FINAL DESIGN ANALYSIS REPORT

WORK ASSIGNMENT D003825-31.1

WEST SIDE CORPORATION SITE OU NO. 1
JAMAICA

SITE NO. 2-41-026
QUEENS COUNTY, NY

Prepared for:
NEW YORK STATE
DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 Broadway, Albany, New York

Erin M. Crotty, Commissioner

DIVISION OF ENVIRONMENTAL REMEDIATION

URS Corporation
282 Delaware Avenue
Buffalo, New York 14202

G3616

June 2003

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OPERABLE UNIT NO. 1

DESIGN ANALYSIS REPORT

Prepared for

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 BROADWAY
ALBANY, NEW YORK 12233

Prepared by

URS CORPORATION
282 DELAWARE AVENUE
BUFFALO, NEW YORK 14202

~~JANUARY~~ APRIL 2003

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1.0 INTRODUCTION

1.1 Scope

This report presents the design rationale, criteria, computations, and analysis for a remedial design at the West Side Corporation site (Site No. 2-41-026). This work is being performed for the New York State Department of Environmental Conservation (NYSDEC) under Work Assignment D003825-31 of the NYSDEC Standby Contract. This document has been prepared under Task 3.2, and represents part of the ~~90%~~100% design phase submission for the project.~~ This document will be revised as necessary for the 100% design phase~~.

The remedial design addresses soil remediation in three areas, Source Areas 1, 2, and 3, at the West Side Corporation Site (Drawing 3). Soil remediation includes remediation of vadose zone soil in Source Areas 1, 2, and 3 as well as remediation of soil in the saturated zone in a small area within Source Area 1 (i.e., the DNAPL Area) as discussed in Section 1.2. This soil remediation encompasses the remediation of Operable Unit No. 1 (OU1) also known as the on-site operable unit. Groundwater remediation encompass the remediation of Operable Unit No. 2 (OU2) also known as the off site operable unit. OU2 design, construction, and operation activities are being undertaken by the New York City Department of Environmental Protection (NYCDEP). The OU2 groundwater remediation includes the offsite installation of a high capacity (750 to 1,000 gallons per minute) groundwater extraction well (Well 24 New) and a treatment system. Well 24 New has been installed, but is not currently being used.

1.2 Approach

The conceptual approach for remediation of OU1 is presented in the *Revised West Side Corporation In-Situ Thermal Treatment Feasibility Study* (URS 2002a). This approach includes thermal remediation by electrical resistance heating (ERH) in a more heavily contaminated "DNAPL" area within Source Area 1 and soil vapor extraction (SVE) in the remainder of Source Area 1 as well as Source Areas 2 and 3 (Drawing 3).

The main objective of the ERH remediation is to reduce the mass of contaminants in the source area as much as practicable, so that when the offsite groundwater extraction program commences (Section 1.1), there is less source contamination contributing to the plume.

The main objective of the SVE remediation is to reduce volatile organic compounds (VOC) concentrations to concentrations less than or equal to New York State recommended contaminant cleanup levels presented in the Technical and Administrative Guidance Manual (TAGM) #4046. Cleanup goals for VOCs of greatest concern are presented in Table 1-1.

1.3 Description of Areas to be Remediated

The extent of the ERH remediation area is 60 feet by 60 feet (Drawing 3). The estimated depth of remediation in the ERH remediation area is 45 feet. A conceptual view of the lithology in the ERH remediation area is shown in Figure 1-1. As shown in Figure 1-1, the water table was approximately 14 feet below ground surface (bgs) in the ERH remediation area at the time of the remedial investigation. During chemical oxidation pilot testing in 2001, the water table in the DNAPL area was found to be 11 to 13 feet bgs. The volume of the ERH remediation is approximately 6,000 cubic yards assuming that contamination is continuous from the surface to a depth of 45 feet. Appendix 1A includes additional evaluation of the zone for ERH application.

The extent of the SVE remediation area is shown in Drawing 3. The estimated areas for the Source Areas are as follows: 1) Source Area 1 (excluding the ERH area) —28,800 square feet; 2) Source Area 2 – 5,400 square feet; and 3) Source Area 3 – 2,000 square feet (TAMS/GZA2000). On average, contamination extends from 1 to 7 feet bgs in Source Area 1, 1 to 4 feet bgs in Source Area 2, and 1 to 5 feet bgs in Source Area 3. On this basis, the estimated volumes of remediation are 6,400 cubic yards (Source Area 1), 600 cubic yards (Source Area 2); and 300 cubic yards (Source Area 3) [TAMS/GZA 2000]. The volume of remediation is based on average contaminant depths; however, contamination extended to as far as two feet below the average depth in Source Areas 1 and 3 (TAMS/GZA 2000). The water table varies both spatially and temporally. At the time of the RI, the water table was encountered at 10 to 15 feet BGS (Figure 1-1).

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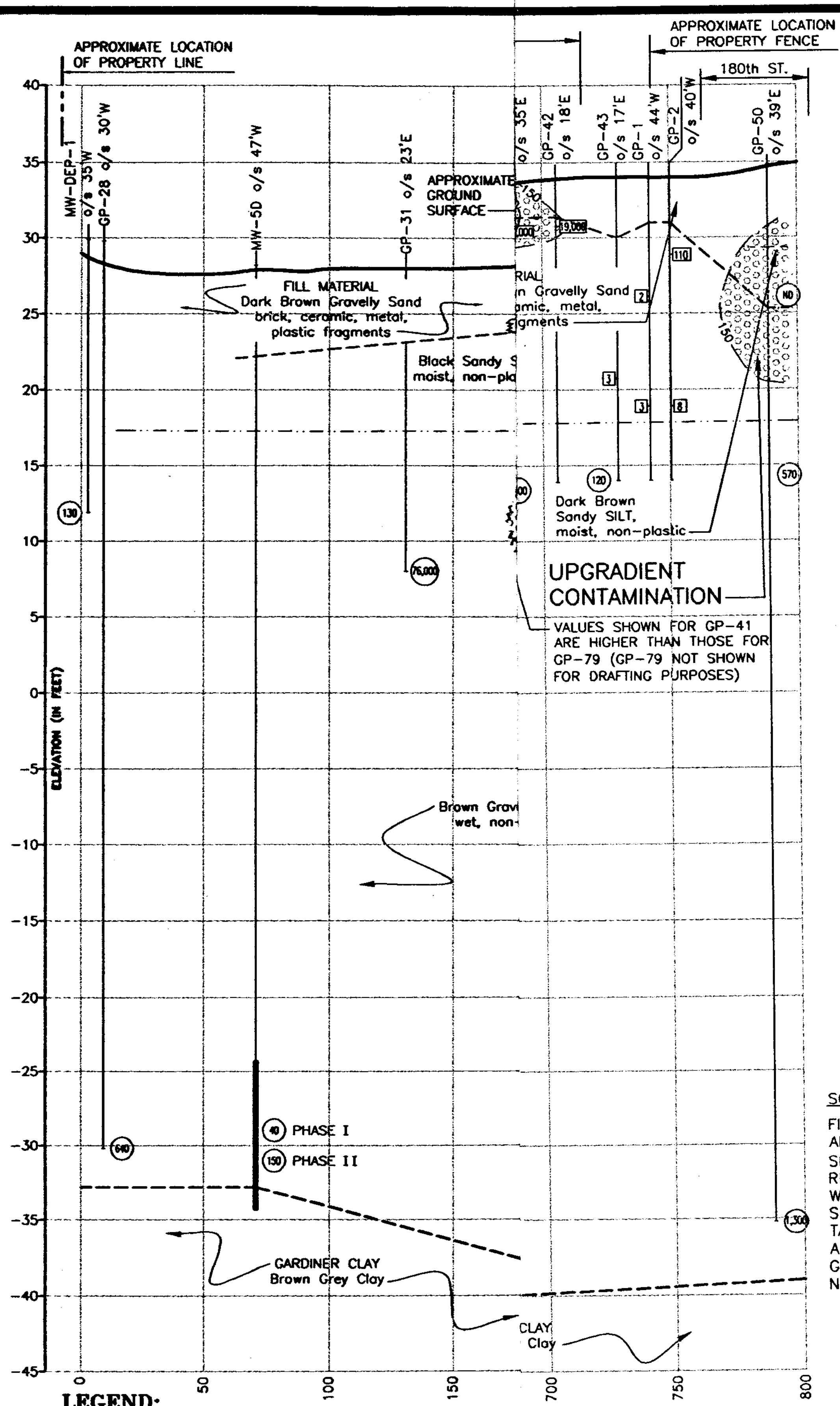


VALUES SHOWN FOR GP-41 ARE HIGHER THAN THOSE FOR GP-79 (GP-79 NOT SHOWN FOR DRAFTING PURPOSES)

SOURCE:

FIGURE 9 TITLED "GEOLOGIC AND ANALYTICAL CROSS SECTION A-A" FROM REMEDIAL INVESTIGATION WEST SIDE CORPORATION SITE REPORT PREPARED BY TAMS CONSULTANTS, INC. AND GZA GEOENVIRONMENTAL OF NEW YORK IN JULY, 2000.

LEGEND:

▭ 220	ANALYTICAL SOIL PCE CONCENTRATION MEASURED IN ppb
(130)	ANALYTICAL GROUNDWATER PCE CONCENTRATION MEASURED IN ppb

300

WEST SIDE CORP

S SECTION IN ERH REMEDIATION AREA

RS

FIGURE 1-1

CC-7398

1.4 Technical Memoranda

NYSDEC and URS have discussed a number of key design issues during the 30% and 90% design phases. The design issues are discussed in three technical memoranda which are included in Appendix 1B. Appendix 1B is referenced in subsequent sections of this DAR as necessary.

1.5 Phased Implementation of On Site Remediation

On site remediation includes ERH and SVE. These technologies will be implemented sequentially. Remediation by ERH will be implemented first, and will be completed before SVE is begun. This phased approach will likely be less costly (because air emissions control units will be less costly) and will offer other construction and operation benefits (see Design Issues – Memo 2 in Appendix 1B).

1.6 Implementation of Off-Site Remediation

A new off site extraction well (Well 24 New) has been installed, but is not currently in operation. The new extraction well will pump at a rate of 750-1,000 gpm. This pumping rate could significantly lower the water table on site, which would impact vapor recovery and treatment efficiency for ERH. Based on discussions with NYSDEC, ERH design is based on the assumption that ERH remediation will be completed before off site groundwater extraction begins, i.e. design is based on steady-state static water level conditions (see Design Issues-Memo 1 in Appendix 1B).

1.7 Site Photos

Photographs of some areas of construction and site features are provided in Appendix 1C.

TABLE 1-1

CLEANUP GOALS FOR SOIL VAPOR EXTRACTION

PARAMETER	GOAL (mg/kg)
Tetrachloroethene (PCE)	1.4
1,2-Dichloroethene (total)	0.3
Trichloroethene (TCE)	0.7
Ethylbenzene	5.5
Xylene (total)	1.2

2.0 SOIL VAPOR EXTRACTION (SVE) SYSTEM

2.1 Description

The SVE system will be designed to extract and treat soil vapor from the unsaturated zone in Source Areas 1, 2 and 3. The objective of system operation will be to remove volatile organic compounds (VOCs) from soil in the vadose zone. The major components of the system include fifteen extraction wells, three blowers, and a catalytic oxidation unit to treat extracted vapors (catalytic oxidation is discussed in Section 4.0).

2.2 Design Criteria

Design criteria for the SVE system are as follows:

Extraction Wells: Extraction wells will be vertical wells (see Design Issues-Memo 1 in Appendix 1B) extending to a minimum ten feet bgs. Wells will extend through contamination, but terminate above the water table. Wells will be constructed using a modified road box design to accommodate valves, fittings and piping so that neither wells nor appurtenances project above the surface. Extraction wells will be configured so that the wells could be opened to atmosphere and act as an air inlet wells, if necessary. Valves will be provided at each well to regulate pressure and flow rate. The well box cover will be designed to handle loading from onsite bus traffic.

Vacuum Monitoring Points: Only a few vacuum monitoring points will be placed on the periphery of the extraction zone(s) to evaluate subsurface performance. Monitoring points are not considered to be highly necessary because the site is covered and wells are closely spaced

Extraction Blower: Three blowers will be used for the entire soil vapor extraction system. Sizing will be based on the results of the pilot test (URS 2001).

Condensate Control: Moisture in the soil gas stream will be removed prior to the extraction blower using an air water separator. Water collected in the separator will be periodically collected, drummed, and shipped offsite.

