

4.0 THERMAL DESORPTION

This section contains information about mobile and stationary process units that employ thermal desorption to remediate soil and the use of asphalt aggregate dryers for soil remediation. Data are included for the treatment of soil contaminated with petroleum fuels and soil contaminated with hazardous wastes.

Key references are two studies that include summarized information about existing soil vapor extraction (SVE) systems in use at field sites (Hutzler, et al., 1989; and PES, 1989), an evaluation conducted under EPA's SITE program (Michaels, 1989a), and an overview paper (Johnson, et al., 1990). The Johnson, et al., paper is given as Appendix E of this report and EPA's Engineering Bulletin on SVE is contained in Appendix F of this report.

4.1 Process Description

In the thermal desorption process, volatile and semi-volatile contaminants are removed from soils, sediments, slurries, and filter cakes. Typical operating temperatures are 350°-700°F, but temperatures from 200° to 1,200°F may be employed. The process often is referred to as low-temperature thermal desorption to differentiate it from incineration, which is a thermal treatment process employing higher temperatures (see Section 8). Thermal desorption promotes physical separation of the components rather than combustion.

Contaminated soil is removed from the ground and transferred to treatment units, making this an *ex situ* process. Direct or indirect heat exchange vaporizes the organic compounds producing an offgas that is typically treated before being vented to the

atmosphere (Vatavuk, 1990). The best single source of information on thermal desorption is contained in a recent EPA Guidance Document (Troxler, et al., 1992). The engineering bulletin prepared by the U.S. EPA (U.S. EPA, 1991) for this technology also contains useful information and is included as part of Appendix F to this report.

After it is excavated, the waste material is screened to remove objects greater than 1.5" to 3.0" in diameter (de Percin, 1991a). In general, any one of four desorber designs are used: rotary dryer, asphalt plant aggregate dryer, thermal screw, and conveyor furnace. The treatment systems include both mobile and stationary process units designed specifically for treating soil, and asphalt aggregate dryers that can be adapted to treat soils. Mobile systems are most often used, due to reduced soil transportation costs and to allow for backfilling of the treated soil. However, stationary systems also are available and may be feasible to provide regional services. Typical specifications for thermal desorption systems are shown in Table 4-1.

The effectiveness of thermal desorption is related to the final soil temperature that is achieved, which in turn is a function of residence time and heat transfer. The temperatures and residence times effective in bench-scale systems also have proved to be effective in pilot-scale systems. Such findings support the use of a bench-scale test to determine the suitability of thermal desorption and the best residence time and temperature to use (de Percin, 1991a). The typical treatment temperature range for petroleum fuels from leaking underground storage tank (LUST) sites is

Table 4-1
Comparison of Features of Thermal Desorption
and Offgas Treatment Systems

	Rotary Dryer	Asphalt Plant	Thermal Screw	Conveyor Furnace
Estimated number of system	40-60	100-150	18-22	1
Estimated number of contractors	20-30	No estimate	9	--
Mobility	Fixed and mobile	Fixed	Mobile	Mobile
Typical site size, Mg (tons)	450-23,000 (500-25,000)	0-9,000 (0-10,000)	450-4,500 (500-5,000)	450-5,000 (500-5,000)
Soil throughput, Mg/hour (tons/hour)	9-45 (10-50)	23-90 (25-100)	3-14 (3-15)	5-9 (5-10)
Maximum soil feed size, cm (inches)	5-8 (2-3)	5-8 (2-3)	3-5 (1-2)	3-5 (1-2)
Heat transfer method	Direct	Direct	Indirect	Direct
Soil mixing method	Shell rotation and lifters	Shell rotation and lifters	Auger	Soil agitators
Discharge soil temperature, °C (°F)	150-300 ^a (300-600 ^a) 300-650 ^b (600-1,200 ^b)	300-600	150-250 ^c (300-500 ^c) 300-250 ^d (600-900 ^d) 500-850 ^e (1,000-1,600 ^e)	300-800
Soil residence time (minutes)	3-7	3-7	30-70	3-10
Thermal desorber exhaust gas temperature, °C (°F)	250-450 ^a (500-850 ^a) 400-500 ^b (800-1,000 ^b)	250-450 (500-850)	150 (300)	500-650 (1,000-1,200)
Gas/solids flow	Co-current or counter-current	Co-current or counter-current	Not applicable	Counter-current
Atmosphere	Oxidative	Oxidative	Inert	Oxidative
Afterburner temperature, °C (°F)	750-1,000 (1,400-1,800)	750-1,000 ^f (1,400-1,800 ^f)	Generally not used	750-1,000 (1,400-1,800)
Maximum thermal duty, Mj/hr (MMBtu/hr) ^g	10,500-105,000 (10-100)	5,300-105,000 (50-100)	7,400-10,500 (7-10)	10,500 (10)
Heatup time from cold condition (hours)	0.5-1.0	0.5-1.0	Not reported	0.5-1.0
Cool down time from hot condition (hours)	1.0-2.0	1.0-2.0	Not reported	Not reported
Total Petroleum Hydrocarbons Initial concentration (mg/kg) Final concentration (mg/kg) Removal efficiency (%)	800-35,000 <10-300 95.0-99.9	500-25,000 ^h <20 ^h Not reported	60-50,000 ND-5,500 64-99	5,000 <10.0 >99.9
BTEX Initial concentration (mg/kg) Final concentration (mg/kg) Removal efficiency (%)	NR <1.0 NR	Not reported Not reported Not reported	155 <1.0 >99	Not reported <0.01 Not reported

^aCarbon steel materials of construction

^bAlloy materials of construction

^cHot oil heat transfer system

^dMolten salt heat transfer system

^eElectrically heated system

^fNot used on all systems

^gTotal duty of thermal desorber plus afterburner

^hVendor information: Soil Purification, Inc.

Source: Troxler, 1991.

400°F to 900°F. For the treatment of soils containing pesticides, dioxins, and polychlorinated biphenyls (PCBs), temperatures should exceed 850°F (de Percin, 1991c). The distillation temperature range will vary with the type of fuel contamination, as shown in Figure 4-1.

