TREATABILITY STUDIES ON

SAMPLES FROM THE PSC INDUSTRIES SITE,

BRUNSWICK WOOD PRESERVE SITE, and

PENSACOLA ESCAMBRIA SITE

USING SIALLON

STRUCTURED DEACTIVATION TECHNOLOGY

Robert A. Evangelista

3128 Almeria Street, P.O. Box 1244
San Pedro, CA 90733-1244
Phone: (310) 519-8343 Fax : (310) 519-8334

Kishor Parikh, Senior Project Manager
Roy F. Weston, Inc./REAC
GSA Depot
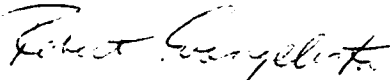Building 209 Annex
Edison, NJ 08837

April 24, 1992

Dear Mr. Parikh:

Please find the following document prepared as the final report of the treatability studies for the immobilization of soil-or sludge-bound contaminants from three sites: Treatability Studies on Samples from the PSC Industries Site, Brunswick Wood Preserve Site, and Pensacola Escambia Site, using Siallon Structured Deactivation Technology.

Sincerely,

KLEENTEK

Robert Evangelista

cc: Tom McDowell, Siallon

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INTRODUCTION

The U.S. Environmental Protection Agency Environmental Response Team (U.S. EPA ERT) was established in 1978 by the National Contingency Plan to provide technical environmental assistance to all U.S. EPA regions, other government agencies, and third world countries through the State Department upon request. The U.S. EPA ERT, along with their Response Engineering and Analytical Contract (REAC) contractor, Roy F. Weston, Inc. (Weston/REAC), have been instrumental in the evaluation and implementation of alternative and innovative technologies at uncontrolled hazardous waste sites.

In addition, the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) Section 121 (b) requests the U.S. EPA to select remedial options that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable." These technologies must provide treatment which "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants." One type of treatment technology that meets the CERCLA mandate is immobilization.

OSWER publication 9380.3-07FS defines immobilization as "any of the technologies which limit the solubility or mobility of contaminants." Therefore, immobilization technologies are those methods whose main effect is to limit the migration of contaminants with or without major modification in the physical state, characteristic or appearance of the waste matrix. To achieve this end, immobilization techniques involve the addition of chemical reagents, and/or various substances to the waste matrix to maintain the contaminants in the lowest possible mobile form.

Cement and pozzolanic materials are the most common used for immobilization. A primary failure for many cement and pozzolanic systems is the interference of organic contaminants on the immobilization process. In cement based and pozzolan based processes, organic solvents and oils may inhibit curing and organic vapor emissions may occur (1).

One technology that focuses primarily on the difficult-to-immobilize oils and petroleum hydrocarbons is the Siallon Structured Deactivation Technology (SDT).

Structured Deactivation Technology

SDT is designed to encapsulate and, hence, immobilize hydrocarbon material. The two-step process first uses a reagent to emulsify the hydrocarbon material in the soil. The second-step reagent reacts with the first step to form a three-dimensional structure surrounding the emulsified hydrocarbon material. The purpose of this structure or shell is to reduce hydrocarbon mobility.

The first step of the SDT process uses a proprietary emulsifier solution. The emulsifier is a blend of reagents with water-based surfactants. The vendor, Siallon, claims the reagent will emulsify organics into micro-droplets two microns or less in size (2).

The second step of SDT treatment is the addition of a proprietary Reactive Silicate solution to the emulsified hydrocarbon. An acid-base reaction occurs between the emulsifier reagent and the Reactive Silicate and forms an amorphous silica structure which encapsulates the micro-droplet of hydrocarbon material. According to the manufacturer, the internal structure of the silica matrix is a complex maze of microcells or chambers which contain the encapsulated hydrocarbon and prevent it from leaching into the environment, effectively reducing the mobility of the hydrocarbon contaminants and its ability to permeate through the soil into the groundwater.

Overview of Treatability Study

The U.S. EPA ERT, through Weston/REAC, has contracted with both Siallon and KLEENTEK for a bench-scale treatability study. The study provides empirical data on the use of SDT for immobilization of particular contaminants contained in selected soil and sludge matrices. The study investigated the degree to which SDT technology could eliminate/minimize the public health and environmental threat via exposure pathways identified at the sites. The study explored the immobilization of matrices from three uncontrolled hazardous waste sites. The sites and their respective matrix type are listed as follows:

* PSC Resources, Palmer, MA   - soil
                                   -sludge
                                   - sludge with added washed sand;
* Pensacola Escambia, Pensacola, FL   - soil;
* Brunswick Wood Preserve, Brunswick, GA   - soil.

The PSC site is the former location of a used oil recovery plant. The PSC site contained two different types of matrices of concern: soil and sludge. Both soil and sludge have high concentrations of petroleum hydrocarbons. During this study, washed sand was added to the sludge to form a third matrix (sludge/sand mixture) which, presumably, may provide the better material-handling characteristic during future pilot-scale tests. Both the Pensacola and Brunswick sites are former wood-treating facilities of the same owner/operator. The contaminants of concern in the soil matrices are creosote and pentachlorophenol, as measured by base neutral/acid (BNA) extractable polyaromatic hydrocarbons (PAHs).

This treatability study was required to explore the treatment effectiveness of a proprietary process in immobilizing hydrocarbon contaminated matrices. Even though SDT is formulated for hydrocarbon contamination, OSWER stresses the need for obtaining empirical data to determine treatment effectiveness: "the effectiveness of immobilization for organics cannot be predicted without testing." (3).

A preliminary treatability study using SDT initially was performed on the PSC Industries site soil, sludge and soil-sludge mixture matrices. BNA extractable PAHs and total petroleum hydrocarbons (TPH) were reduced in the PSC soil matrix by 77% and 82%, respectively, while no reduction was found for the sludge. The results of this preliminary treatability study were promising even though it explored only one emulsifier type at one concentration. The current treatability effort will further evaluate SDT treatment effectiveness for PSC soil and sludge matrices and for soil matrices from the Pensacola Escambia and the Brunswick Wood Preserve sites. This treatability study will explore the remedial effect of emulsifier type and dosage.

Project Objective and Scope

The objective of the immobilization treatability study was to evaluate SDT effectiveness and determine the reagent cost of SDT in reducing the mobility of organic contaminants in U.S. EPA ERT chosen soil or sludge matrices from three Superfund sites.