Piping: Underground piping in trenches will be minimized to minimize the impact on site operations and offsite soil disposal. Pipe connecting extraction wells in Source Areas 2 and 3 to the blowers will be run above grade along the walls of the onsite building to reduce trenching. (See Design Issues – Memo 4 in Appendix 1B). Underground piping will be installed approximately 18 inches below the surface to minimize soil excavation disposal. The pipe will be sloped to allow condensate to drain back to the extraction wells.

Air Emissions: A catalytic oxidation unit will be used to destroy contaminants in soil gas and reduce emissions from the SVE system to acceptable levels (see Section 4.0).

System Automation: The system will be designed so that system monitoring (pressure, temperature, and flow measurements) will be accomplished only on site. A telephone dialer (or similar device) will be installed to notify the operator of an alarm condition, e.g. system shut down.

Surface Cover: The area of extraction for SVE systems are often covered to increase the effectiveness of soil gas extraction. At the West Side Corporation site, the entire extraction area is covered by asphalt. No additional cover system will be employed.

Subsurface Depressurization: A subsurface depressurization system will be installed in the basement of the north end of the onsite building. Depressurization points will be connected to the SVE extraction system (see Design Issues – Memo 4 in Appendix 1B).

2.3 Design Parameters

Design parameters for the SVE system are presented in Table 2-1. The basis for these parameters is in Appendix 2A. The parameters are discussed further below.

2.3.1 Extraction Wells

Extraction well design is based primarily on the results of the SVE pilot test performed in September 2001 (URS 2001). Details of well construction are included on Drawing 11. Well locations are shown on Drawing 3.

Number of Wells: Fifteen (15) vertical extraction wells will be used to extract soil gas from the subsurface. The number of wells and spacing is based on a maximum 50 foot radius of influence determined in the pilot study. In general, wells are placed closer than 50 feet so that the radii of influence overlap. Closer spacing gives greater assurance that remediation will occur in the impacted areas.

Diameter: Extraction wells will be 4 inches in diameter. This is a typical size used for higher flow extraction wells and was the size used for the pilot study.

Screen Length: The screens will extend from 2.5 feet below the surface to 10 to 12 feet below the surface. The screens extend through contamination and terminate above the water table. Most (11 of 15) extraction wells will be installed a depth of 10 feet. Four extraction wells will be installed to a depth of 12 feet. The deeper wells are located near the ERH area where soil contamination in the vadose zone is deeper than other areas in the SVE remediation area.

2.3.2 Vacuum Monitoring Points

Six (6) one-inch diameter PVC wells will be used to monitor subsurface pressure. The screen length and position will be identified to the extraction wells (i.e. 7.5 feet long extending from 2.5 to 10.0 feet below ground surface). In general, these monitoring points are placed near the periphery of the extraction well zone of influence to evaluate the extent of the extraction zone.

2.3.3 Extraction Blowers

Type: Regenerative blowers will be used for SVE. They are one type of blower commonly used for SVE and are best suited for this application because they have relatively large capacities (extraction volumes) at the vacuum (50 inches of water column) required. Rotary lobe blowers and liquid ring pumps are also commonly used, but will not be used because they require more maintenance.

Number: Three blowers will be used. Greater system flexibility is gained by using multiple blowers: Three blowers allows the system to continue extracting soil gas even if one or two blowers are off for repair or maintenance. In addition, it will be easier and more economical to operate the system at a reduced extraction rate in the future, if parts of the source areas are remediated faster than others.

Capacity: The recommended extraction rate for each of the fifteen extraction wells is 35 to 45 cfm (URS 2001). The total design capacity for all three blowers is 750 scfm based the maximum extraction rate from each well and an additional approximately 10% safety factor. The capacity of each blower is 250 scfm.

Pressure: Each blower will produce 50 inches water column vacuum at an extraction rate of 250 scfm. A 50-inch water column vacuum is required to maintain a 40 inch water column vacuum at the extraction wells based on a calculated 10 inch water column system pressure drop between an extraction well and the blower.

2.3.4 Piping

Pipes running below ground surface and connecting the extraction wells to larger collection header pipes will be 4-inch diameter. The headers will be 6 to 8 inches diameter pipe-depending on the total soil gas flow rate in the pipe. These pipe diameters are based on maintaining a maximum 1 inch water column per 100 linear feet of pipe pressure drop in the piping network. The piping will be sloped slightly towards the extractions wells so that any vapors condensing in the pipe are directed back to the extraction wells.

TABLE 2-1

SUMMARY OF SVE DESIGN PARAMETERS

COMPONENT	PARAMETER	VALUE
Extraction Wells	Number	15
	Diameter	4 inch
	Screen Length	7.5 feet to 9.5 feet
	Extraction Rate	35 to 45 scfm each
Vacuum Monitoring Points	Number	6
	Diameter	1 inch
	Screen Length	7.5 feet
Extraction Blower	Type	Regenerative
	Number	3
	Capacity	250 scfm each
	Pressure	50 inches water column each
Piping	Diameter	4 – 8 inches

3.0 ELECTRICAL RESISTANCE HEATING (ERH) SYSTEM

3.1 Description

ERH is a remediation technology which applies electric current in the subsurface to increase subsurface temperatures. The increased temperature causes VOCs (and water) to volatilize. The resulting vapors are subsequently captured, extracted, and treated.

The ERH design will include the following components:

- Electrodes
- Temperature monitoring points
- A steam and vapor collection system, including piping, a blower, and a condenser.
- A vapor treatment system
- A water (condensate) treatment system
- ~~A~~ ERH power control units (PCUs)
- Data acquisition system
- A computer controlled system for monitoring and controlling power

3.2 Design Criteria

Design criteria for the ERH system are as follows:

Power: On site power will be used for electrical heating.

Electrodes: Electrodes will be designed so that discrete subsurface intervals can be heated independently rather than uniformly heating the subsurface. Two vertically distinct electrodes will be used. The lower electrode (extending from 45 to 55 feet bgs) will be used to heat below the remediation depth to create a thermal barrier which will prevent downward migration of contamination. The upper electrode (extending from 10 feet bgs to approximately 45 feet bgs) will be used for contaminant removal.

Vapor Recovery: Vapors will be recovered by vertical vapor extraction wells installed in the same boreholes as the electrodes. One soil vapor extraction well (EW-10) will be installed inside the existing building and connected to the ERH vapor recovery system. This well will be used during the ERH phase to maintain a negative pressure under the building floor slab.

Vapor Condensation and Treatment: Extracted vapors will be condensed. The off gas from the condenser will be passed through a catalytic oxidizer where contaminants will be destroyed and concentrations will be reduced to acceptable levels. Liquids from the condenser will be passed through carbon adsorption units. Appendix 3B provides calculations indicating that no free phone PCE will be present in the condensate. The treated water will be discharged to the sanitary sewer.

Power Control Unit(s) (PCUs): The PCU(s) will be designed to covert three-phase power to six phases (if desired) and adjust voltage to the desired subsurface conditions.

Fencing: The ERH remediation area will be fenced to prevent access to the remediation area. This will be installed as safety precaution to prevent accidental exposure to high voltages (see Design Issues-Memo 1 in Appendix 1B). Requirements for fencing are provided in paragraph 1.6 of Section 01040 of the specifications.

3.3 Design Parameters

Design parameters are presented in Table 3-1. The basis for these parameters is discussed in Appendix 3A. These parameters are discussed further below.

3.3.1 Electrode/Vapor Recovery Wells

Electrode borings will be located approximately 16 to 20 feet apart in a triangular pattern. Two electrodes (an upper and lower) will be installed in each electrode boring. The lower electrode will be installed to produce a thermal barrier below the remediation area in a zone from 45 to 55 feet below ground surface [bgs] (see Section 5.0). The upper electrode will be used to remediate the zone from 10 to 45 feet bgs. A steel screened well (0.020-inch slot size) will be installed at each location which will function both as a vapor recovery well and the upper electrode. For the upper electrode steel shot or another conductive material will be used to fill the annular space around the well from a depth of 10 to 45 feet bgs. The limits of the steel shot determine the length of screened well that can be used as an electrode. Screen located above the steel shot will be used for vapor recovery. Electrode/vapor recovery well construction is shown in Drawing 11.

In addition to the electrode/vapor recovery wells located in the ERH area, one vapor extraction well will be located inside the existing building. This well is not associated with the ERH system, but will tie into the vacuum created by the ERH blowers. The purpose of this well (the northernmost well inside the building) is to create a negative pressure underneath the slab of the building, mitigating the potential for PCE vapors in the work areas of the building. Once the ERH effort has been completed, this well will be connected to the SVE system.

3.3.2 Temperature Monitoring Points

A minimum thirteen (13) temperature monitoring points (TMPs) will be installed in the ERH treatment zone (see Drawing 3) as follows:

- Five inside the treatment area
- Four at the corners of the treatment area
- Four located approximately 10 feet from the boundary of the ERH treatment area in each direction.

The nine TMPs located inside the treatment area and on the corners will be used for performance evaluation, and the four TMPs outside the ERH treatment area will be used for heat migration monitoring. Further discussion on temperature monitoring is presented in Section 5.0.

Thermocouples will be placed at 5 foot intervals at each TMP from a depth of 10 feet bgs to 50 feet bgs. Tubing will be installed at each TMP to allow periodic measurement of subsurface pressure and VOC concentration in soil gas. TMPs will be completed below grade so that temperature measurements can continue after ERH system decommissioning, if necessary, without interrupting normal site traffic flow (see Drawing 11).

3.3.3 Power Control Unit(s) (PCUs)

The power control unit(s) (PCUs) will produce a maximum power output of~~ 2,000 KW~~1,000 KW. The average estimated usage is ~~1,300~~800 KW. Because two separate power supply services will be used to provide sufficient power, separate PCUs may be required. The PCU will be controlled by an onsite computer or a remote computer. The PCUs will be equipped with automatic shut-off controls for safety, and manually operated emergency shut off controls.

3.3.4 Extraction Blowers

Two rotary positive-displacement (or similar) vacuum blowers will be installed to extract subsurface vapors. Each blower will be capable of extracting the required vapor volume (460 scfm) for ERH remediation; however, only one blower will be in operation at a time. In this way, ERH remediation will not be interrupted if blower maintenance or repair is required.

3.3.5 Condenser

The condenser will be required to condense steam generated by ERH treatment and extracted by the electrode/vapor recovery wells. The estimated heat duty (required heat removal) for the condenser is 5 million BTU per hour. Approximately 250-500 gallons per minute of cooling water will be required to remove heat from the vapor stream in the condenser.

3.3.6 Cooling Tower

A cooling tower will be required to remove heat from cooling water used in the condenser. Assuming cooling water will have to be cooled 20°F, a cooling tower with a 25 horsepower fan will be required.

3.3.7 Piping

Pipes connecting the ERH extraction wells to the larger manifolds and the ERH blowers will be constructed of CPVC, which is suitable for the high temperatures of the steam and vapor collected. Because of its short duration, and because the ERH area will be fenced to limit access, all of the ERH piping will be installed aboveground. The aboveground ERH lines will be insulated as a safety precaution to prevent burns, and to limit the amount of vapor that condenses within the piping.

3.3.8 Carbon Adsorption

Carbon adsorption will be used to treat the condensed water prior to discharge. Two carbon units will be used in series, each containing at least 125 pounds of carbon, as described in paragraph 1.6 of Section 11302 of the specifications.

3.3.9 Gas Treatment

Extracted gas and vapors will be treated by an air emissions control system as described in Section 4 of this DAR.

TABLE 3-1

SUMMARY OF ERH DESIGN PARAMETERS FOR ERH

COMPONENT	PARAMETER	VALUE
Electrodes	Number of Boreholes	12 - 18
	Number of Electrodes per Borehole	2
	Depth of Borehole	55 feet
	Depth of lower electrode	45 – 55 feet bgs
	Depth of upper electrode	10 – 45 feet bgs
Vapor Recovery Wells	Number	12 - 18
	Diameter	4-inch
	Depth (in sand)	10 feet
	Screen Length (in sand)	7 feet ±
Temperature Monitoring Points	Number	13
	Depth	55 feet
	Thermocouple Interval	5 feet
	Number of thermocouples per point	9
Power Control Unit	Power Output	~~2,000~~ 1,000 kilowatts Total
Extraction Blowers	Type	Positive Displacement
	Number	2
	Capacity	460 scfm (each)
Condenser	Heat Removal	5 million BTU/hr
	Condensate Generation Rate	~~6~~ 4 gallons per minute
	Cooling Water Required	250 - 500 gallons per minute
Cooling Tower	Fan	25 horsepower

4.0 AIR EMISSIONS CONTROL

4.1 Description

Air emissions will be generated by both the SVE and ERH systems. Emissions from both these systems will be controlled (treated) before discharge to the atmosphere.

4.2 Design Criteria

Design criteria for air emissions control are as follows:

Control Technology: A catalytic oxidizer will be used to control emissions from the SVE and ERH systems.

