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Flameless Thermal Oxidation

INNOVATIVE TECHNOLOGY SUMMARY REPORT

demonstrated at

M Area
Savannah River Site
Aiken, SC
in cooperation with
the U.S. Department of Energy
Oak Ridge Operations

prepared for

U.S. Department of Energy
Office of Environmental Management
Office of Technology Development

September 1995

U.S. Department of Energy

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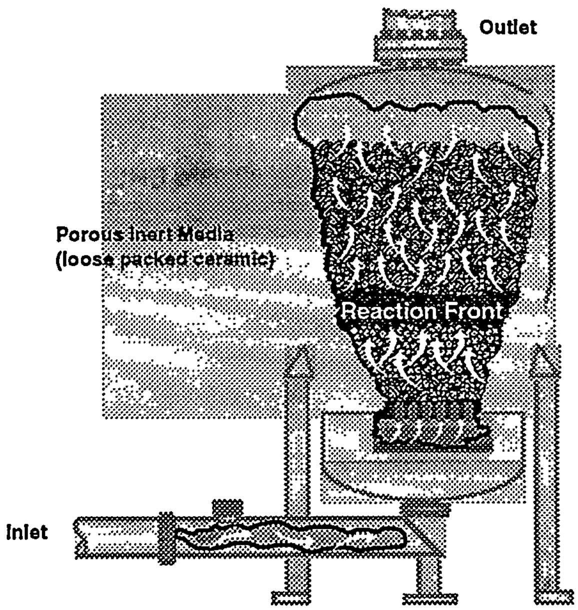
SECTION I

SUMMARY

Technology Description

The Flameless Thermal Oxidizer (FTO) is a commercial technology offered by Thermatrix, Inc. The FTO has been demonstrated to be an effective destructive technology for process and waste stream off-gas treatment of volatile organic compounds (VOCs), and in the treatment of VOC and chlorinated volatile organic compounds (CVOCs) off-gases generated during site remediation using either baseline or innovative in situ environmental technologies. The FTO process efficiently converts VOCs and CVOCs to carbon dioxide, water, and hydrogen chloride. When FTO is coupled with a baseline technology, such as soil vapor extraction (SVE), an efficient in situ soil remediation system is produced.

The innovation is in using a simple, reliable, scalable, and robust technology for the destruction of VOC and CVOC off-gases based on a design that generates a uniform thermal reaction zone that prevents flame propagation and efficiently oxidizes off-gases without forming products of incomplete combustion (PICs).



- The FTO provides destruction and removal efficiencies (DREs) in excess of 99.99% for hydrocarbons and CVOCs.
- The FTO unit yields extremely low NOx formation (typically < 2 ppmv) and extremely low CO formation (typically below the limits of detection) as measured from the effluent stream.
- The FTO can compensate for operations of low flow rates with low concentrations to high flow rates with high concentrations without affecting DRE.
- The FTO unit operates with a low pressure drop across the FTO reactor, typically < 3 inches of water.
- The FTO unit has been applied to gas flow rates ranging from 1 scfm to 6500 scfm.
- The Thermatrix FTO offers low capital and operating costs.
- The FTO is engineered to operate safely and includes the following safety design features:
  - operations below lower explosion limits,
  - inherent flame arrestor (ceramic matrix), and
  - large heat sink (ceramic matrix) to accommodate process fluctuations.
- The FTO has been permitted for many hazardous air pollutant (HAP) control applications.

Technology Status

A full-scale demonstration was conducted at the Savannah River Integrated Demonstration site where DOE has tested a number of off-gas treatment technologies.

U.S. Department of Energy
Savannah River Site
M Area Process Sewer/Integrated Demonstration Site
Aiken, South Carolina
April to May 1995

- The demonstration was conducted by the Savannah River Technology Center by a scientific team that had evaluated and analyzed technical and economic performance of other off-gas treatment technologies.

The demonstration site was located at one of the source areas within the 1-mile^2 VOC groundwater plume. Before the application of FTO coupled to SVE, the trichloroethylene (TCE), tetrachloroethylene (PCE), and 1,1,1-trichloroethane (TCA) concentrations in the off-gas ranged from 157 to 291 ppm, 243 to 737 ppm, and 12 to 21 ppm, respectively. The site conditions are described in more detail in Appendix A.

Key Results

- In 22 days of continuous operation treating DOE Savannah River Site wellhead SVE effluent, a total of 11.17 Kg of total CVOC was destroyed with no identifiable products of incomplete oxidation observed in any outlet sample.
- The Thermatrix unit successfully met and exceeded the 99.99% DRE for PCE at operating conditions of 1600°F and 5 scfm.
- All of the analyzed outlet samples were found to be below the analytical methodology detection limit with respect to any of the primary CVOCs in the inlet stream.
- The concentrations of TCE and TCA in the inlet feeding from the well were too low to enable a DRE measurement of > 99.99%; however, PCE is the major contaminant and typically the most difficult to destroy using thermal techniques and, therefore, the DRE for PCE is viewed as representative of the technology's true performance.
- In tests in which the feed stream was spiked with PCE, TCE, and TCA, the respective DREs were measured at > 99.995%, > 99.99%, and approaching 99.99%, respectively. These values represent the minimum DREs attained as all of the outlet samples were determined to be below the limit of detection of the analytical methodology with respect to PCE, TCE, and TCA.

The FTO is commercially available through Thermatrix, Inc.; more than 20 units have been placed in operation.