The concentration of contaminants before and after treatment was measured by chemical analyses provided by Weston/REAC or Weston/REAC contracted laboratories. The primary parameters used for evaluating the effectiveness of SDT immobilization were: 1) total petroleum hydrocarbon; 2) base neutral/acid extractable polyaromatic hydrocarbons by gas chromatograph (GC) and/or gas chromatograph with mass spectroscopy (GC/MS); and 3) toxicity characteristic leaching procedure (TCLP). From the U.S. EPA ERT analytical data, Siallon and KLEENTEK have made recommendations. However, the U.S. EPA ERT and Weston/REAC will make the final determination on whether SDT effectively minimizes or eliminates the ability of a particular matrix

to be a source of groundwater contamination, to be a human contact hazard, and to endanger the environment.

A secondary objective is preliminary economic data on SDT to explore the ability of SDT to be implemented at a reasonable cost. For each experiment, the cost of immobilizing reagents has been provided.

The project scope of the treatability study included the following tasks:
* write a proposal/work plan
* develop a treatability protocol
* perform bench-scale treatability study on soils and sludge from three sites
* perform bench-scale treatability study on pure sand as a control
* coordinate with the Weston/REAC Project Manager
* evaluate the data and present the findings in a written report

METHODOLOGY

Overview of Site Sampling and Treatability Studies

The soil and sludge samples were obtained from the three sites and transferred in five-gallon buckets with locking lids by Weston/REAC. The site samples were hand-screened with a quarter-inch screen to remove rocks and debris and hand-mixed with a trowel to insure relative matrix uniformity.

The SDT treatability studies were performed by the KLEENTEK Project Manager/Engineer in communication with the Siallon Project Manager. Studies were conducted in a mobile treatability laboratory provided by Weston/REAC at the Brunswick Wood Preserve site in Brunswick, Georgia. Samples from the PSC and Pensacola sites were shipped to Brunswick, Georgia, for treatment.

To determine the remedial effectiveness of SDT, the treated and untreated samples from this study were analyzed for TPH, for semivolatile PAHs, and for TCLP heavy metals. Because SDT does not form a monolithic structure after application on soil or sludge, unconfirmed compressive strength and hydraulic permeability were not evaluated.

Analytical Criteria

The SDT immobilization process involves the addition of chemical reagents to the contaminated matrix that combine chemically and/or physically to decrease the mobility of the contaminants of concern.

The analysis of treated matrices for TPH and BNA extractable PAHs on untreated and treated samples are used to determine the net reduction of hydrocarbon contaminants due to the effect of SDT treatment. Semivolatile BNA extractables and TPH follow the procedure described in "Test Methods for Evaluating Solid Waste" SW846, a publication of the U.S. EPA. These types of aggressive extraction analyses for treated matrices by immobilization techniques, generally classified as Total Waste Analyses (TWA), are becoming the standard by which all immobilization processes will be evaluated. An OSWER directive succinctly states the reason for this trend:

> "EPA believes that given the uncertainty associated with immobilization of organics, the most stringent leachability test available (i.e., TWA) should be used to demonstrate the effectiveness of the technology. A successful demonstration using TWA provides a measure of assurance regarding the leachability of organics. ... One or more other leachability tests may also be used in conjunction with TWA to insure the remedy is protective and can meet the remediation levels for the site-specific conditions." (3).

Another leachability test used in conjunction with TPH and semivolatile extractables was TCLP. This extraction procedure, described in 40 CFR Part 268, involved grinding the sample and then subjecting the ground material to an acetic acid leachate at pH5. This test is designed to simulate a co-disposal landfill environment with municipal waste. The leachant is evaluated to determine if target contaminants are found above the regulatory limit, which is set at 100 times the drinking water limit.

Experimental Procedure

For each contaminated soil or sludge matrix, the experimental variables were emulsifier type and reagent dosing. A 2x2 experimental grid was established for treating each contaminated matrix. (Table 1) Each 2x2 experiment, comprised of using two types of proprietary emulsifiers, CA8 and VR. The type of emulsifiers were coded E_1 and E_2 respectively, and were constant throughout the overall treatability study. The Reactive Silicate reagent was not varied during the study. To reduce the number of samples generated, and hence, experimentation cost, duplicate (replicate) experiments were not performed.

The immobilization reagent dosing was dependent on the concentration of organic contaminants, the amount of total petroleum hydrocarbons (TPH) - if known before treatment, and the characteristics of the matrix. Therefore, for each matrix, the dosing (C_1 and C_2) of reagents was varied (Table 1). Only the sludge and sludge:sand matrices were tested at C_2 only. The C_1 designated the lower dosing, C_2 the higher. Matrices with high known or suspected concentration of organic contaminants received proportionately high doses of reagents. When insufficient analytical data was available for an accurate calculation of dosing, the best estimate of the effective dose was made by both the Siallon Project Manager and KLEENTEK Project Manager/Engineer. Even though the dosage of emulsifier was varied between matrices, the same dosing percent (volume/weight) of emulsifier was used for both emulsifiers during the treatment of a particular matrix. The amount of silicate was maintained proportionally equal to the amount of emulsifier throughout the treatability study. Hence, the dosage of Reactive Silicate reagent mirrored the dosage of CA8 emulsifier on a 1 to 1 basis, while Reactive Silicate to VR emulsifier ratio was 1.2 to 1.

For each matrix, cement was mixed with at least one experimental condition to explore the effectiveness of an additional barrier to contaminants (Table 1). Selected samples cured at least 24 hours after SDT reagent addition , then a twenty percent (w/w) mixture of Portland Type 1 cement was applied to SDT-treated matrices. To provide the least amount of variability between the cementation experiments, cement was added to samples only treated with VR emulsifier at the lowest dosage (E_2C_1), except for the sludge and sludge/sand matrices where VR was only added at the high dosage (C_2).

The experimental conditions were kept constant for all experiments. For each experiment, all matrices were weighed to 2,000 grams, were mixed with reagents at the highest speed possible for that matrix in a table-top batch mixer and were cured for at least 24 hours before laboratory analysis. All reagents were maintained at room temperature, 22 to 27 · C, and each reagent was mixed with each matrix for five minutes. The same KLEENTEK Project Manager/Engineer performed all experiments in the treatability study and gave custody of all samples to the Weston/REAC Project Manager immediately after treatment. Analyses were performed on site in the U.S. EPA ERT's mobile laboratory by Weston/REAC or off-site by a contract laboratory with each laboratory performing only one type of analysis.

This paragraph lists the general experimental procedures of the preliminary treatability study for PSC soil and sludge: please refer to the final report for experimental design details (4). CA8 emulsifier was added with equal amounts of silicate to PSC soil, soil/sludge mixture, and sludge at a ratio of reagent:hydrocarbon::1:2. The concentration of hydrocarbon was quantified by TPH analysis. Reagents were mixed with soil on a continuous basis in a laboratory-scale pug mill.

