



Project Summary

Mobile System for Extracting Spilled Hazardous Materials from Excavated Soils

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A technique was evaluated for the scrubbing or cleansing of excavated soils contaminated by spilled or released hazardous substances. Laboratory tests were conducted with three separate pollutants (phenol, arsenic trioxide, and polychlorinated biphenyls [PCB's]) and two soils of significantly different character (sand/gravel/silt/clay and organic loam).

The tests show that scrubbing of excavated soil on site is an efficient approach for freeing soils of certain contaminants but that the effectiveness depends on the washing fluid (water + additives) and on the soil composition and particle-size distribution. Based on the test results, a full-scale, field-use, prototype system was designed, engineered, fabricated, assembled, and briefly tested under conditions where large (>2.5 cm) objects were removed by a bar screen. The unit is now ready for field demonstrations.

The system includes two major soil scrubbing components: a water-knife stripping and soaking unit of novel design for disintegrating the soil fabric (matrix) and solubilizing the contaminant from the larger particles (>2 mm) and an existing, but re-engineered, four-stage countercurrent extractor for freeing the contaminants from smaller particles (<2 mm). The processing rate of the system is 2.3 to 3.8 m³/hr (4 to 5 yd³/hr), though the water-knife unit (used alone) can process 11.5 to 13.5 m³/hr (15 to 18 yd³/hr). The complete system requires auxiliary equipment, such as the EPA-ORD physical/chemical treatment trailer, to process the wastewater for

recycling; under some circumstances, provision must be made to confine and treat released gases and mists. Treatment residues consist of skimmings from froth flotation, fine particles discharged with the used washing fluids, and spent carbon. The principal limiting constraint on the treatability of soils is clay content (high weight-percent), since breaking down and efficiently treating consolidated clays is impractical or not economically attractive. Most inorganic compounds, almost all water soluble or readily oxidizable organic chemicals, and some partially miscible-in-water organics can be treated with water or water plus an additive.

During limited laboratory extraction tests, phenol was very efficiently removed from both organic and inorganic soils, whereas PCB and arsenic clung more tenaciously to the soils and were released less readily into the washing fluids. The extent to which the system has practical, cost-effective utility in a particular situation cannot be determined until preliminary, bench-scale lab work has been performed and acceptable limits of residual concentrations in the washed soil are adopted. Laboratory tests show that soil scrubbing has the capability of vastly speeding up the release of chemicals from soils, a process that occurs very slowly under natural leaching conditions.

Note that this system requires excavation of the soil, which can subsequently be replaced or transported to a low-grade landfill. In situ washing of contaminated soil, a process in which the contaminated area is isolated for

example, by grouting, and then water-flushed with removal of the wash water at a well-point is an alternative. The overall efficiency of the soil washing system is greater than that currently being achieved by in situ methods.

Based on the laboratory program, a series of steps (water-knife size reduction; soaking; countercurrent extraction; hydrocyclone separation; and waste fluid treatment for reuse) was selected as the most suitable process sequence for the prototype system. The system was constructed for the U.S. (EPA) and is now being subjected to field evaluation. However, soils rich in humus, organic detritus, and vegetative matter can present special problems in the extraction of certain hazardous substances, which may not partition between the solid and fluid phases to a practical and necessary extent.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The leaching of hazardous materials from contaminated soils into groundwater is recognized as a potential threat to the Nation's drinking water supplies. Such situations occur as the result of accidental spills of hazardous substances and from releases at the many uncontrolled hazardous waste disposal sites now known to exist across the country. Current removal/remedial technology is largely limited to the excavation and transfer of such soils to suitably sealed or lined landfills where uncontrolled leaching cannot occur.

Onsite treatment can be a more cost-effective solution to the problem. In some research projects, contaminated soils have been isolated by injected grout, trenched slurry walls, steel piling, etc., and then subjected to in situ leaching. The effectiveness of such a process is limited by, among many factors, the permeability of the soil in its undisturbed state. Economic and effectiveness factors cannot be generalized but are situation-specific.

An alternative process is needed for those situations in which permeability or other factors prevent effective in-situ leaching and where landfilling is too costly. The proposed technology — the

subject of the current effort — consists of excavation, onsite but above-ground treatment of the contaminated soil, and return of the treated soil to its original site. Excavation of the soil from its natural state opens a number of options for improved separation of contaminants through better (high energy) mixing and the potential for using different solvents. Such cleanups can also be carried out more quickly than they could by the leaching of a more or less compact natural soil (cost factors not being considered). This engineering approach has also made it possible, or more convenient, to incorporate any control devices that may be needed to reduce emissions of particulates or fumes into the air column and/or to treat the contaminated wastewaters generated during the processing.

