Desorption and Incineration

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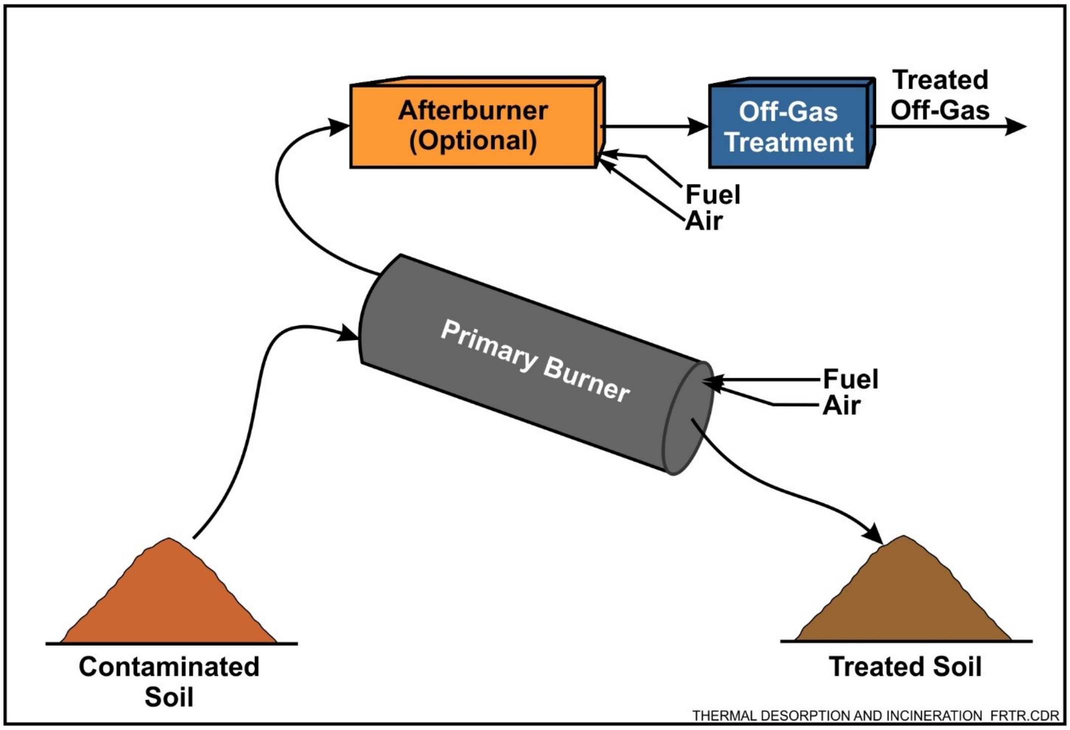
Schematic



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Thermal Desorption and Incineration

Introduction

Ex situ thermal treatment, including thermal desorption and incineration, relies on heat to remove contaminants of concern (COCs) from contaminated media, such as soil and sediment

[1]. Thermal desorption is a physical process designed to remove contaminants at relatively low temperatures, ranging from 90 to 560°C, from the solid matrix. The contaminated media is heated to volatilize water and organic contaminants, followed by treatment in a gas treatment system. Incineration operates at much higher temperatures, ranging from 870 to 1,200°C. Incineration systems are designed to volatilize and combust (in the presence of oxygen) halogenated and other recalcitrant organic compounds in soil and sediment that are difficult to remove at lower temperatures.

Other Technology Names

Low Temperature Thermal Desorption (LTTD)
High Temperature Thermal Desorption (HTTD)
Thermal Oxidation

Description

Thermal desorption and incineration rely on the generation of heat to remove COCs either through volatilization or oxidation. Soil or sediment is excavated and transported to the treatment facility, which can be a mobile treatment system operated on site or can be off site at a stationary commercial disposal facility. These ex situ thermal treatment methods are similar to in situ thermal treatment methods in that a target design temperature must be achieved and maintained for a specific period of time (residence time). However, ex situ treatment offers several advantages compared to in situ treatment, including shorter treatment duration2 and efficient mixing, and therefore, more uniform removal of COCs. The primary disadvantages include the time and cost required to excavate and store/handle soil prior to treatment, and the larger space needed to stockpile the material until treatment is performed and/or the additional cost to transport the material to an off-site treatment facility.