TABLE 1. EXPERIMENTAL CONDITIONS

Site	Matrix	Experimental Condition	Emulsifier Type	Emulsifier Concentration (v/w %)	Silicate Concentration (v/w %)
PSC	Soil	E_1C_1	CA8	8	8.0
PSC	Soil	E_1C_2	CA8	12	12.0
PSC	Soil	E_2C_1	VR	8	9.6
PSC	Soil	E_2C_2	VR	12	14.4
PSC	Soil	E_2C_1&cement	VR	8	9.6
PSC	Sludge	E_1C_2	CA8	20	20.0
PSC	Sludge	E_2C_2	VR	20	24.0
PSC	Sludge	E_2C_2&cement	VR	20	24.0
PSC	Sludge:sand*	E_1C_2	CA8	20	20.0
PSC	Sludge:sand*	E_2C_2	VR	20	24.0
PSC	Sludge:sand*	E_2C_2&cement	VR	20	24.0
Pensacola	Soil	E_1C_1	CA8	1	1.0
Pensacola	Soil	E_1C_2	CA8	2	2.0
Pensacola	Soil	E_2C_1	VR	1	1.2
Pensacola	Soil	E_2C_2	VR	2	2.4
Pensacola	Soil	E_2C_1&cement	VR	1	1.2
Brunswick	Soil, organic	E_1C_1	CA8	1	1.0
Brunswick	Soil, organic	E_1C_2	CA8	2	2.0
Brunswick	Soil, organic	E_2C_1	VR	1	1.2
Brunswick	Soil,organic	E_2C_2	VR	2	2.4
Brunswick	Soil, organic	E_2C_1&cement	VR	1	1.2
Control	Washed sand	E_1C_1	CA8	1	1.0
Control	Washed sand	E_2C_1	VR	1	1.2

* Sludge: sand::1:2

ANALYTICAL RESULTS

For this treatability study, matrices from three sites were mixed with SDT to immobilize hydrocarbon contaminants. Several analytical methods were used to evaluate SDT's ability to immobilize these contaminants. Due to budget constraints, not every experimental condition for each matrix was evaluated by every analytical method; therefore, a sample key (Table 2) was created to list which analyses were performed for each experiment. The Weston/REAC Project Manager made the final decision about which samples received which method(s) of analyses.

Consolidated analytical testing results of the treated and untreated matrices are provided in Tables 3 through 9. The complete analytical reports for this treatability testing are not provided in this report but are in the possession of the Weston/REAC Project Manager. The total petroleum hydrocarbon results for all sites, including the preliminary study for the PSC site, are listed in Table 3. BNA extractable PAHs are segregated by the type of detection instrument. The GC analyses are presented in Tables 4 and 5 for the Pensacola and Brunswick sites, respectively, and the GC/MS results are contained in Tables 6 and 7, and 8 for the Pensacola and Brunswick sites, respectively. Table 8 contains the GC/MS results of the preliminary study for the PSC Industries site; GC or GC/MS analyses were not done for the PSC site samples from this treatability study. The TCLP analyses are presented in Table 9.

TABLE 2. SAMPLE KEY

Site	Sample Type	Analytical Methods				Sample Number (s)
		GC/MS	GC	IR	TCLP	
Pensacola	untreated soil	X	X	X	X	12811; D-11
	E_1C_1		X	X	X	12799; MD0263
	E_1C_2	X	X	X	X	E_1C_2/Pensacola;MD0619
	E_2C_1		X	X	X	127800; MD0264
	E_2C_2	X	X	X	X	E_2C_2/Pensacola;MD0620
	E_2C_1 with cement			X	X	12959
Brunswick	untreated soil			X	X	12953;C-11;MD0277
	E_1C_1	X	X	X	X	09448; MD0277
	E_1C_2	X	X	X	X	09446; MD0621
	E_2C_1	X	X	X	X	09449;E_1C_2/Brunswick
	E_2C_2	X	X	X	X	MD0622
	E_2C_1 with cement			X	X	12960; E_2C_2/Brunswick
PSC	untreated soil			X		
	E_1C_1			X		12784: MD-0254
	E_1C_2			X		12786; MD-0256
	E_2C_1			X		12785; MD-0255
	E_2C_2			X		12787; MD-0257
	E_2C_1 with cement			X	X	12956
PSC	untreated sludge			X		
	E_1C_2			X		12790; MD-0258
	E2C2			X		12792; MD-0259
	E2C2 with cement			X	X	12957:
	untreated sludge: sand					
	E_1C_2			X		09446
	E_2C_2			X		09447
	E_2C_2 with cement			X	X	12958
Controls	untreated washed sand			X		12793; MD-0260
	untreated washed sand			X		A 15061
	E_1C_1			X		A 15062
	E_2C_1			X		A 15063

TABLE 3. TREATABILITY STUDY RESULTS OF THE IMMOBILIZATION OF HYDROCARBONS AS MEASURED BY TOTAL PETROLEUM HYDROCARBON (TPH)

Site Matrix Treated	Untreated Matrix TPH (ppm)	SDT Emulsifr1 at Conc 1 (ppm)	TPH Reduction (%)	SDT Emulsifr1 at Conc 2 (ppm)	TPH Reduction (%)	SDT Emulsifr2 at Conc 1 (ppm)	TPH Reduction (%)	SDT Emulsifr2 at Conc 2 (ppm)	TPH Reduction (%)
PSC Industies Site									
Soil	28200	39100	0.0	32300	0.0	29600	0.0	25700	8.9
Soil with cement	28200	--	--	--	--	16200	42.6	--	--
Soil, preliminary study	61600	11200	81.8	--	--	--	--	--	--
Sludge	96300	--	--	69700	27.6	--	--	63100	34.5
Sludge with cement	96300	--	--	--	--	--	--	64200	33.3
Sludge,preliminary study	17500	22000	0.0	--	--	--	--	--	--
Sludge:sand :: 1:2	32100	--	--	20100	37.4	--	--	19300	39.9
Sludge:sand with cement	32100	--	--	--	--	--	--	22300	30.5
Sludge:soil :: 1:2,prelim study	81000	35100	56.7	--	--	--	--	--	--
Brunswick									
Soil	9670	11400	0.0	11700	0.0	12100	0.0	9910	0.0
Soil with cement	9670	--	--	--	--	2440	74.8	--	--
Pensacola									
Soil	5260	4350	17.3	4640	11.8	4320	17.9	4240	19.4
Soil with cement	5260	--	--	--	--	6690	0.0	--	--
Control									
Washed sand	51	822	--	--	--	23	--	--	--
Washed sand	ND	--	--	--	--	--	--	--	--

Note: TPH concentration of the untreated sludge:sand matrix is estimated based on the sludge concentration and sludge:sand ratio

