한국지하수토양환경학회 추계학술발표회
2002년 9월 13일~14일 부 산 대 학 교

Low Temperature Thermal Desorption (LTTD) Treatment of Contaminated Soil

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Abstract

Low temperature thermal desorption (LTTD) has become one of the cornerstone technologies used for the treatment of contaminated soils and sediments in the United States. LTTD technology was first used in the mid-1980s for soil treatment on sites managed under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or Superfund. Implementation was facilitated by CERCLA regulations that require only that applicable regulations shall be met thus avoiding the need for protracted and expensive permit applications for thermal treatment equipment. The initial equipment designs used typically came from technology transfer sources. Asphalt manufacturing plants were converted to direct-fired LTTD systems, and conventional calciners were adapted for use as indirect-fired LTTD systems. Other innovative designs included hot sand recycle technology (initially developed for synfuels production from tar sand and oil shale), recycle sweep gas, travelling belts and batch-charged vacuum chambers, among others. These systems were used to treat soil contaminated with total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs) and dioxin with varying degrees of success. Ultimately, performance and cost considerations established the suite of systems that are used for LTTD soil treatment applications today.

This paper briefly reviews the development of LTTD systems and summarizes the design, performance and cost characteristics of the equipment in use today. Designs reviewed include continuous feed direct-fired and indirect-fired equipment, batch feed systems and in-situ equipment. Performance is compared in terms of before-and-after contaminant levels in the soil and permissible emissions levels in the stack gas vented to the atmosphere. The review of air emissions standards includes a review of regulations in the U.S. and the European Union (EU). Key cost centers for the mobilization and operation of LTTD equipment are identified and compared for the different types of LTTD systems in use today. A work chart is provided for the selection of the optimum LTTD system for site-specific applications. LTTD technology continues to be a cornerstone technology for soil treatment in the U.S. and elsewhere. Examples of leading-edge LTTD technologies developed in the U.S. that are now being delivered locally in global projects are described.

Key words: Low temperature thermal desorption, LLTD, TPH, PAHs, PCBs, dioxin

Introduction

Low temperature thermal desorption (LTTD) systems have been used to treat contaminated soil in the United States since 1985. One of the first applications was the low temperature thermal aeration (LTTA) system operated by Canonie Environmental at the McKin Superfund site in Gray, Maine. The project involved removal of about 8,500 cubic meters (m^3) of soil contaminated with volatile organic carbon (VOC); specifically BTEX, 1,2-dichlorobenzene, 1,2-DCE and other chlorinated solvents, and petroleum hydrocarbons.

The base unit used for the treatment was a rented asphalt plant. The excavated soil was heated to around 315 ℃ in a direct-fired rotating kiln to vaporize the contaminants into the flue gas stream where they were removed by adsorption onto granular activated carbon. The soil was treated to less than 20 ppb residual contamination, then backfilled into the excavation.

The success achieved using asphalt plant equipment to treat soil lead to a virtual explosion of LTTD technologies and service contractors in the environmental remediation marketplace in the U.S. Innovative designs included a hot sand recycle technology initially developed for synfuels production(1, 2), a recycle sweep gas process, travelling belts (3), indirectly heated screws (4, 5), calciners (6), direct-fired plants (7) and batch charged vacuum chambers, among others (8). These systems were used to treat soil contaminated with total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs) and dioxin with varying degrees of success. Ultimately, performance and cost considerations established the suite of systems that are used for LTTD soil treatment applications today.

Over the years, three basic system designs were developed and implemented for the treatment of excavated soil:

- □ Continuous feed, direct-fired units for TPH and low to medium boiling contaminants
- □ Continuous feed, indirect fired units for high concentration TPH contaminants or contaminants that could form products of incomplete combustion (PICs), specifically dioxins and furans, and
- □ Batch feed units operating under partial or high vacuum for modularized operations on small quantities of soil.

Virtually all LTTD treatment of soils in the U.S. has been performed using one of these three methods.

Key LTTD Design Features

The key design features that affect all the performance and cost of all LTTD systems are:

- □ Equipment transportability (mobilization and demobilization)
- □ The method of heat transfer (conduction, convection or radiation) and soil temperature achieved
- □ The number and skill level of people needed to operate the plants, and
- □ The method of handling volatilized contaminants (adsorption, condensation or thermal oxidation)

Virtually all LTTD designs establish some compromise among these basic features to fit particular performance and/or regulatory requirements for soil treatment.