Thermal desorbers effectively treat soils, sludges, and filter cakes and remove volatile and semi-volatile organic compounds. Some higher boiling point substances such as PCBs and dioxins may also be removed (if present). Inorganic compounds are not easily removed with this type of process, although some relatively volatile metals such as mercury may be volatilized. Temperatures reached in thermal desorbers generally do not oxidize metals (de Percin, 1991a).

The soil is most effectively treated if its moisture level is within a specified range due to the cost of treating waste with a high water content. The typical acceptable moisture range for rotary dryers and asphalt kilns is 10-30%, (Troxler, 1991 and SPI, 1991), while thermal screw systems can accommodate higher water loadings of 30-80%. For removal of VOCs, the soils ideally should contain 10-15% moisture because the water vapor will carry out some of the VOCs (de Percin, 1991c).

High-molecular-weight organic compounds may foul or plug baghouses or condenser systems. Therefore, the types of petroleum products that can be treated by specific technologies may be limited. Rotary dryers typically can treat soils that have an organic content of less than two percent. Thermal screw units may treat soils that contain up to 50% organics. (Troxler, 1991).

Thermal desorbers may operate near or above 1000°F, so some pyrolysis and oxidation may occur in addition to the vaporization of water and organic compounds. Collection and control equipment such as afterburners, thermal oxidizers, fabric filters, activated carbon, or condensers prevent the release of the contaminants to the atmosphere (de Percin, 1991a). Various types of thermal desorption systems can produce up to nine residual process streams: treated soil, oversized media rejects, condensed contaminants, water, particulate control dust, clean off-gas, phase separator sludge, aqueous-phase spent carbon, and vapor-phase spent carbon (de Percin, 1991b).

Thermal desorption has the following advantages over other treatment processes:

- A wide range of organic contaminants can be treated; and
- The systems can be mobile.

There are a number of advantages compared with incineration. Thermal desorbers operate at lower temperatures, so significant fuel savings may result (Vatavuk, 1990). They also produce smaller volumes of off-gases to be treated. Thermal desorption also differs from incineration with regards to the regulatory and permitting requirements and the partitioning of metals within the process residual streams. Perhaps most importantly, thermal desorption enjoys more public acceptance than other thermal treatment methods (de Percin, 1991a).

Potential limitations of the treatment process exist as well. Thermal desorption does not destroy contaminants; it merely

Figure 4-1. Soil Treatment Temperature Guide.

Source: Troxler, et al. 1992

strips them from the solid or liquid phase and transfers them to the gas phase. Therefore, devices to control VOC emissions are necessary. The efficiency of the thermal desorption process will vary with the chemical and physical properties of the specific contaminants. Metals (e.g., lead) tend to remain in the soil after treatment, so additional soil processing or treatment may be required (e.g., stabilization).

A generalized schematic diagram of a thermal screw, thermal desorption process is shown in Figure 4-2; the system shown most closely resembles Weston's LT³ system. Other designs may use different types of control technology. Information about specific vendor designs is given below. The information is based primarily upon the use of portable remediation units, but the information should be generally applicable to other types of thermal desorption, such as rotary drum aggregate dryers.

4.1.1 X*TRAX™ by Chemical Waste Management, Inc.

The X*TRAX™ system is a transportable, indirectly heated rotary dryer, that treats up to 100 tons per day of soil and sediment contaminated with hazardous wastes. Propane fires an outer shell, which then heats the soil to 300°-900°F. Nitrogen gas sweeps the water and organic vapor to gas treatment and mitigates explosion hazards. Gas treatment consists of condensation, refrigeration, and carbon adsorption. The liquid water is separated from the liquid organic compounds and used for dust control (de Percin, 1991b).

4.1.2 Taciuk by SoilTech, Inc.

The Taciuk system is a two-zone, double-shell rotary dryer that treats up to 25 tons per hour of soil and sediments contaminated with hazardous wastes. The solids enter the first zone of the inside shell where temperatures of 300°F vaporize water and VOCs. Entry into the second zone of the inside shell enables additional organic compounds to be volatilized and pyrolyzed at temperatures of 1000°F.

The high temperature solids enter the outer shell where they transfer heat to the inner shell. Fired natural gas or propane heats the annulus between the shells. A cyclone, baghouse, caustic scrubber, and carbon adsorber treat the combustion gases while a condenser liquefies gases from both zones. Non-condensable gases from pyrolysis help to heat the system (de Percin, 1991b).

4.1.3 LT³ by Roy F. Weston, Inc.

The Low Temperature Thermal Treatment, or LT³ system, treats up to 20 tons per hour of soil and sediment using two banks of four heated screws. The process primarily is used for treating hazardous wastes. The combustion of propane heats transfer oil, which is pumped through the screws, heating the shell to 600°F. The combustion gases sweep the water and organic vapor to the gas treatment system (de Percin, 1991b).

4.1.4 DAVES by Recycling Sciences, Inc.

The Desorption and Vapor Extraction System (DAVES) treats contaminated material in a fluidized bed where it is fed along with hot air. Gas-fired

Figure 4-2. Generalized Process Diagram for Thermal Screw-Based Thermal Desorption.

heaters heat the air to 1000°-1400°F. The hot air vaporizes water and organic compounds and carries them to the gas treatment system. Gas treatment consists of a cyclone, baghouse, venturi scrubber, chiller, and carbon adsorber (de Percin, 1991b).

4.1.5 ReTec by Remediation Technologies, Inc.

The ReTec thermal desorption system operates at capacities of 0.5-3.5 tons per hour and is designed to treat soils contaminated with organic compounds and oily sludges. If the waste material has a high moisture content, the process begins with a dewatering step. Dewatered filter cakes from the press are fed to storage hoppers and then transported to the dryer by a covered conveyer.

The Holo-Flite Processor consists of a jacketed trough, which houses a double-screw mechanism. The heat-transfer fluid (thermal oil or steam) is circulated through the trough jacket can. The material enters and exits the dryer through rotary air-locks to prevent leakage of ambient air into the processor. The gas flow from the dryer, which is designed to remove moisture and the organic compounds with low boiling points, passes through a particle removal system, quench chamber, condenser, and activated carbon beds (Abrishamian, 1991).