TABLE 4. PENSACOLA SITE RESULTS FOR THE IMMOBILIZATION OF BNA EXTRACTABLE PAHs AS MEASURED BY GC ANALYSIS

Polyaromatic Hydrocarbons (PAHs)	Detection Limit (ppm)	Untreated Soil (ppm)	Emulsifr1 Compound at Conc 1 (ppm)	PAH Reduction (%)	Emulsifr1 Compound at Conc 2 (ppm)	PAH Reduction (%)	Emulsifr2 Compound at Conc 1 (ppm)	PAH Reduction (%)	Emulsifr2 Compound at Conc 2 (ppm)	PAH Reduction (%)
Naphthalene	57.9	17.7	126.3	0.0	47.0	0.0	180.5	0.0	41.6	0.0
Acenaphthylene	57.9	13.0	12.0	7.7	13.6	0.0	16.5	0.0	16.3	0.0
Acenaphthene	57.9	490.3	468.6	4.4	421.1	14.1	654.2	0.0	500.7	0.0
Fluorene	57.9	531.4	492.7	7.3	576.4	0.0	708.0	0.0	556.5	0.0
Phenanthrene	115.9	1655.8	1633.9	1.3	1211.8	26.8	1696.0	0.0	1451.8	12.3
Anthracene	57.9	731.0	703.1	3.8	1239.1	0.0	1089.9	0.0	832.6	0.0
Carbazole	57.9	212.0	234.6	0.0	495.7	0.0	382.1	0.0	297.6	0.0
Fluoranthene	57.9	902.5	777.5	13.9	847.7	6.1	1016.4	0.0	842.9	6.6
Pyrene	57.9	558.3	483.7	13.4	381.5	31.7	620.0	0.0	521.9	6.5
Benzo(a)anthracene	57.9	183.2	174.3	4.9	96.0	47.6	208.7	0.0	113.1	38.3
Chrysene	57.9	153.7	143.9	6.4	106.8	30.5	191.2	0.0	123.4	19.7
Benzo(b)fluoranthene	57.9	47.6	48.5	0.0	51.3	0.0	71.4	0.0	31.6	33.6
Benzo(k)fluoranthene	57.9	51.9	50.7	2.3	0.0	100.0	71.8	0.0	0.0	100.0
Benzo(a)pyrene	57.9	32.0	37.8	0.0	22.2	30.6	55.0	0.0	19.4	39.4
Indeno(1,2,3-cd)pyrene	57.9	20.7	13.9	32.9	0.0	100.0	23.2	0.0	0.0	100.0
Dibenzo(a,h)anthracene	57.9	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(g,h,i)perylene	57.9	12.3	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
TOTAL PAHs		5613	5402		5510		6985		5349	

TABLE 5.   BRUNSWICK SITE RESULTS OF THE IMMOBILIZATION OF BNA EXTRACTABLE PAHs
RESULTS OF GC ANALYSIS

Polyaromatic Hydrocarbons (PAHs)	Detection Limit (ppm)	Untreated Soil (ppm)	SDT Emulsifr1 Compound at Conc 1 (ppm)	PAH Compound Reduction (%)	SDT Emulsifr1 Compound at Conc 2 (ppm)	PAH Compound Reduction (%)	SDT Emulsifr2 Compound at Conc 1 (ppm)	PAH Compound Reduction (%)	SDT Emulsifr2 Compound at Conc 2 (ppm)	PAH Compound Reduction (%)
Naphthalene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
Acenaphthylene	67.5	ND	ND	NA	39.6	NA	25.7	NA	33.8	NA
Acenaphthene	67.5	121.8	14.5	88.1	0.0	100.0	38.1	68.7	0.0	100.0
Fluorene	67.5	ND	24.8	NA	56.9	NA	43.5	NA	46.9	NA
Phenanthrene	67.5	71.3	74.3	0.0	98.3	0.0	120.6	0.0	80.0	0.0
Anthracene	67.5	20.2	0.0	100.0	42.7	0.0	0.0	100.0	35.2	0.0
Carbazole	67.5	16.4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
Fluoranthene	67.5	43.3	30.3	30.0	70.7	0.0	58.8	0.0	57.6	0.0
Pyrene	67.5	24.5	23.2	5.3	74.3	0.0	49.3	0.0	61.9	0.0
Benzo(a)anthracene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
Chrysene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
Benzo(b)fluoranthene	67.5	16.6	39.3	0.0	33.9	0.0	43.0	0.0	17.6	0.0
Benzo(k)fluoranthene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
Benzo(a)pyrene	67.5	ND	16.5	NA	25.0	NA	18.6	NA	ND	NA
Indeno(1,2,3-cd)pyrene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
Dibenzo(a,h)anthracene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
Benzo(g,h,i)perylene	67.5	ND	ND	NA	ND	NA	ND	NA	ND	NA
TOTAL PAHs		314	223		441		398		333	

Polyaromatic Hydrocarbons (PAHs)	Detec-tion Limit (ppm)	Untreated Soil (ppm)	SDT Emulsifr1 at Conc 2 (ppm)	PAH Compound Reduction (%)	SDT Emulsifr2 at Conc 2 (ppm)	PAH Compound Reduction (%)
TABLE 6. PENSACOLA SITE IMMOBILIZATION OF BNA EXTRACTABLE PAHs AS MEASURED BY GC/MS ANALYSIS						
Naphthalene	120	21	46	0	41	0
2-Methylnaphthalene	120	190	230	0	220	0
1-Methylnaphthalene	120	96	97	0	120	0
Biphenyl	120	17	37	0	32	0
2,6-Dimethylnaphthalene	120	69	72	0	77	0
Acenaphthylene	120	ND	ND	NA	ND	NA
Acenaphthene	250	410	380	7	480	0
Dibenzofuran	120	270	270	0	300	0
Fluorene	120	460	530	0	500	0
Phenanthrene	120	1100	1200	0	1200	0
Anthracene	120	570	1300	0	790	0
Carbazole	120	60	300	0	140	0
Fluoranthene	120	600	610	0	710	0
Pyrene	250	360	330	8	390	0
Benzo(a)anthracene	120	100	80	20	97	3
Chrysene	120	97	84	13	86	11
Benzo(b)fluoranthene	120	66	0	100	0	100
Benzo(k)fluoranthene	120	ND	ND	NA	ND	NA
Benzo(e)pyrene	250	ND	ND	NA	ND	NA
Benzo(a)pyrene	120	ND	ND	NA	ND	NA
Indeno(1,2,3-cd)pyrene	120	ND	ND	NA	ND	NA
Dibenzo(a,h)anthracene	120	ND	ND	NA	ND	NA
Benzo(g,h,i)perylene	120	ND	ND	NA	ND	NA
Pentachlorophenol	120	ND	ND	NA	ND	NA
TOTAL PAHs		4486	5566		5183	