Contacts

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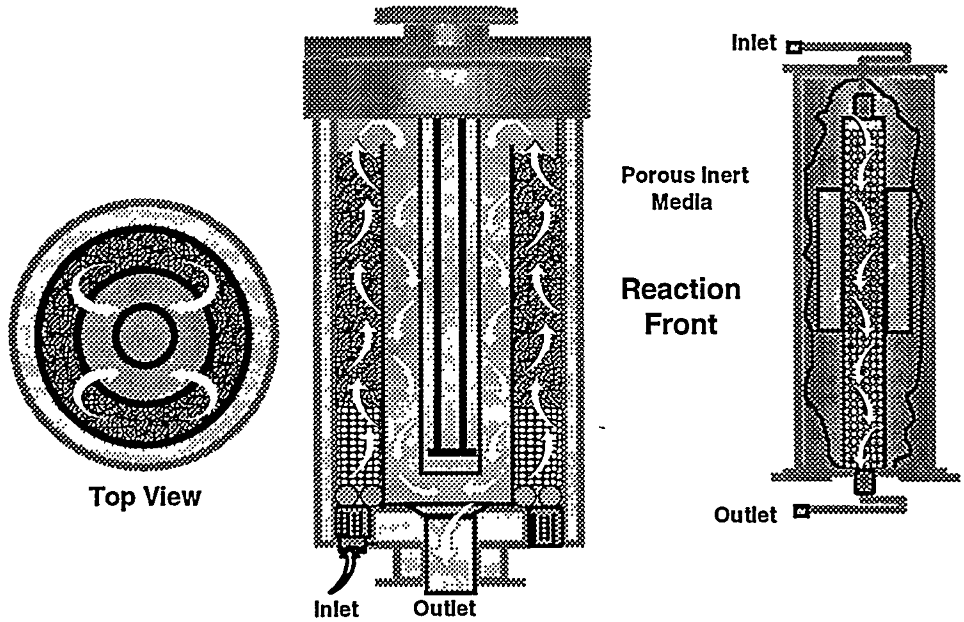
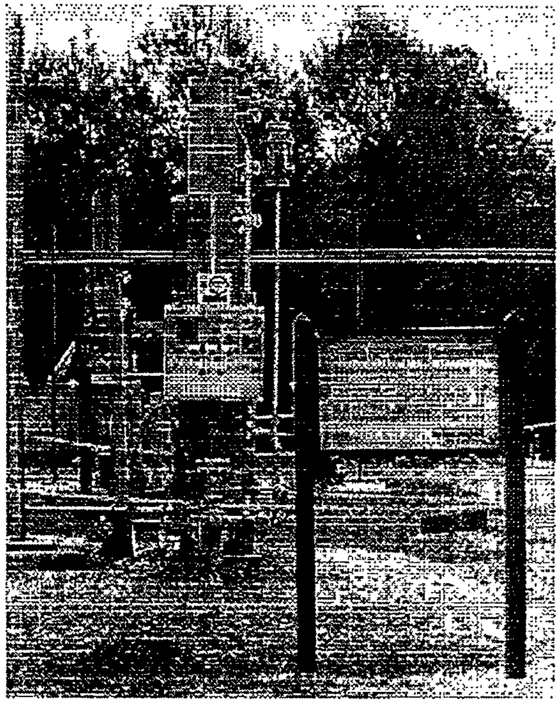
TECHNOLOGY DESCRIPTION

Overall Program Schematic

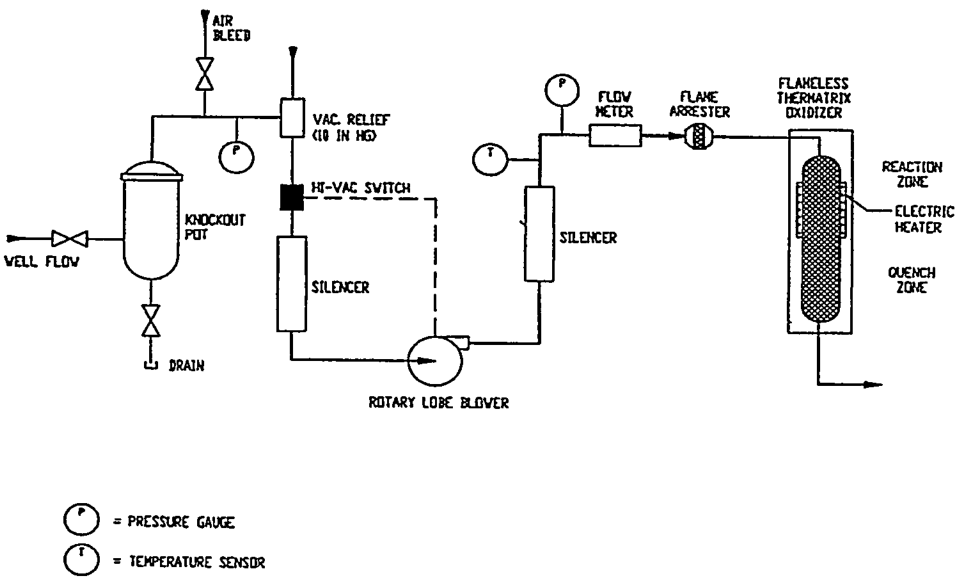


- The Thermatrix FTO technology achieves uniform thermal oxidation of CVOCs and VOCs using a heated packed-bed reactor typically filled with saddle- and spherical-shaped inert ceramic pieces.
- The oxidation of organic compounds occurs in a uniform thermal reaction zone contained in the packed bed of an inert ceramic matrix typically maintained at temperatures of 1600°-1850° F.
- The FTO design eliminates problems of temperature gradients, mixing, and resulting formation of PIC and HAP.
- The large thermal mass of the inert ceramic matrix enables it to store or release large amounts of heat without rapid changes in temperature and provides flame suppression within the FTO reactor.

