

IN-SITU THERMAL DESTRUCTION (ISTD) OF MGP WASTE IN A FORMER GASHOLDER: DESIGN AND INSTALLATION

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ABSTRACT: In Situ Thermal Desorption (ISTD), also known as In-Situ Thermal Destruction, is being used to remediate a gasholder containing residual coal tar at a former manufactured gas plant (MGP) site in Massachusetts. When the gasholder was decommissioned, it was backfilled with soil and debris. The walls and base of the holder are intact, enclosing a volume of approximately 2,013 cubic yards (CY) (1,539 m³). Water was present at a depth of approximately 3 ft (0.9 m) below ground surface (bgs) within the gasholder. Based on limited soil investigations within the gasholder, residual coal tar was present throughout the soils and the bottom 4 ft (1.2 m) of soil was saturated with coal tar DNAPL. ISTD is being used to remediate the gasholder in a step-wise fashion to achieve Massachusetts soil cleanup standards that are protective of human health and groundwater, with respect to polycyclic aromatic hydrocarbons (PAHs), benzene, petroleum hydrocarbons and other compounds.

Laboratory results on a sample of the tar indicate that a modest, 100°F (56°C) increase in temperature results in a 20-fold decrease in viscosity. Thus, raising the soil temperatures will increase the fluidity and recoverability of the tar. Initially the heaters will operate at low temperatures, during which water and recoverable tar will be removed from the gasholder via two liquid extraction wells. Once the water and recoverable tar have been removed, the heaters will be ramped up to their full operating temperature and the soil will be heated to a minimum target temperature of 617°F (325°C). Soil in close proximity to the heater wells will become superheated, which will result in substantial in-situ destruction of the organic compounds. Air will be injected around the thermal wells to prevent coke from forming close to heater-vacuum (H-V) wells and obstructing subsurface vapor flow.

INTRODUCTION TO ISTD TECHNOLOGY

The TerraTherm ISTD process applies thermal conduction heating (THC) and vacuum to remediate soils contaminated with a wide range of organic compounds. Heat and vacuum are applied simultaneously to the soil with an array of vertical or horizontal heaters, under imposed vacuum. Heat flows through the soil primarily by thermal

conduction from a network of electrically powered heating elements (“heater” wells). Because the heater well temperature is easily controlled, they can operate at any desired temperature between ambient and ~1500°F (~800°C). This allows the heating process to be tailored to the needs of the particular project.

The ISTD process employs several mechanisms to achieve the remedial standards for a particular site. As the soil is heated, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) in the soil are vaporized and/or destroyed by: (1) evaporation into the subsurface air stream; (2) steam distillation; (3) boiling; (4) hydrolysis; (5) oxidation; and (6) pyrolysis (thermochemical decomposition in the absence of oxygen) (Baker and Kuhlman, 2002). The vaporized water and contaminants are drawn counter-current to the heat flow into the vacuum extraction wells (H-V wells).

ISTD technology has been proven to be highly effective in treating a variety of SVOCs that are at least as recalcitrant as PAHs (Stegemeier and Vinegar, 2001). Of particular interest relative to the treatment of PAHs from MGP sites are the Tar Drum experiments performed by Shell Oil Co. (Hansen et al., 1998), which demonstrated that, with proper design, ISTD can effectively and safely treat all organic contaminants present in MGP waste and achieve non-detect concentrations. A companion paper (Bierschenk et al. 2004) presents recent results of ISTD treatment of PAHs at Alhambra, CA.

The conductive heating process is very uniform in its vertical and horizontal sweep. This is because thermal conductivity values vary over a very narrow range, regardless of soil type. The uniform thermal properties of soil result in uniform heating of the target treatment zone (TTZ). Thus, with proper design, it is possible to ensure that 100% of the TTZ will achieve at least the target temperature. In addition, the soil immediately adjacent to the H-V wells becomes superheated, enabling rapid oxidation and/or pyrolysis reaction rates for vapors that get drawn through it (Baker and Kuhlman, 2002). The combined effectiveness of both heat and vapor flow leaves no area untreated.

