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INNOVATIVE IN SITU TREATMENT TECHNOLOGIES FOR CLEANUP OF CONTAMINATED SITES

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Summary

In situ treatment of waste and soil at contaminated sites offers an alternative to the traditional approach to site remediation involving excavation and redisposal or onsite isolation. The in situ "Detoxifier" is an innovative technology/equipment potentially capable of implementing a range of in situ treatment methods (e.g., air/steam stripping, neutralization, solidification/stabilization, oxidation, etc.). It is an adaptation of the drilling technology providing capabilities for in situ delivery of treatment agents in dry, liquid, slurry, or gaseous form to the soil and thorough mixing and homogenization of a vertical column of soil. The recent field demonstration of the mobile system in a full-scale site remediation application at a site in Southern California was documented. The soil at the site was contaminated with hydrocarbons from leaking underground fuel storage tanks. Steam and hot air were used to strip hydrocarbons from the soil; the off gas was processed in a treatment train and recycled to the soil. By adjusting treatment conditions, the total petroleum hydrocarbons concentration in the soil could be reduced from an initial level of 5,000 ppm or higher to less than 100 ppm. Based on field demonstration results, the equipment vendor is developing designs for a more powerful and compact Detoxifier with enhanced off gas treatment capabilities.

Introduction

An examination of remedial responses which have been completed, are ongoing, or have been recommended for contaminated sites indicates cleanup strategies generally involving removal of waste/contaminated soil for disposal at a commercial landfill and/or site isolation using physical barriers [1,2]. There are, however, some major limitations and concerns associated with remediation approaches which rely on the use of existing technologies such as liners, caps, slurry walls, grout curtains, etc. for long-term waste containment (onsite or at new offsite locations) and/or which involve waste excavation and redisposal. Chief among these limitations and concerns are the following:

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- Although there have been significant improvements in the design and construction, and hence in the performance of containment systems such as landfills and surface impoundments, uncertainty remains regarding the ability of these systems to provide long-term environmental protection. Numerous cases of failures of the containment systems have been reported (e.g., see Refs. 3–6);
- Exposure of workers, the general public, and the environment to additional risks associated with site excavation; and with temporary storage, transportation, and redisposal of excavated materials;
- Growing scarcity of approved offsite facilities for waste redisposal and the high cost of and the increasing public opposition to schemes involving waste relocation;
- Increasing criticism of onsite waste isolation and/or waste relocation at offsite facilities as short-sighted strategies that merely transfer the problem to future generations or to new locations [1,7].

Because of the above limitations and concerns, waste treatment, which can provide a more effective and permanent remediation solution than site isolation and/or waste relocation, is beginning to receive increased attention. In the past, however, waste treatment in general, and in situ or in-place treatment in particular, have not been generally viewed as a viable option. This has been primarily because of the unavailability of reliable and demonstrated technologies with adequate throughput capacity for processing large volumes of wastes or contaminated soil within reasonable time frames and at acceptable costs. It has been argued that if the analysis of the remediation costs includes the cost for implementation of a comprehensive design and construction QA/QC program, which is required to ensure improved performance, and/or cost of the corrective action associated with failure of the disposal methods, then treatment systems which provide more permanent remedies may in fact prove to be most cost effective solution in the long term. The present unavailability of suitable treatment technologies has thus been attributed to a heretofore lack of emphasis on waste treatment and the consideration of short-term rather than long-term cost effectiveness.

Treatment of wastes and contaminated soils can be accomplished via offsite or onsite treatment of the excavated materials or by in situ or in-place treatment (i.e., without excavation).

In situ treatment would be the preferred option, as it offers the following advantages:

- Eliminates safety, environmental, and the public health risks directly associated with excavation, transportation, storage, and handling of hazardous materials;
- Does not require additional land areas for treatment systems (e.g., as would be needed with land spreading for biotreatment);

- In the absence of excavation, there should not be a significant increase in volume and hence need for additional disposal capacity;
- Decontaminated soil is left in place (i.e., it does not have to be taken to another location for disposal).

The objective of this paper is to review the possibilities and current limitations of technologies for in situ waste treatment. The review includes the description of a new technology (trademarked "Detoxifier"), the first full-scale field demonstration of which was recently documented. This application involved decontamination of soil contaminated with hydrocarbons from leaking underground fuel storage tanks.