Demonstration of Thermatrix Technology



Aboveground System



- The source of the air/CVOC feed gas used in this demonstration was well AMH-4, one of seven horizontal wells at the DOE SRS Demonstration Site.
- The well was pumped with a small SVE unit capable of providing up to 10 scfm of flow.
- The SVE system removed contaminant vapors and air from the subsurface; the vapors were passed through a knockout pot to remove any entrained moisture.

- The effluent from the SVE unit was fed directly to the inlet of a Thermatrix ES - 300H for treatment by FTO with the SVE pump providing the motive force for the FTO feed stream.

- CVOCs extracted from the soil by the SVE unit were oxidized in the Thermatrix oxidizer to form CO_2, H_2O, and HCl.

- The small scale of the demonstration permitted operation of the FTO without a caustic scrubber to remove the HCl produced. In large-scale operations, the FTO effluent stream would be coupled with a caustic scrubber.

PERFORMANCE

Demonstration Plan

- Performance of the technology has been assessed using information from the demonstration at SRS.
- Three operational modes were tested during the demonstration:
  - Preliminary testing to determine optimal parameters for continuous operation (2.5 days)
  - Continuous operation testing stage (22 days)
  - Spike testing stage to increase the level of detection for determining DRE (2 days)

Treatment Performance

Summary

- The FTO successfully destroyed a CVOC air/gas mixture generated by SVE at the SRS Demonstration Site.
- The FTO unit achieved > 99.995% DRE for PCE and >99.95% DRE for TCE and total CVOC during the continuous testing phase of the 22-day demonstration.
- During the demonstration, concentrations of PCE, TCE, and total CVOC in the FTO influent decreased as a result of the continual removal of CVOCs from the subsurface by SVE. Lowered concentrations of the FTO influent limited the minimal concentrations of CVOC that could be detected in the FTO effluent.
- Over a 2.5-day period, the FTO influent stream was spiked with 950 to 3060 ppmv total CVOC in an effort to extend the detection limits of FTO effluent, and DREs were measured at >99.995% for total CVOC.
- Throughout the continuous testing stage and the spike test phase, no PICs or HAPs were detected in the FTO effluent.
- During the continuous testing stage and the spike test phase of the demonstration 11.27 and 1.5 kg total CVOC were destroyed, respectively.
- The only downtime experienced over the course of testing was to change the oil in the rotary pump of the mini-SVE every 10 days (approximately 1 hour per oil change).

Key System Parameters

- The FTO was operated in a continuous mode at 5 scfm and 1600° F for 22 days.
- The FTO operated with minimal attention and required no maintenance or repairs for the 6 weeks of the demonstration.
- CVOCs were extracted from the subsurface from a horizontal well by means of a mini-SVE unit and supplied to the FTO at 5 scfm.
- The FTO influent CVOC concentrations during the preliminary and continuous demonstration operation varied from 400 to 1000 ppmv with typical equilibrium concentrations of 400 to 600 ppmv.

- The FTO was electrically heated, though methane or propane would be the heat source for large-scale remediation with a >100 scfm throughput.

- The demonstration site air permit did not require caustic scrubbing of the HCl released from the treatment of CVOCs by the FTO technology, but a caustic scrubber would be required during full-scale site remediation.

Amount of VOCs Destroyed

- During the preliminary testing stage of the demonstration, the optimal operating conditions for the FTO were verified at 5 scfm and 1600°F and >1.5 Kg total CVOC were destroyed during this phase of the demonstration. The parameters tested are described in the table below.

- During 22 days of continuous operation, the FTO destroyed 11.17 Kg of CVOCs.

- The vapor contaminants consisted primarily of PCE (70.5%), TCE (28.2%), and 1,1,1-trichloroethane (TCA = 1.2%).

- The FTO successfully destroyed the targeted chlorinated organics with a DRE >99.99% at its design conditions of 5 scfm and 1600° F.

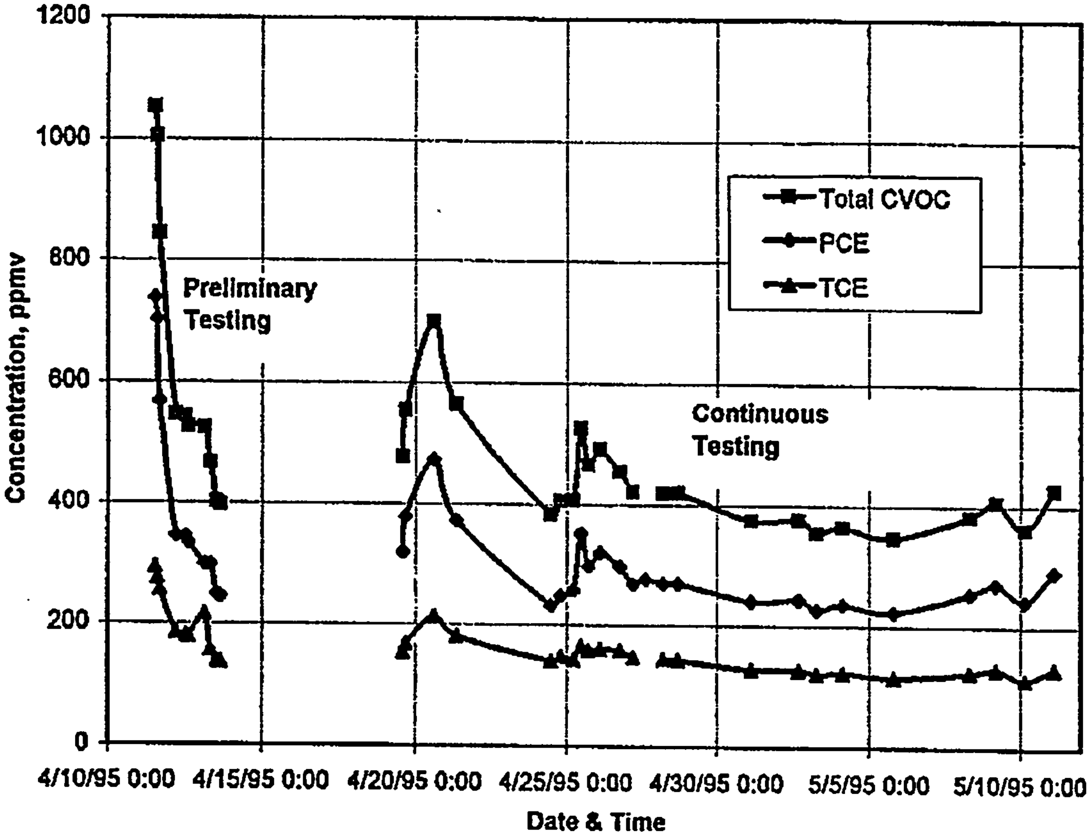
- The spike testing stage of the demonstration confirmed that the FTO could accommodate high CVOC concentration gas streams and >1.5 Kg total CVOC were destroyed during this stage of the demonstration at DRE > 99.995%.