The partially treated soil leaves the dryer and enters the processor, where the soil is subjected to temperatures between 500 and 900°F and shorter residence times (relative to the drying step) to remove the organic compounds with high boiling points. Molten salt, heated by an electric or fuel-fired heater, is used as the heating medium for the processor. The molten salt does not

produce off-gases, and it is non-toxic, non-flammable, and easily cleaned up if spilled. Inert gas added to the processor inhibits oxidation and enhances vaporization of contaminants. Off-gases from the processor undergo treatment with cyclones, a semi-volatile organic separator, chilled condenser, and activated carbon beds. A solids cooler lowers the temperature of the solids to less than 180°F for safe handling (Abrishamian, 1991).

4.2 Identification of Air Emission Points

The air emissions associated with thermal desorption come from several sources. The point sources of air emissions vary widely with each process. The stack of an afterburner vents combustion products, as does a fuel-fired heating system if the combustion gases are not fed into the desorber. The fuel-fired heating system typically operates with propane, natural gas, or fuel oil. If the VOC emission controls consist of a baghouse, scrubber, and vapor phase carbon adsorber, the offgas will contain small concentrations of the original contaminants, as well as products of any chemical reactions that might occur.

The volume of off-gas from a thermal desorption unit depends on the type of processor. Devices that are heated indirectly have offgases composed of volatilized VOCs and water from the soil being treated and, possibly, some sweep gas used to carry the contaminants out of the device. This volume of gas is typically 1,000 to 5,000 acfm (Troxler, 1991). In directly heated units, the off-gas contains volatilized contaminants and water, but also the combustion gases used to heat the soil. The result is a much larger volume of off-gas that needs to be treated, around 10,000

to 50,000 acfm (Troxler, 1991). Therefore, off-gases from indirectly heated units, i.e. thermal screws, can be treated with smaller chemical/physical systems, such as a baghouse or a condenser, followed by an afterburner.

Fugitive emissions from area sources may contribute significantly to the total air emissions from a remediation site. Probably the largest source is excavation of the contaminated soil. Other sources may include the classifier, feed conveyor, and the feed hopper. Fugitive emissions from the components of the thermal desorption system and controls are possible as well. Emissions also may emanate from the waste streams such as exhaust gases from the heating system, treated soil, particulate control dust, untreated oil from the oil/water separator, spent carbon from liquid or vapor phase carbon adsorber, treated water, and scrubber sludge.

4.3 Typical Air Emission Species of Concern

The volatile and semi-volatile contaminants under remediation are the species emitted if no destruction or other chemical treatment has taken place.

Combustion products such as particulate matter, nitrogen oxides (NO_x), carbon monoxide (CO), and acid gases may be emitted if a destructive control device, such as an afterburner, is used or if the heating system is fuel-fired. In some cases, pyrolysis occurs to a certain degree in the dryer, so products from these reactions also may be emitted.

4.4 Summary of Air Emissions Data

Air emissions from thermal desorption systems are influenced by the waste characteristics, the desorption process, and the emissions control equipment. As noted above, pyrolysis may occur at the elevated temperatures in the desorber. Dioxins, furans, and phenol concentrations have been reported to increase with temperature (Foster, et al., 1992). The emissions data presented below are divided into two categories: emissions for asphalt aggregate dryers and emissions for other mobile units.

4.4.1 Air Emissions Data for Asphalt Aggregate Dryers

The VOC emissions from asphalt aggregate dryers will vary by several orders of magnitude depending on whether afterburners are used as a control device. These treatment systems typically do not employ VOC controls, unless they have been modified for soil remediation.

Soil Purification, Inc. (SPI), a subsidiary of a leading manufacturer of asphalt plants, has estimated the typical emissions for soil treatment in a modified asphalt aggregate dryer. This system consists of a direct-fired rotary drum operating at 550-1000°F. A primary cyclonic tube collector and pulse-jet baghouse are used to control particulate emissions. A thermal oxidizer (i.e., afterburner) destroys organic compounds in the off-gas stream (99-99.99% efficiency). Based on a processing rate of 35-60 tons per hour, typical emissions from this type of unit are:

- Particulate: 0.02-0.03 gr/dscf; and
- Total VOC: 0.1-5 lb/hr.

Data are given for three asphalt plants that were modified for the treatment of petroleum contaminated soils. Summaries of the soil properties and emission characteristics at these plants are presented in Tables 4-2a and 4-2b. Afterburners were not used on any of these systems. Each site is discussed in more detail below.

Soil contaminated with diesel fuel and gasoline were treated at an asphalt plant with a 450 tons/hour capacity at 5% moisture (Barr, 1990). Soil enters the dryer opposite of the burner and flows countercurrent to the combustion gases. This configuration allows the VOCs which desorb from the soil in the upper portion of the dryer to exit the system without exposure to the burner flame. The results presented for this plant represent worst-case conditions because all of the VOCs volatilized from the soil may not be destroyed and no additional VOC control device is present (Barr, 1990). The hot exhaust gases are routed to a wet scrubber and a cyclonic demister. The gas is then emitted to the atmosphere through the stack.

The feed rate for the diesel fuel and gasoline contaminated soils for the test runs were 280 and 255 tons/hour, respectively. The air pollution control equipment accommodates 80,000 acfm at 300°F (Barr, 1990). The soil headspace concentrations and removal efficiencies are reported for the remediation tests. Measured total hydrocarbon (THC) emission rates for these tests were 254 and 310 lb carbon per hour (i.e., about ten times the typical emission rate during asphalt production). Emission rates of particulate matter were 64 and 67 lbs/hour.

A second trial burn was performed on a soil contaminated with petroleum

hydrocarbons. The plant treats up to 120 tons/hour of soil at temperatures around 350-400°F (Batten, 1987). The exhaust gas from the system contained 129 and 175 ppmv of THC above background. THC's were emitted at a rate between 30.4 and 47.7 lb/hr. The estimated emission factor for total non-methane hydrocarbons was 0.21 to 0.26 lbs per ton of soil treated. Based on the results, Batten (1987) concluded that hydrocarbon controls would be necessary in order for the system to meet air pollution control requirements.