The purpose of this project was to carry out appropriate laboratory studies and to develop, design, and construct a full-scale system capable of treating a wide range of contaminated soils. The existing system will be useful for the correction of long-standing (remedial) contamination problems (waste disposal sites), as well as for the emergency cleanup of spills and for the prompt removal of released wastes.

Discussion

To meet the objectives of the program, specific criteria were identified for the solvent, the soils, the pollutants, and the process.

To be suitable for field use in such a process, the solvent or extracting fluid should have the following characteristics:

1. A favorable separation coefficient for extraction,
2. Low volatility under ambient conditions (to reduce air contamination effects),
3. Low toxicity (since traces of extractant may remain in the cleansed soil),
4. Safety and relative ease of handling in the field,
5. Recoverability for reuse.

The selected solvent must be able to separate the contaminant from the soil, preferably using a minimum volume of solvent so that the equipment can be kept compact. In addition, the solvent must be readily separable from the soil fines to

allow return of the decontaminated soil to the site and to permit treatment and reuse of the solvent. High volatility in the solvent can contribute to unacceptable losses and can, when coupled with flammability, exacerbate health and safety risks for the workers.

Following a brief evaluation and screening of potential solvents (including organics), consideration of all the above-cited factors clearly indicated that water was suitable as the primary target solvent. The use of additives such as acids or bases, oxidizing or reducing agents, or wetting agents was judged to be a reasonable approach for enhancing removal efficiency. Though certain organic solvents can meet most of the solvent criteria and may have definite advantages in specific cases, a decision was made early in the project to limit the investigation to water-based systems.

The range of soils that is encountered in a cleanup situation is very broad, encompassing fine, highly cohesive clays, sandy soils, silts, soils high in organic matter, etc. Though processes can be devised to handle any or all of these materials, certain contaminated soils do not require exhaustive extraction and others do not lend themselves to an extractive process. The organic content of a soil can affect the ease of size reduction and the efficiency of extraction. The pH of a soil can affect the extraction efficiency for a particular contaminant. When the soils and contaminants have cationic or anionic qualities, ion exchange (partition factors cannot be neglected.

For purposes of this investigation, two soils were selected as suitable representatives of many that might be encountered. These were a granular (sandy), essentially cohesionless inorganic soil (containing some fine sand and about 20% clay) and a highly organic (18.4%, mostly as peat and humus) commercial topsoil.

Though spill situations and waste disposal sites may differ in many ways (such as the portion of a contaminant that is tightly bound to the soil versus the amount loosely associated in the voids), plans for the test program emphasized the spill situation by using freshly prepared mixtures of soil plus contaminant. Funding was insufficient to support work with aged or weathered contaminated soils that are more representative of dumpsites.

The actual process for the planned system must include excavation and transfer to the processing equipment, screening to remove large (>2.5 cm)

objects, size reduction to maximize soil-solvent contact, extractive treatment, separation of contaminated solvent from (relatively) decontaminated soil particles, and return of the soil (either "as is" or after drying) to the excavation.

Excavation can be readily handled by conventional earthmoving and construction machinery. Size reduction of soils can be accomplished with various, commercially available equipment, including rotary scrubbers, log washers, attrition scrubbers, and high intensity water-knives. The properties of each were considered, and the water-knife was chosen as the most versatile unit; it was also suitable for both disintegrating clay-like lumps and for scrubbing the loosely held contaminant from the resulting smaller (>2 mm) components.

For the decontamination process to be effective with a wide range of water-insoluble and tightly held contaminants on small particles (>2 mm), follow-on multi-stage extraction was judged to be necessary. The use of countercurrent extraction allows several stages of extraction with minimum solvent use. Clearly, the final system also requires equipment to separate fines from the solvent, both between extraction stages and after the last stage. Gravity separators, clarifiers, and filters were generally inappropriate for the planned system; hydrocyclones were selected for evaluation.

The three hazardous contaminants selected for testing were phenol, arsenic trioxide, and PCB's. These were chosen because of the frequency with which they are encountered in spills and the range of physical and chemical characteristics they offer. Laboratory tests were carried out to assess the effects of different water-based solvents and different processing conditions on these three chemicals mixed with the two soil types noted earlier. The results of these studies were then used to design the full-scale prototype.

