United States
Environmental Protection
Agency

EPA/540/S5-91/003
March 1992

EPA

SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Technology Demonstration Summary

BioTrol Soil Washing System for Treatment of a Wood Preserving Site

A SITE Program demonstration of one configuration of soil washing process developed by BioTrol, Inc., was carried out at the MacGillis and Gibbs wood treatment facility in New Brighton, MN. The processing train, so called BioTrol Soil Washing System (BSWS), consists of three units:

- The BioTrol Soil Washer (BSW) - a volume reduction process, which uses water to separate contaminated soil fractions from the bulk of the soil.
- The BioTrol Aqueous Treatment System (BATS) - a biological water treatment process.
- The Slurry Bioreactor (SBR) - a BioTrol biological slurry treatment process conducted in an EIMCO BIOLIFT™ reactor.

At the MacGillis and Gibbs site, where pentachlorophenol (penta) and polynuclear aromatic hydrocarbons (PAHs) are the contaminants of primary concern, the BSW separated the feed soil into relatively uncontaminated sandy fraction that accounts for the majority of the feed soil, contaminated woody fractions, and a small fraction of fine clay and silt particles. Contaminant removal, defined by the difference between the concentrations of penta in the feed soil and the washed soil, was between 87% and 89% in tests with soil with low penta content (130 mg/kg) and high penta content (680 mg/kg). For total PAHs the removal efficiencies were 83% and 88% in the two tests. The process is particularly attractive where the washed soil material would meet site-specific regulatory requirements for return to the site without further treatment.

The BATS, using a penta-specific *Flavobacterium,* degraded between 91% and 94% of the penta in the process water from the two soil washer tests. PAH concentrations were below detection limits and removals could not be determined.

The contaminated fines are only a small fraction of the original feed soil (<10%) at this site but contain over 50% of the original penta mass. Biological treatment of the slurry of these fines in the SBR required a longer-than-expected acclimation period. Consequently, it can only be estimated that removal levels for penta and PAHs of over 90% can be attained once steady-state operation is achieved.

Costs were estimated for an integrated, commercial-scale system and also for each process operating independently. Incineration of woody material segregated by the soil washing accounts for the major portion (76%) of the costs.

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the SITE program demonstration that is fully documented in two separate reports (see ordering information at back).

Introduction

The Superfund Innovative Technology Evaluation (SITE) Program was instituted in 1986 to promote the development and application of innovative technologies to the remediation of Superfund and other sites contaminated with hazardous wastes. The National Priorities List (NPL) includes 56 sites contaminated with penta and creosote-derived PAHs from wood preserving practices. Soil washing and subsequent biodegradation of the organic contaminants at such sites potentially could be an attractive means for remediation of such sites and, consequently, an appropriate topic for investigation under the SITE Program.

This Project Summary highlights the results of an evaluation of a specific arrangement of the three technologies of the BSWS. The system consists of multiple stages of physical abrasion, attrition, flotation, and washing of excavated soil in the BSW. This is accompanied by biodegradation of solubilized contaminants in the BATS and biodegradation of contamination adhering to fines in the SBR. While the BATS was compatible with the BSW in capacity, the SBR unit provided by Eimco was considerably smaller.

The site selected for the evaluation is a wood preserving facility in New Brighton, MN, where creosote and penta were used for several decades. The facility, owned and operated by the MacGillis and Gibbs Company, is currently using the newer chromated copper arsenate (CCA) preservative and improved technology to minimize site contamination.

Process Description

Soil previously excavated from two areas on the site was used to provide test soils with two levels of penta contamination. The weighted average concentrations of penta in the two soils were 130 and 680 mg/kg.

In the proprietary BSW process, the soil is first screened to remove large material. It is then subjected to slurrying with water, froth flotation, attrition/classification, thickening, and dewatering using a combination of vibrating screens, a mixing trommel, flotation and attrition units, hydrocyclones, spiral classifiers, and dewatering centrifuges. The test units are mounted on a 42-ft semi-trailer with drop-down sides. It is readily transportable to a site for evaluation. With this sequence, the soil is segregated into a large volume of relatively uncontaminated sandy material called washed soil, contaminated woody debris, and a much smaller fraction of contaminated fines. The washed soil is dewatered and returned to the site if in compliance with required cleanup levels, which were not known for this site.