Proposed technologies and key problem areas

Based on the technologies that have been developed and are used in conventional water and wastewater treatment and in mining, oil and gas, and chemical process industries, a number of processes and systems have been proposed for in situ treatment [8]. These methods use biological, chemical, physical, or thermal methods to degrade, detoxify, extract, or immobilize contaminants. The leading technologies among those proposed are:

- Bioreclamation for treatment of contaminated soil and/or groundwater;
- Air stripping and soil vapor extraction for the removal of volatile organics from soil;
- Vitrification to bring about destruction of organics and to convert the inorganic residues and the soil matrix into an inert, glassy material;
- Soil washing to remove contaminants from the soil by use of appropriate extractants/eluents;
- Use of the in situ Detoxifier which is potentially capable of implementing a range of treatments including air/steam stripping, solidification/stabilization, neutralization, and oxidation.

The operating principles and certain desirable features and limitations of these technologies are highlighted in Table 1.

In situ treatment processes have not generally been subjected to rigorous engineering analysis or testing under a variety of field conditions. This analysis or testing would determine technical feasibility and costs for application to the range of conditions encountered at contaminated sites. These conditions reflect variations within a site and among sites with respect to the type of contaminants encountered and the hydrogeological and environmental settings. Thus, the type of contaminants, the depth to groundwater, and the permeability and uniformity of the geological media through which the treatment agent(s) must be moved and within which the treatment agents and reaction products must be contained would be expected to have significant impacts on the efficiency, cost, uniformity, and environmental acceptability of the cleanup operation. Some areas of potential technical problems that must

TABLE 1

In situ site remediation technologies

Technology	Principle/description	Desirable features	Limitations	Ref.
Bioreclamation	Degradation of organic contaminants to inert or less harmful products via action of suitable bacteria which are developed in or added to contaminated soil or groundwater. Oxygen and nutrients are added to the system to support biological growth (see Fig. 1)	Simple, low cost, and safe method Has been demonstrated to be effective at more than 30 organic spill sites	Generally limited to applications involving localized groundwater contamination (organic spills) Not applicable where the contaminants are refractory or are present at toxic levels pH adjusting chemicals, oxygen, and supplementary nutrients may be provided Effective, proven methods for uniform distribution of oxygen and nutrients in the subsurface (especially to significant depths) do not exist Channeling and uneven treatment may result due to nonhomogeneity of soil and/or formation of precipitates and biological deposits For contaminated soils, the applications seem to be limited to very shallow depths Not recommended for low hydraulic conductivity soils (requires hydraulic conductivities perhaps exceeding 10^{-3}-10^{-2} cm/s) Difficult to monitor or control process	9-13

Air stripping	Forcing clean air into the soil through injection wells and withdrawal of contaminated soil through extraction wells (see Fig. 2). The contaminated air is vented to an emission control system or the atmosphere, depending on contaminant levels	Simple, possibly low cost, and safe method (with proper controls) Has been tested on a pilot scale Can treat significant soil depths in the unsaturated zone	Applicability limited to cases involving volatile compounds; low groundwater table; and loose, sandy formations Proper location and design of wells require good knowledge of subsurface characteristics Channeling and uneven treatment may result due to nonhomogeneity of subsurface Not recommended for low hydraulic conductivity soils (requires hydraulic conductivities perhaps exceeding 10^{-3}-10^{-2} cm/s) Difficult to monitor or control treatment progress and completeness Limited field experience and operating data available	14, 15
Vapor extraction	Application of vacuum to subsurface media to volatilize and remove contaminants. The vacuum may be applied through vertical extraction wells (low water tables) or horizontal extraction systems (high water tables). The contaminated air may require treatment before discharge to the atmosphere	Same as for air stripping Has been used to remove chemical spills before reaching groundwater	Same as those listed for air stripping	16, 17

Table 1 (continued)

Technology	Principle/description	Desirable features	Limitations	Ref.
Soil washing	Flushing or rinsing of contaminant from soil using suitable solutions (e.g., surfactants). Treatment solution can be delivered via gravity (flooding, ponding, surface seepage) or forced systems (e.g., injection pipes); unused treatment agents and by-products collected via gravity (e.g., open ditches and trenches, porous drains) or forced systems (e.g., well points)	Can provide for recovery of chemicals in cases involving spills of individual chemicals	Not feasible when complex wastes containing a range of contaminants with different solubility characteristics are involved Difficult to limit reaction to target contaminants (i.e., prevent loss of treatment agents through side reactions or sorption/retention by soil) Proper location and design of wells require good knowledge of subsurface characteristics Channeling and uneven treatment may result due to nonhomogeneity of subsurface Treatment rate can be very slow Difficult to monitor or control treatment progress and completeness Limited field experience and operating data available Recovered contaminant solution can be very dilute and large in volume and hence costly to treat and dispose of	18–20