ISTD has a destruction/displacement efficiency that approaches 100%, allowing attainment of stringent levels of treatment. This is a result of the ability to uniformly heat the soil to the boiling points of the contaminants of concern (COCs) and to maintain these temperatures for many days. Laboratory treatability studies and field project experience have confirmed that a combination of high temperature and long residence times result in extremely high overall removal efficiency (>99%) of even high boiling SVOCs. Every one of the eleven completed ISTD field projects has achieved the required levels of the COCs, even though their initial soil concentrations were often very high (Stegemeier and Vinegar, 2001). The low levels of COCs in the vapor that are not destroyed in-situ are conveyed to the aboveground AQC system for removal.

APPLICATION OF ISTD TO MGP SITES

TerraTherm has developed a flexible, three-level approach to the remediation of MGP wastes, whereby one or more levels can be utilized, usually sequentially.

Level One, or thermally enhanced non-aqueous phase liquid (NAPL) recovery, is most applicable to locations such as gasholders containing highly viscous coal tar residuals. In these cases, it is often desirable to remove separate-phase coal tar because it can be disposed as a relatively small volume of concentrated waste. If the coal tar is not pumpable at ambient temperatures, raising its temperature in-situ can make it much more

readily recovered because the viscosity of various types of NAPL depends strongly on temperature.

Level Two concerns the removal of more volatile/mobile fraction of COCs. This is accomplished through the application of low-temperature heating (approximately 212°F [100°C]). Studies performed at the Gas Technology Institute on soil contaminated with coal tars indicate that if the light-end hydrocarbons are volatilized (at temperatures approaching the boiling point of water), the coal tar residuals will solidify (Bhupendra et al, 2002). This is similar to the removal of plasticizers during the production of plastics. The remaining constituents (e.g., higher molecular weight PAHs) present in the immobile mass may effectively be precluded from leaching to groundwater. This approach offers a cost savings relative to higher-temperature ISTD, and achieves an environmentally acceptable endpoint.

Level Three. At some MGP sites, including the site in North Adams, MA that is the subject of this paper, the remedial goals are intended to address risks associated with possible dermal contact and/or ingestion of the PAHs. Remediation must achieve very low residual carcinogenic PAH concentrations, i.e., < 1 mg/kg. In the past, this type of stringent remedial goal could only be achieved by excavating the soil and treating it aboveground or transporting it off-site. The prospect of excavation and aboveground/off-site treatment or disposal of gasholder wastes raises a host of potentially problematic issues that need to be considered site-by-site, including odors; the possibility of unforeseen obstacles to excavation; the risk of volume growth; liability; and attendant costs. With the advent of ISTD, however, MGP wastes can be thoroughly treated in-situ by heating the targeted soil and waste to temperatures >617°F (>325°C) (Figure 1).

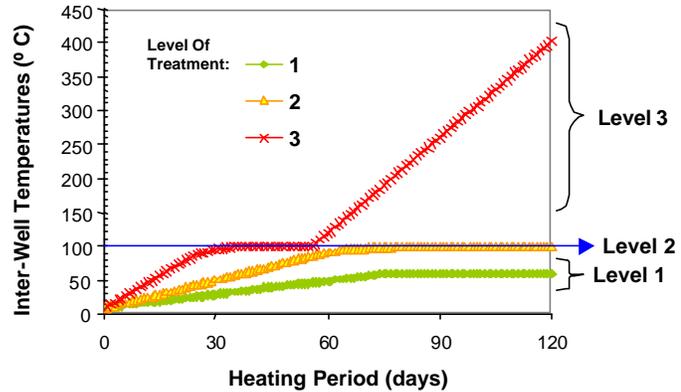


FIGURE 1. Typical heating progression for various levels of ISTD treatment.

SITE BACKGROUND

The subject Site is currently used as a Regional Operations Center for Massachusetts Electric Company (MEC), a subsidiary of National Grid USA. The Site is located directly adjacent to the confluence of the north and south branches of the Hoosic River. The surrounding area contains properties in commercial, industrial and residential use. Table 1 outlines the Treatment Zone dimensions.