The Soil Cleanup System (SCS, from Earth Purification Engineering, Inc.) was demonstrated in the treatment of diesel-contaminated soil from a leaking underground fuel tank in Kingvale, California. The SCS is an asphalt recycling unit modified to treat contaminated soils. The offgas from the rotary kiln is routed to dual cyclones, an exhaust cooler, and a baghouse. The soil exits the system at 775°F. The emission rates for non-methane VOCs and semi-volatile organics were 1.04 and 1.57 lb/hour, respectively, or 0.44 and 0.67 lb/ton assuming 1.25 ton/yd³ (SCS, 1990).

4.4.2 Air Emissions Data for Mobile Units

Thermal desorption has been used at many sites for the treatment of soils contaminated with various materials. Examples are described below. Additional data are given in the case studies in Section

Table 4-2
Characteristics of Asphalt Aggregate Dryers

Table 4-2a. Typical Soil Properties^a

Parameter	Initial Concentration (ppm)	Final Concentration (ppm)	Removal Eff. (%)
Benzene	0.11-39.5	<0.01-0.06	84.5-99.9
Toluene	0.27-<2	<0.01-0.1	NA
m,p-Xylenes	<0.8-<3	0.2-1.2	<75
o-Xylenes	3.1-15.6	<0.01	99.7-99.9
Total Xylenes	13.1	0.1	99.2
Ethylbenzene	0.11	<0.01	>90
THC	39-393	5.7-9.5	85-97.5
Diesel	1875	<1	>99.9

^aBased on two or three installations depending on the parameter.

Table 4-2b. Typical Offgas Characteristics^b

Parameter	Stack Concentration	Units
Benzene	4.3-8.6	ppmd
Toluene	0.6-0.8	ppmd
m,p-Xylenes	0.42-3.5	ppmd
THC	129-2,800	ppm
Naphthalene	5,136-6,757	$\mu\text{g}/\text{Nm}^3$
Acenaphthylene	634-901	$\mu\text{g}/\text{Nm}^3$
Acenaphthene	317-638	$\mu\text{g}/\text{Nm}^3$
Fluoranthene	405-763	$\mu\text{g}/\text{Nm}^3$
Phenanthrene	385-645	$\mu\text{g}/\text{Nm}^3$
Anthracene	<1.4-427	$\mu\text{g}/\text{Nm}^3$
Fluoranthene	24-135	$\mu\text{g}/\text{Nm}^3$
Pyrene	32-111	$\mu\text{g}/\text{Nm}^1$

^bBased on two installations. Emission control equipment consists of a wet scrubber and cyclonic demister.

4.9, including data on dioxin and furan emissions.

According to Weston Services, Inc., the use of their full-scale LT³ system on the Springfield, Illinois cleanup of gasoline and No. 2 fuel oil-contaminated soils produced stack emissions that were in compliance with federal and state regulations, including VOCs, HCl, CO, and particulates (Nielson and Cosmos, 1989). The emission rate of BTEX was 1079 grams/hour before controls and 21 grams/hour after the control devices.

ReTec's thermal adsorption unit was used in the remediation of coal tar-contaminated soil. Molten salt in a thermal screw was used to indirectly heat the soil to approximately 450°F. The soil was treated at a rate of 100 pounds per hour. The controlled emissions of BTEX were 0.26 grams per hour or 0.011 lb/ton (U.S. EPA, 1991).

At the McKin Superfund Site in Gray, Maine, soil containing primarily trichloroethylene (TCE) was treated by Canonie Environmental Services Corporation. Temperatures varied between 150 and 380°F, and the capacity was 1-4 cubic yards per batch. To achieve 0.1 ppm TCE concentration in the treated soil, the temperature was adjusted to 300°F for 6-8 minutes (Webster, 1986). The total reported emission rates were 24 g/hr.

The Thermotech Systems Corporation's Portable Soil Remediation Unit was used to treat petroleum contaminated soils in Washington, D.C. and Grand Rapids, MN. The unit has air pollution controls for particulate matter (dust collector) and organics (thermal oxidizer). For the Washington, D.C. site, the particulate, BTEX, and TPH emissions

were 5.0, 0.13, and 0.42 pounds per hour, respectively. The emission rate for particulates from the Grand Rapids site was 2.4 lb/hr (Thermotech, 1990-1991).

U.S. Waste Thermal Processing's Mobile Thermal Processor, Model 100, was used to treat gasoline- and diesel-contaminated soils. The transportable treatment unit consists of a primary furnace with an afterburner to incinerate the combustibles. The offgas from the afterburner is routed to a wet scrubber for particulate removal. The soil exit temperature is maintained between 300 and 650°F, and the afterburner operates at 1800°F, with a minimum residence time of 0.5 seconds. The scrubber is a dual-venturi collision scrubber. The test was performed on soil at 5000 and 5500 mg/kg contamination levels of gasoline and diesel fuel, respectively. The particulate emission rates were 4.2 and 2.7 lb/day (Remedial Technology Unit, 1990).

The Todds Lane Soil Remediation Plant handles soils contaminated with petroleum hydrocarbons. Pollution control devices include a cyclone, multiclones, a baghouse, and an afterburner. The maximum anticipated concentrations of certain VOCs in the soil were used to estimate the emission rates of the compounds after the afterburner, assuming 99% efficiency. The total emission rate for BTEX was determined to be 2.1 pounds per hour (United Engineers and Constructors, 1991).

The Soil Remediation Unit (SRU) 202 consists of a rotary kiln, an afterburner, and a baghouse. This unit was used to treat contaminated soil, and the emissions were reported as follows: particulate - 1.7 to 2.5

lb/hr and VOC - 0.1 to 0.74 lb/hr (Air Consulting and Engineering, 1991).

The pilot-scale X*TRAX system uses an externally-fired rotary kiln for the treatment of soils contaminated with hazardous wastes. The offgas is first treated in a liquid scrubber where particulate matter is removed. The gas is then cooled further to allow for condensation of the contaminants. The gas is routed through a particulate filter and to a carbon adsorber where most of the remaining organics are removed. The VOC emissions ranged from 0.01-0.08 lb/day for the treatment of clay and sandy soils (U.S. EPA, 1991).