Equipment Transportability - Equipment transportability becomes a major issue when the amount of soil to be treated at a site is small, say less than 15,000 tons. In this case, smaller (or modular) equipment that is easily set-up and removed may have a significant cost advantage over larger equipment that is more costly to move and install.

Heat Transfer Considerations - The method of heat transfer determines the rate at which the soil can be heated to the temperature needed to remove the volatile components. More efficient heat transfer means less energy consumption per ton of soil treated and higher soil treatment rates resulting in lower unit treatment cost. The most efficient heat transfer (convection and radiation) is direct contact by cascading soil through an open burner flame. The least efficient is downward heat transfer through a fixed soil bed by conduction. Virtually all LTTD units use heat transfer designs within these boundaries.

Number and Skill Level of Operators - The complexity of the equipment determines the number and skill level of operators needed to treat the soil. The labor factor can be significant in determining treatment cost since most LTTD systems operate on a 24-hour per day, 7-day per week basis.

Method of Handling Vaporized Contaminants - The method of handling vaporized contaminants depends to a great extent on the type of contaminant, its concentration in the feed soil and regulatory requirements. Typical handling methods for different contaminants are summarized in Table 1.

Table 1: Comparative Methods for managing volatilized contaminants.

Soil Contaminant	Typical Disposal Method
VOCs	Condensation or vapor phase GAC adsorption
Total Petroleum Hydrocarbons	Incineration in a secondary treatment unit (thermal oxidizer) or condensation for recycle if the concentrations in the feed soil and sediment are more than 10 percent by weight
PAHs	Thermal oxidation
Pesticides	Thermal oxidation or condensation depending on regulations
PCBs and dioxins	Condensation and on-site or off-site destruction. On-site destruction is usually by reductive dechlorination
Mercury	Condensation and recycle

The simplest method of handling volatilized contaminants (except mercury) is on-site destruction by thermal oxidation. This disposal method is almost always preferred except where there is an economic incentive to condense and collect a recycleable product, or thermal oxidation is prohibited by regulation.

Thermal oxidation of the flue gas stream frequently is regarded as incineration. Its use when treating soil contaminated with chlorinated hydrocarbons may incur significant public and regulatory resistance. In such cases condensation and on-site or off-site disposal is usually the selected remedy.

Examples of Commercial LTTD Systems

The general features of LTTD systems that have been used for commercial treatment of contaminated soil are summarized in Table 2. As shown in Table 2, direct-fired systems typically are the lowest cost systems to operate because of the high throughput rates achieved by direct heat transfer and the simplicity of the thermal oxidation system for contaminant destruction. Most TPH and PAH soils in the U.S. are treated using this method.

Indirect-fired and batch systems typically are used to treat chlorinated organic contaminants or soils with high concentrations of TPH that would exceed the explosion limit in the primary treatment unit (PTU) of a direct-fired system.

Table 2. Typical Features of Different LTTD Designs

Feature	Direct-Fired	Indirect-Fired	Batch Feed
Treatment Rate, ton/hr	10 to 100	3 to 30	10 to 15 for 8 modules
Contaminants Treated	TPH, PAH	TPH, PCB, Pesticide, Dioxin	TPH, PCB, Pesticide, Dioxin, Mercury
Soil Temperature, ℃	350 to 550	350 to 550	Up to 800
Flue Gas Rate, m^3/mn	420 to 1,450	75 to 150	<100
Contaminant Destruction Method	Incineration	Condensation and Disposal	Condensation and Disposal
Typical Labor per shift	2 to 3	3 to 4	4 to 5
Typical Costs, $US	50,000 to 500,000	150,000 to 750,000	50,000 to 100,000
Treatment Price, $/ton	25 to 50	100 to 200	50 to 100
Fuel, MJ per ton	5,000	2,000	1,200
Electricity, KVA	450	300	450

How Direct-fired LTTD Units Work

Indirect-fired LTTD units typically employ concentric rotating kilns (calciner) where the heat is applied by burners in the annulus between the two kilns and transferred to the inner soil charge by conduction.

The process involves heating contaminated soil to between 315 ℃ and 500 ℃ in an unlined rotating kiln primary treatment unit (PTU). The flue gas containing the partially burned hydrocarbons is passed through a hot cyclone that collects coarse dust particles greater than 80 microns. The flue gases exiting the cyclone are burned in a secondary treatment unit (STU) at between 1,000 ℃ and 1,100 ℃ with a minimum residence time of 0.5 seconds to destroy the hydrocarbons. The hot gases are quenched to about 225 ℃ before removing the fine dust in a baghouse and releasing the gases to the atmosphere through a stack. Quenching is necessary to avoid burning the filter bags in the baghouse

The treated soil is discharged to a pug mill where it is mixed with dust collected from the hot cyclone and baghouse. Water is added to re-moisturize the soil and prevent fugitive dust emissions. The product soil is stockpiled for sampling and disposal.