TABLE 1. Target Treatment Zone dimensions.

	Target Treatment Zone (TTZ) Dimensions				
	Actual Diameter (ft [m])	Vertical Interval (ft [m] bgs)	Volume (ft ³ [m ³])	Depth to Groundwater (ft [m])	Tar Interval (ft [m] bgs)
N. Adams MGP Site	62 [18.9]	0-18 [0-5.5]	54,343 [1,539]	3 [0.9]	12-18 [3.7-5.5]

The Site was developed as an MGP site around 1860 and operations continued until 1952. MEC obtained ownership of the entire site in 1972. During MGP operations, several different types of gas manufacturing operations were conducted at the site, including coal carbonization and later, carbureted water gas. The site housed gasholders, storage tanks, switch houses, purifier boxes, retorts and other gas manufacturing equipment.

CONTAMINANTS OF CONCERN AND REMEDIAL OBJECTIVES

The COCs include PAHs such as benzo(a)pyrene [B(a)P]; benzene, toluene, ethylbenzene and xylene (BTEX); and petroleum hydrocarbons (Table 2).

TABLE 2. General characteristics of soil requiring treatment and remedial goals.

Compound	Boiling Point (°F [°C])	Soil Concentration within TTZ			Cleanup Objective (mg/kg)
		Mean (mg/kg)	Maximum (mg/kg)	Minimum (mg/kg)	
Benzo(a)pyrene	923 [495]	6	14	<0.7	<0.7
Benzene	176 [80]	2,643	6,200	1	<10
Total Petroleum Hydrocarbons (TPH)	NA	45,481	230,000	265	<200

Treatment objectives for the MGP site include the elimination of Dense Non-Aqueous Phase Liquids (DNAPL) so they no longer pose a threat of future release to groundwater, and reduction of concentrations of VOCs, SVOCs, Volatile Petroleum Hydrocarbons (VPH), and Extractable Petroleum Hydrocarbons (EPH). Treatment is to levels below Massachusetts Contingency Plan (MCP) “S-3/GW-1” standards so that residual risk is minimized. Table 2 includes several of the predominant COCs and the associated cleanup objectives.

SIMULATION MODELING

We based the initial model conceptualization on a reported gasholder diameter of 55 ft (16.8 m), with 7 H-V and 12 heater-only (H-O) wells at a spacing of 11.9 ft (3.6 m).

To model this setup, we employed the Steam, Thermal, and Advanced Processes Reservoir Simulator (STARS), a finite difference simulator that has been developing since the early 1980s by the University of Calgary and CMG, Inc. It is the leading non-isothermal oil field model. STARS is a three-dimensional, multi-phase and multi-component model that accounts for site composition, permeability, capillary pressure and reactions of all fluid and solid components.

Destruction Reactions. Numerous destruction reactions can occur in ISTD, falling into four general categories:

1. Oxidation in air in reactions similar to those that take place during combustion. Its rate is governed by the volume of oxygen that is available, i.e., limited by depth, permeability, position in array of heaters, in situ pressure, etc.
2. Steam reforming is akin to reactions taking place in olefin pyrolysis, wet air oxidation, supercritical water oxidation or water-gas shift reactions. Water is

available in abundance (especially on a molar basis) at most sites, and can be a major source of oxygen necessary to form carbon oxides. The products will include hydrogen and carbon oxides. Hydrous pyrolysis is related to the reactions that take place in wet air oxidation, except that it takes place in liquid water.

3. Coking is the recombination of unsaturated radicals formed during pyrolysis into larger agglomerates, e.g., stripping hydrogen from B(a)P forms radicals that dimerize or polymerize into large non-volatile high-carbon content, innocuous compounds (coke).
4. Oxygen or water can convert coke into carbon oxides and water, or carbon oxides and hydrogen.

To honor the expectation that most in-situ destruction reactions occur within the hot soil near the H-V wells, the model incorporated literature values of the kinetics for each reaction category. As an example, the half-lives for B(a)P at 1,100°F (590°C) in the proximity of H-V wells range from 7 to 30 seconds for oxidation, steam, coking and water-gas reactions (Weast et al, 1985).