Vitrification	A soil melting technology whereby electric current is passed between electrodes placed in the ground; the soil and contained materials are converted to a stable glass. Evolved gases are trapped (under a cover placed on the top of the treatment area) and sent to a treatment unit or vented directly to the atmosphere	Experience available from applications to radioactive waste The product glass is inert	Limited data for cases involving hazardous wastes Available technology and cost data are from small-scale tests Emission control and design requirements not fully defined for applications involving large sites and as a factor of site and contaminant characteristics	21
In situ Detoxifier	A novel adaptation of the drilling technology capable of in situ delivery of treatment agents to the soil and thorough mixing and homogenization of a vertical column of the soil (see text for detailed description and discussion of technology)	A variety of in situ treatment methods (e.g., air/steam stripping, neutralization, solidification/stabilization, oxidation, etc.) are potentially possible Thorough mixing and homogenization of soil and treatment agents result in uniform treatment Online monitoring permits good process control and adjustment in treatment conditions to achieve desired level of treatment Closed-loop operation Treatment system is completely mobile System field demonstrated in an application involving decontamination of soil contaminated with hydrocarbons	Treatment depth possibly limited to 60 feet (current experience limited to treatment depths of less than 25 feet) Has only been field tested in one application involving air/steam and chemical treatment of hydrocarbon contaminated soil at a site with low groundwater table	22

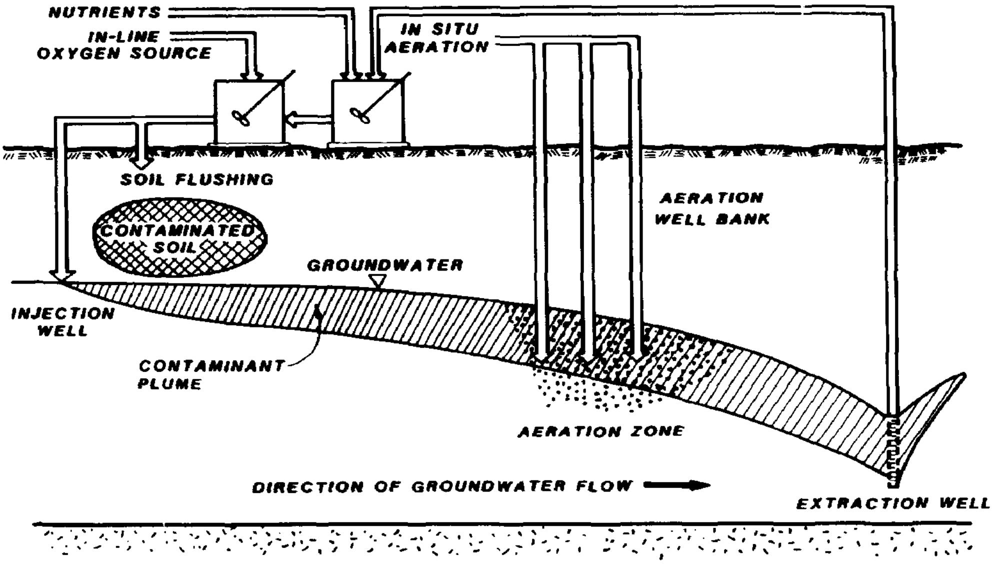

Fig. 1. Bioreclamation technology for treatment of contaminated soil and groundwater [13].

be addressed through R&D studies and field validation programs relate to the following:

- The development or selection of suitable treatment agents (given the complex, nonhomogenous, and variable nature of the wastes encountered at contaminated sites);
- The techniques and procedures for the delivering, distributing, and mixing of the treatment agents in the subsurface;
- The means for containing the input and reaction products within the target zone.

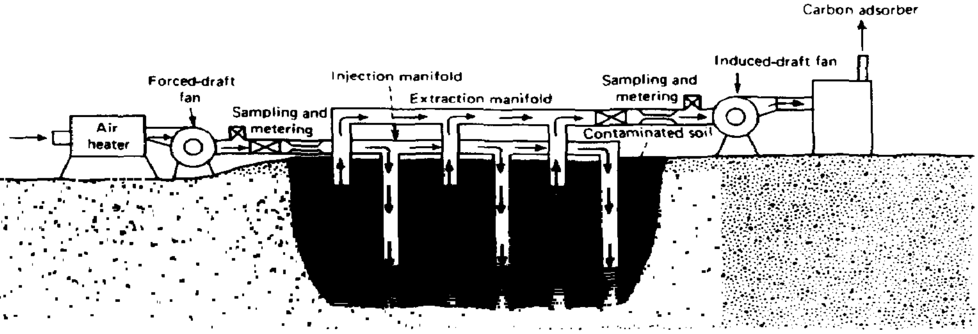

Fig. 2. Air stripping removal of volatile organic compounds [15].