Calculated Destruction Removal Efficiencies (DREs) During Preliminary Testing

Operating Conditions (time on stream[a])	PCE DRE	CVOC DRE
1600°F & 5 scfm (30 min)	9.99932E-01[b]	9.99382E-01
1600°F & 5 scfm (2.5 hrs)	9.99929E-01[b]	9.99352E-01
1600°F & 7 scfm (1 hr 15 min)	9.99700E-01	9.99087E-01
1500°F & 5 scfm (12 hrs)	9.87157E-01	9.90782E-01
1700°F & 5 scfm (1 hr 15 min)	9.99971E-01[c]	9.99705E-01
1400°F & 5 scfm (2 hrs)	9.98467E-01	9.98754E-01
1400°F & 5 scfm (14 hrs)	9.91007E-01	9.93651E-01
1400°F & 5 scfm (19 hrs)	5.29836E-01	6.16475E-01
1500°F & 3.5 cfm (1 hr 15 min)	9.99797E-01[d]	9.98387E-01
1500°F & 3.5 cfm (3 hrs)	9.99794E-01[b]	9.98363E-01

a = time on stream from establishment of current operating parameters
b = ND, normal split
c = < MDL, minimum split
d = < MDL, normal split

AMH-4 Well Concentrations (FTO Inlet) vs Time During Demonstration



Results of Spike Tests

	Conc'n (ppmv)				Calc. DRE[a]			
	PCE	TCE	TCA	Total CVOC	PCE	TCE	TCA	Total CVOC[b]
First Day No Sparge[c]	307	133		447	.999967	.999699		.999886
Sparge-1	448	242	125	954	NC	NC	NC	NC
Sparge-2	551	279	204	1126	.999982	.999856	.999804	.999913
Sparge-3	1037	607	456	2182	.999990	.999934	.999912	.999957
Second Day No Sparge	293	126		432	.999966	.999684		.9999881
Sparge-1	946	490	280	1742	.999989	.999918	.999857	.999948
Sparge-2[d]	1915	778	386	3087	.999995	.999949	.999896	.999971

NC = no outlet sample taken
a = outlet analysis for all primary constituents were nondetect. Reported DREs are minimum values (i.e., DRE>listed value).
b = total CVOC primary constituents listed in table.
c = sparge is the addition of concentrated CVOC to the FTO influent
d = well flow off, total flow is ambient air + sparge flow.

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

- FTO is an off-gas treatment technology that can be readily coupled with baseline or innovative remediation technologies or manufacturing processes where VOC and CVOC vapors are generated.
- FTO has been demonstrated to effectively destroy VOCs and CVOCs in off-gases from many sources, including:
  - CVOC off-gas from SVE of subsurface contaminated with PCE, TCE, and TCA;
  - VOC and petroleum vapors including the BTEX class of compounds from soil remediation, oil recycle, and manufacturing processes;
  - treatment of pulp plant noncondensable gases containing sulfur compounds;
  - treatment of methylene chloride emissions generated during pesticide production; and
  - treatment of wastewater from a chemical company containing butyl chloride, benzyl chloride, ethyl chloride, and toluene.

Competing Technologies

- Baseline technologies for treatment of CVOC and VOC off-gas from remediation processes include:
  - thermal oxidation,
  - catalytic thermal oxidation, and
  - adsorption/recovery.
- On a performance level, the flameless thermal oxidation technology can readily exceed destruction or removal efficiencies achieved by either thermal catalytic techniques or by adsorption/recovery systems.

Technology Maturity

- The FTO is a mature technology that has been successfully commercialized by Thermatrix, Inc.
- The FTO has been successfully installed and is currently operating more than 30 units in the private sector in 16 states, France, and the United Kingdom.
- The FTO technology can be scaled and tailored to site specific conditions and can be readily incorporated into existing treatment trains or manufacturing processes.
- Other innovative technologies are currently under development by DOE, including (1) activated carbon by steam reforming, (2) gas-phase bioreactor, (3) membrane separation; (4) high-energy corona, (5) silent discharge plasma, (6) xenon flashlamps, (7) pulsed combustion, and (8) solvent recycle.
- FTO is a destructive technology that differs from thermal oxidation by preventing formation of PIC and HAPs during the destruction process.

