USE OF IN-PILE THERMAL DESORPTION® (IPTD®) TO TREAT PERSISTENT ORGANIC POLLUTANTS IN DREDGED SEDIMENTS

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ABSTRACT

This paper will provide background and description of the use of in-situ thermal treatment for remediation of sediment with VOCs and other persistent organic pollutants in contaminated sediments. Recent advances in the field have led to the deployment of an innovative method that utilizes heating, extraction and treatment processes for on-site waste consolidation piles. This technique has proven to be effective on contaminated soil and sediment.

In-situ thermal treatment technology offers proven performance with recalcitrant chlorinated organic contaminants, even in clayey, moist soil. Thermal treatment can enhance soil vapor extraction and NAPL recovery effectiveness. At higher temperatures 95-99% or more of the contaminant mass is destroyed by pyrolysis and/or oxidation reactions within the soil.

Recent advancements in thermal treatment technology have led to its use in treating contaminated sediments. Contaminated sediments are dredged and or dewatered in-situ, followed by thermal treatment. Sediments are consolidated into treatment piles or boxes, which are subsequently heated.

Treatment cells composed of insulated, covered soil piles, and treatment containers composed of insulated boxes are equipped with electrically-powered heating elements. Whether in piles or in boxes, the In-Pile Thermal Desorption® (IPTD®) process uses thermal conduction heating (TCH) to provide energy for within-the-soil remediation. IPTD® "hot boxes" are designed to be inexpensively emptied and refilled for quick batch change-out and efficient utilization of off-gas treatment equipment.

Keywords: Remediation, POPs, Dredged material treatment, Contaminated sediment

INTRODUCTION

This paper will provide background and description of the use of in-situ thermal treatment for remediation of sediment with volatile organic contaminants (VOCs) and other persistent organic pollutants in contaminated sediments. Recent advances in the field have led to the deployment of an innovative method that utilizes the heating, extraction and treatment processes for on-site waste consolidation piles. This technique has proven to be effective on contaminated soil and sediment.

History

The in-situ thermal desorption and in pile thermal desorption (ISTD/ IPTD®) family of technologies was originally developed by Shell Exploration and Production (Shell E&P), in the 1980s to accomplish enhanced oil recovery. In 1994, Shell Technology Ventures, Inc., established TerraTherm Environmental Services Inc. (TESI) to be a stand-alone remediation company offering ISTD/ IPTD® services to both the public and private sectors. Shell subsequently elected to exit the environmental cleanup business. In January of 2000, Shell donated the ISTD/ IPTD® rights within the USA to the University of Texas at Austin (UT), and a new company, TerraTherm, Inc. (TerraTherm) secured the exclusive license from UT to commercialize ISTD/ IPTD® within the USA. In 2002, Shell granted TerraTherm exclusive rights to commercialize the ISTD/ IPTD® technology outside the USA.

Shell E&P and TerraTherm have invested over $40M since the early 1990s on basic research and development of thermal conduction heating (TCH) for soil and groundwater remediation. Through these efforts, ISTD/ IPTD® has been demonstrated to be effective in removing a variety of contaminants from a variety of media (soil, sediment, areas of fractured bedrock, etc.) including polychlorinated biphenyls (PCBs), pesticides, chlorinated volatile organic compounds (CVOCs), polyaromatic hydrocarbons (PAHs), polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/PCDF), and heavy and light petroleum hydrocarbons.

Throughout the early 2000s, TerraTherm completed a variety of thermal remediation projects (chlorinated solvents (CVOCs), manufactured gas plant (MGP) waste, fast turnaround projects, persistent organic pollutants (POPs) projects, etc.

In the late 2000s, TerraTherm continued to expand its capabilities and partnerships. In 2008, TerraTherm utilized ISTD to successfully treat 48,000 cubic yards of CVOC-contaminated soil for the U.S. Air Force at Memphis Depot, TN. The project was awarded the Secretary of Defense Award for Environmental Restoration in 2009. TerraTherm is under a $37M contract with the U.S. Agency for International Development to implement the largest IPTD® project to date, at Danang Airport in Vietnam. TerraTherm is treating 73,000 m3 of dioxin-contaminated soil and sediment in a large aboveground pile structure (see http://www.usaid.gov/vietnam/environmental-remediation).