Delivery and recovery systems: key to successful in situ treatment

The success of in situ treatment would depend to a great extent on the availability of equipment and procedures capable of delivering, distributing, mixing through, and recovering the treatment agents, all at a reasonably fast rate. Although a number of delivery and recovery methods have been proposed, these techniques have not generally been evaluated in a remedial application in a field setting. The exception is for certain cases involving bioreclamation of groundwater contaminated with biodegradable organics [11,12] or the addition of solidification agents to sludges in ponds, pits, and lagoons [23,24]. These methods are reviewed in several recent publications [19,20,25].

The proposed techniques involve delivering treatment agents such as ambient or heated air or aqueous solutions containing surfactants and oxidizing agents. Delivery can be via gravity (e.g., flooding, ponding, or surface seepage) or via forced systems such as injection pipes. Recovering the unused treatment agents and byproducts can be accomplished in two ways. The first is via gravity (e.g., open ditches and trenches and porous drains). The second way is via forced or vacuum systems (e.g., well points, induced draft fans, and "leachate" collection underdrains).

Although the proposed material delivery and recovery systems have not been fully tested, purely technical considerations and the available limited data from EPA-sponsored R&D and from actual site cleanup involving decontamination of spill-impacted soils indicate considerable difficulty in a field situation application. In light of the above discussion and the information in Table 1, these difficulties stem from several sources:

1. Nonhomogeneity and variable properties of the waste/soil media through which the treatment agents must be moved, which can give rise to channeling and nonuniform or incomplete treatment;
2. Slow treatment rate due to slow rate of fluid flow, especially in low permeability media or where treatment can result in formation of precipitates or biological deposits;
3. Potential for spread of contamination and the requirement for containment of the treatment agents and the reaction products within the target zone.

Thus, the applicability of many of the proposed in situ treatment technologies may be limited to cases where the contamination zone is:

- Permeable formation;
- Homogeneous;
- Relatively small in aerial extent or small areas can be segregated;
- Located in a hydrogeological setting where control of contamination and groundwater pollution can be achieved.

The in situ Detoxifier

ATW, Inc. and Calweld, Inc. have addressed some of the above-mentioned delivery, mixing, and monitoring problems and the uncertainty about the thoroughness and uniformity of treatment. These firms, located in Santa Fe Springs, California, have manufactured a very innovative equipment for in situ waste treatment and soil decontamination.* The technology is currently being marketed in the U.S. under the trade name Detoxifer by Toxic Treatments (U.S.A.) Inc. (San Mateo, California). The first version of the system (Detoxifier I) was recently evaluated at a site in Southern California in a full-scale application of the technology for decontamination of soil contaminated with hydrocarbons.**

The heart of the Detoxifier technology is the "process tower" (see Fig. 3) which is essentially a drilling and treatment agent dispensing system, capable of penetrating the soil/waste medium to depths of 25 ft (7.6 m) or more. The process tower consists of an assembly of two cutter/mixer bits connected to separate, hollow Kelly bars. The bits overlap and rotate in opposite directions. The rotating action provides for simultaneous cutting and mixing of the soil/waste material. Treatment agents (in dry, liquid, vapor, or slurry form) can be conveyed through the hollow Kelly bars and ejected through feed jets and orifices to the mixing area. A rectangular shroud covers the mixing area to minimize dust generation and capture gas and vapor released during the subsurface treatment. The captured off gas is treated in a process train and recycled through the process tower to the treatment zone.

The off gas from the shroud is monitored continuously. The output is used to adjust the treatment conditions, including the length of treatment, to achieve desired treatment objectives.

In actual site cleanup, the treatment of an area is on a block-by-block basis. For example, the area to be treated is divided into rows of blocks, with the process tower being moved to an adjacent block after the treatment of a block is completed. (The process train and the control room are tractor mounted. The components of the off gas treatment train and auxiliary support equipment are mounted on trailers and, hence, are also mobile.) Figure 4 presents the dimensions of a treatment grid cell, including the effective area which is treated at each location that the treatment equipment is operated on. As noted in the figure, each bit assembly is capable of drilling a hole of 4.5 ft (1.4 m) in diameter. To cover all the areas to be treated, the drill is positioned with about 10-percent overlap of the grid cells. With this overlap, the effective treatment

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*According to ATW, Inc., United States and foreign patents for the methods and processes shown or described herein have been issued or are pending.

**CH2M HILL was one of the three consulting firms retained by Toxic Treatments (U.S.A.) Inc. to document the operation of the Detoxifier at this site and to analyze the results. The information presented here is excerpted from the report which was submitted to Toxic Treatments (U.S.A.) Inc. [22]. The review of the technology and field results here does not imply endorsement or promotion of the technology by the author or CH2M HILL.