COST

Introduction

- Information in this section was prepared from data provided to the Hazardous Waste Remedial Actions Program (HAZWRAP) by Thermatrix, Inc., and the Savannah River Technology Center (SRTC). HAZWRAP was tasked by the DOE Office of Technology Development to perform an independent cost analysis of the technology being demonstrated.
- The FTO provided by Thermatrix, Inc. for the demonstration was a small electrically heated 5 scfm unit without an integrated caustic scrubber.
- The site provided a low flow rate of contaminants during the demonstration, which the FTO handled with excellent technical performance.
- The FTO technology process is scalable, based on the experience of Thermatrix, and provides the basis for extrapolation of economic performance at higher flow rates.
- The conventional technologies of thermal oxidation, catalytic thermal oxidation, and adsorption/recovery technology were used as the baseline against which FTO was compared for the treatment of CVOC off-gas from SVE of the vadose zone at the demonstration site. The technologies were tested at the site with similar contaminant streams using comparable analytical methods. To compare the three technologies, a number of assumptions were made:
  - For the purposes of estimating economic performance, calculations were based on a gas recuperative style remediation grade Thermatrix FTO unit capable of treating 400 scfm of SVE well head/SVE gaseous effluent.
  - An SVE concentration of 400 ppmv (equivalent to 3.7 lb/hr CVOC) was used a basis for calculating economic performance.

Capital Costs

- Capital costs of the baseline and competing technologies of thermal oxidation, catalytic thermal oxidation, and adsorption/recovery technology are comparable with the FTO technology.
- The capital cost of the FTO used in this demonstration was $50,000.
- For the purposes of estimating economic performance, the capital cost of a 400-scfm, gas-heated FTO is $160,000.
- Capital equipment costs are amortized over the useful life of the equipment, which is assumed to be 10 years, not over the length of time required to remediate the site.

Operating Costs

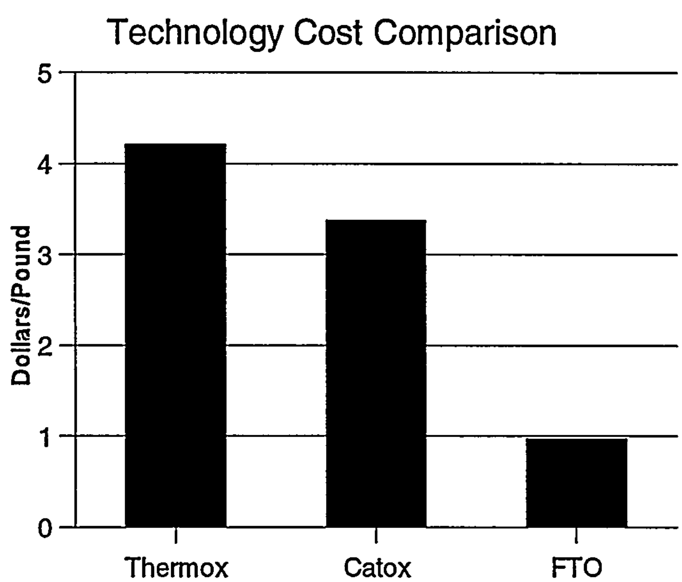
- The annual operating costs of the baseline, competing, and innovative technologies are comparable.
- However, the innovative technology FTO exceeds DRE (>99.99%) of competing technologies.
- Thermal catalytic techniques will typically achieve 98% to 99% destruction of PCE.
- Adsorption technologies, when operated at reasonable bed loadings, achieve similar removal efficiencies.
- Reliability and durability of the Thermatrix FTO are slightly higher than baseline or competing technologies.
- Thermal catalytic systems need periodic cleaning or replacement of the catalyst, the frequency of which is highly site dependent (typically, cleaning may be required yearly and replacement required every 3 years).
- The adsorption end of the recovery methods is simple and durable. The regeneration systems involve mechanical equipment subject to routine breakdown or replacement.
- Additional considerations in the evaluation of economic performance of the FTO technology include:
  - Total operating costs (including capital recovery, energy, labor, and maintenance) vary from $1 to $20 per pound of solvent treated for competing and baseline technologies, with the FTO estimated at $0.72/lb. (Thermal catalytic technologies typically cost $1.65–$2.35/lb CVOC destroyed.)

- The bulk of the total costs typically originate from capital recovery and labor, with the FTO technology requiring less maintenance than competing or baseline technologies.

- Energy costs are often viewed as an indicator of a technology's total costs, but typically comprise only 15–20% of the total operating costs.
  - Direct thermal destruction technologies will typically require about twice the energy input of thermal catalytic techniques.
  - Heat recapture systems coupled with thermal technologies decrease system energy requirements, but the savings due to heat recovery must be balanced against the added capital and maintenance costs of a heat exchanger and the need for corrosion protection from HCl generated from destruction of CVOC.
  - Solvent recovery methods will generally require 1/4 to 1/3 of the energy used for thermal techniques.
- Calculations based on the above assumptions put the cost of CVOC destruction at $0.72/lb ($1.58/Kg) CVOC destroyed.
- Common costs not evaluated because of use in all technology systems but that would be required are:
  - The destruction technologies demonstrated at SRS did not include acid scrubbers that would be necessary for full-scale continuous operations. Labor and maintenance costs for the scrubbers (including handling and disposition of the caustic solutions) would probably exceed that for the thermal units themselves.
  - Recovery systems carry an added cost for solvent handling and secondary waste stream disposition.
  - However, handling acid scrubber material and waste for thermal units should be on the order of costs for solvent recovery handling.

Cost Summary

- With this inlet feed concentration, the Thermatrix unit would also require ~315,000 Btu/hr supplemental fuel (natural gas), at a cost of $6,920/yr and minimal electricity at $525/yr.



SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

- The SRS site was previously used for several in situ remediation demonstrations associated with the VOCs in Non-Arid Soils and Groundwater Integrated Demonstration (VNID) funded by the DOE Office of Technology Development. Air discharge permits for the demonstration site are in place, and a letter of intent to the South Carolina Department of Health and Environmental Control served as an amendment to the existing air permits.

- The small scale of the demonstration permitted operation of the FTO without a caustic scrubber to remove the HCl produced. In large-scale operations, the FTO effluent stream would be coupled with a caustic scrubber.

- The FTO has been permitted for operation in California and in New Jersey, which both have strict clean air standards and has been permitted in other states, in addition to 14 other states, France, and the United Kingdom.

- Permit requirements for future FTO applications are expected to include:

  - Air permit for discharge of treated vapor,
  - CERCLA and RCRA permitting depending on site-specific requirements,
  - NEPA review for federal projects, and
  - U.S. DOT certification if propane is transported to the site for operating a large-scale (100 scfm) FTO unit.

- Permit requirements will differ from state to state and for specific applications (e.g., CVOCs vs VOCs).

Safety, Risks, Benefits, and Community Reaction

Worker Safety
- Health and safety issues for the installation and operation of FTO are essentially equivalent to those for other thermal oxidative or thermal catalytic off-gas treatment technologies.
- FTO treatment of CVOCs produces HCl, which would require neutralization of the acid. Safety issues similar to those associated with wastes generated from baseline adsorption technologies like Granulated Activated Carbon would also apply to FTO caustic scrubber waste.
- The FTO contains safety interlocks that prevent potential worker exposure to contaminant vapors in the event of power or system failure.
- Level D personnel protection was used during the installation and operation of the FTO.

Community Safety
- The FTO does not produce any significant routine release of contaminants. No known hazardous by-products are produced.
- No unusual or significant safety concerns are associated with the transport of equipment, samples, or other materials associated with the FTO.
- FTO has no open flame, thus eliminating community concerns about incineration.

Environmental Impacts
- The FTO has a low profile and requires little space.
- Visual impacts are minor, and the FTO creates little noise or heat, even in close proximity.

Socioeconomic Impacts and Community Perception
- The FTO has minimal economic or labor force impact.

- The general public has little familiarity with the FTO; however, the technology has gained public acceptance.
- FTO is not viewed by the general public as an incineration technology because there are no open flames, and FTO has found acceptance as a "clean" technology.

LESSONS LEARNED

Design Issues

- The FTO is designed to utilize heat provided by the thermal oxidative reaction.
- The FTO unit would have a lower energy requirement and concurrent lower operational cost when treating contaminated off-gases with a high heat of combustion (ca. 30 Btu/scf).
- CVOCs have a low heat of combustion (<2 Btu/scf at 1000 ppmv each of PCE and TCE) requiring resistance heating or addition of propane to maintain destruction performance.
- The design of the FTO is robust; the FTO required minimal maintenance throughout the demonstration.

Implementation Considerations

- Treatment of CVOC vapors using the FTO would require incorporating a caustic scrubber into the treatment system to neutralize HCl generated by the oxidation of CVOCs.
- Applications <100 scfm would require adequate power for resistance heating.
- Applications >100 scfm would require access to propane either by pipeline or by tanker.

Technology Limitations/Needs for Future Development

- The FTO is most energy efficient when treating compounds with a high heat of combustion (e.g., petroleum hydrocarbons) where heat recapture can boost operational efficiency.
- Moderate to high flow rates (>100 scfm) and contaminated vapor concentrations (>500 ppmv) improve the overall efficiency of operation and destruction of CVOCs by the FTO.

Technology Selection Considerations

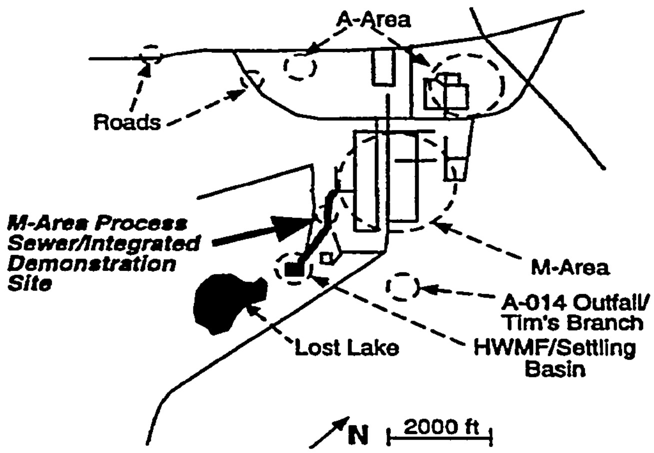
- The FTO technology coupled with a baseline or innovative in situ remediation technology would be most effective during the early stages of remediation when contaminant concentrations tend to be high.
- The FTO has good application to manufacturing, process waste streams, and remediation processes when the flow rate and contaminant concentrations are moderate to high.
- The FTO technology has been demonstrated at SRS and in the private sector to be effective, efficient, reliable, and cost-effective in the destruction of VOC and CVOC vapors.
- The FTO technology is competitive in cost with, and achieves comparable or higher destruction efficiencies than, commercially available baseline technologies for off-gas treatment, including thermal oxidative techniques, thermal catalytic techniques, and adsorption/recovery technologies.

DEMONSTRATION SITE CHARACTERISTICS

Site History/Background

- The Savannah River Site's (SRS's) historical mission has been to support national defense efforts through the production of nuclear materials. Production and associated research activities have resulted in the generation of hazardous waste by-products now managed as 266 waste management units located throughout the 300 mile² facility.
- The A and M Areas at Savannah River have been the sites of administrative buildings and manufacturing operations, respectively. The A/M-Area is approximately 1 mile inward from the northeast boundary of the 300-mile² Savannah River Site. Adjacent to the site boundary are rural and farming communities. Specific manufacturing operations within the M-Area included aluminum forming and metal finishing.

