 3 Extract	Test 4 Feed	Test 4 Pass 6 Treated Sediment	Test 4 Pass 4 Extract	Test 4 Pass 6 Extract
Cadmium, ppm	35.7	32.5	44.0	42.8	NR(1)	32.0	62.3	6(2)	87.5	120.0	5	5
Chromium, ppm	596	581	761	816	3	525	1020	20	1480	1790	26	31
Copper, ppm	1790	1650	1990	1740	5(2)	1320	2570	6(2)	2650	3700	5	4
Lead, ppm	619	587	792	892	NR(1)	520	1100	NR(1)	1300	1800	35	40
Zinc, ppm	2150	2220	2680	2610	5(2)	1900	3550	8(2)	5370	7260	15	15
Total Residue, %	23.3	18.2	15.0	9.4	NR(3)	19.4	10.3	NR(3)	16.4	5.6	NR(3)	NR(3)

Notes:
1. Not reported, severe matrix effects.
2. Matrix effects indicated.
3. Not reported, insufficient sample volume for analysis method.

EP Toxicity

RCRA regulations at 40 CFR 261.24 specify test methods for determining if a solid waste exhibits the characteristic of EP (extraction procedure) toxicity. The maximum concentration of contaminants for the characteristic of EP Toxicity is shown in Table C-4. Also shown are analytical results for (1) two samples taken from a composite of drummed harbor sediment collected by COE during the waste presampling and (2) a sample of demonstration Test 4, Pass 6 treated sediment. Concentrations for each sample shown are less than the regulatory maximum for the definition of the EP toxicity characteristic.

Feed and Extraction Temperature

Feed and extraction temperatures were stable for Tests 3 and 4. Feed temperatures ranged between 60 and 70 degrees F while extraction temperatures ranged between 60 and 80 degrees F. However, data for Test 2 indicate that feed temperatures fell about 15 degrees F below the minimum specification after pass 5. This caused extraction temperatures to drop, with pass 9 falling 4 degrees F below the minimum specification, 60 degrees F.

The developer attributes much of the fluctuating extraction efficiencies calculated for Test 2 to the low feed temperatures, although other factors were probably important. These factors include cross contamination in the treated sediments collection tank. In addition, reentrainment of solvent in decanter underflows may have caused disproportionately large effects on low concentration sediments. Each factor must be addressed by the developer in the design of a full-scale system.

Table C-4. EP Toxicity Characteristics of Treated and Untreated Sediments

Units (Parts Per Million)

	Composite Sample of Waste Presampling Drums		Treated Sediment	Maximum Concentration Allowable for Characteristics of
	Sample 1	Sample 2	Test 4, Pass 6	EP Toxicity
Arsenic	0.011	0.008	<0.005	5.0
Barium	0.16	0.15	0.36	100.0
Cadmium	0.11	0.12	0.30	1.0
Chromium	0.18	0.098	0.053	5.0
Lead	0.34	0.23	0.16	5.0
Mercury	<0.0002	<0.0002	<0.0002	0.2
Selenium	<0.005	<0.005	<0.02	1.0
Silver	<0.015	<0.015	0.015	5.0

Note: < indicates detected less than the detection limit shown.

Operating Conditions

The system specifications that CF Systems requires for normal operation were discussed in Section 3. In this section, observed operating conditions are summarized and operating data are interpreted with respect to treatment efficiency. In tables throughout this section, mean operating data are shown as well as the range of data recorded for each mean value. Generally, the technology accommodated wide ranges of operating conditions, although precise operational control was limited since all controls were manual rather than automatic.

Extraction Pressure

Pressures in both extractors used in the system were fairly stable for all tests. Pressure levels were close to the nominal level of 240 psig. The maximum pressure, 285 psig, was below the 300 psig maximum specification. The minimum pressure, 190 psig, was above the 180 psig minimum specification. Because pressures were so stable, no relationship between extraction efficiency and extractor pressure was apparent.

Feed Flow Rate

The feed flow rate ranged consistently, throughout the tests, from 0.6 to 1.4 gpm. This range compares well with the 0.2 gpm minimum specification and the 1.5 gpm maximum specification.

Solvent Flow Rate

The solvent flow fluctuated outside the minimum specification, 8 lb/min, and the maximum specification, 15 lb/min throughout Tests 2, 3, and 4. Because of this wide

variation, it was suspected the flow meter was malfunctioning. In Test 4, an alternative measuring device was used and flow measurements continued to show wide variations.

The variable solvent flows caused the solvent/feed ratio also to fluctuate widely. This ratio was calculated as solvent (lb/min)/feed (gpm)/feed density (lb/gal). The minimum solvent-to-feed ratio specification, 1.0, was not met on Pass 2 of Test 4 based on mean data. Individual readings frequently exceeded the 1.0 to 2.0 specification range. A pass-by-pass comparison of solvent/feed ratios to extraction efficiencies was attempted but no direct correlation or trend was apparent.

Nonetheless, it is believed that the solvent/feed ratio is a significant factor in process design since the solubility of an organic in liquified propane-butane is the fundamental basis for the extraction. With higher solvent/feed ratios, the feed is exposed to a larger amount of solvent and extraction efficiency should increase. However, these relationships were not observed, given the available data.