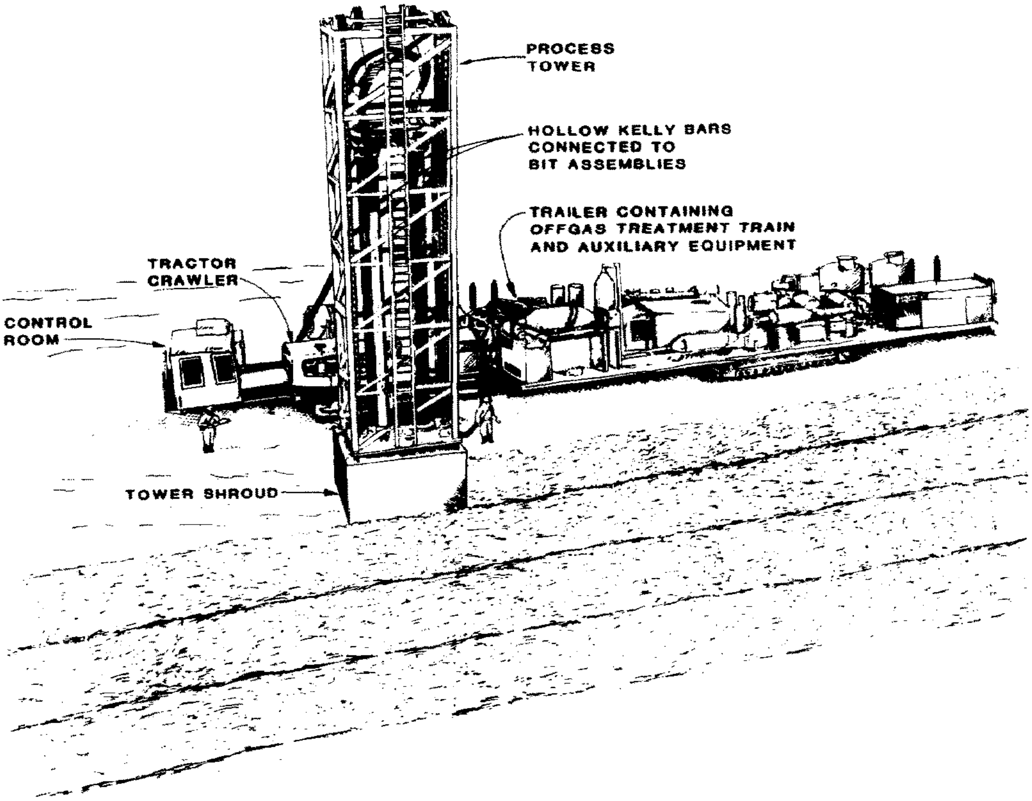

Fig. 3. The in situ Detoxifier.

area, or a treatment block, is about 3.25 ft by 7.3 ft (0.99 m by 2.23 m). This area is shown with the dotted line in Fig. 4.

The important features of the Detoxifier system are the following:

- Delivery of the treatment agent(s) directly to the treatment zone;
- Thorough mixing and homogenization resulting in effective contact between the treatment agent(s) and the contaminant;
- Closed loop nature of the operation;
- Ability to use a range of treatment agents in liquid, gas, solid, and slurry forms, thus providing versatility and ability to implement a range of treatment including stripping of volatile organics (with hot air and/or steam), oxidation, reduction, precipitation, neutralization, and stabilization/solidification;
- Mobile nature of the treatment system.