Sequencing of Remediation: ERH remediation will be completed before SVE remediation begins. The catalytic oxidizer(s) will be sized to treat only one emissions stream at a time (see Design Issues-Memo 2 in Appendix 1B).

Fuel: Natural gas (available onsite) will be used to fuel the catalytic oxidizer burner.

Destruction Efficiency: A minimum 95% destruction efficiency for volatile organic compounds (VOCs) will be required.

Safety: The catalytic oxidizer will automatically shut down if incoming vapor concentrations exceed 25% of the lower explosive limit (LEL).

4.3 Design Parameters

Design parameters for air emissions control are presented in Table 4-1. These parameters are discussed in Appendix 4A. Calculations to estimate emissions for purposes of completing an air permit application are presented in Appendix 4B.

TABLE 4-1

SUMMARY OF AIR EMISSIONS CONTROL DESIGN PARAMETERS

PARAMETER	VALUE FOR SVE	VALUE FOR ERH
Vapor Flow Rate	750 scfm	460 scfm
Average VOC Mass Flow Rate	50 lbs/day	50 lbs/day
Peak VOC Mass Flow Rate	500 lbs/day	Not Determined

5.0 OPERATIONAL STRATEGY FOR ELECTRICAL RESISTANCE HEATING (ERH) SYSTEM

5.1 Initial Heating

5.1.1 Overview

Initial heating will take place in a two step process. The much less contaminated zone below the zone of suspected DNAPL will be heated first. This approach is taken to provide a thermal barrier. As contaminated zones are heated, the viscosity of the DNAPL will decrease. Although surface tension remains fairly constant, DNAPL ganglia held in place by surface tension may mobilize as liquids due to the decreased viscosity. Although the density differences between PCE and water narrow somewhat with increasing temperature there is a chance that PCE DNAPL may migrate downward before temperatures have risen to the boiling point. By creating a thermal barrier below the zone of suspected DNAPL, any mobilized contaminant would migrate into a zone that is already at the boiling temperature. When these contaminants reach this zone, they will vaporize rather than continuing on as liquids. This would arrest the downward migration of PCE the contamination.

In order to provide sequential heating, each zone will have to be capable of being heated independently. Therefore the specifications will require that at a minimum, two independently operated and controlled electrodes, segmented by depth, be installed at each electrode location.

5.1.2 Boiling Temperature Definition

The initial heating scheme described in this section, as well as the Performance Monitoring requirements described in the next section, rely on predicted boiling temperatures. These boiling temperatures vary with depth, and would be different with or without the presence of a separate DNAPL phase. When only a single liquid phase (water) is present, the boiling temperature is defined as the temperature where the vapor pressure of water equals the hydrostatic pressure at a given depth.

Where both water and PCE DNAPL are present, the boiling point is lower. Since both these free phases contribute independently to the total vapor pressure exerted by subsurface fluids, then equilibrium will shift to the vapor phase (i.e. both liquids will "boil") when the sum of the vapor pressures of these two liquids reach "ambient" pressure. The "ambient" pressure would be one atmosphere at the top of the water table, but would increase deeper in the aquifer according to the hydrostatic pressure.

URS performed a calculation estimating the two-phase boiling temperatures at the water table (~12 feet bgs), and at five foot intervals from 15 feet bgs to 45 feet bgs (see Appendix 5A). The boiling points were found to vary approximately linearly from about 88°C at the water table to about 108°C at 45 feet bgs.

These temperatures are estimated based on the water table at 12 feet bgs. Prior to the start of remediation, the actual depth to groundwater will be measured and target temperatures adjusted accordingly. During remediation, the water table may rise due to the vacuum drawn on the vadose zone by the vapor recovery program, and the boiling action caused by the heat input. However, this is not expected to significantly affect the boiling points estimated based on existing hydrostatic pressure. The boiling point at depth is governed by the absolute pressure, which is the hydrostatic pressure plus the "atmospheric" pressure above the water table. The increased hydrostatic pressure during vapor recovery is offset by the lower "atmospheric" pressure at the top of the water table, resulting in an absolute pressure at depth similar to pretreatment conditions. Any increase in water table elevation that is caused by bubble formation in the treatment zone will not contribute significantly to hydrostatic pressure since the effective density of the water will be commensurately reduced by the presence of lighter steam bubbles in the liquid.

Realizing that boiling temperatures will rise as DNAPL is removed through volatilization and dissolution, the contractor will also be required to supply electrical power at a minimum rate once target temperatures are reached. Once boiling has been achieved, most energy added to the subsurface goes towards volatilizing water and volatile organic contaminants with secondary amounts to conductive losses. Energy requirements for boiling would not change significantly with temperature. Thus, as boiling points rise following removal of DNAPL, requiring a minimum power input will ensure that the contractor maintains boiling conditions needed to cause steam stripping of dissolved PCE from the groundwater.

URS estimated the minimum energy input through calculating the energy required to boil water at a sufficient rate, and estimating the amount of heat lost through convection and conduction. The first step in this process is establishment of the "sufficient rate" of boiling. Ideally, the rate of steam generation would be set through derivation of steam/water ratios in the subsurface suitable for effective steam stripping removal of dissolved PCE contaminants. However, applying ex-situ standard steam stripping design techniques to the subsurface would require use of too many assumptions to be meaningful. Furthermore, the mass transfer from dissolved phase to steam phase would be much more efficient than with conventional ex situ steam stripping since the steam bubbles are generated directly from the contaminated water thus providing gas/liquid equilibrium conditions immediately upon bubble formation. Rather, URS selected a minimum steam stripping rate by considering ~~two~~ three factors: hydraulic control provided by the steam generation, ~~and~~ review of condensate removal rates at other successful implementations of ERH technology, and considering rule-of-thumb rates of energy input typically used by ERH vendors. Additionally, the amount of energy realistically available at the site ~~must be~~ was also considered.

By evaluating a range of simplifying assumptions regarding the hydraulic behavior of the ERH treatment zone, URS estimated that a steam generation rate equivalent to between 1.3 and 10 gpm of condensed steam would be sufficient to recover, in a timely manner, the increased volume of water in the source zone resulting from thermal expansion during heating (see Appendix 5B). Although these calculations show that ERH would not, even in the absence of steam generation, significantly increase the rate of contaminant migration from the source zone (due to thermal expansion or increased DNAPL dissolution rates), maintaining a net influx into the treatment zone is beneficial to overall remediation of the site (i.e. OU1 and OU2), and increases the contaminated water that is treated by this technology.

Supplementing these calculations, URS reviewed condensation rates (the best available measure of steam generation rates) at two other sites where such data were available. Normalized for the volume of the treatment area at the West Side site, condensation rates at the sites reviewed ranged from 3.4 gpm to 12.42 gpm (see Appendix 5C). However, these rates were scaled on a volume basis from smaller sites. Approximate rates of condensate may not necessarily scale linearly with volume, and these calculated rates may be higher than what would truly correspond to treatment of 6,000 yd^3 of soil.

Based on this evaluation, URS selected that power input to the system should be sufficient to generate steam corresponding to ~~6~~3 to 4 gpm when condensed. The second step in establishing the minimum energy requirement is determining the energy required to generate this amount of steam.

The energy required to boil ~~6~~3 to 4 gpm of groundwater includes the heat of vaporization of the water, plus the energy input needed to balance conductive losses (convective losses are found to be minimal). The heat of vaporization required to boil ~~6~~ 3 to 4 gpm of groundwater is calculated to be ~~1,000~~500 to 670 KW (see appendix 5D). Conduction losses are estimated to be ~~300~~150 to 300 KW (decreasing as the duration -of boiling increases).~~for a total minimum energy input requirement of 1,300 KW. Conduction losses will decrease with time as the surrounding aquifer heats up~~. Based on these analyses, URS has selected an average heating requirement of 800 KW. This will provide sufficient boiling to accelerate the treatment process and offset conduction losses. It also allows use of approximately 1,000 KW of electrical power available, while allowing for 80% uptime efficiency and/or allow power for blowers and other ancillary equipment. ~~Thus maintaining a constant minimum power input of 1300 KW will over time increase the rate of steam generation, resulting in more efficient treatment.~~

5.1.3 Sequential Zone Heating

The suspected DNAPL zone extends to 45 feet bgs. Therefore, the zone from 45 to 55 feet bgs will be heated first to provide the barrier protection zone. Because this zone is not believed to contain DNAPL, the boiling temperatures of this zone are calculated based on an assumption of only one liquid phase is present (e.g. no DNAPL). This results in a higher target temperature for these zones, specifically 120°C at 45 feet bgs and 122.5°C at 50 feet bgs.

Because there is a delay between the onset of electrical resistance and achieving target temperatures, the contractor may start the heating of the DNAPL zone before the thermal barrier zone reaches pure water boiling temperatures. However, the barrier zone must be brought to the boiling temperature of a water/DNAPL mixture, which is 108°C at 45 feet bgs and 110°C at 50 feet bgs, prior to starting heating of the DNAPL zone. Measurement of temperature compliance is discussed in the following section.

5.2 Contractor Performance Monitoring and Evaluation

The prime performance requirement for the contractor will be a requirement to achieve certain temperature criteria throughout the treatment area.

The following temperature goals are set for the DNAPL zone (based on two-phase boiling) and in the thermal barrier zone (based on water-only boiling):

	Depth (Feet Bgs)	**Temperature °C**
(two-phase zone)	15	90
	20	94
	25	97
	30	100
	35	103
	40	105
(one-phase zone)	45	120
	50	122.5

In actual practice, there will not be a sharp distinction between the two-phase (DNAPL) zone and the one-phase zone. However, it is not possible to predict where in the DNAPL zone sufficient portions of DNAPL ganglia are or are not present to better specify zone-specific temperature goals. By requiring higher single-phase concentrations in the barrier zone (by comparison, the two-phase temperatures for 45 and 55 feet are 100°C and 110°C, respectively), the design minimizes the chance of vertical migration and maximizes the extent to which dissolved phase PCE in this zone is steam-stripped from this zone.

The contractor will be required to monitor temperatures at 13 horizontal locations, and at ~~nine~~eight depths at each location. The vertical locations will be at five-foot intervals starting at about 10 feet bgs. Of the 13 locations, 9 will be within the zone of heating and will be used to measure successful treatment performance. Of these 9, four will be located at the corners of the 60 × 60 foot area, and the other 5 located within the square. The remaining 4 temperature monitor locations will be located 10 feet to the north, south, east, and west of the treatment area. These locations will monitor temperature for informational purposes only. In summary, the horizontal locations are:

- locations at the corners of the treatment area square
- locations within the treatment area
- locations that will be 10 feet away from the center of each side of the treatment area square

The contractor will be required to achieve an average of 95% of the calculated boiling points at the nine in-zone measurement locations, at each depth at or below the groundwater level. The percentage compliance will first be calculated at each temperature monitoring point, based on the calculated boiling point which in turn is based on the depth of water at which the thermocouple was originally installed. Because various temperature scales are not related proportionally, the percentage metric is defined to be calculated based on measurement of temperature in degrees Celsius. If temperatures above the theoretical boiling point are achieved (due to absence of DNAPL), then the temperature monitoring point would be assigned a 100% compliance value (i.e. not, for example, 110%). The 72 individual percent compliances (nine locations × ~~approximately~~ eight depths) will then be averaged to obtain the average compliance. Since temperature will be monitored on a continuous basis, percentage calculations will be performed once per day. Additionally, no single thermocouple should read below 80% of its depth-specific target temperature.

5.3 Remediation Progress Monitoring

5.3.1 Remediation Progress Definition

The measurement of the progress of PCE removal from the subsurface is distinct from the contractor performance requirements. Remediation progress monitoring, although physically performed by the remediation contractor, will be carried out to provide NYSDEC with information with which to make decisions regarding duration of system operation.

5.3.2 Mass Basis as the Primary Progress Metric

The primary mechanism of remediation progress monitoring will be measurement of the amount of PCE that has been removed from the subsurface. The intent of defining a remediation progress metric is to provide a default condition where the treatment can be declared substantially complete and where only asymptotic removal rates are being achieved.