Process water from the BSW is treated at a rate of 10 L/min (3 gpm) in the BATS, a multiple-stage fixed-film bioreactor. Indigenous bacteria are supplemented with a penta-specific *Flavobacterium* to accelerate biodegradation. The system is first acclimated for about 2 wk by recycle of contaminated water. Nutrients are added and the pH and temperature are adjusted automatically as needed. Air is injected at the base of each bioreactor cell through a series of sparger tubes. The design of the BATS is such that a minimum of operator attention is required.

The fines produced by the BSW can be dewatered and disposed of by conventional technology such as incineration. An attractive alternative is aerobic biodegradation in a 3-stage, stirred SBR operating in a cascade mode. A growth of both indigenous and a penta-specific *Flavobacterium* are acclimated for at least 1 wk to prepare the system but it was found that the acclimation period is dependent on penta concentration. For the demonstration, slurry was diverted to a storage tank during the soil washing of the more highly contaminated soil (680 mg/kg penta) and then fed to the small scale SBR unit (180 L capacity) over a 14-day test period at a flow rate of 24 mL/min. Membrane diffusers provide the necessary air for aerobic treatment. Temperature and pH are automatically controlled.

Woody debris, also containing significant levels of penta and PAHs, is containerized for disposal by conventional technology such as incineration.

Test Program

Tests established that most of the contaminants (penta and PAHs) are associated with the fine particle fraction of the soil, making the BSW process well suited for concentrating the contaminants in a small fraction of the feed soil. Particle size and contaminant distribution for the various output fractions from the BSW process are also provided. However, these results cannot be related directly to the operation of the BSW.

The BSW is designed to operate continuously. For this demonstration, tests were carried out using two soil piles. The first test used a feed soil with a weighted average penta concentration of 130 mg/kg (average penta: 112.8±19.8 mg/kg) and lasted about 50 hr. About 11,000 kg of contaminated soil was treated. The second test was carried out over about 150 hrs, with a total of about 18,000 kg of feed soil containing a weighted average of 680 mg/kg penta (average: 657.8 ± 228 mg/kg) treated. Average throughput rates in the two segments of the study were 220 and 160 kg/hr, respectively.

During each test, the different output solids and the process water were weighed and sampled for extensive analyses, including penta, PAHs, metals, dioxins, oil/grease, TOC, chloride, organic halide, solids content, etc. All sampling and analyses during the demonstration program followed approved EPA or Standard Method protocols. Flow rates for the input and output streams were calculated using measured differences in the output over time increments.

The water used to slurry the soil for processing consisted of varying ratios of municipal water, an aqueous solution of polymer used to thicken the fines stream, and treated effluent from the BATS. The volumes of these were also measured to establish an overall material balance. The water from the BSW process was analyzed for parameters similar to those noted above, both as produced and before it was introduced into the BATS. The effluent from the BATS was also carefully analyzed to establish contaminant removals attributable to the biological action.

Similarly, the contaminated fines slurry was analyzed before and after treatment in the SBR. In this case, because of the solids in the slurry (~11% solids), the solid and liquid phases of the slurry were analyzed separately for the critical parameters (penta and PAHs).

Results

Predemonstration particle size and contaminant analyses indicated that the fines, constituting 5% to 8% of the combined output mass, contained approximately 30% of the penta and PAH contamination in the output streams. However, the procedures used in these tests do not allow the results to be related directly to the segregation achieved in the BSW.

BioTrol Soil Washer

Wide fluctuations in the feed soil rate were encountered during the soil washing of both soil piles due to mechanical problems and the consistency of the soils. Nevertheless, the BSW succeeded in segregating the feed soil into relatively uncontaminated washed soil, contaminated woody debris, and a slurry of contaminated fines amounting to only a small percentage of the feed soil mass. Considerable penta is also dissolved into the process water.

Removal efficiency was defined by the developer as:

$$\% \text{ Removal efficiency} = 100 \times \left(1 - \frac{\text{washed soil conc.}}{\text{feed soil conc.}}\right)$$

On the basis of weighted average penta concentration in the washed soil versus penta in the feed soil, the removal efficiency was 89% in the test with the low penta concentration soil and 87% in the test with the high penta concentration. Within each test of the soil washer, the concentration of penta retained by the washed soil remained relatively constant (9% and 11% of output, respectively). In addition, the mass and penta content of the washed soil remained relatively uniform, regardless of fluctuations in feed soil flow rate or input penta concentration, suggesting that maximum removal had been achieved from that soil. In the two tests, the bulk of the penta in the output streams was found in the fine silt and clay fraction (34% and 27%, respectively), the process water (40% and 34%, respectively), and the coarse and fine woody material (14% and 29%, respectively).