Thermal desorption and incineration systems are similar in design, usually consisting of a hopper, a screen to remove debris and large rocks, feed conveyers, the combustion chamber, and a vapor treatment system. Both can be designed and constructed to be continuous feed or batch feed. The primary difference is that thermal desorption systems operate at a lower design temperature, which is sufficiently high to achieve adequate volatilization of COCs, whereas incineration systems must attain a greater temperature needed to chemically oxidize or decompose the COCs. In both, heat is generated either from fuel combustion, usually natural gas or propane, or electrical input into a burner. Systems can be designed for direct contact of the contaminated media with the flame or indirect contact, in which the media is rotated slowly through a heated kiln to separate the COCs from the media (soil, sediment, gravel). Additional information pertaining to each of these ex situ thermal treatment technologies is provided below.

Thermal Desorption

Thermal desorption is a physical separation process and is not designed to destroy organics. Wastes are heated to volatilize the contaminants, which are transported using a carrier gas or vacuum to a vapor treatment system for removal/transformation into less toxic compounds. The bed temperatures and residence times are designed to volatilize selected contaminants but typically will not oxidize them.

Historically, thermal desorption processes have been categorized into two groups, including HTTD and LTTD, based on the operating temperature of the desorber:

- **HTTD** heats the soil to 320 to 560°C. The higher temperatures serve to remove less volatile compounds that have a greater affinity for soil/sediment and/or lower vapor pressures such as creosote, coal tar and polychlorinated biphenyls (PCBs).
- **LTTD** heats the soil to between 90 and 320°C. LTTD can remediate petroleum hydrocarbons and volatile organic compounds (VOCs) in all types of soil.

However, in practice, there are inconsistencies in how vendors refer to their equipment. Therefore, it is important to understand the temperature that can be achieved by a desorption unit, and obtain confirmation from the vendor that it can treat the COCs present in a particular waste material.

Continuous applications consist of two principal designs, including a rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. The dryer is normally inclined and rotated. Thermal screw units utilize screw conveyors or hollow augers to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. Both types of designs ensure adequate mixing of the treatment media with the carrier gas.

Incineration

Incineration operates at temperatures sufficiently high to generate the necessary cracking and oxidation reactions to convert COCs to non-toxic combustion end products. Incinerators are typically operated between 760 and 1,650 °C to ensure removal of COCs. In addition to the temperature applied, the residence time and adequate mixing of the media are important to adequately remove COCs and ensure efficient operation of the incinerator. For complete thermal destruction to take place, the residence time is typically 30 to 90 minutes for solid waste and 0.5 to 2.0 seconds for liquid waste (USEPA, 1998).

In addition to a fuel source, oxygen is required to maintain the flame. Either pure oxygen or ambient air is supplied for the oxygen source. Pure oxygen is used to create greater levels of heat when high temperatures are required. The organic compounds are converted into carbon dioxide and water vapor end products as a result of complete combustion. Other vapor phase emission byproducts of incineration can include: particulate matter; nitrite oxides, nitrates, and ammonia (for nitrogen-containing wastes); sulfur oxides and sulfate (for sulfur-containing wastes); and halogen acids (for halogenated wastes and per- and polyfluoroalkyl substances [PFAS]). The generation of acid gases from oxidation of halogenated waste could create a corrosion issue depending on the concentration of halogenated compounds.

Incinerators typically consist of a primary combustion chamber (i.e., primary burner or kiln) into which the contaminated media is fed. In this unit, the organic contaminants are volatilized and destroyed. The residual material (such as soil and sediment in the kiln) may be cooled for disposal or may require treatment (e.g., solidification/stabilization to reduce metal leachability) prior to disposal. The off gas from the kiln is collected in a secondary combustion chamber or afterburner, where organics and other byproducts of incomplete combustion are further destroyed. Off gas is collected from the afterburner, cooled, and may be further treated prior to discharge. The treatment varies depending on the type of COCs present and characteristics of the material initially treated.

Vapor Treatment and Air Pollution Control

Thermal desorption and incineration systems generally require treatment of the off gas to remove COCs, particulates and/or other byproducts. Specific requirements are dictated by the type of thermal treatment process used, the types of COCs present, destruction efficiency (in the case of incineration), the types of byproducts that are formed, and the location of the site (i.e., rural versus urban). Off-gas emissions from thermal desorption typically consist of the target VOCs or semi-volatile organic compounds (SVOCs) being treated. Treatment of vapors generated by incineration can require more complex treatment than vapors generated by thermal desorption due to the presence of acid gases such as hydrochloric acid (HCl) and other off-gas byproducts generated by the combustion process such as nitrogen dioxide and oxides of nitrogen (collectively referred to as NOx) and sulfur oxides (referred to as SOX). A description of various vapor treatment processes is found here.