In Situ Thermal Desorption Process Description

In Situ Thermal Desorption (ISTD), is a soil remediation process in which heat and vacuum are applied simultaneously to subsurface soils with an array of heater and extraction wells. No excavation of subsurface soil is necessary. Thermal conduction accounts for the majority of heat flow from the high temperature (~800 °C) electrically powered heaters. As soil is heated to target temperatures above the boiling point of water that are applicable to treatment of persistent organic pollutants (POPs), volatile and semi-volatile contaminants in the soil are vaporized and treated by a number of mechanisms, including: (1) evaporation into the subsurface air stream with application of vacuum, (2) steam distillation into the water vapor stream, (3) boiling, (4) oxidation, and (5) pyrolysis. The vaporized water and contaminants are drawn by the vacuum into the extraction wells. Thermal Desorption (ISTD) installations can have several different possible configurations, and can have different air pollution control (APC) systems depending on various factors. A generalized conceptual system design is presented in Figure 1.

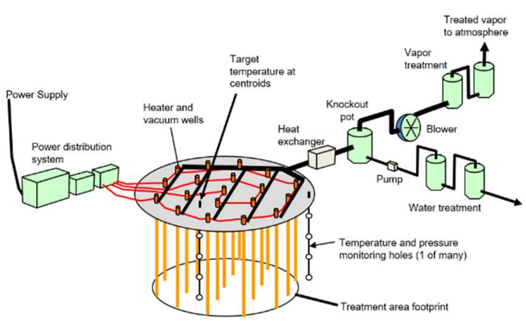

Fig. 1 Conceptual sketch of ISTD process.

Each heater well contains an electrically powered heating element with an operating temperature of approximately 750 - 800°C, modulated by silicon controlled rectifiers. Extraction wells are installed vertically, horizontally or at an angle. Depending on subsurface conditions, extraction wells can be configured for vapor extraction or multi-phase extraction as needed.

Compared to processes such as steam injection, conductive heating is very uniform in its vertical and horizontal movement. Furthermore, during treatment of POPs, transport of the vaporized contaminants is enhanced by the creation of permeability that results from desaturation of the heated soil. Flow paths are created even in tight silt and clay layers, which allow controlled collection and capture of the vaporized contaminants. Very high removal efficiency (approaching 100%) can be reached in the heated soil. This occurs because the soil can, if needed, be heated to high temperatures (e.g., >300 °C) for a prolonged period of time. Thus this bulk soil heating method results in much greater destruction and removal efficiency (DRE) and cleaner emissions than conventional thermal desorption in rotary kilns, in which the soil is heated only for seconds or minutes.

Background on In Situ Thermal Treatment of POPs

Project experience has confirmed that a combination of high temperature and residence time results in extremely high overall removal of high boiling point contaminants or Persistent Organic Pollutants (POPs) from the soil. Data indicate that 95% to 99% or more of the contaminant mass is destroyed in situ, as the vaporized contaminants pass through superheated soil close to the heater wells. Vapors are treated with an APC system to remove any vaporized contaminants that have not been destroyed in situ.

At ambient temperatures POPs have very low volatility. Their effective removal is facilitated by conductively heating the soil, which raises their vapor pressure, allowing them to be volatilized and removed in the vapor stream. Selection of the target temperature is made based on the contaminants being treated. When POPs such as polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/PCDF), polychlorinated biphenyls (PCB) and halogenated pesticides are heated to approximately 300 °C, they become volatile and are readily desorbed from the soil or sediment. Figure 2 displays a plot of vapor pressures of selected contaminants at a range of temperatures to illustrate this point.