Initial Modeling – Configuration 1. TerraTherm’s initial design was based on a 55 ft (16.8 m) diameter gasholder. Initially we envisioned that six H-V wells would be arrayed around the perimeter of the gasholder, with a seventh at the center. H-O wells would fill in the remainder of the hexagonal pattern. The resulting pie-shaped model Element of Symmetry (EOS), which includes two H-V and two H-O wells is depicted in Figure 2.

The initial round of modeling predicted the need for design adjustments. The three main problems were: 1) coke buildup in and near H-V wells; 2) lack of convection to move contaminants to the H-V wells; and 3) slow removal of residual contaminant in the cooler bottom layer. For this configuration, the large mass of contaminant in the gasholder (~76,000 lb or ~35,000 kg) was simply too large to destroy in-situ without excessive coking, and there were not enough reactants available (primarily water) to consume the coke that was formed (MKTS, 2001). Insufficient air influx limited convection and in-situ destruction, and the model predicted that the gasholder was not remediated within 180 days. Further modeling was required to focus on increasing power to the outer and deeper zones, reducing coke buildup, and improving convection of fluids in the deepest zone.

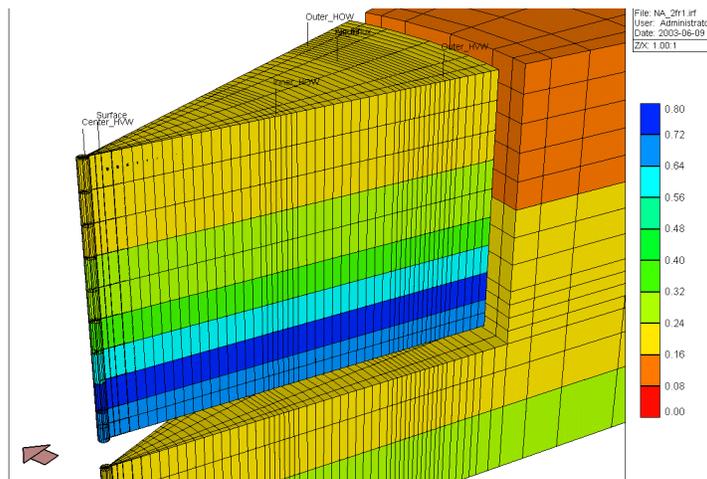


FIGURE 2. Three-dimensional 1/12th EOS showing water saturation after dewatering the gasholder.

Revised Modeling – Configuration 2. The Configuration 1 modeling indicated that more energy needed to be applied near the edges of the gasholder to compensate for perimeter heat losses.

By shifting the positions of the H-V wells inward, and most of the H-O wells outward, more heat would be provided near its edges and retained within the gasholder. The outer heaters were therefore moved closer together and the distribution of heat in the outer and inner patterns was rebalanced. Air injection was provided adjacent to each heater. At the H-O wells, the purpose of the air was to convect away or oxidize residual COCs. At the H-V wells, the purpose was to oxidize coke and vaporize COCs. In other respects, the Configuration 2 simulations were similar to those described above.

Figure 3 presents the simulated COC, gas and water production under Configuration 2. Conversions are as follows: 1 bbl/d is equivalent to 5,040 lb/d (2,290 kg/d), and 1 ft³/d is equivalent to 0.000694 scfm (0.0000196 m³/min). The figure shows that COC production is predicted to decline steadily after reaching 0.03 bbl/d or 151 lb/d (69 kg/d) 20 days after the vacuum is turned on. This is about 3% of the peak production under the previous operating scenarios. The missing COCs are being coked or oxidized. It is predicted that an estimated 98% of the COCs remaining in the gasholder at the end of the first phase of heating/liquid extraction period will be destroyed. Most of this destruction is attributed to the higher influx of air under this Configuration.