Equipment Evaluation

Size Reduction and Extraction

A series of tests was conducted with the water-knives, first using a local, available, uncontaminated soil sample. Numerous approaches to exposing the soil to the water-knife jets were tried and abandoned (refer to the full report). Only when the soil was contained in a truncated, cone-shaped, tilted rotary-screen drum (2-mm mesh openings) was the desired lump breaking obtained. The

first tests were performed in an 18-in. trash basket (top ID = 15 in.; bottom ID = 12 in.) in which 50% of the bottom sidewall (up to 8 in.) was cut away in four sections that were overlain with various mesh screens. (The device was re-engineered for the actual testing.) In the bench apparatus, approximately two-thirds of the soil was washed out through the screen within the first 2 min of treatment with 4.5 L/min (1.2 gal/min) of water at a pressure of 4.9 kg/cm² (70 psi) and a drum speed of 10 to 20 rpm. Further experiments indicated that a three step sequence was needed to achieve the best decontamination:

1. Low-pressure wash,
2. Soaking, followed by stripping, and
3. Low-pressure fresh-water wash.

Liquid-Solid Separation

To study the separation of soil fines from water, a full-sized hydrocyclone (227 L/min) was used with different inflow rates (and pressures) and different concentrations of both soils. Though the results of these tests show that the hydrocyclone is suitable for each soil, they also indicate that the solids were better concentrated in the underflow from the inorganic soil. With both soils, the overflow contained a small but significant amount of fines (0.7% to 3.7%), which would require additional separation. Passing this overflow through the hydrocyclone in a second treatment was not notably effective in removing these fine solids.

Because the hydrocyclone was too large for routine use in the laboratory study of contaminant removal from soil, simply gravity settling in a beaker was evaluated and found to represent a good simulation of the separation achievable with the hydrocyclone.

Extraction Tests

Tests were carried out with the three chemicals (all three were not used in all experiments) to establish the following:

- a) probable loading on a soil column,
- b) distribution on particles of different sizes, and
- c) effect of extraction with different solvents on particles of different sizes.

Column Loading Studies

A stock solution of the contaminant equal in volume to the void space in the column was added to a 15.2-cm (6.0-in.) column of soil (various moistures and densities) and allowed to drain for 24 hr. The contaminant remaining in the column was calculated on a dry weight basis, based on the amount of fluid that drained from the column. Modified gas chromatographic and atomic absorption methods (described more fully in the report) were used. Results obtained with the three materials are shown in Table 1. Note the heavy loading of phenol, which represents the situation that might exist shortly after a spillage onto soil.

Distribution Tests

Different procedures were used with phenol and with arsenic trioxide to evaluate their distribution on particles of different sizes. For phenol, dry soils were first size-classified with a sonic fractionation device. Each fraction was then wetted with a stock solution of phenol. After 18 hr, the fractions were rinsed with water and analyzed. For arsenic, the soil from the column dosing tests was dried, size fractionated, and then analyzed. High recoveries (based on analyses) were achieved in both cases.

With phenol, these tests indicated that approximately 90% of the contaminant was absorbed (or retained interstitially) on the larger particles (0.6 to 2 mm*) of the organic soil. These somewhat unexpected results also appear to be a consequence of nonuniform distribution of organics in the different particle-size fractions. Tests confirmed that the fine particles contained predominantly organic degradation products rather than plant tissues, which remained primarily with the larger particles. Such differences may make it necessary, in some cases, to presoak the soil for efficient extraction.

Unexpected results were also obtained when testing the distribution of phenol on the inorganic soil. The relatively low adsorption by the finer particles was attributed to differences in internal porosity and chemical composition between the large and small particles rather than the proportionately greater surface area (calculated on a weight basis) of the fine particles.

The results obtained with arsenic trioxide on the organic soil were similar to those obtained with phenol. With the

* Nominal sizes are given for screens.

inorganic soil, however, the arsenic compound exhibited the normally expected relationship between particle size (i.e., surface area) and amount adsorbed. That is to say, because of the greater surface-to-mass ratio, more adsorption occurs per unit weight of fines.

PCB's were not tested to any great extent because of their low solubility and the hazards involved in working with them. Time and funding constraints also influenced this decision to curtail PCB studies.