Table 5-1 presents a statistical summary of the contamination as measured in a 10 × 12 foot subsection of the 60 × 60 foot main source area that was sampled as part of the chemical oxidation pilot study (URS 2002b):

Table 5-1
Statistical Summary of Soil Sample Analyses
Before and After Chemical Oxidation Treatment

PCE (m~~µ~~g/kg)

	Vadose		Saturated		Combined	
	Before	After	Before	After	Before	After
No. of Samples	0.009	0.010	0.030	0.030	0.039	0.040
Max. PCE conc. (µg/kg)	6,100	10,000	320	6,600	6,100	10,000
Min. PCE conc. (µg/kg)	ND	0.005	ND	0.001	ND	0.001
Arithmetic mean (µg/kg)	615	015	22	238	174	432
Geometric mean (µg/kg)	0.419	0.639	0.152	0.228	0.191	0.295
Median (µg/kg)	0.038	0.045	0.044	0.096	0.043	0.096

Although additional sampling was conducted during the RI, this data set represents the most intensive investigation of the zone that would be treated in situ. Especially considering the limited number of RI samples taken in this source zone were consistent with the levels observed during the chemical oxidation pilot testing, the pilot test data set is used as the basis of the PCE mass calculations. Based on the arithmetic mean from these data, we may assume an average concentration of about 200 mg/kg. This value was arrived at by taking a value at the lower end of the "combined" arithmetic means yet at the upper end of the arithmetic mean of the saturated zone, since more treatment would be directed towards the saturated zone (the vadose zone is presumed to be readily treated by the vapor recovery portion of these technologies). Based on a

200 mg/kg basis, approximately 4,000 pounds of PCE may be present in the 60 ft × 60 ft (area) × 45 ft (depth) source zone. However, experience has shown that using such estimates for the purposes of remediation planning can be inaccurate. Therefore, remediation progress will be monitored to determine when the removal rates are trending toward an asymptotic low point.

The rate of PCE recovery is expected to be high at first as the high levels in soil gas are recovered upon start up of the vapor recovery system. This recovery is only vadose zone PCE, not the saturated zone PCE that is the main target of ERH treatment. The concentrations, and thus recovery rate of PCE should decrease rapidly after start up. However, within a few weeks, as the saturated zone reaches boiling temperatures, the rate of PCE recovery should rise again through a peak, and then tail off. Because the initial PCE concentrations and recovery rate should be high due to initial soil gas removal, and the height of the recovery peak depends on subsurface mass transfer conditions in the subsurface, it is difficult and not very meaningful to define the substantially complete point based on a predetermined fraction of early-phase PCE concentrations.

Instead, the substantially complete guidelines will be set on a mass recovery basis. The area under the mass recovered vs. time curve is the overall mass recovered. Effective treatment will be defined as reaching an asymptotic condition where the weekly rate of PCE collection represents only a small fraction (for example around 1%) of the total PCE collected since start up. No fixed percentage value is established to determine whether the system should be operated further, or conversely, shutdown. NYSDEC would retain flexibility in these decisions.

5.3.3 Mass Removal Rate Technique

The PCE mass removal rate will be calculated by multiplying PCE concentrations by the extraction rate. PCE concentrations can be measured in two places: (1) in the recovered gas stream in the manifold after the gas streams from all vapor recovery wells are joined together, and (2), in the gas and condensate streams following the condenser. Measurement of the gas before the condenser is complicated by the high temperature of this material, and the fact that some moisture, and possibly some PCE, may condense following sample collection. Measurement following the condenser means that two streams must be measured to account for all recovered PCE: the gas stream, and the condensate stream. Because of the difficulties involved with sampling upstream of the condenser, and because the vast majority of the PCE would remain in the vapor stream following the condenser, sampling would be required only downstream of the condenser. Although most PCE would remain in the vapor stream, both the vapor and liquid streams from the condenser will be analyzed. In order to best calculate the total mass recovered, data need to be collected on a regular, intensive basis. Samples will be taken and analyzed every two days. The mass fraction of PCE to be collected in the aqueous condensate is expected to be much lower than the mass fraction collected in vapor from the condenser. Following the peak in mass recovery rates, the frequency of condensate sampling may be reduced to once per week to reduce costs.

Getting a total mass recovery requires that the flow rates of each of these post-condenser streams be measured. On an ongoing basis, the total flow of each of these streams will be measured and recorded.

5.4 Supplemental Sampling

5.4.1 Soil Sampling

To document the extent of remediation accomplished, confirmatory soil samples will be collected. The confirmatory soil samples would be used to evaluate the effectiveness of the ERH technology and the potential need for future groundwater controls at the site. They might also be used as a basis to continue ERH remediation. As with mass recovery measurements discussed in section 5.3, soil sampling results would not be used as a basis to measure contractor's performance.

Confirmatory soil sampling, whatever its outcome, is not expected to provide a firm basis for restarting the ERH system, provided that ERH performance and operating (P/O) data, as described in section 5.3, had previously justified shutting the system down. ERH would not be shut down if the P/O data indicated high ongoing levels of removal. On the other hand, if the P/O data indicated non-improving (e.g., asymptotic) and low removal levels, there is no reason to think that restarting the system in its current configuration would improve treatment efficiency or be cost-effective.

Notwithstanding the above arguments, the contract documents will include the flexibility to restart ERH as an option. Such flexibility is warranted by the innovative nature of the technology, the site's high profile and aggressive schedule, the potential for unknown future agency or public input concerning "walk-away" criteria, and the possibility that confirmatory soil sampling may ultimately play a larger role than anticipated.

The Contractor will be required to collect and analyze a specific quantity of samples (to be specified in the contract documents). Special techniques will be specified for sample collection to minimize the potential for loss of volatile organics from the sample. These techniques would include immediate capping of the sample collection tube followed by immediate cooling in an ice water trough. When cooled, the sample sleeve would be cut open, and a core would be taken from the sample and placed in a vial for delivery to the laboratory. Samples would be taken from random locations throughout the area and depth of treatment. The results of these samples will be submitted to the NYSDEC for review and evaluation.

5.4.2 Groundwater Sampling

Because of the large extent of the plume, extending far offsite, absolute remediation of groundwater is not a goal of ERH treatment. However, for the same reasons why confirmatory soil samples will be taken, groundwater samples will also be taken before and after treatment. Groundwater will be sampled from eight newly installed wells. Four shallow/deep pans will be installed. Wells shall be located as shown on Drawing 4. Because temperatures would be high, special techniques would be required for groundwater sampling. Specifically, groundwater would be pumped out of the well and through a heat exchanger coil to reduce its temperature prior to placement in the sampling container.

6.0 UTILITIES

6.1 Utility Requirements

Utilities required for the remedial systems include electricity, gas, water, and sewer. These requirements are discussed below.

Electric: The major power requirements is for the ERH power control unit. The estimated maximum power input for ERH is ~~2,000~~ 850 to 950 KW. Additional power will be required for blowers and pumps. The total estimated power requirement is ~~2,100~~1,000 KW. A typical power control unit operates on a typical voltage of ~~12,470 to 13,800~~480 volts.

Natural Gas: Gas will be required for the catalytic oxidizer. The estimated gas requirement is 400 standard cubic feet per hour (scfh).

Water: Cooling water will be required to condense steam extracted by ERH vapor recovery wells. The estimated water recirculation requirement is 250-500 gallons per minute.

Sewer: Water (condensate) from the ERH system will be treated and discharged to the sanitary sewer located on 180th Street. Permit requirements for discharge are discussed in Section 7.0.

6.2 Existing Utilities

Existing utilities are shown on Drawing 2. They are described below.

Electric: Electrical power is available on site. Utility poles are located on the property about 100 feet south of the bus garage. The nearest location with 13,200 volt power will be determined.

Natural Gas: There is a natural gas line on site. A meter is located on the east side of the onsite bus garage.

Water: Water is available on site. Water valves are located on 180th Street.

Sewer: Several sewer manholes are located on 180th Street. Sewers are regulated by the New York City Department of Environmental Protection (NYCDEP).

7.0 PERMIT REQUIREMENTS

Preliminary evaluation indicates that application or approvals will be required for the discharge of condensate after treatment and air emissions. Permit requirements are discussed below.

Discharge of Treated Water: Treated water from the condenser will be discharged to the sanitary sewer. Discharge is regulated by the New York City Department of Environmental Protection (NYCDEP). Permit requirements will be discussed and negotiated between NYSDEC and NYCDEP. Once requirements have been clarified, URS will submit the necessary information to the NYCDEP for the discharge to the sewer.

Air Emission: URS will submit a permit application equivalent to the NYSDEC for emissions from the thermal oxidizer(s) used for ERH and SVE.

8.0 OPERATION, MAINTENANCE, AND MONITORING

This section of the DAR outlines the general requirements for preparation of an operation, maintenance and monitoring (OM&M) manual for the site, outlines the components of the long-term sampling program, and identifies who will be responsible for performing the various components of the operations and maintenance.

8.1 Manual Preparation

Development of an (OM&M) manual will be a required element of the contract documents. The OM&M manual must contain a description of all components of the site remedy, instructions for operation and maintenance of the systems, contingency plans, and long-term monitoring plans, including sampling protocols and health and safety procedures. The OM&M manual must be complete with sufficient information and instruction in order to allow the Department, or a subcontractor to the Department, to effectively operate the remedial systems at the site. Because the ERH system will be constructed, operated and removed by the Contractor prior to turnover to the Department, this component of the remediation will not be addressed by the OM&M manual.

The contractor, who will supply all of the technical information for the remediation systems and equipment, will first develop the manual during construction. The manual will then be updated and completed by the Department who will add all of the requirements in regard to the monitoring of the systems and measuring progress in the overall site remediation. The manual will be developed in an electronic format to the extent possible to allow for periodic revisions and updates as required.

8.2 OM&M Manual Outline

The preliminary outline proposed for the OM&M manual is as follows:

- Introduction – including purpose and scope of the manual

- Remediation Overview – a general description of the site remediation activities and a summary of all appropriate background information.

- SVE System Description – a description of the overall system and all components, including general design criteria, equipment model numbers, and supplier information

- SVE System Operation – startup and shutdown procedures, alarm procedures, and typical operating parameters

- SVE Maintenance and Inspection –routine maintenance checklists and tasks for all system components including troubleshooting guidelines

- SVE System Sampling –monitoring requirements and sample collection requirements associated with the operation of the SVE system. Includes the measurement of vacuums and flowrates from the SVE extraction wells, collection of vapor samples from the wells and from the system discharge after treatment.

- Long-Term Monitoring – a summary of all site monitoring and sampling requirements not directly associated with the operation of the SVE system. Includes frequencies and locations for the collection of water levels and groundwater samples.

- Utilities – a summary of all utility connections, account numbers, billing information, contact persons, and copies of all permits

- Site Maintenance and Housekeeping – housekeeping procedures for the operation of the SVE system including handling and disposal procedures for condensate, exhausted carbon, and all other incidentals generated by the operation of the system.

- Recordkeeping and Reporting – detailed procedures and forms for recording and reporting O&M events and data. Outlines report formats, trend analysis, and documents repairs, replacements, or other system modifications. Includes report distribution information.

- Contingency Plans – outlines procedures and methods to handle problems that could reasonably occur at the site.

Appendices to the manual will include:

- Record Drawings
- Equipment Manuals and Technical Literature
- Warranties
- Record of Decision
- Discharge Permits
- Monitoring and Maintenance Forms
- Boring Logs
- Well Construction Information
- Health and Safety Procedures
- Sampling Protocols and Quality Assurance / Quality Control Procedures

8.2 Long-Term Monitoring

Additional monitoring not directly associated with the SVE or ERH systems will be conducted to document the remedial progress at this site. While the ERH activities at this site will be relatively short-term, source removal and the operation of the groundwater extraction system on the adjacent property will continue to have a significant impact on the groundwater at this site. Long-term monitoring will include measurement of water levels across the site and periodic collection of groundwater samples for VOC analysis. A total of 10 monitoring wells are proposed for sampling, 5 shallow wells and 5 deep wells. Table 8-1 summarizes the wells proposed for the quarterly sampling.

8.3 OM&M Responsibility

The following section outlines the major OM&M tasks at this site, and identifies the party that will be responsible to carry out these tasks. In general, the contractor will be responsible for the performance of OM&M activities while the contractor is actively involved with the construction and operation of the remedial systems at the site. Once the contractor's work has been completed, the Department will be responsible for the OM&M, most likely through a standby contractor (engineer).

8.3.1 Contractor OM&M Responsibilities

- ERH operation, including all associated sampling and monitoring
- SVE operation until system turnover to Department, including all associated sampling and monitoring, provision of supplies and disposal of all waste streams
- Performance of site-wide monitoring (groundwater elevations and monitoring well samples across the site) until turnover of the SVE system to the Department (assumed to consist of three quarterly sampling events)
- Preparation of the "Draft" OM&M manual
- All recordkeeping and report preparation until turnover of the SVE system to the Department
- All other activities as identified in the OM&M manual

8.3.2 Department/Engineer OM&M Responsibilities

- Review of the Contractor's OM&M manual submittal. Preparation of remaining sections not associated with the Contractor.