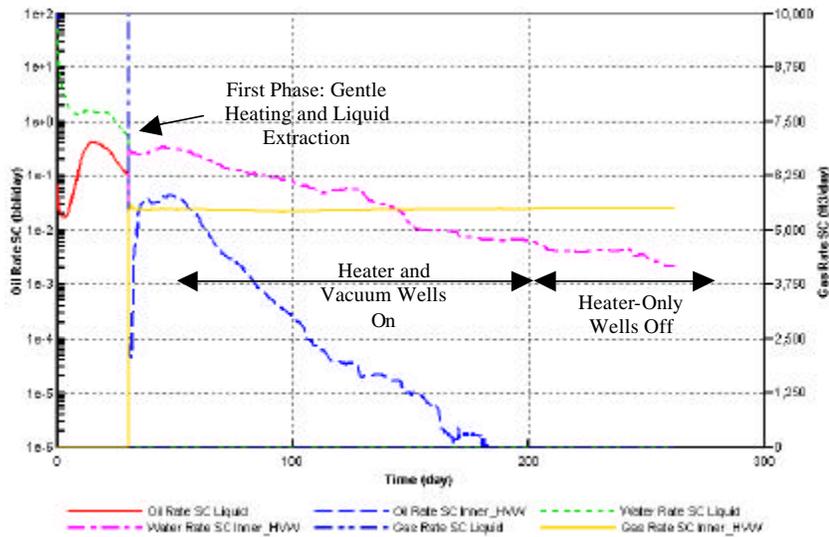


FIGURE 3. Production during preheating with maximum heater temperature of 800°F (430°C).

Figure 4 shows that only a small amount of the original COCs is predicted to remain in the model at the end of the 180-day treatment period. As with the previous scenarios, the COCs remain in the bottom and at the back wall of the model. However, the COCs that had condensed in the previously uncontaminated surface layers are not present because this time the model allowed air to leak in near the surface, as it would because the walls of the gasholder do not extend to the surface cover. Moreover, the amount of COCs remaining at 180 days is predicted to be 0.02% of the COC mass originally in the model. Almost half of the original COC mass was predicted to be

destroyed, and about half was produced as liquid during the first phase of the heating process.

Balanced heat input into both the inner and outer patterns within the gasholder, and increased air influx to oxidize coke and COCs in situ are predicted to eliminate accumulation of COCs at the bottom of the gasholder and result in removal or destruction of 99.98% of the COCs (coal tar) within 180 days of heating (see also the blue curve in Figure 3).

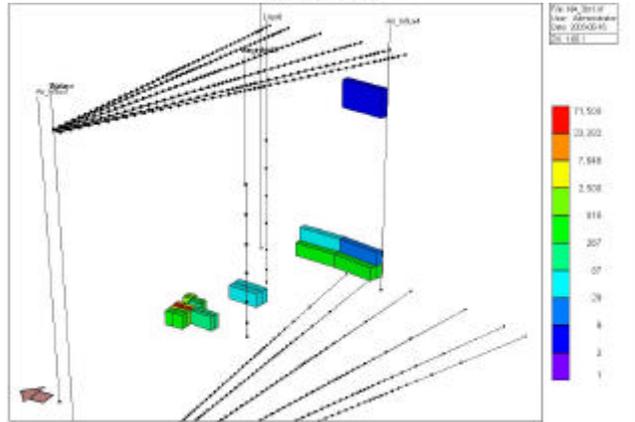


FIGURE 4. Residual COC concentration (ppm) at 180 days – Configuration 2.

DETAILED DESIGN AND IMPLEMENTATION

A total of 20 thermal wells (6 H-V wells and 14 H-O wells) had been specified to treat the soil within the 55-ft (16.8 m) gasholder, with each thermal well to be installed to the bottom of the gasholder ~18 ft (5.5 m) BGS. While installing the well field, however, TerraTherm found that although its depth was accurately reported, the actual inside diameter of the brick-walled gasholder turned out to be 62 ft (18.9 m), with the result that its area was 27% larger than previously reported, and its total volume 2,010 CY (1,537 m³). Consequently, the well field layout was once again revised with 16 (rather than 12) equally-spaced H-O wells around the outside ring, and three (rather than one) H-O wells positioned in a triangular pattern around the center of the gasholder inside the intermediate ring of six H-V wells, for a total of 25 thermal wells (Figure 5).