Water-Knife Stripping Tests

Contaminated soil samples were subjected to 1 min of stripping by the water knife to remove particles smaller than 2 mm. Residual contaminants on the remaining (larger than 2 mm) particles were then determined. The results (Table 2) show the value of additional washing or extraction, at least for phenol and arsenic trioxide.

Chemical Extraction Tests

Since water is not the optimum extractant for all contaminants tested, and since most of the contaminants will be absorbed by and adsorbed on the smaller (<2 mm) particles, a series of tests with the following aqueous solutions was conducted to determine whether extraction efficiency could be improved:

- water + sulfuric acid to pH 1
- water + sodium hydroxide to pH 11
- water + 7.5% sodium bisulfate
- water + 5.0% sodium hypochlorite
- water + 1.0% TWEEN 80
- water + 1.0% MYRJ 52
- water + 5.0% methanol

For the inorganic soils contaminated with phenol, all extractions were highly efficient, with removals greater than 87%. Only for the organic soil could the difference between solvents be considered significant, with the sodium hydroxide solution being the most effective solvent. A portion of the data presented in the report is summarized in Table 3. The relative and actual importance of the residual contaminant on the soil should not be ignored, nor should the fraction of solvent remaining in the soil (not shown in Table 3). When the residual level of contamination is

Table 1. Maximum Column Loadings

| Contaminant | Organic Soil (mg/g soil) | Inorganic Soil (mg/g soil) |
|------------------|--------------------------|----------------------------|
| Phenol | 453.2 | 48.3 |
| Arsenic trioxide | 5.0* | 0.75* |
| PCB | 25.6 | 3.0 |

*As arsenic (As).

Table 2. Effect of Washing on Large Particles*

| Soil | Test Time (min) | % Removal | | |
|-----------|-----------------|-----------|--------------------------------|------|
| | | Phenol | As ₂ O ₃ | PCB |
| Inorganic | 15 | 97.9 | 28.9 | 21.4 |
| | 30 | 98.2 | 52.1 | 50.0 |
| | 60 | 98.8 | 42.2 | 21.4 |
| | 120 | 99.1 | 52.1 | 28.6 |
| Organic | 15 | 60.7 | 47.7 | |
| | 30 | 79.2 | 55.8 | |
| | 60 | 86.0 | 54.0 | |
| | 120 | 91.6 | 59.0 | |

*2 to 12.7 mm

Table 3. Solvent Extraction: Representative Single-Washing Tests*

| Contaminant | Soil** | Solvent | Initial Soil Dose (mg/g dry soil) | % Removal | Supernatant Concentration (mg/L) | Residual Soil Concentration mg/g |
|--------------------------------|--------|---------------------------------------|-----------------------------------|-----------|----------------------------------|----------------------------------|
| Phenol | I | Water | 48 | 98.6 | 1,190 | 0.68 |
| | O | Water | 452 | 77.8 | 17,600 | 100.4 |
| | | NaOH (pH 11) | | | 88.4 | 20,000 |
| As ₂ O ₃ | I | Water | 0.75 | 42.7 | 16 | 0.43 |
| | | H ₂ SO ₄ (pH 1) | | 85.3 | 32 | 0.11 |
| | O | Water | 5 | 75.0 | 375 | 1.25 |
| | | H ₂ SO ₄ (pH 1) | | | 85.0 | 425 |
| PCB | I | Water | 3 | 24.6 | 72 | 2.66 |
| | | 1% Tween 80 | | 37.5 | 110 | 1.88 |
| | O | Water | 26 | 48.3 | 418 | 13.2 |
| | | 1% Tween 80 | | | 23.8 | 366 |

* Extractant to dry solids 10:1 (w/w).

** I = inorganic; O = organic.

sufficiently low, the treated soil may no longer require disposal as a hazardous material, e.g., in a safe landfill.

Samples of phenol-contaminated organic and inorganic soils were also subjected to multiple extractions. These tests demonstrated that continued removal of phenol did occur, even when the extractant was recovered solvent (water) from a previous stage and already contained phenol. Residual phenol concentrations of 30 mg/kg (0.03 mg/g)

of soil were achieved after four countercurrent extractions of the inorganic soil.