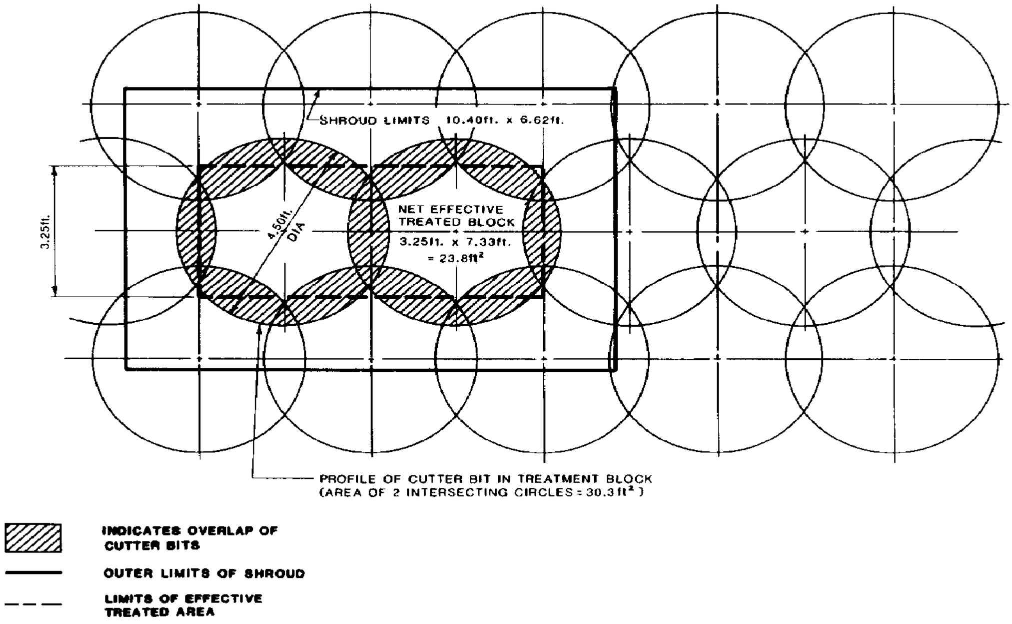

Fig. 4. Treatment block dimensions.

Detoxifier components and the treatment train

As noted above, the off gases collected in the process tower's shroud are passed through a treatment train before being recycled to the treatment zone. The unit processes comprising the treatment train are selected and designed based on the type and level of pollutants which are to be removed from the off gases.

Figure 5 shows the treatment train and auxiliary support components for the Detoxifier I, which was used for remediation of a hydrocarbon-contaminated site in Southern California. Heated air and steam (and, in some cases, an aqueous solution of an oxidizing agent) were the treatment agents used at this site.

For discussion purposes, the treatment train shown in Fig. 5 can be broken down into the following components:

- The process tower, including the drill bit assemblies, tower shroud, and the rotary and hydraulic motors which control the up-and-down and rotating motions of the drill assemblies (see Fig. 3);
- The control room containing the online monitoring equipment;
- The crawler tractor, which moves the drilling rig, the control room, and a diesel engine power generator;