Site Layout



- The M-Area operations resulted in the release of process wastewater containing an estimated 3.5 million lbs of solvents. From 1958 to 1985, 2.2 million lbs were sent to an unlined settling basin, which is the main feature of the M-Area Hazardous Waste Management Facility. The remaining 1.3 million lbs were discharged from Outfall A-014 to Tim's Branch, a nearby stream, primarily from 1954 to 1982.
- Discovery of contamination adjacent to the settling basin in 1981 initiated a site assessment effort eventually involving approximately 250 monitoring wells over a broad area. A pilot groundwater remediation system began operation in February 1983. Full-scale groundwater treatment began in September 1985.

Contaminants of Concern

Contaminants of greatest concern are 1,1,2-trichloroethylene (TCE), tetrachloroethylene (PCE), and 11,1,1-trichloroethylene (TCA).

Property at STP*	Units	TCE	PCE	TCA
Empirical Formula	-	$ClCH=CCl_2$	$Cl_2C=CCl_2$	CH_3CCl_3
Density	g/cm^3	1.46	1.62	1.31
Vapor Pressure	mmHg	73	19	124
Henry's Law Constant	$atm*m^3/mole$	9.9E-3	2.9E-3	1.6E-2
Water Solubility	mg/L	1000-1470	150-485	300-1334
Octanol-Water Partition Coefficient; K_{ow}	-	195	126	148
STP = Standard Temperature and Pressure; 1 atm, 25°C				

Nature and Extent of Contamination

- Approximately 71% of the total mass of VOCs released to both the settling basin and Tim's Branch was PCE, 28% was TCE, and 1% was TCA.

- The estimated amount of dissolved organic solvents in groundwater in concentrations greater than 10 ppb is between 260,000 and 450,000 lbs and is estimated to be 75% TCE. This estimate does not include contaminants sorbed to solids in the saturated zone or in the vadose zone. The area of VOC-contaminated groundwater has an approximate thickness of 150 ft, covers about 1200 acres, and contains contaminant concentrations greater than 50,000 μg/L.

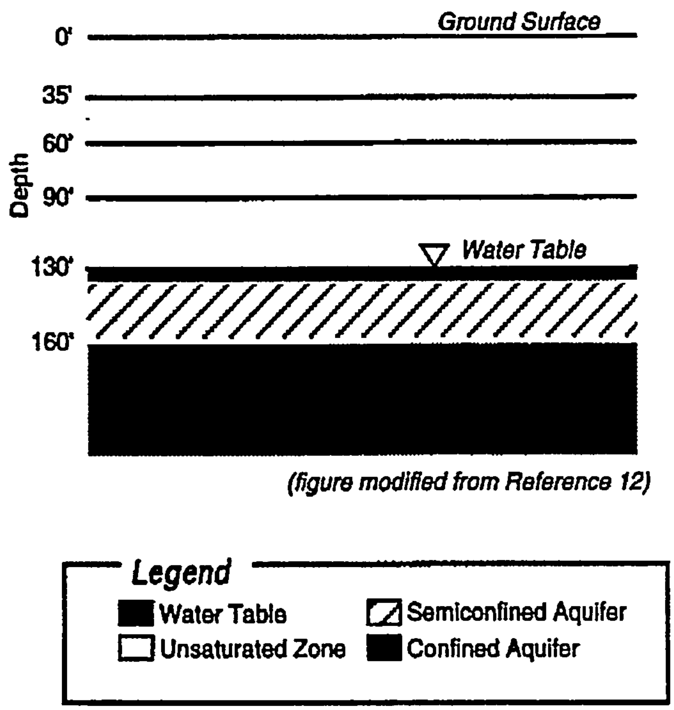
- Dense, nonaqueous-phase liquids found in 1991 present challenges for long-term remediation efforts.

- Vadose zone contamination is mainly limited to a linear zone associated with the leaking process sewer line, solvent storage tank area, settling basin, and the A-014 outfall at Tim's Branch.

Contaminant Locations and Hydrogeologic Profiles

Simplified schematic diagrams show general hydrologic features of the A/M Areas at SRS.

Vadose Zone and Upper Aquifer Characteristics



(figure modified from Reference 12)

Sediments are composed of sand, clay, and gravel.

Clay layers are relatively thin and discontinuous, with the exception of the clay layers at a 160-ft depth and a thicker zone of interbedded clay and sand found at a 90-ft depth.

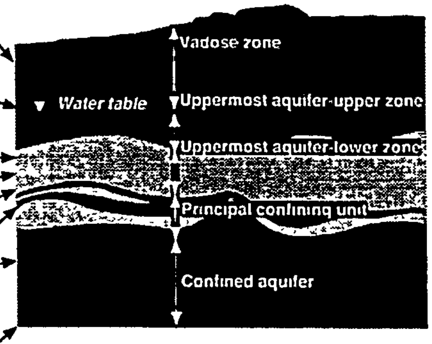
The water table is approximately 135 ft below grade.

A moderate downward gradient appears to exist beneath the M-Area. Vertical flow rates have been estimated to be 2 to 8 ft/year.

Radial flow outward from a groundwater plateau under most of the A/M-Area exists. Flow is approximately 15 to 100 ft/year.