Development Status and Availability

The following checklist provides a summary of the development and implementation status of thermal desorption and incineration:

- ☐ At the laboratory/bench scale and shows promise

☐ In pilot studies

☒ At full scale

☐ To remediate an entire site (source and plume)

☒ To remediate a source only

☐ As part of a technology train

☒ As the final remedy at multiple sites

☒ To successfully attain cleanup goals in multiple sites

Techniques to distribute liquid amendments in an aquifer are available through the following vendors:

☒ Commercially available nationwide

☐ Commercially available through limited vendors because of licensing or specialized equipment

☐ Research organizations and academia

Applicability

Contaminant Class Applicability Rating for Thermal Desorption and Incineration Technologies

(Rating codes: ● Demonstrated Effectiveness, ◐ Limited Effectiveness, ○ No Demonstrated Effectiveness,

◊ Level of Effectiveness dependent upon specific contaminant and its application/design, I/D Insufficient Data)

nhalogenated VOC	**ogenated VOC**	**nhalogenated SVOC**	**ogenated SVOC**	**ls**	**rganics**	**adionuclides**	**nitions**	**erging Contaminants**

Non	Hal	Non	Hal	Fue	Inor	Ra	Mur	Eme
●	●	●	●	●	○	◐	●	I/D

Thermal treatment technologies are applicable at sites where high COC soil concentrations or direct waste burial is present, and a short timeframe is necessary to allow for continued use or redevelopment of the site. On-site treatment also allows for reuse of the treated soils to reduce restoration costs and limit potential future liability associated with off-site disposal. Thermal desorption is used to treat soils containing VOCs and SVOCs that can be desorbed and volatilized including, but not limited to, high concentrations of halogenated and nonhalogenated VOCs, gasoline-range fuels, and light/dense non-aqueous phase liquids, making it well-suited to treat material excavated from refineries, coal tar sites, wood-treating and creosote sites among others. HTTD systems can effectively treat SVOCs, polycyclic aromatic hydrocarbons, PCBs, and some pesticides. Early bench studies and small-scale field applications also show potential viability for treating PFAS. Conversely, LTTD is well-suited to treat nonhalogenated VOCs and fuels, but can be used to treat SVOCs at reduced effectiveness. Metals are not typically treated using thermal desorption and incineration technologies.

Incineration can be used to effectively treat non-volatile and recalcitrant contaminants such as PCBs, dioxins, volatile metals, and ordnance compounds. Incineration is also a viable option for pure liquids and sludges or other non-soil waste streams not amenable to LTTD or HTTD. It can be used to treat compounds that are treated by thermal desorption, but is generally not designed for this purpose unless these contaminants are part of a mixed waste stream (due to the greater operating costs of incineration systems).

Inorganics (other than volatile metals) and radionuclides are not effectively removed using these technologies.

Cost

Similar to many in situ remediation technologies, the most critical cost factors are associated with the contaminant mass to be treated, the nature and extent of contamination (i.e., size of the treatment area), and number of electrodes/wells required. In addition, the contaminant type and treatment objectives (e.g., containment, source treatment) can have an impact on cost. Major cost drivers include:

On-Site Treatment Costs

- Volume of contaminated media requiring treatment. A greater volume of contaminated material necessitates larger treatment systems or more treatment units. Although the total cost of a project increases as the volume of the contaminated media increases, the cost per unit volume of media generally decreases.
- Material handling and excavation dewatering/slope stabilization requirements, particularly for a larger quantity of rocks or debris, high percentage of fines, or high moisture content.
- Equipment type and complexity.
- Vapor treatment requirements, which are impacted by the types of contaminants treated, their concentrations, regulatory requirements, and public concerns or nuisance issues.
- Availability and cost of utilities and sufficient electrical capacity at the site or need to upgrade.
- Air or oxygen supply requirements.
- Need for continuous 24-hour operations.

Off-Site Treatment Costs

- Volume of contaminated media requiring transportation and treatment.
- Material handling, excavation dewatering/slope stabilization requirements (particularly for larger quantity of rocks or debris, high percentage of fines, or high moisture content).
- Transportation costs in the case of off-site disposal, which are significantly impacted by the proximity of the site to the treatment facility.

The list above highlights those cost dependencies specific to in situ thermal treatment and does not consider the dependencies that are general to most ex situ remediation technologies. Click here for a general discussion on costing which includes definitions and repetitive costs for remediation technologies. A project-specific cost estimate can be obtained using an integrated cost-estimating application such as RACER® or consulting with a subject matter expert.

Duration

Thermal desorption and incineration technologies treat contaminated media much faster than other chemical- or biological-based technologies. Treatment time is a function of the volume of material that must be treated, required residence time of the material in the combustion chamber, and the size and number of treatment units. In addition, removal of debris and large rocks can increase treatment time for thermal desorption and incineration systems, and high moisture content can increase treatment time for thermal desorption. Hence, throughputs of units vary substantially.