Polyaromatic Hydrocarbons (PAHs)	Detection Limits (ppm)	SDT Emulsifr1 at Conc 1 (ppm)	SDT Emulsifr1 at Conc 2 (ppm)	SDT Emulsifr2 at Conc 1 (ppm)	SDT Emulsifr2 at Conc 2 (ppm)
Naphthalene	120	ND	ND	ND	ND
2-Methylnaphthalene	120	ND	ND	10	ND
1-Methylnaphthalene	120	ND	ND	9	ND
Biphenyl	120	ND	ND	ND	ND
2,6-Dimethylnaphthalene	120	25	29	34	20
Acenaphthylene	120	ND	ND	ND	ND
Acenaphthene	250	ND	ND	ND	ND
Dibenzofuran	120	ND	ND	ND	ND
Fluorene	120	ND	ND	ND	ND
Phenanthrene	120	16	ND	12	ND
Anthracene	120	ND	ND	ND	ND
Carbazole	120	ND	ND	ND	ND
Fluoranthene	120	ND	ND	ND	ND
Pyrene	250	20	28	ND	ND
Benzo(a)anthracene	120	ND	ND	ND	ND
Chrysene	120	ND	ND	ND	ND
Benzo(b)fluoranthene	120	ND	33	ND	ND
Benzo(k)fluoranthene	120	ND	ND	ND	ND
Benzo(e)pyrene	250	ND	ND	ND	ND
Benzo(a)pyrene	120	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	120	ND	ND	ND	ND
Dibenzo(a,h)anthracene	120	ND	ND	ND	ND
Benzo(g,h,i)perylene	120	ND	ND	ND	ND
Pentachlorophenol	120	ND	ND	ND	ND
TOTAL PAHs		61	90	65	20

TABLE 7. BRUNSWICK SITE IMMOBILIZATION OF BNA EXTRACTABLE PAHs AS MEASURED BY GC/MS ANALYSIS

TABLE 8. PSC SITE PRELIMINARY STUDY FOR THE IMMOBILIZATION OF BNA EXTRACTABLE PAHs AS MEASURED BY GC/MS ANALYSIS

Polyaromatic Hydrcarbons (PAHs)	Untreated Soil (ppm)	SDT Emulsf2 Treated (ppm)	PAH Compound Reduction (%)	Untreated Soil & Sludge (ppm)	SDT Emulsf2 Treated (ppm)	PAH Compound Reduction (%)	Untreated Sludge (ppm)	SDT Emulsf2 Treated (ppm)	PAH Compound Reduction (%)
Naphthalene	ND	ND	--	50.4	47.4	6.0	135.3	157.1	0.0
2-Methylnaphthalene	ND	ND	--	95.0	51.2	46.1	132.4	138.8	0.0
Acenaphthylene	ND	ND	--	39.3	18.7(J)	52.4	58.9	57.4	2.5
Acenaphthene	ND	ND	--	13.6(J)	6.9(J)	50.3	21.5	22.9	0.0
Dibenzofuran	ND	ND	--	6.4(J)	3.1(J)	51.6	9.5(J)	8.4(J)	11.6
Fluorene	ND	ND	--	35.4	18.9(J)	46.6	53.8	55.3	0.0
Phenanthrene	4.2(J)	1.3(J)	67	123.7	55.7	55.0	187.8	193.7	0.0
Anthracene	--	--	--	29.4	13.4(J)	54.4	42.4	42.3	0.2
Di-n-butylphthalate	ND	ND	--	2.1(J)	0.0	100.0	3.1(J)	3.3(J)	0.0
Fluoranthene	13.6(J)	2.4(J)	82.3	50.7	23.0	54.6	63.3	70.1	0.0
Pyrene	18.0(J)	4.2(J)	76.7	64.2	24.1	62.5	85.3	73.1	14.3
Benzo(a)anthracene	63.0(J)	1.4(J)	97.8	22.0	10.5(J)	52.3	31.4	28.9	8.0
Bis(2-Ethylhexyl)phthalate	48.0(J)	8.9(J)	81.4	39.7	19.0(J)	52.1	6.2	8.7(J)	0.0
Chrysene	8.7(J)	2.2(J)	74.7	21.6	10.1(J)	53.2	31.0	27.0	12.9
Benzo(b)fluoranthene	8.9(J)	2.1(J)	76.4	13.1(J)	6.1(J)	53.4	15.1(J)	13.0(J)	13.9
Benzo(k)fluoranthene	6.8(J)	1.6(J)	76.5	9.6(J)	4.4(J)	54.1	10.0(J)	7.5(J)	25.0
Benzo(a)pyrene	13.6(J)	3.1(J)	77.2	20.4	9.9(J)	51.4	27.3	24.7	9.5
Indeno(1,2,3-cd)pyrene	11.8(J)	2.6(J)	80.0	13.1(J)	6.4(J)	51.1	13.9(J)	13.2(J)	5.0
Benzo(g,h,i)perylene	ND	2.6(J)	--	14.1(J)	7.1(J)	49.6	16.6(J)	13.9(J)	16.3
TOTAL PAHs	140	32	77	664	336	49	945	959	0

TABLE 9. TREATABILITY STUDY RESULTS OF THE IMMOBILIZATION OF HEAVY METALS AS MEASURED BY TOXICITY CHARACTERISTIC LEACHING PROCEEDURE (TCLP)

Site	matrix treated	Experimental Condition	Lead (mg/L)	Copper (mg/L)	Total Cr (mg/L)	Chromium6 (mg/L)	Chromium3 (mg/L)	Arsenic (mg/L)
PSC	soil	Untreated	112.00	--	--	--	--	--
		E1C1	121.00	--	--	--	--	--
		E1C2	124.00	--	--	--	--	--
		E2C1	1.62	--	--	--	--	--
		E2C2	1.15	--	--	--	--	--
		E2C1&cement	--	0.07	0.08	<0.50	0.08	<0.05
	sludge	Untreated	7.30	--	--	--	--	--
		E1C2	17.80	--	--	--	--	--
		E2C2	0.18	--	--	--	--	--
		E2C2&cement	--	<0.03	<0.03	<0.50	<0.03	0.06
	sludge:sand :: 1:2	E1C2	16.00	--	--	--	--	--
		E2C2	0.11	--	--	--	--	--
		E2C2&cement	--	<0.03	0.04	<0.50	0.05	<0.05
Brunswick,	soil	Untreated	--	<0.03	<0.03	<0.01	<0.03	<0.05
		E1C1	--	<0.03	<0.03	<0.01	<0.03	<0.05
		E2C1	--	<0.03	<0.03	<0.01	0.00	<0.05
		E2C1&cement	--	<0.03	0.05	<0.01	0.06	<0.05
Pensacola,	soil	Untreated	--	<0.03	<0.03	<0.01	<0.03	<0.05
		E1C1	--	<0.03	<0.03	<0.01	0.00	<0.05
		E2C1	--	<0.03	<0.03	<0.01	0.00	<0.05
		E2C1&cement	--	0.08	0.05	<0.01	0.05	<0.05
Control,	washed sand	Untreated	<0.05	--	--	--	--	--

DISCUSSION OF RESULTS

Total Petroleum Hydrocarbon (TPH)

Pensacola site soil showed little reduction of TPH after the addition of SDT (Table 3). Results ranged from 11.8 to 19.4 percent TPH reduction after treatment by emulsifiers at dosages of 1% and 2% (v/w). The spread in the range of TPH reduction between experiments is very small, indicating a consistent effect due to SDT between emulsifiers and between concentrations.