- SVE operation upon system turnover to Department, including all associated sampling and monitoring, provision of supplies and disposal of all waste streams
- Performance of site-wide monitoring (groundwater elevations and monitoring well samples across the site) upon turnover of the SVE system to the Department
- All recordkeeping and report preparation upon turnover of the SVE system to the Department
- All other activities as identified in the OM&M manual

9.0 PROJECT CONSTRUCTION SCHEDULE

Figure 9-1 shows the proposed construction schedule for the remedial action at the West Side Corporation site. The schedule is based on a Notice-to-Proceed (NTP) date of August 15, 2003.

For the purpose of determining Substantial Completion for the work at the site, the work was broken into four separable parts of completion. Generally, these parts are defined as follows:

Part A -	Startup and Test ERH	125 Days from NTP
Part B -	Complete ERH and Remove System	385 Days from NTP
Part C -	Startup and Test SVE	90 Days from Part B
Part D -	Turn System Over to the Department	200 Days from Part C

REFERENCES

Tams Consultants, Inc. (TAMS) and GZA Geo Environmental of New York (GZA) 2000. Feasibility Study West Side Corporation Site; prepared for NYSDEC, Albany, NY: July.

URS Consultants, Inc. (URS) 2001. SVE Pilot Test Report; prepared for NYSDEC, Albany, NY: December

URS Consultants, Inc. (URS) 2002a. Revised In-Situ Thermal Treatment Feasibility Evaluation; prepared for NYSDEC, Albany, NY: August

New York State Department of Environmental Conservation (NYSDEC) 2000. Record of Decision West Side Corporation Site Operable Unit No. 1 (On-Site); NYSDEC, Albany, NY: July.

URS Consultants, Inc. (URS) 2002b. West Side Corporation Site, No. 2-41-026, Chemical Oxidation Pilot Test Report, prepared for NYSDEC, Albany, NY. January.

APPENDIX 1A

ZONE OF ERH APPLICATION

ZONE OF ERH APPLICATION

In situ thermal treatment will be applied to treat subsurface contamination at an area and depth inferred by measurements taken during subsurface investigations conducted in 1999 (GZA 2000) and 2001 (URS 2002), and by historical information about the location of former PCE storage tanks. Five 10,000-gallon storage tanks were located along the east side of the southern portion of the West Side Corporation site building. The tanks were installed side by side for a north-south width of about 60 feet. The area where the tanks were located was sampled during the remedial investigation through collection of soil gas, groundwater, and soil samples. Although the sampling density throughout the site was relatively high, fine-grained delineation of the extent of DNAPL contamination beneath the tank location was not performed. The presence of DNAPL is presumed by the presence of very high soil concentrations (up to 1% PCE detected during chemical oxidation pilot testing) in samples beneath the tank locations, and by the presence of PCE in shallow groundwater at concentrations exceeding the PCE solubility in MW-8S and its replacement, MW-88S. The region near the tank locations was tested by soil and soil gas measurements taken by Geoprobe samples GP-12, GP-16, GP-36, GP-37, GP-38, and in the immediate downgradient areas by GP-6 and GP-35 augmented by groundwater measurements by MW-7S and MW-7D.

ERH treatment is intended to reduce the mass of PCE acting as a future source primarily by volatilizing PCE DNAPL. It is thus targeted to where DNAPL is most likely to be present. It is not aimed to treat all the soil and groundwater contamination at the West Side Corp. site. The following text summarizes the available data that is the basis for applying ERH treatment to a zone of 60 × 60 feet in area, and to a depth of 55 feet.

Vertical Extent

Source area contamination at depths greater than about 20 feet below ground surface (bgs) was investigated only through deep wells MW-8D (and its replacement MW-88D) near the tank locations, the downgradient MW-7D (and its replacement MW-77D), and soil boring samples taken to depths of about 40 to 45 feet during the chemical oxidation pilot test. MW-88D suggests that contamination extended to about 40 feet below ground surface. The soil and soil gas measurements taken from this borehole lead to testing soil down to depths of 45 feet bgs during the chemical oxidation pilot study. These sets of samples showed elevated PCE concentrations (for example, greater than 100 mg/kg) in four of 20 samples taken at about 40 feet bgs (although the most striking aspect of the data was the high degree of variability among the samples taken in relatively close proximity to each other). Therefore, the pilot test data can not be used as evidence that contamination is limited to a maximum depth of about 40 feet bgs.

The conclusion that very high concentrations of PCE, including DNAPL, do not extend much beyond 40 feet bgs is based, rather, on the organic vapor measurements taken at five-foot intervals during the installation of MW-8D. Whereas volatile readings in the upper 40 feet were elevated (as were geoprobe soil gas samples taken elsewhere near the former tank location to depths of about 20 feet bgs), these measurements consistently drop after 40 feet bgs, with an exception at 45 feet bgs (note, however, that groundwater concentrations are elevated at the screened interval located 60 to 70 feet bgs atop the Gardiner clay although this may be due to artifacts from the installation of well MW-8D). The remedial design adopts the interpretation made in the RI that contamination is limited to the upper 40 feet bgs based on the MW-8D organic vapor readings. However, application of ERH will extend to depths of 55 feet bgs. This is primarily intended to provide a heated zone *below* the lowest DNAPL present. However, it does also provide additional protection should DNAPL remain undetected at depths of about 40-50 feet bgs.

Horizontal Extent

Among soil gas, soil and groundwater samples taken in saturated zone (the zone targeted by ERH treatment), the highest concentrations detected are found in the two boring locations (GP-36 and MW-8D) located beneath the former tank location. This is especially true for the organic vapor measurements, which were taken at the highest density throughout the site and thus provide the best direct comparison. However, the organic vapor readings in saturated zone geoprobe samples drop only by about half in samples taken from geoprobe samples taken just outside the of former tank area (GP-12, GP-16, GP-37, GP-35) compared to the samples taken beneath the former tank area (GP-36, MW-8D). While this is probably due to dissolved PCE in the groundwater plume, the lack of a dramatic change means that existing soil and soil gas data can not be considered to definitively define the DNAPL extent to be limited to the former tank area. Rather, the horizontal extent or ERH application is determined primarily by the dimensions of the former storage tanks, and the presumption that PCE DNAPL would migrate predominantly straight down due to the absence of prominent lower-permeability soil strata that would otherwise hold up its vertical migration.

Affect of Extent Assumptions on Design

The high density of sampling in the relatively small area evaluated during the chemical oxidation pilot testing suggested that the DNAPL was dispersed in isolated deposits throughout the saturated zone tested, presumably held by capillary forces. Detection of DNAPL is at best a hit-or-miss exercise using direct sampling techniques. It would not, therefore, make sense to implement a sampling program to further define DNAPL contamination. This DNAPL may be mobilized as a flowing liquid by the heat (as viscosity changes with temperature) rather than vaporized and recovered by the vapor recovery system. However, the goal of the source remedy is to remove as much PCE as possible, not complete elimination of PCE contamination. Migration of dissolved PCE outside the "box" is expected upon startup of the offsite extraction well 24 new in any event. Thus, some minor PCE "escape" would not be significant in the scope of the overall remedy, considering that the vast majority of the PCE would be removed by ERH even if some isolated PCE ganglia were not addressed by ERH. Therefore the uncertainties in actual DNAPL distribution do not call for expanding the treatment "box" beyond the dimensions established above.

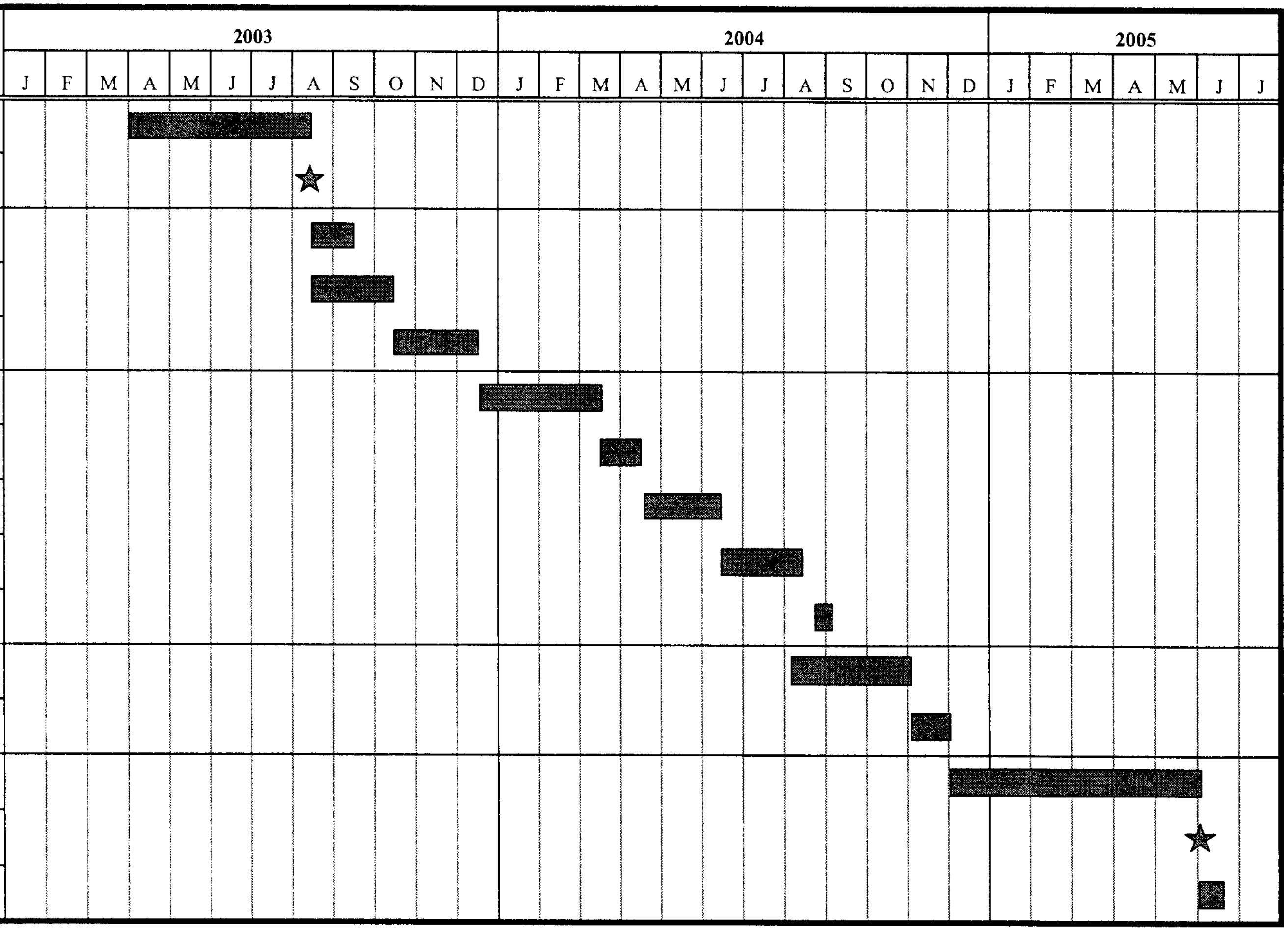
Table 8-1
Summary of Site-Wide Monitoring

Monitoring Well	Monthly VOC Analysis During ERH Activities	Quarterly VOC Analysis[2]	Quarterly Water Levels[2]
MW-1S			X
MW-1D			
MW-22S		X	X
MW-33S			X
MW-3D			
MW-4S		X	X
MW-4D			
MW-55D		X	
MW-66S		X	X
MW-6D			
MW-7S	X	X[1]	X
MW-77D	X	X[1]	
MW-88S	Decomm.		
MW-88D	Decomm.		
MW-9S	Decomm.		
MW-9D	Decomm.		
MW-101S[3]	X	X[1]	X
MW-101D[3]	X	X[1]	
MW-102S[3]	X		X
MW-102D[3]	X		
MW-103S[3]	X		X
MW-103D[3]	X		
MW-104S[3]	X		X
MW-104D[3]	X		
MW-105D[3]		X	X
MW-106D[3]		X	X

NOTES:
1. Samples will not be collected during quarters that the monthly ERH samples are being collected.
2. One of the quarterly measurements should directly preceed the startup of the ERH system, and one should directly preceed the startup of the SVE system.
3. Wells that are being installed as part of the remedial contract.