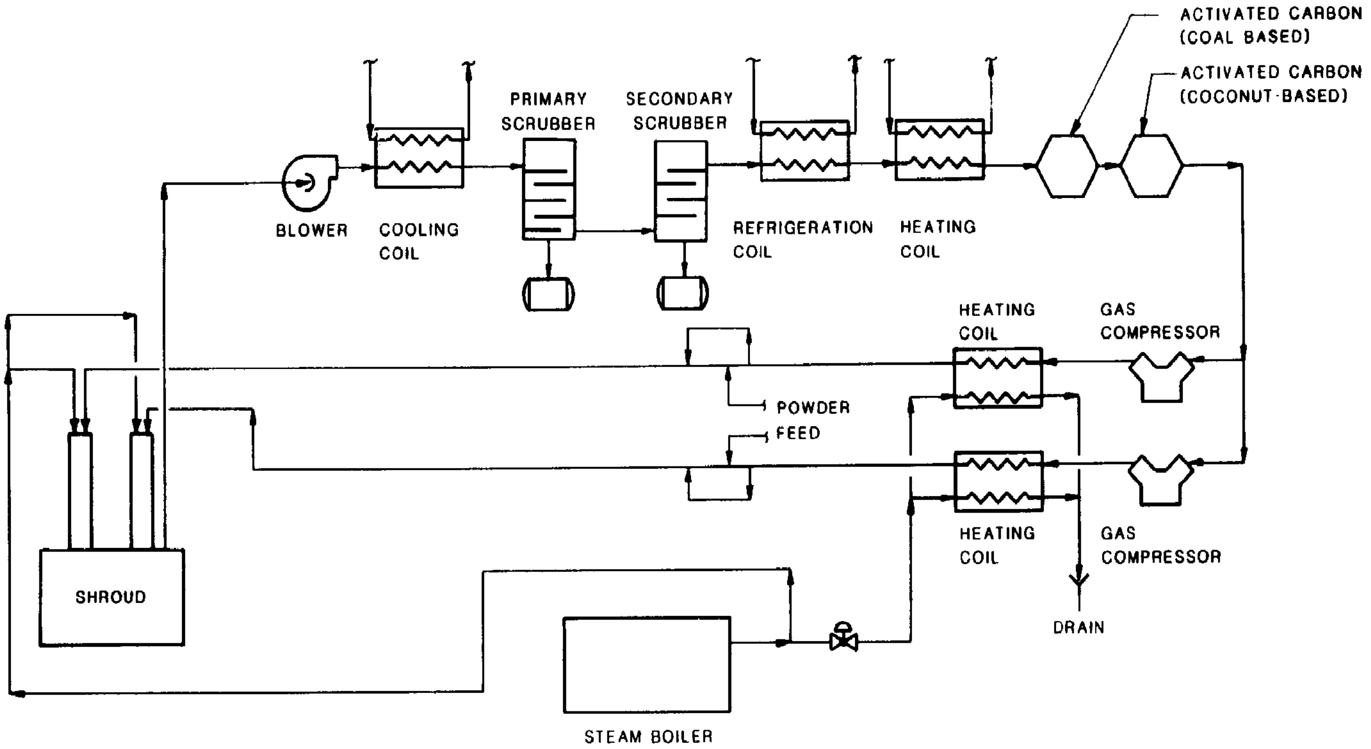

Fig. 5. Treatment train used at the Southern California site.

- Gas treatment and power feed systems, mounted on two trailers, and consisting of:
  - Suction blowers,
  - Cooling coil,
  - Demisters,
  - Refrigeration and heating coils,
  - Activated carbon adsorption unit,
  - Powder storage bins and feeding system,
  - Primary and auxiliary compressors;
- Mixing and pumping systems (trucks) for preparing the treatment agent solution;
- Steam production boiler, mounted on a separate trailer.

At the Southern California site, the off gas from the shroud, which contained the exit air, steam, and volatilized hydrocarbons, was cooled and passed through three demisters of differing designs. The gas was then passed through a refrigeration coil to condense and remove excess moisture. It was subsequently heated, when necessary (see below), before entering the activated carbon adsorption unit. Westate Carbon, Los Angeles, California, supplied the carbons used in the adsorption unit. The particular brands used were CO-601 (coal based) and CC-601 (coconut shell). (The preferred temperature range for the removal of hydrocarbons from gas streams with these particular brands of carbon is in the ambient (about 75°F) to 100°F range (~24–38°C). Since the temperature of the gas exiting the refrigeration coil was always above 75°F, there was no need to heat the gas following refrigeration before it entered the adsortion unit.)

Following carbon adsorption, the gas was split into two streams (one for each drill bit), compressed, reheated, and was recycled to the treatment zone through the two Kelly bars in the process tower. As shown in Fig. 5, if powder (solidification agent) addition is to be employed, the heated gas stream would be diverted to the powder feed system before entering the Kelly bars. In the center of each Kelly is a separate line which receives steam and treatment solutions at the top and delivers them to the soil through screw-on type nozzles located along the drill bit mixer assembly.

Operating experience and key results from site remediation

As noted previously, the remediation at a hydrocarbon-contaminated site in Southern California was the first full-scale field demonstration of the Detoxifier technology. The site formerly contained underground fuel storage tanks. Leakage from the tanks had resulted in soil contamination with total petroleum hydrocarbon (THC) concentration levels in the top 25 feet of soil, generally in the 100–1,000 ppm range. One segment of the site had THC values in excess of 15,000 ppm.

The 10,315-square-foot treatment area was subdivided into rows containing 433 treatment blocks. Of these, 246 blocks were treated to a depth of about 15 ft (4.6 m), and the remaining 187 blocks were treated to a depth of about 22 ft (6.7 m). The shroud off gas was monitored continuously using an online THC analyzer with a flame ionization detector and a strip chart recorder. The readout provided the basis for a determination by the operator for the required dosages of the treatment agents and the treatment time. Soil samples were also obtained from many blocks before and after treatment (generally at depths of 5, 10, and 21 ft – 1.5, 3.0 and 6.4 m) and analyzed by a commercial laboratory for total hydrocarbons. A computerized data base management program was used to process and analyze the large volume of information on treatment conditions used (i.e., temperature, depth, cycles, and duration of treatment) and results obtained on a block-by-block basis.

The key aims of the remediation effort at the subject site were to:

- Demonstrate the capability of the system to dispense treatment agents at desired depths, to provide good mixing and homogenization of the mixture, and to recover contaminants (i.e., hydrocarbons);
- Evaluate the adequacy of the various components of the treatment train (in particular, the scrubbers, and the activated carbon adsorption units) under a range of treatment conditions;
- Identify and provide the data base for any needed design improvements to the Detoxifier and the various components of the treatment train.

The remediation was considered a success insofar as the above objectives were achieved. The field data, which are still being analyzed, indicate that by adjusting the treatment conditions (i.e., amounts of air and steam used, and the rate and duration of treatment in terms of speed and number of up and down movements of the drill bit), the THC levels in the soil could be reduced to less than 100 ppm via hot air/steam stripping. The results also indicate that off gas monitoring via online THC analysis can provide a reasonably accurate basis for assessing completeness of in situ treatment and hence the decision by the operator to move the equipment to a new block. One key problem area was the quick overloading of the carbon adsorption system when treating soils with very high levels of hydrocarbons. This necessitated frequent replacement of the carbon charge.