Weighted values were used for stream masses and penta concentrations in calculating masses because sampling intervals varied and different masses were collected during the different sampling periods; consequently standard deviations could not readily be calculated and would not have the usual meaning. Arithmetic averages and standard deviations for stream flows, masses, and penta concentrations which indicate that the two calculation methods do not provide greatly different results are provided in the report.

Mass balances for input and output streams and, particularly for penta concentrations, varied widely in the two tests with considerably higher combined masses found in the output streams than in the input. While the explanation for this is not certain, there is some reason to believe that the soil washing improves the accessibility of the solids during the solvent extraction step of the analyses. Summaries of the results for the two tests are presented in Tables 1 and 2. The full report provides more extensive data on concentrations and masses.

Results with PAHs paralleled those observed for penta except that much smaller concentrations were found in the process water, which is consistent with the lower solubility of the PAHs. The silt and clay fraction contained 61% of the PAHs in the low penta soil washing test and 55% in the high penta soil washing test while the washed soil retained slightly more PAHs than penta (18% and 15%, respectively). Removal efficiencies in the two tests were calculated to be 83% and 88%.

In addition to the copper, chromium, and arsenic expected from the CCA wood treatment now in use, analyses were carried out for a number of other metals. Removal efficiencies for copper, chromium,

Table 1. *Results of Low Penta Soil Washing Test*

	As-is wt. kg	Penta conc ppm	Penta mass[1] mg	Penta mass[1] %[2]	Total PAHs conc ppm	Total PAHs mass[1] mg	Total PAHs mass[1] %[2]
Input							
Feed Soil	*1.00*	*130*	*130*	*100*	*247*	*247*	*100*
Municipal Water	*5.45*	*0*	*0*	*0*	*0*	*0*	
Thickener Sol'n	*0.82*	*0*	*0*	*0*	*0*	*N/A*	
Total	*7.27*		*130*			*247*	
Output							
Washed Soil	*1.18*	*14*	*16.5*	*9*	*42*	*49.7*	*18*
Coarse Oversize	*0.14*	*170*	*23.8*	*13*	*309*	*44.9*	*16*
Fine Oversize	*0.06*	*96*	*5.8*	*3*	*208*	*12.3*	*4*
Fine Particle Cake	*0.22*	*270*	*59.4*	*34*	*778*	*170*	*61*
Combined Dewatering Effluent	*5.00*	*14*	*70.0*	*40*	*0.5*	*2.5*	*1*
Total	*6.60*	*175.5*				*279*	
% Removal Efficiency		*89*			*83*		

[1] Mass refers to the mass of contaminant in the as-is weight of each fraction obtained from treatment of 1 kg of feed soil.
[2] Refers to percent of total input or output, respectively.

Table 2. *Results of High Penta Soil Washing Test*

	As-is wt. kg	Penta conc ppm	Penta mass[1] mg	Penta mass[1] %[2]	Total PAHs conc ppm	Total PAHs mass[1] mg	Total PAHs mass[1] %[2]
Input							
Feed Soil	*1.00*	*680*	*680*	*98.3*	*404*	*404*	*99.7*
Municipal Water	*0.22*	*0*	*0*	*0*	*0*	*0*	
Thickener Sol'n	*0.75*	*0*	*0*	*0*	*0*	*N/A*	
BATS Effluent	*4.12*	*2.8*	*11*	*1.7*	*0.2*	*0.9*	*0.3*
Total	*6.09*	*691.5*				*405*	
Output							
Washed Soil	*1.31*	*87*	*114*	*11*	*48*	*61.8*	*15*
Coarse Oversize	*0.18*	*1400*	*252*	*24*	*535*	*92.2*	*22*
Fine Oversize	*0.06*	*900*	*54*	*5*	*463*	*25.8*	*6*
Fine Particle Cake	*0.22*	*1300*	*286*	*27*	*1064*	*230.5*	*55*
Combined Dewatering Effluent	*4.50*	*80*	*360*	*34*	*1.9*	*8.6*	*2*
Total	*6.27*		*1066*			*419*	
%Removal Efficiency		*87*			*88*		

[1] Mass refers to the mass of contaminant in the as-is weight of each fraction obtained from treatment of 1 kg of feed soil.
[2] Refers to percent of total input or output, respectively.

and arsenic were in the range of 48% to 70% (based on concentrations in feed soil and washed soil). Barium, lead, and mercury were the only metals found at significant concentrations in the output streams. Once again, the fine particle cake contained the bulk of the mass of each metal for which sufficient data were available.