Table 9-1
Proposed Construction Schedule
West Side Corporation Site Remediation

Task	Begin	End
1. Bid Period	04/01/03	08/15/03
2. Notice to Proceed	08/15/03	
3. Mobilization / Utility Installation	08/15/03	09/12/03
4. Install ERH System	08/15/03	10/16/03
5. Startup and Test ERH System (Part A Completion)	10/16/03	12/18/03
6. Operate ERH	12/18/03	03/18/04
7. Collect Soil Samples / Reporting	03/18/04	04/15/04
8. Restart ERH System (if required)	04/15/04	06/17/04
9. Phase Two Operation (if required)	06/17/04	08/12/04
10. Decommission ERH System (Part B Completion)	08/20/04	09/03/04
11. Install SVE System	08/05/04	11/04/04
12. Startup and Test SVE System (Part C Completion)	11/04/04	12/02/04
13. Operate SVE	12/02/04	06/02/05
14. Turn System Operation Over to the Department	06/02/05	
15. Restore Site and Demobilize (Part D Completion)	06/02/05	06/20/05



NOTES:

1. All dates shown are approximate based on an assumed 8/15/03 date for Notice-to-Proceed.
2. Completion Parts refer to Section VI, Attachment A of the Contract Documents.
3. Schedule is based on "worst case" assumption that restart and additional operation of the ERH system will be required.

N:\11172744.00000\EXCEL\project schedule (table 9-1)

APPENDIX 1B

DESIGN ISSUES MEMO

DESIGN ISSUES – MEMO #1
October 1, 2002

Issue 1: Vertical vs. Horizontal Wells

While the ROD does not specifically require the use of horizontal wells underneath the existing building at the site, both the FS and the ROD were based on this assumption. However, ***URS recommends using vertical wells to extract soil vapor from underneath the building.***

A decision on the use of vertical vs. horizontal wells rests on three main criteria:

(1) Implementability
(2) Effectiveness in capturing contaminated soil gas plumes, and
(3) Impact on building operations

URS recommends this change based on the following analysis:

Implementability:

- Considering that there is no construction information available for the existing building, any subsurface structures or other obstructions are unknown. The likelihood of encountering an obstruction during drilling will be less with vertical wells than horizontal.

- Regardless of other obstructions, there is most likely a deep foundation to the building that will have to be partially excavated and cored to get access underneath the building.

- The cost to install vertical wells is expected to be much less than the cost to install horizontal wells.

Effectiveness

- There is not expected to be any significant difference in the effectiveness of horizontal versus vertical wells.

- The SVE pilot test estimated a radius of influence up to 50 feet, which is much greater than the 20-foot radius of influence assumed in the FS report. This would minimize the number of wells that would need to be installed within the building in order to adequately capture the soil gas plume beneath the building.

Impacts on Building Operations

- Based on the locations of subsurface samples previously collected from inside the building, it is assumed that sufficient access is available for installation of the wells. This will have to be verified with Atlantic.

- If vertical wells are installed at the site, there will be more impact on the inside use of the building as compared to the horizontal wells, which would be installed wholly from outside the building. However, assuming that the use of vertical wells is acceptable, URS proposes that all wells, piping, etc. will be installed below grade, or run vertically to the ceiling to minimize the impact on the operations inside the building.

Issue 2: Isolating Treatment Area

In order to protect site personnel from accidental exposure to the high voltages introduced to the subsurface by the electrodes, ***URS recommends that the entire treatment zone be fenced off during the operation of the ERH system.*** Although exposure to stray voltages is not likely under normal circumstances (the system is designed to allow flow only between electrodes), the use of a fence is considered to be an added protection. Furthermore, this would allow installation of the plumbing and wiring required for ERH implementation above grade, avoiding an estimated $30,000 cost otherwise required to bury these items. Fencing of the treatment area, including a small buffer around the treatment area would isolate an area of about 5,000 square feet from use during treatment. Additional area will be required for the of gas treatment equipment, the condensate treatment equipment and the power control unit.

Issue 3: Start-up Time for Well 24 New

URS recommends that the startup of offsite well 24 new be delayed until after ERH treatment is completed, i.e., approximately one year from now. Despite the groundwater modeling that has been completed, operation of this well would introduce many uncertainties into the design, especially considering the dynamic conditions that would be encountered as the system approaches steady state, or would be encountered if the well were turned off for any reason. Operation of this well would lower the water table. Although this would not significantly affect the amount of energy required to treat the source area, it would complicate the decision regarding where to place the top of the electrodes, including the conductive packing between the electrodes and the borehole walls. Furthermore, the offsite well would change flow patterns, presumably increasing flow through the source zone. Increasing the flow above 1 foot per day would start to significantly increase electricity costs due to convective losses. Flow rates above 10 feet per day would be prohibitively expensive.

DESIGN ISSUES – MEMO #2
October 9, 2002

Issue 4: Sequencing of ERH and SVE

One of the early design issues raised in our September 11, 2002 correspondence was the possible sequencing of ERH and SVE operations. Based upon anticipated cost savings, as well as simplified construction and operation considerations, ***URS recommends that the two systems be operated sequentially, with ERH preceding SVE operations.***

Cost Savings: Most of the cost savings associated with sequential operation of ERH and SVE are based on the fact that the off-gas treatment system will be designed to treat the vapors from only one technology at a time, and therefore be smaller than a system designed to treat both technologies operating concurrently. In addition to the reduced capital costs for this smaller off-gas system, operational costs will also be significantly less. The reduction in operating costs increases with increased operation duration. However, since the duration of treatment (especially SVE) is unknown at present, the real dollar amount of the operational cost savings cannot be fixed.

System Construction / Operation Benefits: There are also construction and operation benefits associated with sequenced operation, including:

- The ERH system will more significantly impact Atlantic by fencing off an important area of their site. By sequencing operations, the Contractor will be able to concentrate the initial efforts on getting the ERH system up and running. This should cause the least impact to Atlantic's operations. The contractor can use the time while ERH is in operation to work on the construction and installation of the SVE system. This is based on the assumption that the ERH equipment is rented and, therefore, should be more readily available than the SVE equipment, which additionally will require construction of a treatment building or skid.

- Contract administration and payments to the Contractor will be easier to determine if each system is kept as a separate completion item. If both systems concurrently share the off-gas treatment system and one of the systems is delayed for any reason, the determination of completion dates, payment terms, etc. may become complicated.

- The area for treatment with ERH is a small portion of the larger Source Area 1 to be treated with SVE. If the two systems operate concurrently, it would be more difficult to distinguish how much remediation is being accomplished via each of the two systems. Separate operation of the ERH system will allow for a more straightforward evaluation of the results.

Issue 5: Confirmatory Soil Samples

Another early design issues raised in our September 11, 2002 correspondence was need for confirmatory soil sampling, and the relationship between soil sampling and the determination of a "walk-away" point for the remedial contractor. ***URS recommends that confirmatory soil samples be collected, but that they not be used as criteria for determining the Contractor's "walk-away" point. Rather, the confirmatory soil samples would be used to evaluate the effectiveness of the ERH technology and the potential need for future groundwater controls at***

the site. The "walk-away" point would be based upon operating and performance data (to be addressed in future design memoranda). URS further recommends that, for maximum flexibility, the contract documents be structured to provide for restarting the ERH system as an alternate bid item.

Rationale: URS believes that confirmatory soil sampling, whatever its outcome, would not provide a firm basis for restarting the ERH system, provided that ERH performance and operating (P/O) data had previously justified shutting the system down. ERH would not be shut down if the P/O data indicated high ongoing levels of removal. On the other hand, if the P/O data indicated non-improving (e.g., asymptotic) and low removal levels, there is no reason to think that restarting the system would improve treatment efficiency or be cost-effective. In addition, for confirmatory soil sampling to be used as a walk-away criterion for the Contractor, there would need to be a stronger statistical "before-versus-after" comparison than we feel would be likely to exist on the basis of sampling results. This, plus the anticipated high cost of providing for the restart of ERH within the base bid, and the accompanying prolonged disruption of normal site activities, seem to weigh against the use of confirmatory soil sampling for this purpose.

Bid Alternate: Notwithstanding the above arguments, we recommend providing the flexibility to restart ERH as an option, or bid alternate, within the contract documents. Such flexibility is warranted by the innovative nature of the technology, the site's high profile and aggressive schedule, the potential for unknown future agency or public input concerning walk-away criteria, and the possibility that confirmatory soil sampling may ultimately play a larger role than we recommend. Under the bid alternate approach, the contract documents would include separate bid items for the following: (1) ERH standby time; (2) ERH restart costs; and (3) ERH monthly operation costs. These optional items would be exercised at the discretion of the NYSDEC.

Confirmatory Soil Sampling: For the purposes describe above, confirmatory soil sampling will also be included in the contract documents. The Contractor will be required to collect and analyze a specific quantity of samples (to be determined by URS and the NYSDEC). The results of these samples will be submitted to the NYSDEC for review and evaluation.

DESIGN ISSUES – MEMO #3

October 15, 2002

Performance Requirements Issues

This memorandum addresses two related design issues: the requirements for measuring the performance of the contractor (that is, defining the minimum requirements) and the determination of the "walk away point". This determination of the end point of treatment is not a criterion that we are placing on the vendor since insufficient information exists to expect vendors/contractors to guarantee contaminant removal performance of the system.

Issue 6: Contractor Performance Requirements

URS recommends that the prime performance requirement for the contractor will be based on subsurface temperatures. The contractor will be required to achieve certain temperature criteria throughout the treatment area for a fixed lump sum cost, and then maintain these temperatures for reimbursement on a per-week cost. The per-week cost would include separate costs for electricity, which would be reimbursed on an "actuals" basis up to a maximum amount bid.

The temperatures that must be achieved are based on the temperatures that correspond to a volatilizing mixture of the two liquid phases present: water and PCE. Since both these free phases contribute independently to the total vapor pressure exerted by subsurface fluids, then equilibrium will shift to the vapor phase (i.e. both liquids will "boil") when the sum of the vapor pressures of these two liquids reach "ambient" pressure. The "ambient" pressure would be one atmosphere at the top of the water table, but would increase deeper in the aquifer. It is valid to assume that the pressures deeper in the aquifer will be equal to the hydrostatic pressures exerted by the water at the given depths below the water table. Actual ambient pressures at depth may be slightly lower once boiling starts since the bubbles may reduce the apparent density of water. This would be consistent, also, with a net inflow into the heated area as water flows to replace the water that is lost as steam. This flow pattern would imply a lower pressure, and thus lower temperature, in the boiling zone.

URS performed a calculation estimating the two-phase boiling temperatures at the water table (~12 feet bgs), the bottom of the treatment area (~55 feet bgs or ~43 feet below the water table), and in the middle of these two zones. The boiling points were found to vary approximately linearly from about 88°C at the water table to about 112 °C at 55 feet bgs. The variation of boiling point with depth does not mean that some zones will boil and others will not. At each and every pressure, heat will continue to be absorbed as it is produced by electrical resistance. Heat will be absorbed either to increase temperature in accordance with the local heat capacity of the water, DNAPL, and sand, or, once the boiling point is reached, will be absorbed by the heat of vaporization, being used to convert liquids to gas. While there will be some conduction of heat from the higher temperatures at deeper depths to the higher elevations, this will be dwarfed by the convective transfer of heat from the lower regions to the upper regions. The produced gases will cool as they rise to the lower-boiling-point regions higher up. However, the gasses will not condense, as the boiling points are lower in these lower pressure zones.

The contractor will be required to monitor temperatures at 12 horizontal locations, and at eight depths at each location. Of the 12 locations, 8 will be within the zone of heating and will be used to measure successful treatment performance. Of these 8, four will be located at the corners of the 60 × 60 foot area, and the other 4 located within the square. These inner four samples must be further located at the center of 4 of the triangular grids that will be formed by the electrode placement. The remaining 4 temperature monitor locations will be located 10 feet to the north, south, east, and west of the treatment area. These locations will monitor temperature for informational purposes only. In summary, the horizontal locations are:

- 4 locations at the corners of the treatment area square,
- 4 locations within the treatment area, each located at the center of electrode grid triangle, and
- 4 locations that will be 10 feet away from the center of each side of the treatment area square.

The vertical locations will be at five-foot intervals starting at ~3 feet below the water table (15 feet bgs), to ~38 feet below the water table (50 feet bgs).

The contractor will be required to achieve an average of 95% of the calculated boiling points at the eight in-zone measurement points. The percentage compliance will first be calculated at each temperature monitoring point, based on the calculated boiling point which in turn is based on the depth of water at which the thermocouple was originally installed. The 64 individual percent compliances (eight locations × eight depths) will then be averaged to obtain the average compliance. Since temperature will be monitored on a continuous basis, percentage calculations will be performed once per day. ***Additionally, no single thermocouple should read below 80% of its depth-specific target temperature.***

To structure the bid items for these requirements, URS would require a lump sum bid from the contractor for getting the entire treatment zone (including the thermal barrier) to target temperatures as defined above. Once target temperatures are reached, payment would be on a per-week bid price for system operation, with the requirement for maintaining temperatures during operation.