Design Variations

Common design variations used by thermal treatment vendors include:

- □ Concurrent flow (burner and feed at the same end of the PTU) versus countercurrent flow (burner and feed at opposite ends of the PTU) to treat soil with high moisture and a high percentage of fines
- □ High temperature steel construction in the PTU to achieve higher exit soil temperatures. High temperatures are needed for high boiling point contaminants such pesticides, polychlorinated biphenyl (PCB), etc.
- □ Vertical as opposed to horizontal STU to reduce dust settling and slagging and improve dust removal efficiency. Dust settling problems and the need for frequent cleanouts can significantly reduce equipment on-stream time and throughput rates.
- □ STU located at the end of the gas train to improve dust removal before burning volatilized hydrocarbons.
- □ Improved PTU seals to permit safe treatment at total hydrocarbon levels above

about 1.5 percent by weight in the soil, and

- Heated screw as opposed to a rotating kiln PTU

As indicated in Table 2, direct-fired systems are preferred from a cost standpoint when treating large quantities of low-level contaminated soil.

How do Indirect-fired LTTD Units Work?

Indirect-fired LTTD units typically employ concentric rotating kilns (calciner) where the heat is applied by burners in the annulus between the two kilns and transferred to the inner soil charge by conduction.

The organic is desorbed from the soil and passed into a venturi scrubber where it is quenched by direct contact with recycled cooling water. The treated soil is discharged into a pug mill and moisturized to reduce fugitive dust as before.

The mixed condensate and quench water is discharged from the venturi scrubber to a settling vessel to separate organic, dust and water. The cooled gas is passed through a de-mister or coalescing filter then pumped through a non-contact secondary condenser that is cooled by water circulating through a water chiller. This step is designed to remove high vapor pressure, low boiling contaminants from the gas stream. In some cases (depending on the contaminant) the cleaned gas can be circulated to the burners. In others, the gas is further treated with vapor phase granular activated carbon before being discharged to atmosphere.

Settled condensed contaminant and sediment is pumped from the settling vessel for further treatment or disposal. Floating oil is skimmed off for recovery. The separated water is cooled in a heat exchanger by no-contact water circulating from cooling towers. The cooled water is re-circulated to the venturi scrubber for quench.

In many cases a more sophisticated water treatment process is required to prevent contaminant build up in the circulating water. Depending on the application, these water treatment processes may use the following treatment equipment:

- Chemical oxidation in stirred vessels to destroy dissolved organic
- UV oxidation
- Dissolved air flotation to improve phase separation
- Acid and caustic addition for chemical reaction and pH adjustment
- Flocculation and polymer addition to improve phase separation
- Staged filtration using bag and cartridge filters
- Polishing with liquid phase granular activated carbon
- Pressure filtration to de-water sludge

In cases involving soils with high fines content or soluble organic, water treatment can become a significant component of the overall process.

Design Variations

Indirect-fired systems are inherently limited by the slow rate of heat transfer by conduction. Design variations used by different vendors of this technology include:

- High temperature steel construction in the PTU to achieve higher soil treatment temperatures
- Hot sand recycle to improve heat transfer efficiency
- Steam stripping to achieve lower contaminant concentrations in the treated soil
- Coupled indirect hot screw drier to remove moisture and reduce heat load in the

calciner (also eliminates the benefits of steam stripping, however)

- Purge inert gas or recycle gas to enhance removal of volatilized contaminants from the soil
- Treatment of the purge gas with a baghouse and thermal oxidizer combination to destroy rather condense the contaminants
- On-site destruction of chlorinated organic contaminant by reductive dechlorination performed in the PTU or in a separate treatment plant.

Some of these innovations can achieve lower levels of residual contaminants in the soil or achieve modest improvements in treatment rates. Indirect-fired systems are typically, but not always, required by the EPA in the U.S. for treating soil contaminated with PCBs or dioxins.

How do Batch Feed LTTD Systems Work?