Similar results were obtained for Total Organic Carbon (TOC) and Total Recoverable Petroleum Hydrocarbons (TRPH), with removal efficiency from the feed soil of 84% and 94%, respectively, in the test using the low penta concentration soil and 81% and 92%, respectively in the test with the high penta concentration soil. It should be noted, however, that the ranges on which these averaged values are based are broad, perhaps reflecting the variability in the sampling of the soil washing.

Analyses were also carried out on the feed soil and each output stream for various polychlorodibenzo-p-dioxins and furans (CDD/CDFs). The octachlorodibenzo dioxin (OCDD) isomer constituted about 65% of the congeners found at measurable concentrations in each soil, and the ratios of congeners were essentially constant for all streams. Again, most of the CDD/CDFs concentrated in the Fine Particle Cake and distribution among the output streams was similar to that found for the PAHs. Removal efficiencies, based on washed soil and feed soil concentrations of total CDD/CDFs, were 92% in the test with the low penta concentration and 97% in the test with the high penta soil.

BioTrol Aqueous Treatment System

Both tests of the BATS were carried out at flow rates of about 10 L/min. Calculated on the basis of flow-weighted mass data, the weighted penta concentrations in the BATS using process water from the low penta concentration soil washer test decreased from about 14 to 1.3 mg/L, equivalent to a removal of about 91%. In the test using process water from the high penta concentration soil washing, weighted influent penta concentrations of 44 mg/L were reduced to 3 mg/L, or a 94% removal. Analytical data for free chloride production and organic chloride consumption were insufficient to establish that the loss of penta occurs by mineralization to chloride, carbon dioxide, and water. Insufficient data for PAHs above the detection limits precluded the estimation of removal efficiencies on the basis of these tests; only acenaphthene was found regularly in influent and effluent. Analyses for metals indicated that there was some decrease during the course of biotreatment. Since none is expected, it may be presumed that metals are adsorbed in/on the biomass in the reactor.

Slurry Bioreactor

The SBR operated at 24 mL/min (0.38 gal/hr), which provided a retention time of about 5.2 days. Problems were encountered with the feed of slurry due to cold ambient temperatures, with variability in feed concentrations (probably due to poor mixing in the storage tank), and with inadequate nutrient feed for the unexpectedly high penta concentrations during the initial days of operation. The solid phase of the slurry that was introduced to the SBR contained an average of 2570 ± 506 mg/kg penta while the liquid phase contained only 59 ± 19 mg/L. Because of these problems and the delay in system response to corrective actions, acclimation was not achieved before sampling was initiated and initial effluent concentrations of penta and PAHs were higher than expected. Only toward the end of the 14 day test period were the anticipated penta and PAH removal levels of 90% reached for both solid and liquid phases of the slurry.

PAHs were not detected in the liquid phase of the influent or the effluent. Even for the solid phase, many of the PAH data were at or below detection and could only be estimated. The high penta concentrations in all the samples contributed to the analytical difficulties and high detection limits. Removal efficiencies calculated for each of seven PAHs using measured or estimated concentrations in the solid phases confirmed that removal was proceeding slower than expected and only attained values in the 90% or higher range after about 7 days. For some of the PAHs, removal efficiency never reached this level (Table 3), and for others the highest level was reached early in the treatment and then decreased over the course of the study. These anomalous results remain unexplained.

Costs

Basic operating and equipment capital costs were provided by the vendor and estimates were made concerning the fraction of feed soil that would be returned to the site as washed soil (assuming cleanup levels are met), that which would be woody debris requiring off-site disposal, and the fraction that would be clay/silt fines amenable to slurry biodegradation. Certain other assumptions were made based on experiences during the demonstration project and certain other cost factors were assumed to be the responsibility of the site owner/operator. The reasoning used in making these estimates or omitting a particular cost category are discussed in the report.

Costs were first estimated for a 0.25 to 0.5 ton/hr pilot scale system similar to that used in the demonstration but operating for only 2 wk and without the costs related to the SITE evaluation. Assuming lease of all equipment, the cost estimated was $6.50/kg or $6000/ton of soil treated. Mobilization and demobilization and lease costs are major contributors to the high cost of such an evaluation.