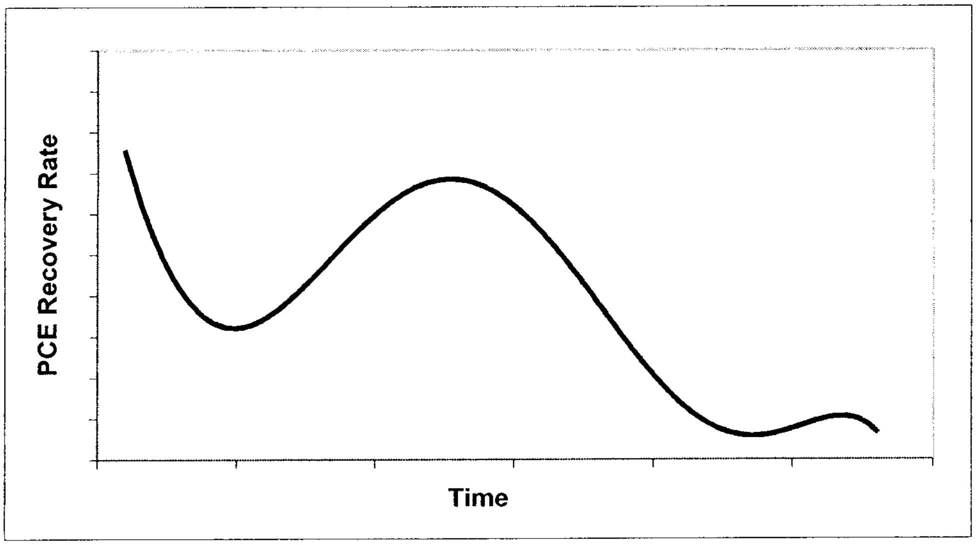
Issue 7: Treatment Performance Measurement

Distinct from the contractor performance requirements is the measurement of the effectiveness of the treatment. Effectiveness is measured by the amount of PCE that is removed from the subsurface. Effectiveness measurement may be supplemented by soil sampling (this was discussed separately in last week's design memo), but is primarily measured through the amount of PCE recovered and the rate at which it is recovered.

URS recommends that effective treatment be defined as reaching an asymptotic condition where the weekly rate of PCE collection represents only 1% of the total PCE collected since start up. However, this 1% value is not intended to be a hard and fast number that will require continued operation, or conversely, early shutdown, of the system. DEC would retain flexibility in these decisions.

PCE recovery can be measured in two places: (1) in the recovered gas stream in the manifold after the gas streams from all vapor recovery wells are joined together, and (2), in the gas and condensate streams following the condenser. Measurement of the gas before the condenser is complicated by the high temperature of this material, and the fact that some moisture, and possibly some PCE, may condense following sample collection. Measurement following the condenser means that two streams must be measured to account for all recovered PCE: the gas stream, and the condensate stream. Getting a total mass recovery volume means measuring the volumes and flow rates of each of these streams. Because of the difficulties involved with sampling upstream of the condenser, and because the vast majority of the PCE would remain in the vapor stream following the condenser, sampling would be required only after the condenser. Although most PCE would remain in the vapor stream, both the vapor and liquid streams from the condenser will be analyzed. On an ongoing basis, the total flow of each of these streams will be measured and recorded as well.

The rate of PCE recovery is expected to be high at first as the high levels in soil gas are recovered upon start up of the vapor recovery system. This recovery is only vadose zone PCE, not the saturated zone PCE that is the main target of ERH treatment. The concentrations, and thus recovery rate of PCE should decrease rapidly after start up. However, within a few weeks, as the saturated zone reaches boiling temperatures, the rate of PCE recovery should rise again through a peak, and then tail off.



The intent of defining an effectiveness performance metric is to provide a default condition where the treatment can be declared substantially complete and only asymptotic removal rates are being achieved. Because the initial PCE concentrations and recovery rate should be high due to initial soil gas removal, and the height of the recovery peak depends on subsurface mass transfer conditions in the subsurface, it is difficult and not very meaningful to define the substantially complete point based on a predetermined fraction of early-phase PCE concentrations. Instead, the substantially complete guidelines will be set on a mass recovery basis. The area under the mass recovered vs. time curve is the overall mass recovered. We will define an asymptotically complete condition to be when the weekly rate of PCE collection represents only 1% of the total PCE collected since start up. In order to best calculate the total mass recovered (i.e., the area under the graph), data need to be collected not only on a regular, intensive basis. Samples will be taken and analyzed every two days.

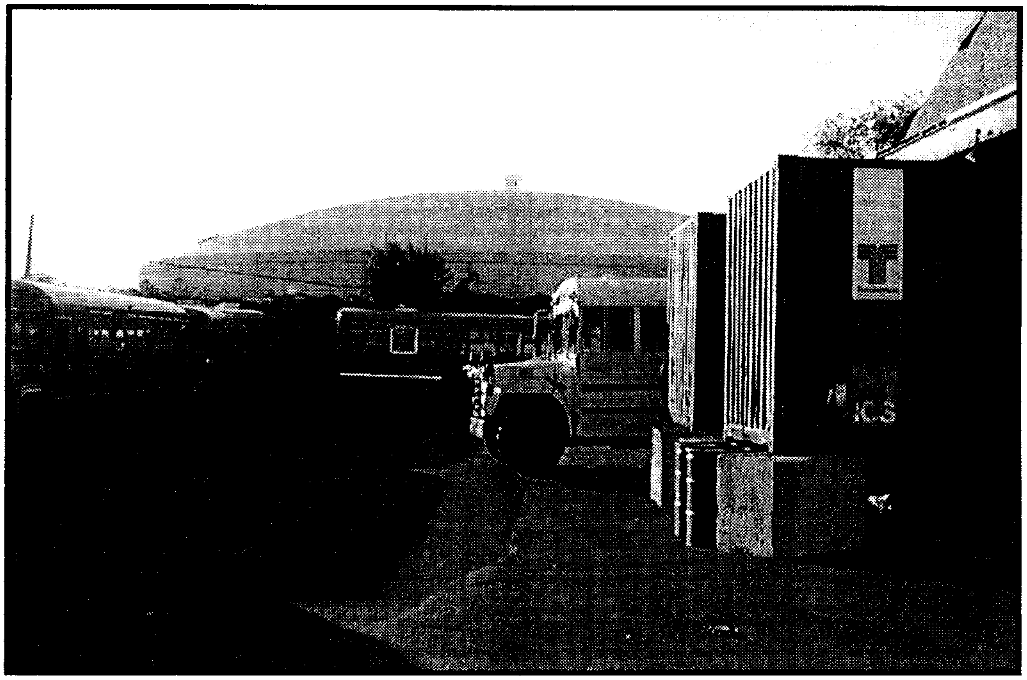
These measurements are to be used as a tool by the DEC to make operational decisions. These data will not be used to define contractor performance. The contractor performance requirements are specified by the temperature requirements outlined in Design Issue #6. The contractor will supply unit rates for weekly operation following achievement of target temperatures. The DEC would direct the contractor to operate the system on a week-by-week basis until the monitoring data suggest that the asymptote is reached.

APPENDIX 1C

SITE PHOTOS

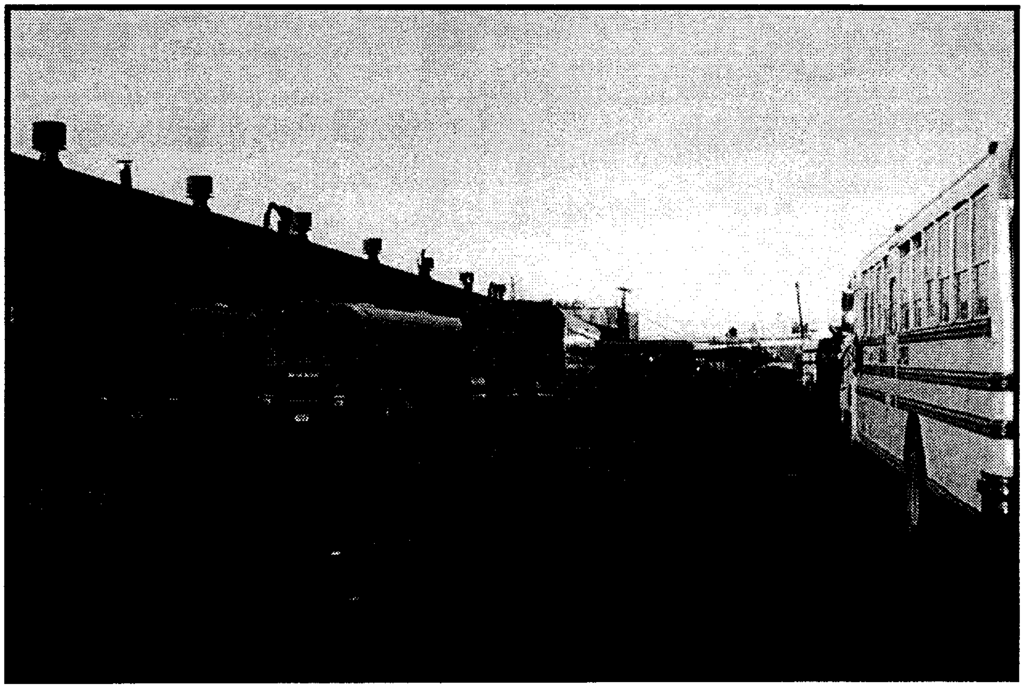
WEST SIDE
Site Photographs

Looking south across area where ERH treatment will be applied.

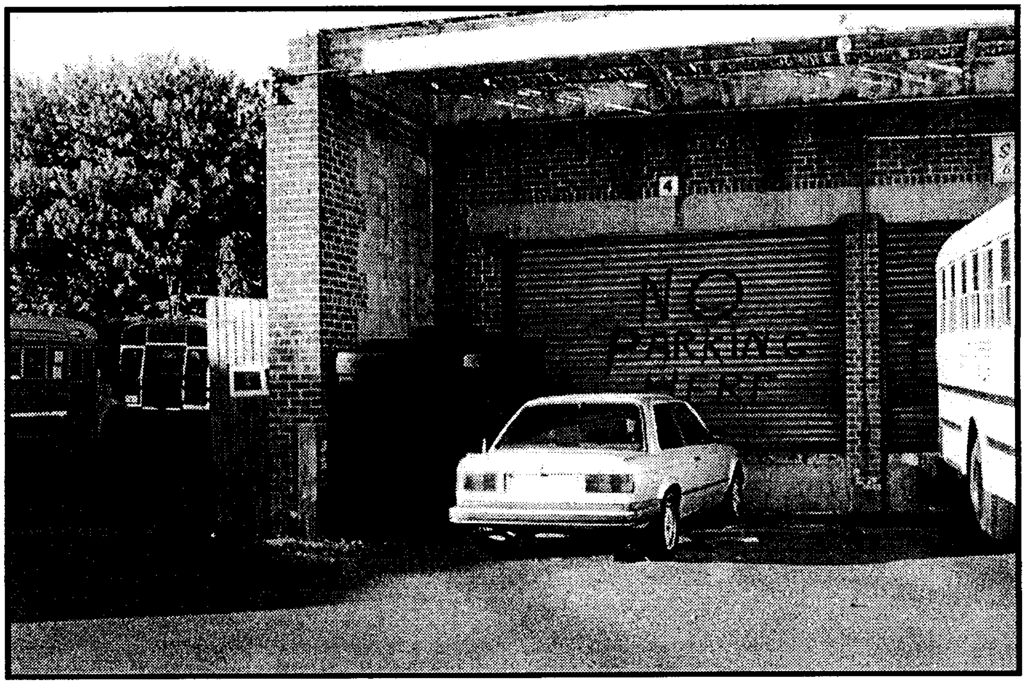


Looking west from south end of building.