In addition, TerraTherm installed a longitudinal air injection tube on the outside of each thermal well. Injection of air into these tubes will help maintain oxidizing conditions within the lower part of the gasholder throughout the remediation process. To track the progress of the heating and well field pressures, 16 temperature

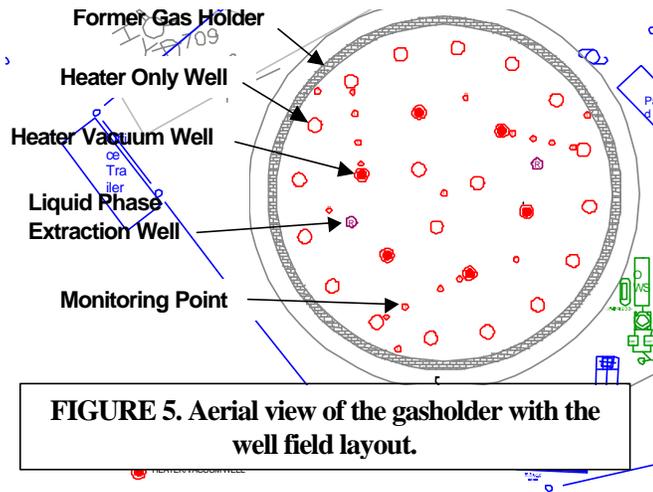


FIGURE 5. Aerial view of the gasholder with the well field layout.

monitoring points and three pressure monitoring points were installed at representative locations throughout the TTZ, each consisting of a steel tube extending to the bottom of the gasholder. About half will contain a multi-depth thermocouple array, while the others will hold a single discrete-depth thermocouple. TerraTherm will monitor each of these thermocouples as the primary method of tracking the progress of heating.

Prior to commencing heating, a pump was used to remove available water from the gasholder at the two recovery wells, consisting of wire-wrap stainless steel well screens with stainless steel riser pipes installed for this purpose. Initial estimates indicated that the gasholder could contain approximately 85,000 gal (322,000 L) of water, of which ~71% was expected to be recoverable, with the remainder being residual water saturation. In actuality, approximately 100,000 gal (375,500 L) was recovered and treated using an oil-water separator, clay-carbon media and two liquid-phase granular activated carbon (GAC) vessels in series. Treated water was held in a storage tank pending receipt of laboratory analytical results. When all discharge requirements were met, the water was discharged via an existing storm drain and discharge outlet.

During the initial phase of gentle heating at reduced power levels, TerraTherm will pump tar and remaining water from the bottom of the recovery wells to the oil-water separator tank. After separation, any water will be treated through GAC as described for dewatering operations. Separate-phase tar will be containerized and stored on-site for subsequent disposal by MEC. Once the majority of free-flowing tar has been removed (expected to take <30 days), tar recovery will be discontinued and full ISTD heating will commence.

TABLE 3. Treatment temperature, duration, and power usage.

	Treatment Temp. (°F [°C])	Treatment Duration (Days)	Power Application Rate (W/ft [W/m])	Power Requirement (kW-hrs and kVA)
North Adams MGP Site	617 (325)	180	300-350 (984-1,184)	600,000 and 240

As described earlier, most contaminants will be destroyed by the ISTD process within the subsurface soil, before vapors reach the H-V wells and are conveyed to the surface. The remaining contaminants that have not been destroyed in-situ will be removed from the produced vapor stream at the surface with an AQC system consisting of a regenerative thermal oxidizer, and back-up vapor-phase GAC.

Dewatering the gasholder began in February 2004 and was completed in March 2004, and the first and second phases of heating will begin in March and April 2004, respectively. ISTD should thus be completed by September 2004, with confirmatory sampling and demobilization to follow.

TerraTherm is conducting this project under a guaranteed, fixed-price contract.

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