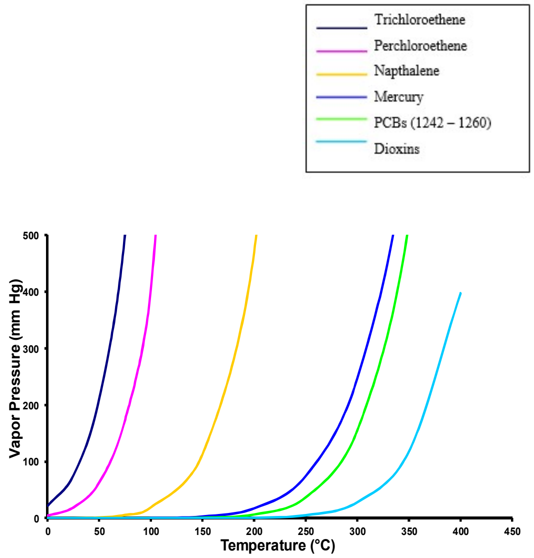

Fig. 2 Vapor pressure vs temperature for various contaminants

Effective removal of most POPs requires a treatment temperature in the range of 200°C up to 335°C. Rigorous laboratory thermal desorption studies have demonstrated that it is not necessary to achieve the boiling point of a compound to accomplish its effective desorption and removal from soil, and this principle has been confirmed by the results of numerous field ISTD projects.

ISTD APC systems are designed to prevent emission of dioxins or furans or their formation in the aboveground treatment units.

APPLICATION OF IN SITU THERMAL DESORPTION TO CONTAMINATED SEDIMENTS

In-Pile Thermal Desorption® (IPTD®) is a soil remediation processes utilizing the same general concepts as ISTD, simply in an ex-situ application. The technology can be effectively applied to dredged contaminated sediments. The IPTD® process utilizes conductive heating and vapor recovery to remediate excavated contaminated soil and/or sediment. Heat and vacuum are applied simultaneously to the treatment piles or cells with an array of horizontal (or vertical) heaters and vapor collectors.

TerraTherm's proprietary technologies, have been used to successfully treat numerous field-scale projects with high-boiling semi-volatile organic compounds (SVOCs) and non-volatile organic compounds, including PCBs, PCDD/PCDF, and polycyclic aromatic hydrocarbons (PAHs).

ISTD/IPTD® has been demonstrated to not create any unintentional POPs (e.g. PCDD/PCDF) during the heating process in treatment soils. In all treatability scale, demonstration scale, and field full scale treatment systems for sites thermally treating PCBs, PCDD/PCDF, all post-treatment soil concentrations have been below established cleanup standards, and in some cases below "background" concentrations.

Generalized Process Schemes

IPTD® installations can have several possible configurations, and can have different APC systems. As shown in Figure 3, a typical IPTD application, sediment or soil is consolidated into temporary constructed lined units. After consolidation, horizontal or vertical heater and extraction wells are installed and connected to the appropriate APC equipment.

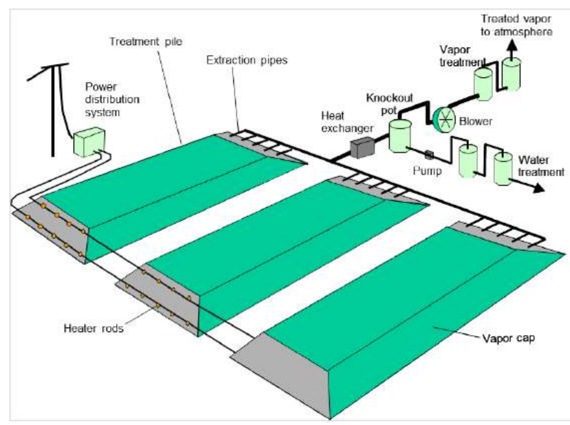

Figure 3. Conceptual sketch of IPTD® process (using horizontal heater wells).

Alternately, mobile thermal treatment units as shown in Figure 4 are becoming commercially available. Specially designed modular units may be shipped to the project. These units are designed with integral conduction heaters, and sufficient insulation to ensure efficient use of energy. The mobile units are aligned adjacent to one another. Piping installed on the cover of the mobile unit incorporates flow, temperature and vacuum monitoring. Typical operation involves a continuous operation of filling, operating and unloading the units.

Modular, containerized APC equipment has also been developed and can be paired with the mobile thermal treatment units. This allows for a cost effective solution by reducing engineering and design costs.