Prototype Design and Construction

The process sequence for full-scale treatment (Figure 1) was finalized, based on the laboratory experiments. The sequence includes initial removal of oversized chunks (>2.5 cm), water-knife

scrubbing to deconsolidate the remaining soil matrix and to strip any contaminant loosely absorbed on the solids (>2 mm) or held in the void spaces of the soil, and four-stage, countercurrent extraction coupled with hydrocyclone separation after each extraction stage to separate the solids (<2 mm) from the liquid. Froth flotation is used to give maximum mixing of extractant and soil in each stage. The overhead extract (mostly sorbent) from the first stage extractor hydrocyclone contains the highest level of dissolved (or dispersed) contaminants and fines. This extract must be clarified and then treated (possibly with activated carbon) before it is recycled.

Note that: chunks (> 2.5 cm) are not normally processable in the system except for moderate washing on a bar screen*; the 2.5-cm to 2-mm as well as the <2-mm fraction, will be used to fill in the excavation; all processing fluids must be appropriately treated. All dust and vapor emissions should be ducted to an air cleaner or scrubber before discharge.

The basic system was constructed according to the design shown in Figure 1.

The water-knife unit (rotary drum-screen scrubber) consists of a tilt-skip loader and hopper feed from which the soil moves into a tiltable 19-m (21-ft) long by 1.4-m (4.5-ft) ID cylinder fitted with end pieces, water-knives, and a rotating mechanism (Figures 2, 3, and 4).

Soil is metered from the tilt-skip reservoir hopper at rates up to 18 yd³/hr onto a manually washed bar screen where >2.5-cm (1-in.) chunks are rejected. The solids then pass into the tilted drum-screen scrubber where it is subjected to first-stage water-knife stripping, water soaking, and finally second-stage water-knife stripping using fresh or partially recycled water. The first section of the scrubber cylinder is 1.3-m (4-ft) long and is fabricated from 2-mm mesh (HYCOR Contra-Shear screen) and equipped with internal water-knives. Solids then move into the 5-m (15 ft) soak cylinder that is fitted with a baffle plate that has a 0.5-m (22-in.) center opening through which solids pass into a 0.7-m (2-ft) long screened, water-knife rinse zone. Fines (<2 mm) pass through the screens, as does the wash water. The coarse particles are voided at the end of

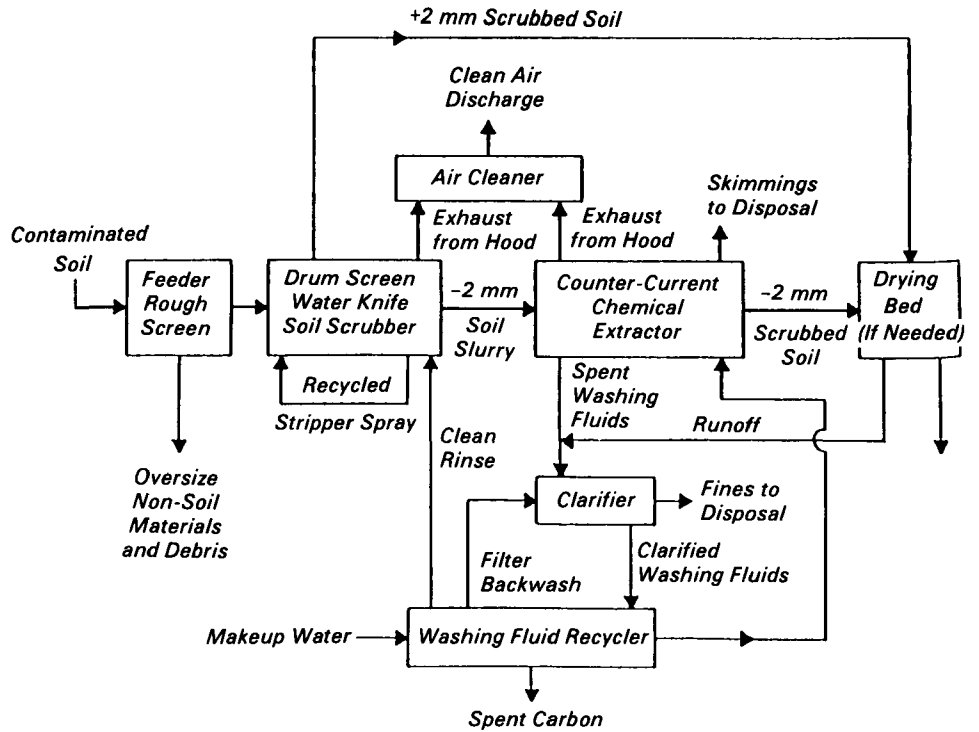


Figure 1. Process flow scheme for soil scrubber.