A pilot-scale test was performed by IT Corporation for the treatment of creosote-contaminated soils at the Burlington Northern Superfund Site. The thermal desorption unit was operated at 1025°F and a residence time of 10 minutes. The treatment unit consists of a rotating desorber tube partially enclosed within a gas-fired furnace shell. Nitrogen is introduced into the system to flush out desorbed contaminants and to maintain an atmosphere that does not support combustion. The offgas is treated with a cyclone, a primary scrubber, a condenser, a demisting filter, a particulate filter, and an activated carbon unit. Finally, the offgas is scrubbed in a secondary scrubber and then discharged to the atmosphere. These values represent the average of six samples (IT, 1991). The IT system was also used to treat PCB contaminated soils at a rate of 40 to 70 pounds per hour. The results of these tests are presented in Table 4-3; the operating temperature and residence time varied for each run.

Control of volatile organic emissions is crucial to the overall success of thermal desorption remediation of contaminated soils. The process uses physical separation driven by heat, so the vaporized contaminants would simply be transferred from one medium (soil) to another (air) if no emission controls were employed.

The types of controls available include both destruction and separation technologies. Typically two to six types of controls are used in series; they are chosen to suit the specific VOC contaminants present and the other pollutants of concern. Liquid-phase and solid-waste streams usually are treated on site or stored for subsequent off-site treatment. Depending on the types of contaminants present and their concentrations, it may be feasible to recover and reuse the volatilized contaminants. The offgas stream often is routed to the burner that provides heat to the dryer.

Typical VOC controls for point sources are briefly described below; Section 5.5 contains additional information. More detailed information is available in a recent EPA report (Eklund, et al., 1992). Asphalt kilns will have similar air emission control devices as mobile thermal desorption units, except that no VOC controls are typically employed and the air flowrates are higher, requiring some differences in design parameters.

Many low-temperature thermal desorption (LTTD) control devices use an off-gas treatment system consisting of a cyclone, afterburner, quench, and baghouse (fabric filter). The cyclone is used to reduce

4.5 Identification of Applicable Control Technologies

Table 4-3
Estimated Emissions of Selected Compounds for the Cleanup
of PCB-Contaminated Soil Using the IT Process

Contaminant	Residence Time (minutes)	Temperature °F	Initial Concentration	Final Concentration	Units	Rate of Uncontrolled Emissions g/hr	Overall Estimated Percent Efficiency	Estimated Emissions Rate g/hr
PCB's	19	1022	37.5	2	ppm	1.14	95%	5.68e-02
2,3,7,8-TCDD	40	1040	260	0.018	ppb	0.00832	95%	4.16e-04
2,3,7,8-TCDD	19	1040	236	0.018	ppb	0.00755	95%	3.78e-04
2,3,7,8-TCDD	10.5	1040	266	0.018	ppb	0.00851	95%	4.26e-04
2,3,7,8-TCDD	24	860	233	0.5	ppb	0.00744	95%	3.72e-04
2,3,7,8-TCDD	5.6	1022	48	0.084	ppb	0.00153	95%	7.67e-05
2,3,7,8-TCDD	20	1031	56	0.23	ppb	0.00178	95%	8.92e-05

the particulate loading on downstream devices. The baghouse may be placed before or after the afterburner; it efficiently removes particulates to low levels. The afterburner oxidizes organics and CO by thermal destruction. Some LTDD systems use an afterburner followed by a quench chamber and a venturi wet scrubber. This system is capable of controlling acid gases if they are a concern. Some systems collect the organic contaminants, as shown in Figure 4-2, rather than destroying them.

4.5.1 Particulate Removal

Off-gases from the desorber typically pass first through a particulate control device. Particles that become entrained in the off-gas stream may be removed with cyclones, venturi scrubbers, or fabric filters. Collected particulates are usually returned to the incoming waste stream and retreated with the soil.

Cyclone collectors remove particles by creating a vortex from the inlet gas stream velocity. Centrifugal acceleration forces entrained particles outward where they collide with the wall and fall to a collection point. Cyclones efficiently remove the bulk of larger particles, however, venturi scrubbers or baghouses are required to remove smaller particles.

Venturi scrubbers are sometimes used to treat desorber off-gas, and efficiently remove particles greater than 0.5 μm in diameter using an aqueous stream. The performance is not affected by corrosive, sticky, or flammable particles, but high collection efficiencies require a higher pressure drop and thus are more costly to operate (Sink, 1991). The scrubber may also serve as the initial condensation stage for water and organic compounds.

The fabric filter may be a series of fine-mesh synthetic fabric bags similar to the type used in asphalt batch plants. An induced draft fan can be used to draw the exhaust gas through a filter. The filter may be a jet-pulse design such that high-pressure (80 psig) air periodically removes accumulated particulates to collection bins. Dust from the bins may then be combined with the contaminated soil for reprocessing. The maximum allowable pressure drop across the filter may be 15 inches of water (Weston, 1990), though 3 to 8 inches of water is typical.

4.5.2 Condenser

Condensers can be used to remove VOCs from a vapor stream if the design is efficient for removing the specific contaminants that are present. This physical separation process operates on the basis of the contaminants' vapor pressures, which vary widely. By reducing temperature or increasing pressure until the saturation vapor pressure is reached, the vapor condenses to a liquid phase and is treated accordingly. Contaminants with high vapor pressures require correspondingly low condensation temperatures. In these situations, a quencher that removes a large portion of the moisture present often precedes the condenser to prevent icing. The coolant may be air, ambient water, brine, chilled water, or refrigerants. A separator directs the vapor/gas and liquid streams to appropriate control systems.

4.5.3 Liquid Phase Treatment

The liquid from the condenser is sometimes partially treated on-site. The liquid is separated by a gravity oil/water separator. The insoluble light organic

fraction is skimmed off the top, placed into 55-gallon drums and stored for off-site treatment. The contaminated water from the separator is passed through carbon adsorption columns and then typically recycled on-site. Potential water uses include dust control, service makeup, and cooling of the treated soil.

4.5.4 VOC Control by Afterburner

Fume incinerators (i.e., afterburners) often are used for the control of VOC emissions from thermal desorption systems, especially for systems used for treating underground storage tank sites. An afterburner used in one system identified in the literature is a 3.5 million-BTU/hr (MMBTU/hr) gas-fired fume incinerator, but afterburners may fire gas at up to 40 MMBTU/hr.