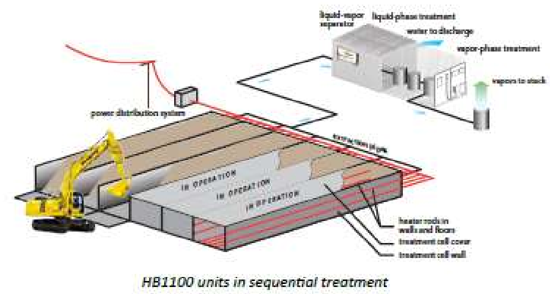

Figure 4. Conceptual sketch of mobile thermal treatment process

Dredged materials to be treated

Overall, ISTD/IPTD® systems are well suited to remove/destroy a wide variety of contaminants including POPs in the subsurface or in aboveground piles or treatment cells.

•ISTD/IPTD® used to treat a broad range of volatile and semi-volatile and other organic contaminants, including PCBs, pesticides, herbicides, PAHs, explosives residues, and PCDD/PCDF.

•IPTD® may be applied to stockpiled soils, drums of contaminated soils/sediments, and/or "Supersacks" of bulk materials, without the need of emptying the drums or supersacks when implemented as shown in Figure 4.

•IPTD® is relatively insensitive to moisture content, fines content, variability in particle size distribution, elevated humic content, coarse fragments, and the presence of dredging debris and including fill materials, ash, clinkers, cinders, brick, glass, metal, and wood fragments. In contrast, a conventional ex situ thermal desorption process using a rotary kiln is much more sensitive to these material properties.

Pretreatment

Dewatering is not required as a prerequisite to IPTD® since it is performed in aboveground piles or treatment cells above the water table. Construction of the piles should be done in a way, however, that facilitates free draining of the dredged materials.

Process Gases

ISTD APC systems are designed to prevent emission of dioxins or furans or their formation in the aboveground treatment units. These systems included the following protective design elements: (a) insertion heaters to preheat the vapor collection manifolds, thereby preventing condensation of off-gases during conveyance from the extraction well field to the treatment unit; (b) a thermal oxidizer (TO) operated at temperatures sufficient to meet air permit mandated destruction removal efficiencies (DRE) (up to 99.9999%), (c) an air-to-air heat exchanger to reduce the temperature of the off-gases at the oxidizer outlet within a fraction of a second to ~120 °C, well below the dioxin formation range; and, (d) polishing of off-gas with granular activated carbon (GAC) adsorbers prior to the discharge stack. The combined destruction and removal efficiency of the in-situ processes and the off-gas treatment achieved using ISTD for the treatment of PCB sites has been demonstrated to be >99.9999% (Table 1).

Table 1 Exhaust gas PCDD/PCDF concentrations

Site	Type	Target Media	Vapor Treatment System	Exhaust Gas Concentration ng-TEQ/Nm^3
Yamaguchi, Japan	IPTD	Sediment	FTO, HE and GAC	0.000018
Alhambra, California USA	ISTD	Soil	FTO, HE and GAC	0.0071
Cape Girardeau, Missouri USA	ISTD	Soil	FTO, HE and GAC	0.0029
Ferndale, California USA	ISTD	Soil	FTO, HE and GAC	0.0055

A second generation of ISTD/IPTD® APC system described in this paper has been tested and shown that it does not require a thermal oxidizer. A sufficiently high DRE can be achieved through a combination of within-the-soil (i.e., ISTD/IPTD®) thermal treatment, and utilizing adsorption of any evolved contaminants on GAC and/or synthetic media.

Vaporized water and contaminants are drawn into the extraction manifold. Contaminant vapors are then removed from the produced vapor stream with an APC system. Only after all the water has been boiled off is the soil temperature able to rise above the boiling point of water (100 °C) to attain the target treatment temperature for treatment of dioxins and other POPs (typically >200-335 °C).

Typically, when treating higher boiling point semi-volatile organic (SVOC) compounds, lower-boiling constituents will be removed from the heated soil during the steam stripping phase around the boiling point of water, 100 °C. Next, higher-boiling compounds will thermally decompose being destroyed by oxidation or pyrolysis within the heated soil during the superheated phase. Thus, the mass of organic compounds arriving at the APC system will be much less than the total mass of organic compounds in the untreated soil or sediment. Data indicate that up to 95-99% of the SVOC contaminant mass in a high-boiling project may be destroyed in-situ (Heron et al. 2010). End products of the decomposition are typically carbon dioxide, water, and chloride.