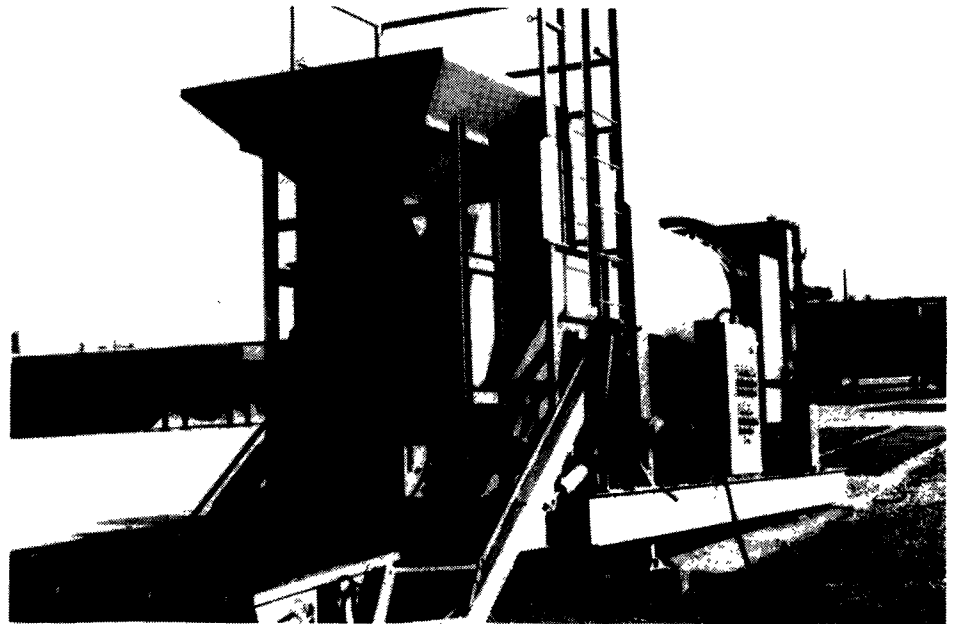


Figure 2. Fully constructed rotary drum screen scrubber.

the drum. The unit can be backflushed as needed. The screens resist buildup of fines (blinding). The actual arrangement of the water-knives and other details of construction are given in the project report.

From the water-knife and soaker unit, the slurry (<2-mm particles) is pumped to the countercurrent extractor. The four-stage countercurrent extraction unit (Figures 5 and 6) has been modified from the so-called EPA beach sand froth

* There are two bar screens. The soil is hosed-reused on a 7.5- or 5-cm (3- or 2-in.) upper screen in the skip-hopper from which large or nondisintegrable chunks are raked off. Washed chunks that pass the upper screens are rejected and removed at the second (lower) bar screen (<2.5 cm [1 in.]).

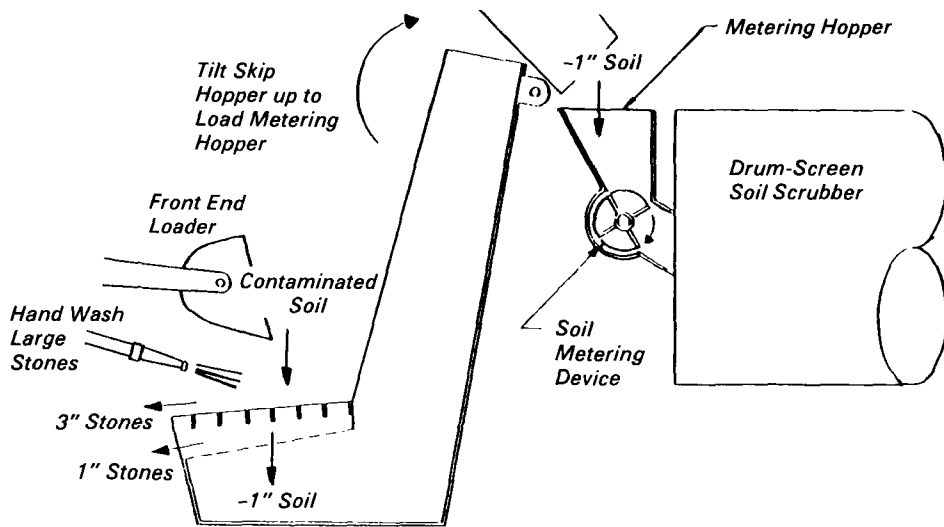


Figure 3. Soil loading and metering system (cross sectional side view).