Implementability Considerations

The following are key considerations associated with implementing ex situ thermal desorption and incineration treatment technologies:

- There are only a small number of vendors that offer mobile or commercial LTTD/HTTD services. No known vendors currently offer mobile incineration services and only fixed off-site commercial incinerators are available.
- Dewatering may be necessary to achieve an acceptable soil moisture content. Heavy rainfall events can hinder material handling and treatment operations and cause schedule delays.
- Because of material handling and treatment equipment operating issues, it is not optimal to perform on-site thermal treatment during cold weather conditions.
- Highly abrasive feed potentially can damage the processor unit. Also, soils with higher percentages of fines or moisture content can become "sticky" and clump together, which can hinder material handling operations or require specialized handling equipment.
- Heavy metals are not effectively treated by thermal desorption or incineration. Metals may remain in the media or in the case of incineration, metals may remain (and concentrate) in the bottom ash or fly ash. Stabilization/solidification of the treatment media or fly ash byproduct may be required prior to disposal.
- An air permit, if required, to operate an on-site thermal desorption unit may be difficult to obtain due to noise, odor, and other concerns. It is important to partner with all project stakeholders to agree on regulations and facilitate acceptance of the technology for use at a site.
- Sufficient space must be available to stage large equipment and manage pre- and post-treatment soil piles. Storm water run-on and run-off prevention/containment systems are also typically required for the soil management and treatment areas.

- A comprehensive soil handling/management and sampling plan is necessary to minimize timeframes of open excavation(s) and the soil storage volume, which can create schedule delays and safety or regulatory issues or result in the generation of contaminated rainfall.
- Debris greater than 60 mm in diameter typically must be removed prior to processing to prevent damage to the treatment system and interfere with treatment efficiency.
- HTTD and incineration can change the properties of soil (e.g., oxidize organic material, sterilize soil, alter leachability characteristics). These changes must be considered when identifying potential end uses for the treated soil.

Below are additional considerations that pertain to each specific technology:

Thermal Desorption

- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.
- There is some ambiguity in the definition of thermal desorption, and its interpretation is applied inconsistently from state to state and project to project. In some instances, in particular where an afterburner is required to treat vapor, a thermal desorption project could be classified as incineration, which could result in additional regulatory requirements and public concerns (NAVFAC, 1998).

Incineration

- Incomplete combustion or other chemical processes associated with this technology may lead to the formation of dioxins and furans or other potentially toxic byproducts.
- Volatile heavy metals, including lead, cadmium, mercury, and arsenic, may leave the combustion unit with the flue gases, thus requiring the installation of gas cleaning systems for their removal.
- Sodium and potassium form low melting point ashes that can react with the brick lining and form a sticky particulate that fouls gas ducts.
- Metals can react with other elements (such as chlorine and sulfur) in the feed stream, forming more volatile and toxic compounds than the original substances designated for incineration; such compounds are likely to be short-lived reaction intermediates that can be destroyed in a caustic quench.
- Oxidation of halogenated compounds create acid gases, and if present at high concentrations, this could create a corrosive environment that must be accounted for in the selection of equipment and materials or construction.

Resources

EPA. On-Site Incineration: Overview of Superfund Operating Experience (1998)
A report prepared to summarize 15 case studies on incineration and to provide technology descriptions under one cover.

EPA. A Citizen's Guide to Thermal Desorption (2012)
A fact sheet intended for public guidance on the method of thermal desorption to clean up pollution at Superfund and other sites.

EPA. A Citizen's Guide to Incineration (2012)
A fact sheet intended for public guidance on the method of incineration to clean up pollution at Superfund and other sites.

ITRC. Technical Guidelines for On-Site Thermal Desorption of Solid Media and Low-Level Mixed Waste Contaminated with Mercury and/or Hazardous Chlorinated Organics (1998)
This guidance document provides guidelines for using thermal desorption to treat certain low-level radioactive mixed wastes contaminated with mercury and/or hazardous chlorinated organics such as chlorinated solvents, chlorinated pesticides, and PCBs.

NAVFAC. An Overview of Thermal Desorption Technology (1998)
A report summarizing and expanding upon the presentation on thermal desorption as part of the "Remediation Innovation Technology Seminar" presented by NFESC in 1998. Contains an overview of several thermal desorption technologies used at various sites in the United States.

NAVFAC. Application Guide for Thermal Desorption Systems (1998)
A guidance document that gives technical information and implementation processes necessary when considering thermal desorption technologies for use in environmental remediation projects at military facilities.

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1. Incineration also is applicable to liquids and sludges; however, the focus of this technology profile is the treatment of soil and sediment. ↩
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