Brunswick site soil (organic type) showed no reduction in extractable TPH after the addition of SDT (Table 3). Results for both types of emulsifiers at low and high concentrations consistently showed no immobilizing effect of SDT on petroleum hydrocarbons. The spread in the range of TPH reduction is nonexistent. The addition of cement to SDT-treated Brunswick soil had a dramatic effect. TPH was reduced by 74.8 percent in Brunswick soil after treatment with SDT followed by cement, as opposed to no reduction in the cement-free experiments.

PSC site soil mixed with SDT during this treatability study showed little or no immobilization for both emulsifiers at low and high reagent dosage. (Table 3). The reduction in TPH, after the addition of SDT reagents, varied from 0 to 8.9 percent. The result of the preliminary treatability study contrasts sharply with this study; the earlier study found an 81.8 percent immobilization as measured by TPH. This result is close to the U.S.EPA regulatory treatment guidelines. Therefore, the two studies offer quite different results for the same soil treated with the same reagents at different dosing in different mixing devises. As observed for both the Pensacola and Brunswick site soils, this treatability study discovered the addition of cement to SDT-treated PSC soil increased the immobilization of TPH to 42.6 percent.

For the PSC sludge or sludge/sand mixture treated in this study, the amount of TPH reduction after SDT processing varied from 27.6 to 39.9 percent (Table 3). A resulting hydrocarbon immobilization significantly higher than for soils from all three sites. The sludge and the sludge/sand matrices were only remediated with a high reagent dosage (C_2 @ 20% v/w) due to the assumed high initial TPH in the untreated sludge. Unlike the above-mentioned soils, the PSC sludge or sludge/sand mixture showed no improvement by the addition of cement to SDT-treated matrix. Respective TPH reductions were 33.3 and 30.5 percent, within the range of TPH reduction for SDT-treated sludge and sludge/sand mixture without added cement. As in the Pensacola and Brunswick experiments, the spread in the range of TPH reductions for all PSC matrices is very low.

The preliminary PSC study, which was done previous to this effort, had comparatively different TPH results for the PSC soil, sludge and soil/sludge mixture. The soil showed an 81.8 % reduction in TPH, while the sludge had no TPH reduction. These results from the preliminary treatability study are considerably different from those of this study. Untreated PSC soil in the current study contained 28,100 ppm TPH, while the preliminary study soil contained 61,600 TPH. Even though the preliminary study soil contained higher concentrations of pretreatment TPH, the percent reduction of TPH due to immobilization was much greater with less dosage of SDT reagents. Concurrently, no reduction of TPH occurred for the preliminary study sludge after SDT application; yet, some hydrocarbon was immobilized during the current study. Like the soil but with an inverse relationship, the TPH in the sludge for this study contained 96,300 ppm while the

sludge sample in the preliminary study contained 17,500 ppm.

Control experiments were performed to check the TPH level of washed sand added to the sludge as a physical conditioner and to explore the effect of the petroleum-based emulsifiers in the TPH analysis. TPH analyses of washed sand without added SDT reagents had concentrations of non-detect and 51ppm, well below the over 5,000 to nearly 100,000 ppm TPH for untreated matrices (Table 3). Washed sand with added SDT reagents (both emulsifier and Reactive Silicate) at a one percent dosage did not show any significant TPH readings for VR emulsifier (E_2); while for the CA8 emulsifier (E1), an 822 ppm TPH reading was found. Hence, from this control experiment, THP values for the Pensacola and Brunswick results were not due to emulsifier. If the THP reading is proportional to the dosage of CA8 used, then the higher emulsifier dosages used for the PSC matrices could lead to 8, 12, or 20 times greater TPH values due to the infrared absorbance during analysis.

In summary, SDT-treated soils showed little or no reduction in TPH. The current set of experiments showed consistent results with little variability in the percent reduction of TPH occurred between experimental conditions for each soil matrix due to SDT treatment. The PSC sludge and sludge/sand mixture also had little variability in the percent TPH reduced between emulsifiers at the high emulsifier concentration (C_2), the only concentration performed for these matrices. Cement significantly improved the immobilization of hydrocarbons in Brunswick soil when added after SDT treatment. Yet, the addition of cement after SDT treatment did not improve the immobilization of hydrocarbons contained in the Pensacola soil and in the PSC sludge or sludge:sand mixture. Control experiments showed that SDT reagents added to washed sand did not increase the apparent TPH reading because of infrared absorbance due to the petroleum-based emulsifier reagent. Finally, the preliminary study results differed from the results of the current study for the PSC soil. For PSC soil, the preliminary study found an 81.8 % TPH reduction after SDT treatment as opposed to the 0 to 8.9 % reduction in the current study.

BNA Extractable Polyaromatic Hydrocarbons (PAHs)

BNA extractable PAH compounds were analyzed by GC with some GC/MS confirmation for Brunswick and Pensacola samples. The PSC samples were not analyzed for these semivolatile PAHs in this effort because according to the Weston/REAC Project Manager, the analytical/chemistry laboratory found that the PSC samples from the preliminary study were too dirty and, hence, troublesome to analyze. However, the PAH results from the preliminary PSC study are included in this report.

The Pensacola site samples show little or no reduction of total PAH compounds by GC analysis (Table 4). A soil sample before treatment contained 5613 ppm total PAHs; after SDT treatment with $E_1@C_1$, $E_1@C_2$, $E_2@C_1$ and $E_2@C_2$, the total PAHs were 5402, 5510, 6985, and 5349 ppm, respectively. Another way of evaluating the data in Table 4 to provide greater analytical certainty is to sum only those selected individual PAHs with untreated concentrations above the analytical detection limit. The sums of the selected compounds for the untreated sample and the above treatment conditions are 5418, 5112, 5376, 6566, and 5240 ppm, respectively. There is essentially no relative change in the data and little or no reduction in PAHs Although PAHs showed little propensity for immobilization, several individual compounds had high reductions after SDT treatment. Benzo (k) fluoranthene and indeno (1,2,3 - cd) pyrene were reduced 100 percent for VR emulsifier; benzo (g,h,i) perylene was reduced 100 percent for all experiments. It should be noted, however, that concentrations of indeno (1,2,3 - cd) pyrene and benzo (g,h,i)

perylene were below the quantification detection limit, the cutoff for analytical certainty.