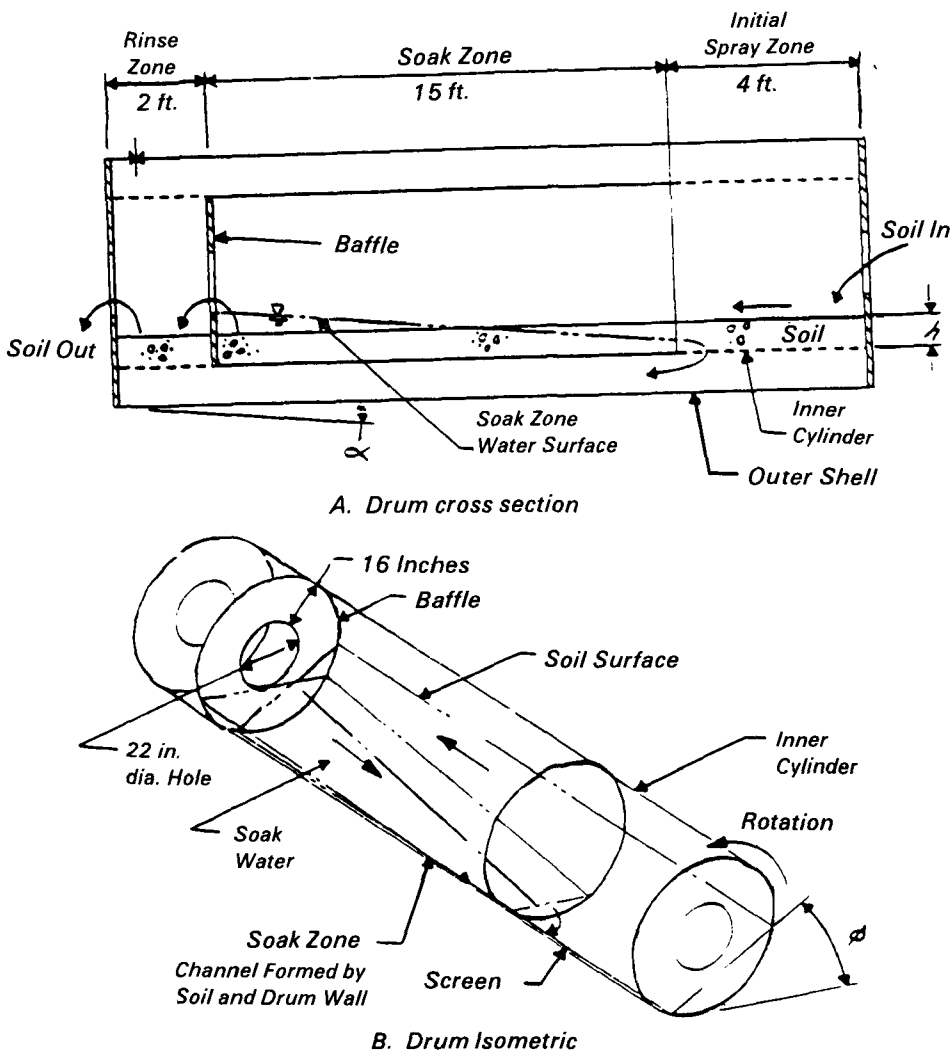


Figure 4. Soak zone description.

flotation unit.* Basically, the washing chamber was partitioned into four sections (3-ft long \times 4-ft wide \times 5-ft deep), each of which has an aerator agitator and a hydrocyclone with pumps and piping. Flow of solids (<2 mm) and fluid is countercurrent with clear water being introduced at the fourth (discharge) chamber (Figure 6). The extraction unit has an on-board diesel generator; the water-knife unit requires external power. The underflow (solids-rich) slurry from the fourth hydrocyclone is discharged to a drying bed.

To achieve mobility, the water-knife unit is skid-mounted for transport by semi-trailer; the countercurrent extractor is integrally attached to a separate semi-trailer. Refer to Figures 2 and 5 for details. Calculations indicate that the total system has a throughput range of 2.3 to 3.8 m^3/hr (3-5 yd^3/hr), but that the water-knife unit alone can process 11.5 to 13.5 m^3/hr (15 to 18 yd^3/hr).