Afterburners typically operate at 1400-1800°F and have a residence time of 0.5-2 seconds. The air that carries the vaporized contaminants serves as the combustion air. The flame vortex exposes the VOCs to temperatures and turbulence necessary for complete combustion. A combustion air (offgas) fan maintains a minimum of three percent excess oxygen exiting the afterburner. Exhaust gases leaving the afterburner are sometimes mixed with ambient air to be cooled and then passed through a scrubber (Weston, 1990). Hot gases typically are quenched with water prior to entering a baghouse.

4.5.5 VOC Control by Carbon Adsorption

Often used as a polishing process after other treatments, carbon adsorption works on the principle that contaminants are physically adsorbed onto the activated

carbon. No chemical change or reduction of the waste amount occurs. Adsorption processes can occur in either the liquid or vapor phase. Regeneration or disposal of spent carbon may also produce emissions, though this is very rarely done on-site.

Liquid-phase carbon adsorption usually treats water containing low contaminant concentrations with a two-stage system. Clean water is often used to cool discharge solids from the desorber and suppress dust formation (Nielson and Cosmos, 1989).

4.5.6 Scrubber

Exhaust gases from thermal destruction processes may be treated in a scrubber to remove particulates or neutralize acid gases. Wet scrubbers use a liquid to absorb pollutants from a waste gas stream; the process is enhanced through a large liquid/gas contact surface area. Wet scrubbers operate by either chemical absorption (reaction between pollutant and liquid), or physical absorption (pollutant trapped by liquid). Dry scrubbers operate by chemical absorption. Acid gases are not typically a concern when processing petroleum-contaminated soils because of low concentrations of halogenated compounds (Troxler, 1991). Particulate scrubbers (venturis) can be employed to capture the particles by impingement and agglomeration with liquid droplets. If a wet scrubber is used to treat the off-gases, a liquid separator is needed downstream of the scrubber, such as a cyclone or mist eliminator.

4.5.7 Miscellaneous System Adaptations and Control Approaches

Other emissions-control techniques include using treated water for dust control and using ultraviolet light. Ultraviolet rays have been used to destroy dioxin in the condensate from the thermal desorption of contaminated soils.

While conducting a pilot study of the McKin Superfund site in Gray, Maine, Canonie Environmental Services Corporation made efforts to control VOC and dust emissions from excavation and aeration processes. The soil was contaminated with trichloroethylene (TCE). Excavation down to 40 feet was conducted with a Kelly bar caisson rig fitted with a digging bucket and attached to a 100-foot crane. Soils discharged from the digging bucket entered a front-end loader equipped with a removable plastic cover. Cylindrical steel caissons were augered into the deep excavation holes to prevent further volatilization (Webster, 1986).

4.6 Capital and Operating Costs for Remediation

Because thermal desorption is virtually never used without controls, the costs reflect emission controls as well as remediation. Most thermal desorption units offered by vendors are predesigned systems with VOC and particulate controls already installed. This is especially true for mobile systems, which are typically housed on flat bed trailers. Asphalt plants do not typically have VOC controls, but if they have been modified to treat soils, the organic control device may already be added.

The costs for thermal desorption (exclusive of emission control costs) for treatment of soils contaminated with petroleum hydrocarbons typically range from \$50 - 125/ton for low temperature

thermal screw units and from \$35 - 100/ton for rotary dryers (Troxler, 1991).

IT Corporation performed a pilot study for cleanup of PCBs on the Rosemount Research Center site of the University of Minnesota. IT estimated that direct operating costs for a full-scale system would be about \$80/ton based on a 10 ton/hour system treating soil with 20 percent moisture. This figure includes \$60/ton for labor, utilities, fuel, materials and supplies, and administrative costs, as well as \$20/ton for depreciation. These are hopper-to-hopper treatment costs; total costs are likely to be \$175 to \$350 per ton (Troxler, 1991). Costs depend on the contaminants present and site conditions. Cost estimations should take into consideration planning and procurement, permitting, site preparation, equipment mobilization, equipment erection/startup, operations, equipment decontamination and demobilization, and site closure (Fox, et al., 1991).

Soil contaminated with Herbicide Orange at the Naval Construction Battalion Center (NCBC) in Gulfport, Mississippi was treated with the IT Corporation's pilot-scale thermal desorption/ultraviolet apparatus (TD/UV). The costs for treating the dioxin-contaminated soil are summarized below and include the cost of ultraviolet destruction technology, which is not typically a part of the thermal desorption process (Helsel and Thomas, 1987):

Amount of Soil, Mg (tons)	Total Cost, million \$	Cost Per Mg, \$ (ton, \$)
9,071 (10,000)	6.0	544 (600)
18,143 (20,000)	8.0	365 (402)
36,287 (40,000)	11.8	268 (295)

Remediation Technologies, Inc. estimates the cost of treating oily soils and sludges to be in the range of \$100-\$300/ton of feed. The costs depend on quantity of waste, term of the contract, and moisture and organic content of the contaminated soil. Estimated costs for some other systems are presented in Table 4-4.

4.7 Capital and Operating Costs for Emission Controls

Costs for emission controls are included in the remediation costs given in Section 4.6. The installed cost of complete thermal desorption systems that include treatment of offgases and condensates usually is about 2-4 times the cost of the thermal units themselves (Abrishamian, 1991).

Cost estimates were determined for thermal oxidizers and fabric filters used with thermal desorption units (See Tables 4-5 and 4-6). The cost estimates were calculated from procedures outlined in various U.S. EPA documents. These values were also compared with vendor quotes. The estimation was performed for gas flow rates of 5,000, 15,000, and 40,000 acfm. The total capital investment was determined for both mechanical shakers and pulse-jet fabric filters and includes equipment and installation costs. Site preparation and construction costs are not included in this

Figure. The results are presented in Table 4-6.

The cost estimate for an afterburner, or thermal oxidizer, was based on similar flow rates (5,000, 15,000, and 40,000 scfm). Two cases were considered for each flow rate: a) no heat exchanger (no heat recovery from the thermal oxidizer) and b) 50% heat recovery. The cost estimates and vendor information are summarized in Table 4-5. As stated earlier, thermal desorption units are typically sold as a predesigned unit that already incorporates the control devices into the total cost of the system.