The Brunswick site samples show little or no reduction of total semivolatile PAHs by GC analysis (Table 5). A soil sample before treatment contained 314 ppm total PAHs; after SDT treatment with $E_1@C_1$, $E_1@C_2$, $E_2@C_1$ and $E_2@C_2$, the total PAHs were 223, 441, 398 and 333 ppm, respectively. As with the Pensacola samples, the Brunswick total PAHs showed little propensity for immobilization. Yet, several individual compounds had high reductions after SDT treatment. Acenapthene was reduced 68.7 to 88.1 percent with CA8 emulsifier and 100 percent with VR emulsifier. Anthracene had the reverse result with 100 percent reduction by CA8 and no reduction by VR. Carbazole showed 100 percent reduction for both emulsifiers. Please note that anthracene and carbazole concentrations were below the quantitative detection limit.
In fact, only 3 compounds out of the 17 compound GC analysis has pretreatment concentration above the cut-off for analytical certainty; therefore, the overall Brunswick soil PAH analysis by GC provided little certainty for an engineering evaluation due to the high detection limits. In fact, the total hydrocarbon concentration may be too high (9,670 ppm TPH) for a reasonable GC detection limit that could adequately discern changes in low levels of BNA extractable PAHs.

The Pensacola site samples showed no reduction of total PAH compounds by confirming GC/MS analyses (Table 6). A soil sample before treatment contained 4486 ppm total semivolatiles; after SDT treatment with $E_1@C_2$ and $E_2@C_2$, the total semivolatiles were 5566 and 5183, respectively. Another presentation of the Table 6 data to provide greater analytical certainty is the sum of only those selected individual PAHs whose untreated concentration is above the analytical detection limit. The sums of, and the selected compounds for the untreated sample and the above treatment conditions are 3960,4850, and 4590 ppm, respectively. There is essentially no relative change in the data and no reduction in PAHs. Only benzo (k) fluoranthene had a high reduction (100% for $E_1@C_2$) after SDT treatment. The agreement between GC and GC/MS total PAHs and individual compounds were quite good, indicating good confirmation of GC results by GC/MS for Pensacola soil.

GC/MS analyses were also performed for BNA extractable PAHs in Brunswick soil samples. Total PAHs after treatment with $E_1@C_1$, $E_1@C_2$, $E_2@C_1$ and $E_2@C_2$ were 61, 90, 65, and 20 ppm, respectively. A pretreatment analysis was not received by KLEENTEK from Weston/REAC. All of the concentration values of the individual compounds are well below the detection limit; therefore, these values have a high degree of uncertainty. This analytical uncertainty is probably the reason these GC/MS values are not in agreement with the GC total PAH concentrations.

PSC soil, sludge and sludge/sand matrices were not analyzed in this study. However, PSC soil and sludge were analyzed by GC/MS during the preliminary study. The PSC soil treated during the preliminary study showed a promising (77%) reduction of total PAHs; PSC sludge was not affected by SDT treatment (Table 8).

In summary, SDT treatment of Pensacola soil did not immobilize most BNA extractable PAHs, the contaminant class of greatest concern at this site. Even though SDT was not effective in reducing total PAHs in Pensacola soil, some individual PAHs, however, had excellent reductions. These Pensacola results were confirmed by GC/MS analysis. On the other hand, the PAH results of the Brunswick soil had a degree of uncertainty because the quantitative detection limits for both the GC and GC/MS analysis exceeded the concentration of the individual PAHs. This fact probably led to the lack of GC/MS confirmation observed for this soil.

The above results reflect the difficulty of immobilizing BNA extractable PAHs found by other studies evaluating other immobilizing techniques. U.S. EPA SITE program evaluation of the HAZCON solidification process concluded that with this technology the "immobilization of volatile

and semivolatile (BNA extractables) does not usually occur." (5). Results of the solidification/stabilization study at the J.H. Baxter site found PAHs were not immobilized after the application of generic additives, such as Type 1 cement or lime/flyash, or proprietary reagents (6).

Toxicity Characteristic Leaching Procedure (TCLP)

After treatment with VR (E_2) emulsifier, PSC soil, sludge and sludge/sand matrices had a large reduction in leachable lead, the only analyte measured by TCLP for the PSC matrices. For PSC soil, the 112 mg/l pretreatment lead was lowered to 1.6 and 1.1 mg/l after C_1 and C_2 dosages, respectively. For the sludge and sludge/sand matrices, which were only treated at the C_2 dosage, 7.3 mg/l of lead was reduced to 0.2, and 16.0 fell to 0.1 mg/l, respectively. (A8 emulsifier had no significant effect on immobilizing lead. The Pensacola and Brunswick TCLP leachable metals (copper, total chromium, chromium^{+6}, chromium^{+3}, and arsenic) were below or slightly above detection limit, thereby providing no useful data.

ECONOMICS

All of the below costs were provided by the vendor, Siallon, and were predicated on commercial pricing. Reagent quantities used were those quantities that gave the best performance in the particular treatability study. The actual reagent cost for any particular site may be different from those listed below due to optimization of reagent concentrations.

Siallon Reagents - Costs

Emulsifier VR	$1.65/L
Emulsifier CA-8	$3.12/L
Reactive Silicate	$2.50/L

Treatment Costs - Chemicals

Pensacola Soil

Emulsifier VR used at 1% V/W	$16.50/1000KG
Cost per ton	$15.00
Reactive silicate used at 1.2% V/W	$30.00/1000KG
Cost per ton	$27.27
Total chemical cost per ton of soil	$42.27

Brunswick Soil

Emulsifier VR used at 1% V/W	$16.50/1000KG
Cost per ton	$15.00
Reactive silicate used at 1.2% V/W	$30.00/1000KG
Cost per ton	$27.27
Total chemical cost per ton of soil	$42.27

PSC Resources Soil   Preliminary Study

Emulsifier CA-8 used at 1% V/W	$31.20/1000KG
Cost per ton	$28.36
Reactive silicate used at 1% V/W	$25.00/1000KG
Cost per ton	$22.72
Total chemical cost per ton of soil	$51.08

PSC Resources Sludge

Emulsifier VR used at 20% V/W	$330.00/1000KG
Cost per ton	$300.00
Reactive silicate used at 24% V/W	$600.00/1000KG
Cost per ton	$545.45
Total chemical cost per ton of sludge	$845.45