Hydrogeologic Units

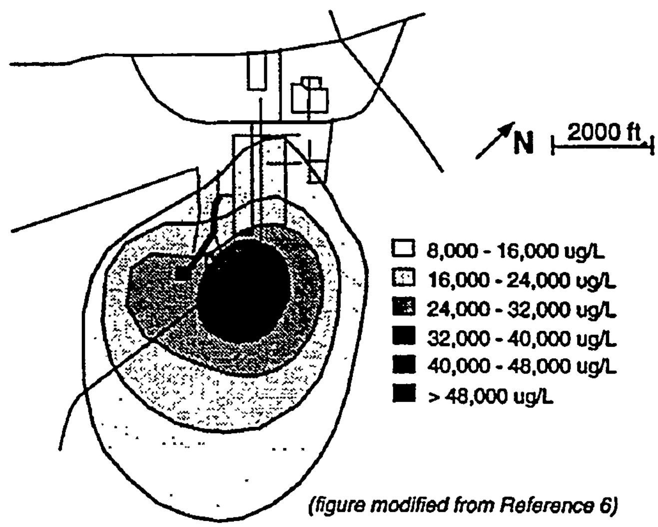
Aquifer Unit	Description	Thickness
Vadose Zone	Poorly sorted mix of sand, cobbles, silt and clay	-57 ft
	Moderate to well-sorted, fine to medium sand containing some pebbles; 13% silt and clay	0-97 ft
	Moderately to well-sorted medium sand; 18% silt and clay	30-55 ft
Water Table Unit	Moderate to well-sorted fine sand with some calcaneous zones; 25% silt and clay; 14% silt and clay beds	16-34 ft
Lost Lake Aquifer — Upper	Well-sorted fine to medium sand; 16% silt and clay; 7% silt and clay beds.	14-60 ft
	Discontinuous clay beds containing 70% silt & clay	
Lost Lake Aquifer — Lower	Moderate to well-sorted medium sand; 17% silt and clay; 7% silt and clay beds	4-44 ft
Crouch Branch Confining Unit	Clay, clayey silt, and poorly sorted fine to coarse, clayey sand; 62% silt and clay; contains 2 major clay layers the lower of which is 10-56 ft thick and is the principal confining unit for lower aquifer zones	32-95 ft
Crouch Branch Aquifer	Very poorly to well-sorted, medium to coarse sands; 5% sand and clay beds; an important production zone for water supply wells in the M-Area	152-180 ft



Metal-degreasing solvent wastes were sent to the A-014 outfall and, via the process sewer, to the M-Area settling basin. Data from hundreds of soil borings, ground water monitoring wells, and a variety of other investigative techniques have established a well-documented VOC plume in both the vadose and saturated zones.

TCE Ground Water Plume (Top View)

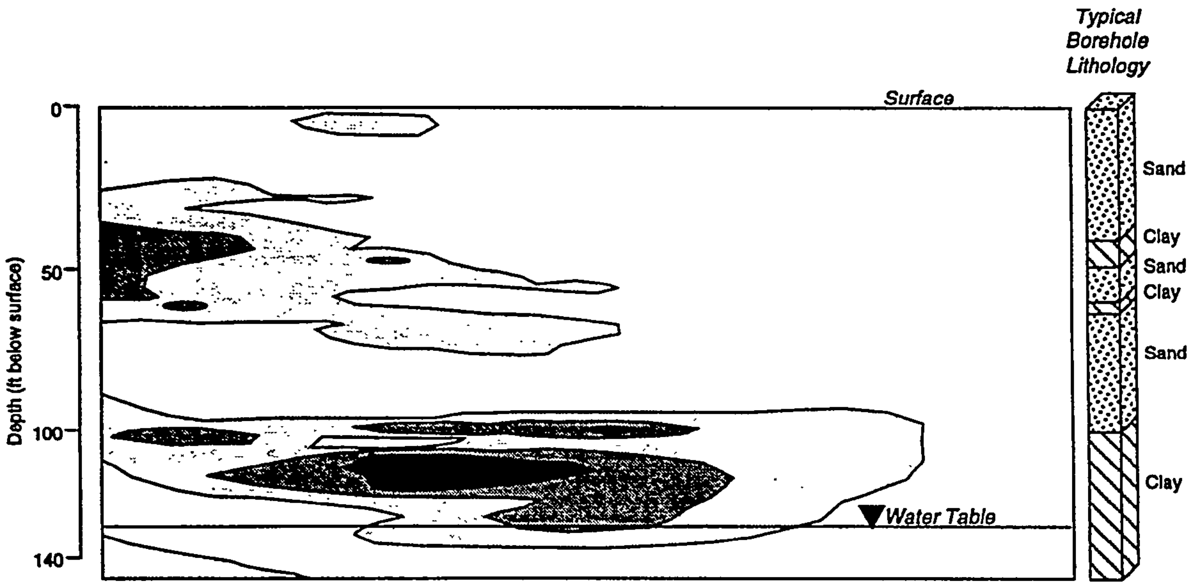
Data from 15 feet below water table in the third quarter of 1990.



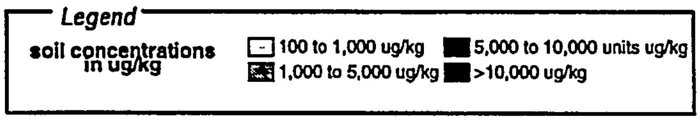
(figure modified from Reference 6)

TCE Concentrations in Soils (West-East Cross Section)

Concentrations and lithology data were acquired in 1991 along an approximately 200-ft cross section of the integrated demonstration site. Concentration contours of TCE in sediments are based on analysis of more than 1000 sediment samples. Highest concentrations of TCE occur in clay zones. These data were collected before the in situ air stripping demonstration was conducted and do not represent pretest conditions for the in situ bioremediation demonstration.



(figure modified from Reference 6)



APPENDIX B

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