Feed Solids

Feed solids content steadily declined during each test. Initial feeds had solids contents ranging from 15 to 22 percent. Final treated sediments ranged from 6 to 11 percent solids. This change is primarily a result of water added to the feed kettle by operating personnel, during each pass. This unnecessary practice caused waste volumes to increase by 33 percent over the course of the demonstration program. Another, but less significant, factor that affected solids content was accumulation of solids in system hardware. The solids mass balance showed that 7 percent of the solids accumulated in the system and were not washed out during decontamination.

Treated sediments that were fed to the unit after Pass 3 of each test, had solids contents below the minimim specification, 10 percent. This dilution of the feed material is believed to affect system performance.

Viscosity and pH

Feed viscosity and pH fell within specifications and did not affect system performance. Viscosities for untreated feed and recycled sediments ranged from 20 to 170 centipoise, well below the 1,000 centipoise maximum specification. This specification was set by the developer only to ensure that the feed would be pumpable. Untreated and recycled sediments had pH values that ranged between 7.3 and 8.5 standard units. This narrow band fell within the 6 to 12 specification range. The developer established this range to prevent corrosion to PCU hardware.

Health and Safety Monitoring

During the demonstration of CF Systems' process unit, personnel were potentially exposed to the contaminated harbor sediments. A monitoring program was conducted to determine potential exposures and provide a basis for selection of proper personal protective equipment. Several types of portable monitoring equipment were used during the various phases of the field investigations, including:

- Portable Organic Vapor Analyzer (Century OVA)
- Portable Photoionization Meter (HNu)
- Combustible gas/oxygen/hydrogen sulfide meters (MSA and Enmet-Tritector)
- Detector tubes and sampling pump (Sensidyne-Gastec)
- Personal air sampling pumps (Dupont-P200).

It was suspected that some level of organic vapors would be encountered, particularly when drums containing contaminated sediments were first opened during the feed preparation phase. Continuous monitoring using both the OVA and HNu instruments was conducted while the drums were being opened. These instruments detected a slight elevation above background levels of organic vapor immediately upon opening the drums. The levels returned to background levels within a few seconds. No measurable levels of hydrogen sulfide or combustible gas were encountered while opening the drums or handling the sediments during the feed preparation phase.

During the various test runs of the extraction unit at the New Bedford site, organic vapors, PCBs, combustible gases, and hydrogen sulfide were monitored. The OVA and HNu meters were used to monitor for organic vapors at all work stations on the extraction unit, while CF Systems and SITE personnel monitored process equipment. The OVA also was used as a survey meter on the process equipment to search for possible fugitive emissions from the equipment. All measurements indicated that organic vapor levels remained in the range of background levels. Two portable combustible gas meters were used to check for elevated levels of propane during the equipment shakedown period and for spot testing during the demonstration. The pilot unit also contained two integral combustible gas detectors located on either end of the unit. During the normal extraction process, combustible gas readings remained at background levels. However, while treated sediment and extract samples were collected, the combustible gas meters indicated that levels exceeding only 20 percent of the lower explosive limit for propane were encountered. These episodes of elevated propane levels generally lasted for less than 60 seconds and

subsided rapidly depending on the length of time sampling occurred and the strength of the wind at the time.

Sampling was conducted using personal sampling pumps and 150-mg charcoal tubes and florosil tubes to determine personal exposures to organic vapors and PCBs, respectively. All air sample results indicated that, if present, organic vapors and PCB levels were present only at levels below the detection limits for the analytical methods. No measurable levels of hydrogen sulfide were detected using either detector tubes or portable monitoring devices.

Treated sediment and extract subsystems were decontaminated with toluene. The final concentration of PCB contained in the treated sediment subsystem toluene wash was 34 ppm, which was below the decontamination goal of 50 ppm. The final concentration of PCB contained in extract subsystem toluene wash was 60 ppm, which slightly exceeded the decontamination goal of 50 ppm. Staging area soils were not affected by any leaks or emissions that may have occurred during the duration of the demonstration.

Equipment and Material Handling Problems

Equipment and material handling problems occurred throughout the demonstration. While these problems did not impede achievement of the developer's treatment goals, they could impact the economic performance of a full-scale commercial system. Some problems were anticipated since relatively small volumes of sediments were batch-fed to a unit that was designed for continuous operation. The nominal capacity of the unit is 700 gallons per day, but only 50 to 100 gallons per day were batch-fed during shakedown on tests 2, 3, and 4. Consequently, the unit irregularly discharged and retained solids with each pass.

Previous use of the unit affected interpretation of semivolatiles data and may have contributed to imbalance of the PCB inventory. Internal surfaces of extract collection hardware collected PCBs as evidenced by mass balances. In addition, Test 3 was interrupted and viscous oils were found accumulating in extract subsystem hardware. PCBs are soluble in oil, which coated the internal surfaces of system hardware. The amount of oil that can coat internal piping and collection tanks could be significant. For example, assume (1) a hardware surface area of 10 square meters, (2) a coating thickness of 0.1 millimeters, and (3) an oil density of 1.0 grams/cubic centimeter. This is equivalent to 100 grams of oils that cling to the internal surfaces of extract subsystem hardware. As a result of this demonstration, CF Systems now requires more rigorous decontamination procedures for the PCU.

Solids were observed in extract samples that were expected to be solids-free. This indicates poor performance or failure of the cartridge filter. An alternative type of filter should be investigated by the developer.

Low-pressure dissolved propane and butane caused foaming to occur in the treated sediment product tanks. This hindered sample collection and caused frequent overflow of treated sediment to a secondary treated sediment product tank. CF Systems states that design of a commercial-scale unit will allow release of solvent entrained in the treated sediment and elimination of the foaming problem.

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