PSC Resources Sludge/Sand Mixture

Emulsifier VR used at 20% V/W	$330.00/1000KG
Cost per ton	$300.00
Reactive silicate used at 24% V/W	$600.00/1000KG
Cost per ton	$545.45

Total chemical cost per ton of sludge/sand mixture	$845.45

After additional pretreatment analysis and optimization of reagent concentrations, reagent costs may be lowered. The expected reagent cost range, according to vendor estimates, is as follows:

Pensacola Soil	$24.00 - $65.00
Brunswick Soil	$30.00 - $70.00
PSC Resources Soil	$40.00 - $85.00
PSC Resources Sludge	$350.00 - $600.00
PSC Resources Sludge/Sand	$350.00 - $600.00

CONCLUSIONS

The effectiveness of a treatment technology for site remediation is based on the reduction of concentration or mobility of the contaminants within a waste matrix. The National Contingency Plan deems a 90 to 99 percent reduction of contaminants of concern "sufficiently effective." (7). The U.S. EPA general guidelines for immobilization as treatment for uncontrolled hazardous waste sites mirrors the regulation, in that "through Total Waste Analysis (TWA), a significant reduction (i.e., a 90 to 99 percent reduction) in the concentration of chemical constituents of concern" (3). This evaluation of the results of these treatability studies will adhere to this guideline for determining acceptability of treatment.

These treatability studies were carried out to investigate the degree to which SDT immobilization technology could reduce the mobility of contaminants of concern, total petroleum hydrocarbons and BNA extractable polyaromatic hydrocarbons. A significant reduction of their mobility could eliminate/minimize the public health and environmental threat from surface runoff, groundwater contamination, human contact, and soil/dust inhalation - the contaminant exposure pathways - at three U.S. EPA Superfund sites. The analytical methods used for measuring the change in contaminant mobility was TPH, BNA extractable PAHs by GC and GC/MS, and TCLP.

In general, the agreement between these analytical methods is very good. This agreement tends to support the conclusions, provides a further control and check for the conclusions, and lends credibility to the analytical values in this study. There is high confidence in the results above the detection limit. Specific conclusions of these studies follow:

* As determined by TPH analysis, the immobilization of hydrocarbons in Pensacola soil by the SDT process does not significantly reduce the extraction of petroleum hydrocarbons. The consistency between the GC, GC/MS, and the IR (THP) readings support this conclusion.

* As determined by TPH analysis, the immobilization of hydrocarbons in Brunswick soils by the SDT process does not significantly reduce the extraction of petroleum hydrocarbons. The GC and GC/MS data mirror these results, but could not support this conclusion because most PAH concentrations were below the analytical detection limit.

* As determined by TPH analysis, the immobilization of PSC soil was not conclusive. PSC soil treated during the current study showed no reduction in petroleum hydrocarbon after treatment: in contrast, the preliminary treatability study found particularly promising results with a 81.8 percent TPH reduction. For the preliminary study, GC/MS data mirrors the TPH results, but could not support this conclusion because most PAH concentrations were below the analytical detection limit. In both the preliminary and current studies, the immobilization of PSC sludge by the SDT process does not significantly reduce the extraction of petroleum hydrocarbons. This result was confirmed by the GC/MS analysis in the preliminary study.

* As measured by TPH analysis, the low variability in the results between experimental conditions for a particular matrix indicates SDT's consistent effect between emulsifiers and between dosage. Alternately, this low variability implies that the independent variables, emulsifier type and dosage, differ little in their effect on the dependent variable, total petroleum hydrocarbon.

* A noticeable increase in the immobility of TPH compounds was discovered after the addition of cement to SDT treated Brunswick and PSC soils. Cement may provide an additional barrier to the extraction of petroleum hydrocarbons in soil. This effect was not observed for PSC sludge samples, where similar results were found for sludge treated with SDT alone or SDT with cement, and was not observed for Pensacola soil.

* High post-treatment TPH values were not attributable to SDT's VR petroleum-based emulsifier at any dosage and CA8 emulsifier at low dosage. Control experiments with washed sand showed low TPH values after SDT reagent addition. Therefore, this experiment discounted a potential false positive interference of the emulsifiers absorbing in the C-H stretch region during infrared spectrometry. The VR's significantly lower TPH value, compared with the CA8, may be the result of the excess silicate used with this emulsifier.

* As determined by GC/MS analysis, the immobilization of Pensacola soil and PSC sludge (the preliminary study) by the SDT process did not adequately reduce the extraction of PAHs. Depending on emulsifier and soil type, SDT may be viable for immobilizing certain specific PAH compounds, such as benzo (b) fluoranthene, benzo (k) fluoranthene, indeno (1,2,3-cd) pyrene, benzo (g,h,i) perylene.

* No conclusion can be made with certainty about the immobilization of PAHs by SDT for PSC and Brunswick soils. The immobilization of PSC soil by SDT (in the preliminary study) may have significantly reduced the extraction of PAHs. The immobilization of Brunswick soil may not have reduced the extraction of PAHs. However, most PAH compounds were below the analytical detection limit. Lower detection limits are needed to increase precision and provide confidence.

* Reagent mixing may affect the immobilization of PAHs by the SDT process. For the PSC soil, the difference between the current study and the preliminary study in the resulting immobilization of extractable TPH may be due to the difference in the reagent mixing between the bench-scale batch mixer, used in this study, and the laboratory-scale continuous mixer, used in the preliminary study.

RECOMMENDATIONS

The following recommendation are made with regard to the application of SDT for immobilizing contaminants of concern at the PSC Industries, Brunswick Wood Preserve, and Pensacola Escambria sites:

1. If the immobilization option is pursued for the soil at the PSC Industries site:

   a. analyze the treated and untreated soil from the current study for BNA extractable PAHs by GC/MS with detection limits below most individual PAH compounds;

   b. perform an on-site, pilot-scale immobilization study using a large-scale representative soil sample;

   c. additional tests should be done for the treated samples for the following physical characteristics: wet/dry resistance, freeze/thaw resistance, and abrasion resistance, to determine long-term effects of SDT on immobilized hydrocarbons.

2. Reanalyze treated and untreated Brunswick soil from this study for BNA extractable PAHs by GC/MS. Give attention to attain the lowest detection limits possible. This reanalysis is necessary to provide data certainty and assurance, which is required before any valid engineering evaluation or reliable conclusion can be made about the effect of SDT on this matrix.

3. As evidenced by the results of this study:

   a. the application of SDT at the Pensacola site is not recommended because of the demonstrated limited effectiveness for the immobilization of this matrix;

   b. the application of SDT for the Brunswick site should be reinvestigated (see #2 above) before a recommendation is made;

   c.The application of SDT for immobilizing PSC soil may have promise and should be tested on a larger scale with attention to quantifiable GC/MS analysis and continuous-type mixing.

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