Batch-feed systems are typically used to treat soil under moderate negative pressure or vacuum. The systems vary from small capacity with short heating cycles (7 tons, 4 hours) to very large capacity with long heating cycles (750 tons, 4 days). The direct-fired systems heat the soil by passing flue gas from a burner through it at around 7% oxygen. The indirect-fired systems heat the soil with radiant heat under partial vacuum at less than 5% oxygen equivalent and distribute heat by convection and conduction using a gas recycle. The smaller systems are frequently coupled in modules for increased throughput.

In the indirect mode, the soil is placed in trays in the desorber and heated by radiant heat transfer. The system is operated under vacuum to reduce both the oxygen partial pressure and the boiling point of the contaminants. The purge gas sweeps the volatilized contaminants from the desorber through a particulate filter and condensation system where the small amount of particulate that is mobilized is filtered out and the organic contaminants are condensed and removed. The heating cycle produces a chromatic separation of low boiling and high boiling contaminants so that a crude initial separation of contaminants can be made.

When the soil reaches the design treatment temperature, the gas is shut off; the treated soil is allowed to cool, then moisturized by probing, or by mixing with water in a pug mill. The gas exiting the condensation system is cleaned of any remaining condensate by treatment in a coalescing filter then polished using vapor phase GAC before being emitted to the atmosphere.

Water and organic condensate are separated by gravity. Typically, the separation is very clean because of the absence of particulate in the condensate. The water is treated using liquid phase GAC. Chlorinated compounds in the organic fraction are separated from the petroleum hydrocarbons by distillation or destroyed by reductive dechlorination. The clean oil is recycled or used on-site as a fuel supplement.

Design Variations

Different vendors have used the batch system to treat a variety of soil types and contaminants including TPH, PCBs, dioxins and mercury. The principal design variations are:

- Reducing labor cost by treating very large batches of TPH contaminated soil (750 tons over several days) by permeating hot flue gas through the soil.
- Reducing mobilization cost by treating small quantities of soil with one or two easily mobilized modules
- Incorporating feed preparation (pelletizing) of high clay soils to ensure adequate and even heat distribution through the soil bed.

- Operating under vacuum to reduce the soil temperature needed to remove volatile contaminants, and
- Substantially reducing energy requirements by avoiding heating large quantities of air.

In general, the large systems are best for treating TPH soil. The small, modular systems are best for treating soil with specialized contaminants such as PCBs, dioxins and mercury.

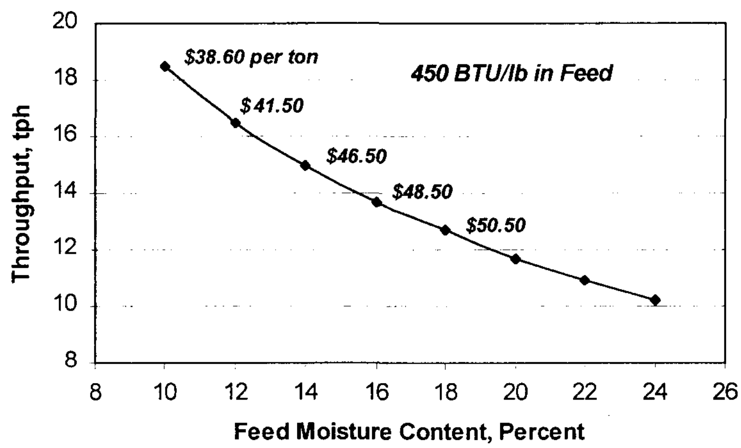
Performance

LTTD performance is measured by the ability to treat soil at a specific throughput rate while removing contaminants to target treatment levels and maintaining acceptable air emissions as specified by the applicable regulations.

Treatment Throughput Rate

The optimum treatment rate depends on the amount of feed preparation performed independent of the type of LTTD unit chosen. The principle factors affecting treatment rate are moisture level, calorific value and the amount of fines in the feed soil. The impact of moisture level in the feed on throughput rate and treatment cost is illustrated in Figure 1.

Figure 4: Effect of Moisture on Throughput Rate



In this example, reducing the feed moisture content from about 18% to 10% increased the throughput rate in a small direct-fired LTTD from about 12.5 ton per hour (tph) to 18.5 tph and achieved a reduction in treatment cost of about $12.00 per ton. Blending and air drying the feed before thermal treatment cost between $2.00 and $4.00 per ton giving a net savings of about $9.00 per ton in treatment cost.