4.8 Equations/Models for Estimating Emissions

Theoretical models based on fundamental principles have been proposed for predicting the evolution of volatile compounds from soil in the thermal desorption process (Lighty, et al., 1990). Both particle desorption and bed desorption were examined. The models are partial differential equations based on mass and energy balances and on the Freundlich isotherm equation. In practice, an assessment of the applicability of thermal desorption for a given site is not based on modeling calculations, but instead on the types of contaminants present in the soil, the physical properties of the soil, and the results of any bench-, pilot- or full-scale test runs. In most cases, the process conditions, such as temperature and residence time, can be modified to yield the desired removal efficiency, though heavier weight petroleum fuels, such as No. 6 fuel oil, may present problems for systems with relatively low operating temperatures. The cost to operate at these process conditions, however, will

Table 4-4
Costs Including Emission Controls for Various Thermal Desorption Units

System	Cost, \$/Mg feed (\$/ton feed)	Soil Characteristics	Soil Feed Rate, Mg/hr (tons/hr)
X*TRAX™, Chemical Waste Management	136-318 (150-350)	30% moisture; <10% organics	--
LT ^{TA} , Canonie Environmental Services, Corp.	73-136 (80-150)	---	27-45 (30-50)
LT ³ , Roy F. Weston	91-109 (100-120)	20% moisture; 10,000 ppm organics	9 (10)

SOURCE: Johnson and Cosmos, 1989

Table 4-5
Cost Information for Thermal Oxidizers

Heat Recovery (%)	Flow Rate (scfm)	Estimated Capital Cost^a (1992 \$)	Vendor Estimates^b
0	5,000	156,000	100,000 ^c
	15,000	209,000	300,000 ^c
	40,000	304,000	--
50	5,000	304,000	150,000 ^c
	15,000	437,000	450,000 ^c
	40,000	580,000	--

^aEstimated capital costs based on correlations given in the OAQPS Control Cost Manual (Vatavuk, 1990).

^bTypical cost from Soil Purification, Inc. given as \$75-300,000 for a thermal oxidizer for a "typical" size system.

^cConversion Technology, Inc.

Table 4-6
Cost Information for Fabric Filters

Filter Type	Flow Rate (acfm)	Estimated Capital Cost ^a (1992 \$)	Vendor Estimates ^b
Mechanical Shaker	5,000	159,000	24,000 ^c
	15,000	298,000	36,400 ^c
	40,000	509,000	--
Pulse-Jet Fabric Filter	5,000	124,000	30,000 ^c
	15,000	205,000	52,000 ^c
	40,000	456,000	--

^aEstimated capital costs based on correlations given in the OAQPS Control Cost Manual (Vatavuk, 1990).

^bTypical cost from Soil Purification Inc. given as \$250-350,000 for a pulsed-jet fabric filter for a "typical" size portable system.

^cDustex Corporation.

Note: Cost difference may reflect differences in installed versus delivered costs.

dictate whether or not thermal desorption is competitive with other remediation options.

Using removal efficiencies obtained from test runs, a mass balance yields the following equation to estimate an emission rate for a volatile compound leaving the desorber. This estimate does not include emissions from excavation or other handling of contaminated soil nor does it include fugitive emissions from the desorber system or from liquid and solid phase waste streams. Combustion gases from the heating system and exhaust gases from afterburners produce additional emissions not taken into account by this estimation method.

$$ER_i = (C_i/1000)(F)(V_i/100)(1 - CE_i/100)$$

where:

ER_i = emission rate for contaminant i (g/hr);

C_i = concentration of species i in contaminated soil (mg/kg);

1000 = conversion factor (mg/g);

F = mass rate of soil treated (kg/hr);

V_i = percentage of contaminant i volatilized; and

CE_i = percent efficiency of control devices.

Default values have been published by the U.S. EPA (Eklund, et al., 1993). The default value for the mass feed rate is 27,200 kg/hr, with a range of 2,700 to 90,800 kg/hr. The default value for the percent volatilized is

dependent on the desorber temperature. For 200 to 600 °F, the values are:

VOCs/BTEX	99.00%
SVOCs/PNA ^a s	90.00%
THC	95.00%
PCBs	50.00%

^a PNA = Polynuclear Aromatic

For desorber temperatures of 600 to 1,000 °F, the values are:

VOCs/BTEX	99.99%
SVOCs/PNAs	99.00%
THC	99.90%
PCBs	99.00%

4.9 Case Studies on Remediation and Air Emissions

Thermal desorption has been used at a number of sites in recent years. However, little performance data from these full-scale operations have been published. Results from five EPA-sponsored projects are presented in this section. These results include thermal desorption effectiveness and air emissions for soil contaminants, VOCs, SVOCs, dioxins, and furans.

4.9.1 Use of LT³ on Pesticides

The Low Temperature Thermal Aeration (LT³) system of Canonic Environmental Services Corporation was used at an abandoned pesticides mixing facility in Arizona. The waste consisted of soil contaminated with toxaphene, DDT, DDD, DDE, and others at a total concentration of 5 to 120 mg/kg. Contaminated soil was heated counter

currently to 730°F in a rotating cylinder, with heat provided by propane or fuel oil. Residence time was 9-12 minutes and the process throughput was 34 tons/hour. The emission controls included cyclones, baghouse, venturi scrubber, and carbon adsorbers. The scrubber liquid blowdown was treated by carbon adsorbers and reused as a wetting agent for the treated soil.

Performance is summarized in Table 4-7 (Peck, 1995). Process streams were sampled for VOCs and SVOCs. Although specific results were not available, stack emissions included acetonitrile, acrylonitrile, chloromethane, benzene, and toluene. The study concluded that these compounds were formed within the process, but dioxins and furans were not formed.

4.9.2 Use of LT³® to Treat Lagoon Sludge Contaminated with VOCs and SVOCs

The Low Temperature Thermal Treatment (LT³) process of Roy F. Weston, Inc. was used to treat a sludge primarily contaminated with 4,4'-methylenebis (2-chloroaniline) (MBOCA) in Michigan. The MBOCA concentration in the sludge ranged from 43.6 to 860 mg/kg. The process equipment consisted of two troughs, each with two hollow-screw conveyors. Hot oil flowed through the screws, heating the sludge to 500-530°F. Residence time was 90 minutes and process capacity was 2.1 tons/hour. The emission controls included a baghouse, air-cooled condenser, refrigerated condenser, and carbon adsorber. Condensed liquids were routed to an oil-water separator, a paper filter, carbon adsorber, and sent to off-site disposal. Process performance is summarized in Table 4-8.