The cost to treat similarly-contaminated soil in an area such as the MacGillis and Gibbs site with an 18.2 metric ton/hr (20 ton/hr) commercial soil washer coupled with three 100 gpm BATS units operating in parallel and three parallel SBR trains capable of treating 23 gpm of slurry was estimated at about $168/ton of soil. Disposal of the contaminated woody material segregated during soil washing accounts for the major portion (76%) of this cost.

Applicability to Other Sites

Based on the demonstration and other information provided by the vendor, the BSWS appears to be attractive for soils where: (1) there is a small fraction of fines, (2) the fines retain the bulk of the contaminants, and (3) the fines can be

Table 3. PAH Removals in the Slurry Bio-Reactor

PAH	Avg. Conc.[1] On Influent Solid mg/kg	Removal Max. %	Removal Day of Test	Removal On Day 14 %
Acenaphthene	53 ± 44	89	7	75
Fluoranthene	277 ± 144	99	14	99
Pyrene	363 ± 121	94	14	94
Benzo(a)anthracene	63 ± 41	87	14	87
Chrysene	89 ± 47	93	14	93
Benzo(b)fluoranthene	69 ± 36	75	14	75
Benzo(a)pyrene	48 ± 41	80	6	71

[1] *Includes measured and estimated values in averages.*

segregated from the bulk of the soil by the BSW process. If the soil contains excessive fines (over about 25%), the benefits of soil segregation by particle size begin to become less evident.

Water soluble contaminants such as penta tend to dissolve in the aqueous process stream and subsequently can be treated biologically in the BATS. Water-insoluble contaminants such as PAHs (as well as adsorbed penta) can be removed from the slurry of fines by biodegradation, as in the SBR, or can be disposed of by conventional means such as incineration.

While no experimental work was done to evaluate such options, it may be feasible to customize the system for removal of other contaminants, such as by adding surfactants, adjusting pH, or adding solvents.

Conclusions

For properly selected soils, the BSWS can segregate a large fraction of relatively uncontaminated washed soil. Whether this soil can be returned to the site after dewatering with no further treatment will be dependent on cleanup requirements; this will have a major impact on the cost-effectiveness of the process.

Soil character, moisture content, particle size distribution, and contaminant concentrations and solubilities all are factors in the efficiency and the operability of the soil washer. For example, the soil washer is most effective when the soil contains 25% or less of fine material such as clay and silt.

Based on the decrease in contaminants in the washed soil relative to the feed soil, contaminant removal efficiencies of just under the vendor's claimed 90% can be achieved by the soil washing process for penta, PAHs, and even dioxins.

Subsequent biotreatment of contaminated soil washer process water in the BATS can achieve over 90% degradation of penta. Degradation of PAHs could not be determined in this study.

The small fraction of fines, even containing very high levels of adsorbed penta, can be subjected to biodegradation in the SBR if adequate acclimation time is allowed. Significant removal of various PAHs is also achieved in the SBR, but to a much more variable level. For maximum cost-effectiveness, the treated fines should then meet regulatory cleanup requirements and be suitable for return to the site.

The cost to treat 1 ton of feed soil in a 20 ton/hr soil washer, combined with the cost to biodegrade the contaminated fines and associated process water before it is recycled and to incinerate woody debris, is approximately $168/ton. Incineration of woody material is the major cost factor.

☆U.S. GOVERNMENT PRINTING OFFICE: 1992 - 648-080/40194

*The EPA Project Manager, **Mary K. Stinson**, is with the Risk Reduction Engineering Laboratory, Edison, NJ 08837 (see below)*

The complete report, entitled "Technology Evaluation Report: BioTrol Soil Washing System for Treatment of a Wood Preserving Site," consists of two volumes:

"Volume I" (Order No. PB92-115 310-V1; Cost: $35.00, subject to change) discusses the results of the six-week field demonstration.

"Volume II", Part A (Order No. PB92-115 328-V2-Pt A; Cost: $43.00, subject to change) and Part B (Order No. PB92-115 336-V2-Pt B; Cost: $43.00, subject to change) contains the technical operating data - laboratory analytical results, etc.

Both volumes of this report will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

A related report, entitled "Applications Analysis Report: BioTrol Soil Washing System for Treatment of a Wood Preserving Site," discusses the applications of the demonstrated technology.

The EPA Project Manager can be contacted at:

Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Edison, NJ 08837

United States
Environmental Protection
Agency

Center for Environmental
Research Information
Cincinnati, OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Official Business
Penalty for Private Use $300

EPA/540/S5-91/003