Reaction Products

Since contaminants may undergo in-situ abiotic transformations (e.g. oxidation, pyrolysis) during heating, there may be products of these reactions present in the effluent (vapor/liquid) streams. One example is the generation of ketones such as acetone and methyl ethyl ketone from heating of natural soil organic matter in topsoil. These compounds are seen at sites where trichloroethene (TCE) and tetrachloroethene (PCE) are thermally treated, and may be present in relatively small amounts in the soil post-treatment; however, ketones are readily biodegradable and have been observed to quickly disappear during the cool-down phase of full-scale application.

Process Effluents

Liquid waste streams are generated through active pumping/dewatering of treatment zones or soil piles, if required. Liquid waste streams are also generated by condensate production via vapor extraction of vaporized water from the treatment zone or soil piles.

Water may also be used on a closed loop or freshwater feed basis for cooling or quenching in the APC system. Any spent water or scrubber liquor is treated to meet regulatory requirements as needed prior to discharge.

Process Residuals

Negligible amounts solid residues are evident in the aboveground manifold piping and APC equipment, because most tend to be filtered out in the soil and because the vacuum applied to the soil is quite low. APC systems are equipped with knock out vessels and filters to capture any carryover of sediment or fines that may occur into the system.

Recent Pilot Test Results

Recent field-scale pilot tests have been conducted utilizing mobile thermal treatment units. The objective of the tests was to confirm that the target temperatures (300°C, 325°C) could be achieved in a predictable time period.

The first test was on petroleum hydrocarbon contaminated soil. The soil was heated to 300ºC for a period of 28 days. The test successfully verified the ability to treat VOCs and light-end SVOCs in a cost-effective small scale treatment system. Electricity consumption was approximately 381 kWh, or about $45.00 US per cubic yard. TPH was measured after thermal treatment to be within residential fill standards.

The second test was designed to treat soil containing waste from Manufactured Gas Plants (MGP) including coal tar, a Dense Non-aqueous Phase Liquid (DNAPL). In this trial the soil was heated to 368°C for a period of 32 days. The test successfully verified the ability to heat soil and treat heavy-end SVOCs utilizing the heated box technology. Electricity consumption was 664 kWh, or about $80.00 per cubic yard. Post treatment sampling confirmed achievement of clean up goals necessary for unrestricted land use.

SYSTEM INFRASTRUCTURE AND REQUIREMENTS

Applicable Project Size

Full-scale ISTD/IPTD® projects generally treat from 1,000 m^3 of contaminated soil, up to hundreds of thousands of cubic meters. Pilot-scale projects, by contrast, may treat considerably smaller volumes. The cost-effectiveness of ISTD/IPTD® projects is a function of size (i.e., volume of soil treated), with lower unit costs (i.e., $/m³) being associated with larger soil volumes. ISTD projects tend to be less cost effective relative to ex situ remediation alternatives when the treatment zone is very shallow (e.g., less than 2 m deep). For such sites, where the contaminants are distributed over a wide area, consolidating the soil into an on-site IPTD® system will often be a more cost-effective and sustainable choice than transporting it off-site.

The introduction of mobile thermal conduction treatment units will likely lead to more economical treatment of smaller volumes of contaminated soil and sediment. These treatment units, coupled with modular APC equipment are designed to be cost effectively mobilized to projects. Each treatment unit is designed to treat approximately 92 M^3 per cycle. Because the heated boxes are modular the treatment system can be expanded to include multiple boxes. Up to four heated boxes operating simultaneously, can be connected to a single modular APC unit. It is envisioned that the technology will be a cost effective alternative to hazardous waste disposal for projects as small as 500 M^3.