Table 4-7
Results for Use of LT^{TA} System on Pesticide-Contaminated Soil

Parameter	Untreated Soil (ppb)	Treated Soil (ppb)	Off-gas to GAC (ppb)	Stack Gas (ng/dscm)
Toxaphene	18,300	<20	<50	<98.6
DDT	18,700	<1.06	<2.0	8.2
DDD	220	<0.39	<1.0	<1.97
DDE	6,980	677	79	1,980
Total PCDD	ND	ND	ND	0.057
Total PCDF	0.1	ND	ND	0.017

Table 4-8
Results for Use of LT³ System on Lagoon Sludge

Parameter	Untreated Soil	Treated Soil	Off-gas to Adsorber	Stack Gas
MBOCA	43.6-860 mg/kg	3-9.6 mg/kg	NA	ND
VOCs:				
Toluene	1-25 mg/kg	<30 µg/kg	8-10 ppmv	"effectively removed"
PCE	690-1900 mg/kg	<30 µg/kg	210-220 ppbv	"effectively removed"
SVOCs:				
3- and 4-methylphenol	3100-20,000 µg/kg	540-4000 µg/kg	ND	ND
bis(2-ethyl hexyl)phthalate	1100-7900 µg/kg	<820 µg/kg	<28 ppbv	ND
TNMHC	--	--	--	6.7-11 ppmv
Total PCDD	0.21 ng/kg	1.52 ng/kg	0.483 µg/dscm	0.0606 µg/dscm
Total PCDF	ND	2.49 ng/kg	0.33 µg/dscm	0.0699 µg/dscm

4.9.3 Use of X*TRAX to Treat PCB Contaminated Soil

The RUST Remedial Services, Inc. X*TRAX Model 200 Thermal Desorption System was used to remove PCBs and other organic contaminants from soil at a site in Massachusetts. The soil was treated in a rotating cylinder which was heated by hot flue gases flowing in an annular region outside the treatment cylinder. The soil was heated in five zones, to an average temperature of 850-928°F. Residence time was about 2 hours and the equipment capacity was 4.9 tons/hour. A nitrogen carrier gas and the off-gases were treated by a concurrent spray scrubber, air-cooled condenser, refrigerated condenser (40°F), and mist eliminator. Most gas was then returned to the process heater, but 5-10% was vented after passing through a 10 µm filter, a high efficiency particulate air (HEPA) filter, and carbon adsorbers. Condensates were separated into water, organic, and sludge streams, with the sludge then mixed with the contaminated soil feed. Separated water was used for scrubber makeup and for wetting the treated soil. The organic stream was sent to off-site treatment. System performance is summarized in Table 4-9.

4.9.4 Use of ATP to Treat PCB Contaminated Soil

The SoilTech ATP Systems, Inc. Anaerobic Thermal Processor was used to remove PCBs and other organic contaminants from soil at two sites, one in New York and one in Illinois. The process was essentially the same at both sites. In a four-step process, the soil is heated to 500°F, 1100°F, 1300°F, and then cooled to 600°F, with a total treatment time of about 30-40 minutes. The soil is indirectly heated

in an anaerobic environment.

Dehalogenation reagents (sodium hydroxide and polyethylene glycol) are added to the contaminated soil prior to its entering the ATP. The process capacity was 10 tons/hour. Off-gases were treated by a cyclone, scrubber, condenser, and a three-phase separator, which produced gas, water, and organic streams. The treated gas was returned to the combustion zone of the ATP. Organics were mixed with inlet soil and water was treated on-site. Performance for the two sites is summarized in Table 4-10. Some SVOCs were present in the soil in low concentrations. However, the SVOCs were either not detectable or were below the practical quantitation limit in both the treated solids and the stack gas. Likewise, some VOCs were also present in low concentrations in the contaminated soil and most were below detection limits in the treated soil samples. Stack gas samples were not analyzed for VOCs.

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Table 4-9
Results for Use of X*TRAX System to Treat PCB-Contaminated Soil

Parameter	Untreated Soil	Treated Soil	Stack Gas
Total PCBs	318 mg/kg	0.863 mg/kg	ND
VOCs:			
Chloromethane	--	--	369.9 µg/m ³
Methyl chloride	--	--	17.6 µg/m ³
Toluene	--	--	3.2 µg/m ³
Total VOCs	--	--	396.6 µg/m ³
SVOCs:			
Hexanedionic acid ester	--	--	70.7 µg/m ³
9-Octadecen-1-ol	--	--	33.7 µg/m ³
Total SVOCs	--	--	188.2 µg/m ³
Total PCDD	310 ng/kg	74.1 ng/kg	0.0304 ng/m ³
Total PCDF	597 ng/kg	93.7 ng/kg	0.0158 ng/m ³
Total 2,3,7,8-TCDD TEQ ^a	28.8 ng/kg	3.47 ng/kg	0.000323 ng/m ³

^a TCDD = Tetrachlorodibenzodioxin
TEQ = Toxic Equivalent

Table 4-10
Results For Use of ATP Process to Treat PCB-Contaminated Soil

PCB Contaminated Soil Treatment in New York

Parameter	Untreated Soil	Treated Soil	Stack Gas
Total PCBs	28.2 mg/kg	0.043 mg/kg	23.1 µg/dscm
Total PCDD	3.2 µg/kg	ND	3.86 ng/dscm
Total PCDF	0.16 µg/kg	ND	5.66 ng/dscm
Total 2,3,7,8-TCDD TEQ	--	--	0.707 ng/dscm

PCB Contaminated Soil Treatment in Illinois

Parameter	Untreated Soil	Treated Soil	Stack Gas
Total PCBs	9761 mg/kg	2 mg/kg	0.837 µg/dscm
Total PCDD	ND	ND	ND
Total PCDF	104 µg/kg	6.05 µg/kg	0.0787 ng/dscm
Total 2,3,7,8-TCDD TEQ	--	--	0

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