Based on the experience for this project, designs are being developed by the technology vendor for fabrication of a more advanced Detoxifier unit (the Detoxifier II), which reportedly will be more powerful and cover a greater treatment area per block. The system will also be more compact (i.e., the components will be housed in one large trailer). To increase the carbon life, the carbon adsorption system will be preceded by an additional treatment step (e.g., a cryogenic unit) which will remove the bulk of the hydrocarbons from the scrubbed off gas before it enters the adsorbers. A schematic process block dia-

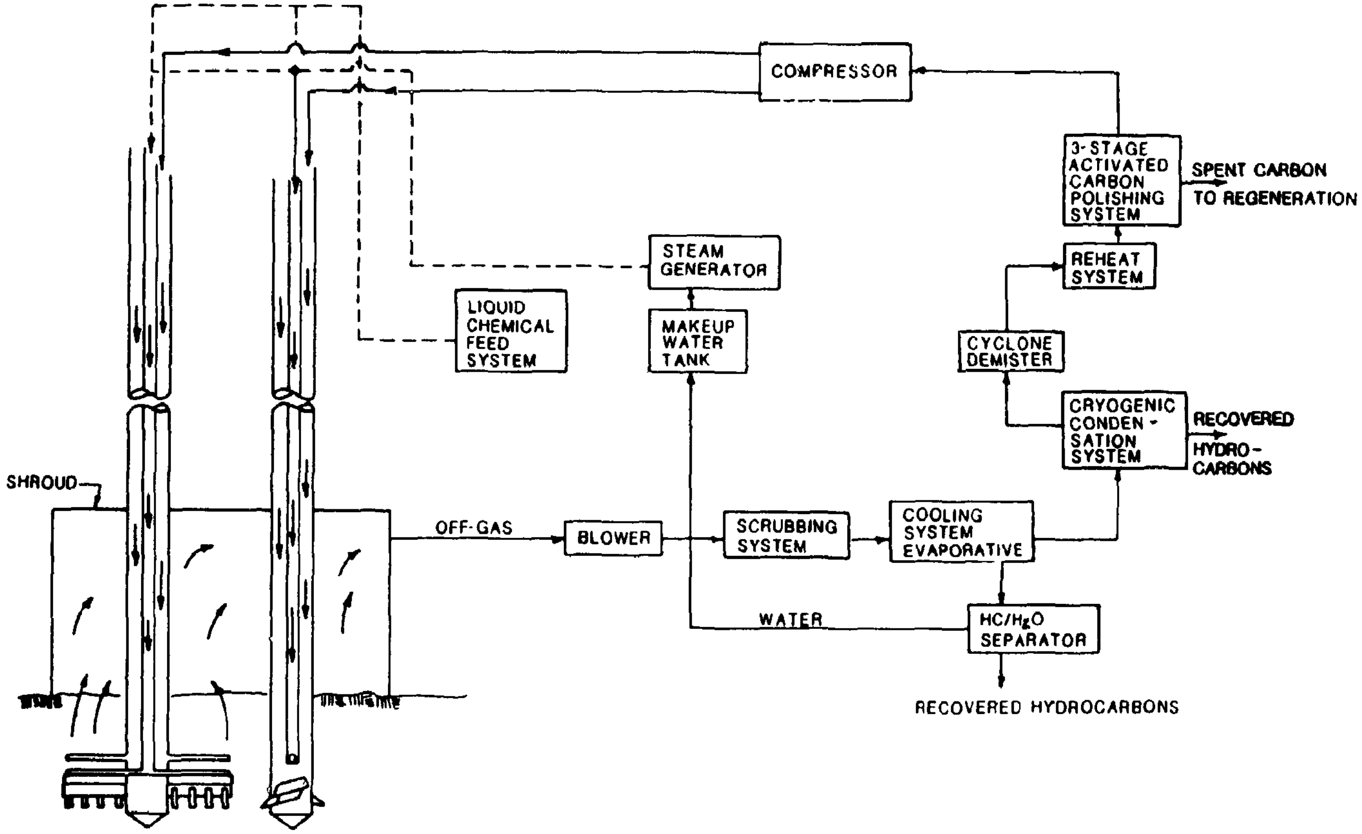

Fig. 6. A process diagram for the Detoxifier II treatment train.

gram for one of the several designs being evaluated for Detoxifier II is shown in Fig. 6.

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