Conclusions

The following conclusions can be drawn from the work carried out during this program and the knowledge gained during that effort:

1. Spill-contaminated soils can be excavated and treated onsite using extraction with water or aqueous solutions for many pollutants that are frequently encountered in such situations.
2. A system capable of decontaminating 2.3 to 3.8 m^3/hr (3-5 yd^3/hr) of soil has been designed and constructed and it is now available for field testing by EPA.
3. Water-knives function as a compact, efficient, and economical means of achieving effective contact between contaminated soil particles and extractant.
4. Countercurrent extraction is an effective process for removing certain adsorbed contaminants from soils and, for the size of equipment needed, hydrocyclones are preferred devices for separating the extracted solids from the extractant.

*Garth D. Guntz, Restoration of Beaches Contaminated by Oil. EPA-R2-72-045 (Washington, D.C.: US EPA, 1972).

5. Laboratory experiments demonstrate that soil characteristics (particle size, distribution, organic content, pH, ion-exchange properties, etc.) are important factors in the removal or retention of contaminants.
6. In addition to the actual percentage of the contaminant removed, the allowable level of pollutant remaining in the soil is an important factor in determining when adequate decontamination has been achieved since the final, residual concentration affects the options available for disposal of the cleansed solids.

Recommendations

Based on the observations made during this investigation, several suggestions are offered for future work.

1. Laboratory screening tests should be performed on a wider range of typical compounds and mixtures encountered in hazardous substance spill and release situations to ensure that appropriately high levels of decontamination can be achieved with this process.
2. The results of this study apply primarily to spill situations. Contaminated soils found at waste disposal sites may exhibit different extraction characteristics because of the extended soil/contaminant contact time and of weathering and in situ reactions. Studies are needed to establish whether and to what extent such changes affect the decontamination process.
3. Other extractant solutions should be evaluated to determine whether the efficiency of the process can be improved without damaging the equipment or increasing the hazards to which the workers are exposed.
4. A wider range of soils should be examined to determine what changes in the system are practical to better cleanse soils with characteristics (e.g., greater cohesiveness and adsorptive properties of clay-or-silt-rich soils) that differ significantly from those of the soils already tested.



Figure 5. EPA Froth Flotation System (beach cleaner) modified as a countercurrent chemical extractor for soil scrubbing.

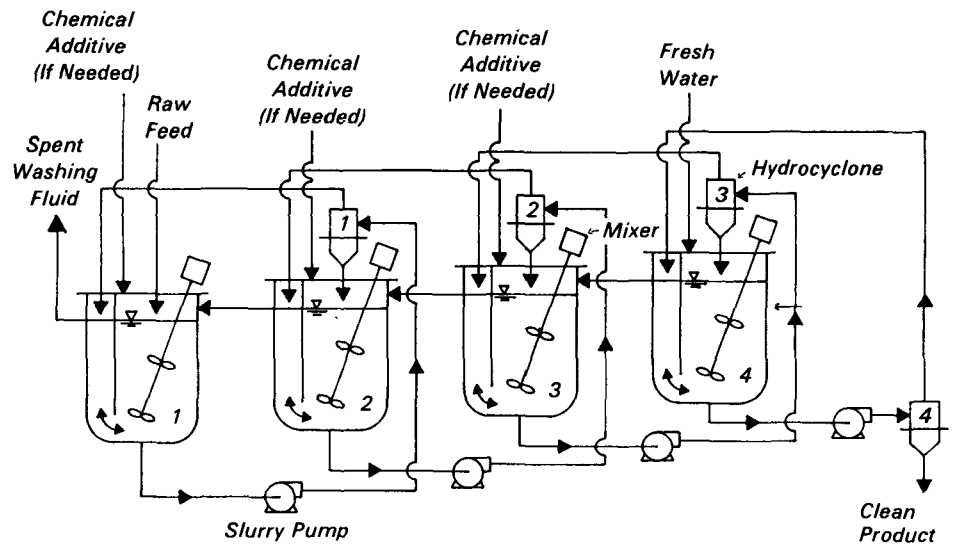


Figure 6. Process flow scheme for soil scrubber.

The full report was submitted in fulfillment of Contract No. 68-03-2696 by Rexnord, Inc., under the sponsorship of the U.S. Environmental Protection Agency.

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The complete report, entitled "Mobile System for Extracting Spilled Hazardous Materials from Excavated Soils," (Order No. PB 84-123 637; Cost: \$11.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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