Major Equipment Needs

The major equipment used in ISTD/IPTD® installations includes:

• A transformer delivering power for the electrical circuits
• A power distribution system with switches, meters, and controllers
• Cables and wiring for the TCH heaters
• ISTD and some IPTD® configurations utilize wells and borings;
  Heater borings
  Vapor extraction wells
  Monitoring points (temperature and pressure)
• Manifold and conveyance piping for extracted fluids
• APC system for extracted fluids

When utilizing the mobile thermal conduction treatment units, the major equipment used includes:

• A transformer delivering power for the electrical circuits
• A power distribution system with switches, meters, and controllers*
• Cables and connecting the treatment units to the controllers
• Monitoring points (temperature and pressure) – installed post filling by direct push
• Manifold and conveyance piping for extracted fluids
• APC system for extracted fluids *

*These items are typically part of the modular APC units.

Typically, an office trailer is used for housing data management computers and other monitoring equipment. The entire process is automated, and as the site is heated, fluids are extracted, cooled, separated, and treated. The subsurface process is monitored using temperature and pressure sensors and detailed sampling and analysis of subsurface fluids.

Figure 5 presents a photograph of proprietary heater elements used in ISTD/IPTD® installations. Electric power flows through the steel rod, causing it to heat resistively. The heater element is isolated inside a steel pipe, with heat moving out into the surrounding soil primarily by thermal conduction.

Energy Requirement

ISTD/IPTD® can be implemented in virtually any location with access to adequate grid-based or portable power supplies. The power required depends largely on how much water is present in the soil, the target treatment temperature and the rate at which groundwater, if any, seeps into the treatment zone. Typical SVOC sites require approximately 400-600 kWh per cubic meter treated.

Figure 5. Proprietary conduction heating elements by TerraTherm

COMMERICAL STATUS OF TECHNOLOGY

Current State

To date numerous demonstrations and full scale projects have been completed treating either SVOCs or high-boiling point contaminants.

Demonstration-scale ISTD/IPTD® projects treating high-boiling contaminants include:

• Missouri Electric Works Superfund Site, Cape Girardeau, MO (PCBs and PCDD/PCDF)(Vinegar et al. 1997; France-Isetts 1998; USEPA 1998)
• US Navy BADCAT, Vallejo, CA (PCBs)(Conley and Jenkins 1998; NFESC 1998)
• Japanese Ministry of the Environment, Yamaguchi, Japan (PCDD/PCDF)(Heron et al. 2010)

Demonstration-scale Heated Box projects have been conducted and successfully treated Petroleum hydrocarbon and MGP wastes.

Full-scale ISTD/IPTD® projects treating SVOCs include:

• US Army Corps of Engineers, Saipan, W. Pacific (PCBs)
• US Navy - Centerville Beach, Ferndale, CA (PCB and PCDD/PCDF) (Conley and Lonie 2000)
• Southern California Edison, Alhambra, CA (PCDD/PCDF, PAHs, and PCP)(Yargeau and Bierschenk 2007; Baker et al. 2007; Baker et al. 2008)
• National Grid, N. Adams, MA (PAHs associated with MGP wastes)(Baker et al. 2006)
• USAID, Danang, Vietnam (TCDD associated with Agent Orange herbicide)(Sorenson et al. 2011)

Expected Future State

Planning and design work has been completed for various IPTD® and Heated Box projects in locations worldwide. Continued adoption of this technology is expected for treatment of SVOCs and high-boiling point contaminants in sediments.

Possible Variants for the Technology

IPTD® and Heated Box technologies allow the unique capability to efficiently thermally treat contaminated sediment and soil in challenging and remote locations. This advancement will allow for thermal remediation in remote locations where the excavation, transport and disposal of the contaminated media had previously been impractical. Continued development of energy efficient system designs coupled with mobile power generation is envisioned by the author.

CONCLUSIONS

Recent advances in the field have led to the deployment of an innovative method that utilizes the thermal conduction heating, extraction and treatment processes for on-site waste consolidation piles. Additionally, a conduction heating unitized mobile system has been developed and demonstrated to be effective for treatment of sediment and soil contaminated with VOC and other persistent organic pollutants.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance and continued dedication of the following individuals to the advancement of the technologies described in this paper.

John Bierschenk, TerraTherm, Ralph Baker, TerraTherm, Gorm Heron, TerraTherm, Dave Brogan, TerraTherm

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