Soil Treatment Results

Typical soil treatment results achieved by different types of LTTD units in commercial operations are summarized in Table 3. The data shows that LTTD processing is capable of achieving very low levels of contaminants in the treated soil provided the correct equipment is selected for the job.

Table 3: Typical Soil Cleanup Data for different types of LTTD Systems.

	Continuous, Direct-fired	Continuous, Indirect-fired	Batch, Direct-fired
Site Name	GCL Superfund Site	BP, Colombia	FCX Superfund Site
Soil Quantity, tons	100,000	40,000	
Treatment Rate, tons per day	200 to 500	100	50 to 100
Contaminant	Creosote, PAH	Petroleum Hydrocarbons	Pesticides and Dioxin
Level in Untreated Soil	Benzo(a)anthracene - 51.4	TPH - 11 percent	DDT - 11 to 200
	Benzo(b)fluoranthene - 36.2		DDD - 20 to 50
	Benzo(k)fluoranthene -29.5		DDE - 20 to 200
	Benzo(a)pyrene - 26.3		Dioxin - 80 ug/kg
	Benzo(a)anthracene - 0.60(8.0)	TPH - 100(300)	DDT - <0.1
	Benzo(b)fluoranthene - 0.62(8.0)		DDD - <0.1
	Benzo(k)fluoranthene -0.56(8.0)		DDE - <0.1(1.0 Total)
	Benzo(a)pyrene - 0.41(1.0)		Dioxin - <0.1(1.0)[1].

Concentrations in mg/kg except where noted. Target cleanup levels in parenthesis. [1]. ug/kg

Air Emissions Results

Typical stack gas emissions for different types of LTTD units are compared with typical U.S. and E.U. emissions standards in Table 4.

Reliable comparisons of stack gas emissions data are difficult to obtain because the reporting units and standards vary from region to region and site to site. The data indicates, however, that LTTD units generally are capable of meeting common air emissions standards for criteria pollutants (NOx, SOx, CO), particulate, hydrocarbons and chlorinated species. Specific items to note in Table 4 are:

- Batch units typically have less particulate emissions than continuous-feed rotating kiln units because the feed is not cascaded through the gas stream.
- Direct-fired units may have higher PCDD/PCDF emissions when treating soil with chlorinated hydrocarbons than indirect or batch fired systems because of the higher flue gas flow rate.

In general air emissions rates can be reduced for most LTTD systems by adding equipment to clean the gas.

Destruction Removal Efficiency - The USEPA defines Destruction Removal Efficiency (DRE) as the mass of contaminant in the air emission compared to the mass in the feed. Typically a DRE of 99.99% (four nines) are required when treating PAHs and pesticide contaminants. That is, the mass air emissions are no greater than 0.1 grams per kilogram of contaminant in the feed. The requirement for treating PCBs and dioxins in soil is six nines (the mass air emissions are no greater than 0.001 grams per kilogram of contaminant in the feed).

Table 4: Comparison of LTTD stack gas emissions with U.S. and E.U. Regulatory Standards.

Component	Typical US Emissions Standards	Typical EU Emission Standards	Example Direct-Fired Unit Emissions	Example Indirect-Fired Unit Emissions	Example Batch Unit Emissions[2.]
SOx (mg/m^3)	200 to 600	50	1.1	1.4	No Data
NOx (mg/m^3)	500	500	133 to 164	145	No Data
CO (mg/m^3)	100	100	2.7[1.]	36	20
PM (mg/m^3)	20 to 120	30	20 to 270	75	0.172
Total PCDD/PCDF, (ng/dscm)	30	0.1	10.95[1.]	0.08 to 0.14	0.04 to 0.16
Total Hydrocarbons, (mg/m^3)	32	10[2]	21	28	No data
HCl Gas (mg/m^3)	4.0	10	No Data	0.02 to 2.0	2.03

[1.]Direct-fired unit treating PCB soil @ 900 mg/kg, [2.]Organic compounds expressed as total carbon, [3.]Batch unit treating pesticide soils.

Frequently the six nines performance requirement can be demonstrated only by spiking the soil with enough contaminant to detect a concentration in the stack gas. In these cases the DRE requirements is sometimes replaced by a specific concentration criterion, usually 0.1 to 0.2 nanograms per dry standard cubic meter (ng/dscm) for dioxin corrected to 7% oxygen.

Conclusions

LTTD technology has been used successfully over a 15-year period to treat contaminated soil. Changes in the technology design over the years have improved treatment efficiency and reduced costs to the extent that the technology should be considered to be a reliable treatment method for soil remediation projects.

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