WEST SIDE
Site Photographs

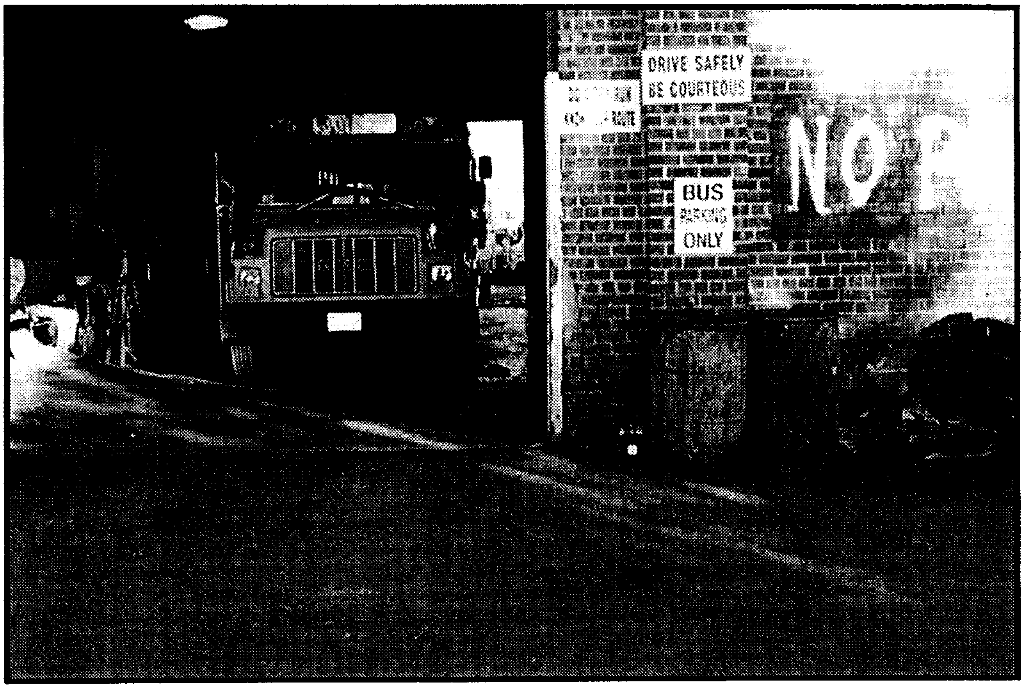


Looking north along east side of building.

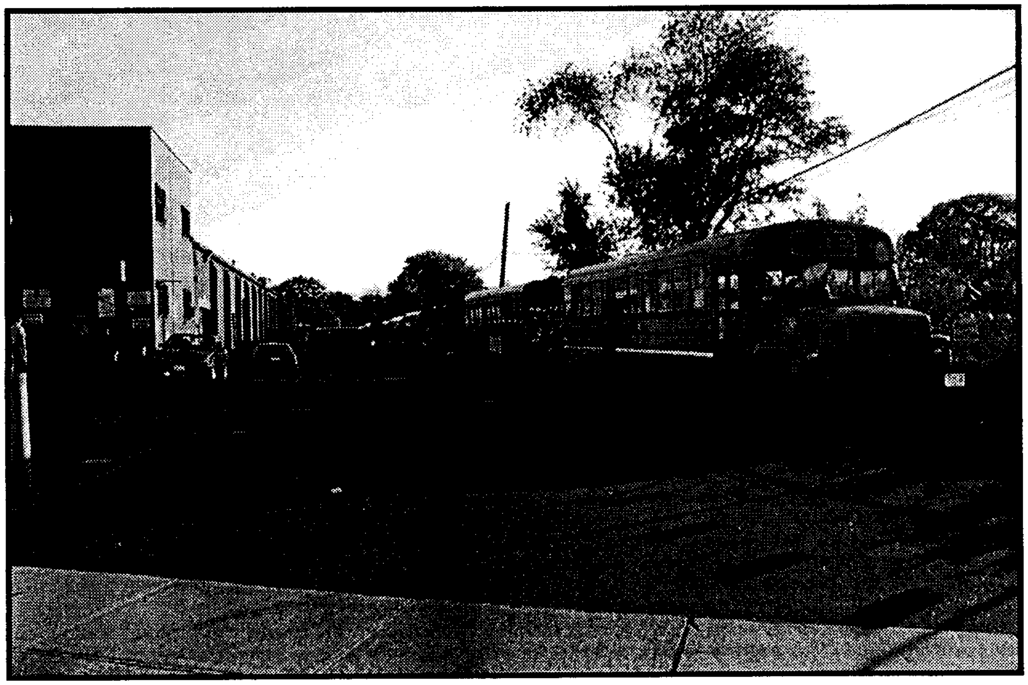


South end of building.

WEST SIDE
Site Photographs

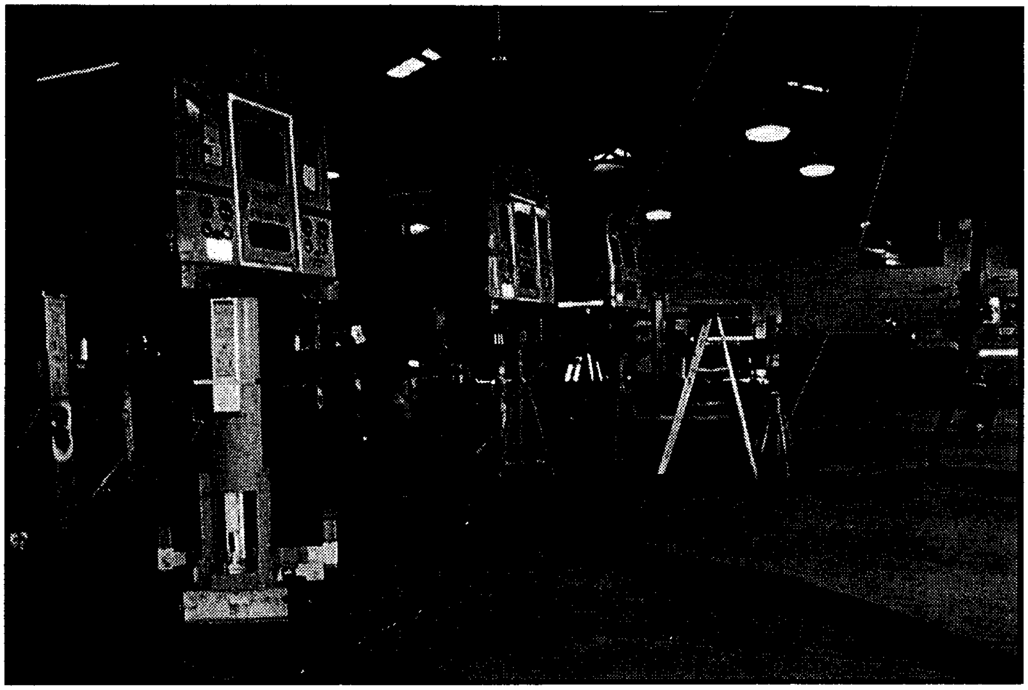


Typical service bay in building.



Looking south from 180th Street along west side of building.

WEST SIDE
Site Photographs



Typical service bays in building.

Looking northwest along 180th Street from side.

APPENDIX 2A

SOIL VAPOR EXTRACTION DESIGN

URS **EXHIBIT 4.7-2**

CALCULATION COVER SHEET

Client: NYSDEC Project Name: West Side Corp.

Project/Calculation Number: 1117161l

Title: SVE System Design

Total Number of Pages (including cover sheet): ~~22~~ ~~23~~ 25

Total Number of Computer Runs: 0

Prepared by: Donald A. McCall DAM Date: 10.1.02

Checked by: Craig W. Pawlewski CWP Date: 10/14/02

Description and Purpose:

Design major components of the SVE system.

Design Basis/References/Assumptions

See Attached.

Remarks/Conclusions/Results:

See Attached.

Calculation Approved by: ______________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:

Project Manager/Date

URS

Appendix 2A - Page 1 of 11
JOB NO.: 11171611
MADE BY: D. McCall DM DATE: 10.29.02
CHECKED BY: CWP DATE: 10/29/02

PROJECT: **West Side Corporation Site Remedial Design**
SUBJECT: **SVE System Design**

Problem: Outline the basis for design for the major SVE system components including:

- Extraction well locations
- Extraction well construction
- Air inlet wells
- Vacuum monitoring points
- Piping design
- Blower design
- Air treatment

References:

1. *Remedial Design Project Management Work Plan / Budget Estimate - West Side Corporation*, URS Corporation, June 2001.
2. *Remedial Investigation - West Side Corporation Site, Vol. 1*, TAMS Consultants and GZA GeoEnvironmental of New York, July 2000.
3. *Feasibility Study - West Side Corporation Site,* TAMS Consultants and GZA GeoEnvironmental of New York, July 2000.
4. *SVE Pilot Test Report - West Side Corporation Site,* URS Corporation, December 2001.
5. *Industrial Ventilation,* American Conference of Governmental Industrial Hygienists, 1980.
6. *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites*, United States Environmental Protection Agency, EPA 510-B-95-007, May 1995.
7. *GAST Specially Designed Products for Environmental Remediation*, Gast Manufacturing, www.gastmfg.com.

MADE BY: D. McCall DM DATE: 10.29.02
CHECKED BY: CWP DATE: 10/29/02

PROJECT: **West Side Corporation Site Remedial Design**
SUBJECT: **SVE System Design**

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8. *Design Issues - Memo #1*, URS Corporation, Inc., October 1, 2002.
9. *Ametek® Rotron ® Industrial Products*, www.rotronindustrial.com

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General Assumptions:

1. SVE will be implemented following the completion of ERH activities in Source Area 1. Although the ERH system may utilize SVE wells for the extraction of soil vapors, that system is considered to be completely separate from this system.
2. It is assumed that all newly installed SVE wells will be located outside of the ERH area, since the area should be mostly "clean." The new SVE system will however have some effect in this area and may provide additional treatment.
3. Other assumptions regarding the design of the SVE system are outlined below in the applicable section.

---

1) Extraction Well Locations

a) SVE will be implemented at three areas of the site, designated as Source Areas 1, 2, and 3.

b) The extents of the source areas as indicated in References 2 and 3 are assumed to be approximate. The source areas were delineated based on soil gas readings with an OVM, and approximate the areas of soil contamination.

c) **The maximum radius of influence for an extraction well is assumed to be 50 feet (Ref. 4).** Wells will be spaced closer to ensure complete coverage in areas where there is a potential for subsurface obstructions and where dictated by the constraints of the site.

d) It is assumed that those wells located inside the building will not have any effect on the soil located outside the foundation of the building. Likewise, the wells located outside the building will not have any effect on the soil located underneath the building.

e) **It is assumed that all extraction wells will be vertical**, including those to be located inside the building. Vertical wells were selected over horizontal wells (as indicated in the Feasibility Study, Ref. 3) due to the lack of information regarding the construction of the building, and the potential for subsurface obstructions. Additional information regarding the use of vertical wells instead of horizontal is included in Ref. 8.

f) The attached Figure 1 shows a suggested layout for the extraction wells. **A total of 15 extraction wells are proposed** as follows:

Source Area 1 -	7 wells outside the building 3 wells inside the building
Source Area 2 -	3 wells
Source Area 3 -	2 wells

A fifty-foot radius is shown around each of the extraction wells. As shown, the suggested spacing provides significant overlap in coverage. The proposed spacing of the wells also allows for flexibility in operation. During the course of operation, it may be beneficial to target extraction from specific areas and/or to operate some extraction wells as air inlet wells.

g) Well locations shown on the attached Figure 1 are approximate. The actual locations will be determined based on specific site conditions, especially for those wells proposed for inside the building.

2) Well Construction

a) **The diameter of the SVE extraction wells is assumed to be 4 inches**, which is typical for the construction of SVE wells, especially at the higher flow rates proposed at this site. A 4-inch diameter well (EW-1) was used for the SVE pilot study.

b) Most of the extraction wells will be installed to a depth approximately 10 feet below ground surface. This allows the wells to be completed above the water table, minimizing the collection of water by the system. It is expected that there will be some local upwelling of the groundwater due to the vacuum, but not enough to cover the screened portion of the well.

At most areas of the site, the contamination is only found in the shallow soil (<10 feet). In some sections of Source Area 1, where contamination is thought to extend deeper into the subsurface, the extraction wells will be installed somewhat deeper to enhance contaminant removal in the vadose zone.

c) The extraction wells will be screened from approximately 2.5 feet below surface to the bottom of the well (minimum 10 feet), for a minimum screen length of 7½ feet. In areas of the site where there is an indication that short-circuiting may be a consideration, the well screen length could be shortened. For instance, if there is a high permeability stone or gravel layer located beneath the floor of the existing building, the bentonite seal at the upper end of the well will be extended to 1 or 2 feet below this layer, and the screen length will be shortened accordingly.

d) **All wells will be constructed and completed at grade.** All monitoring ports, valves, etc. will be installed in a concrete box. The box and cover will be rated to handle the loading from the bus traffic at the site.

3) ***Air Inlet Wells***

a) The SVE pilot test (Ref. 4) demonstrated that a sufficient quantity of air can be withdrawn from this site without the use of air inlet wells, despite the fact that the entire site has been paved.

b) Air inlet or venting wells are sometimes used to enhance the volatilization of contaminants and to control the movement of air. If an adjacent property were contaminated, air inlet wells or a trench would be used to prevent the SVE system from drawing that contamination onto our site. It is assumed that this is not required at this site.

c) Another use of air inlet wells is to eliminate stagnant zones that can occur where the influences from multiple wells intersect. Air inlet wells installed at the stagnant zones improve the flow of air through those areas. Given the size of Source Area 1, and the quantity of extraction wells in this area, stagnation zones are a distinct possibility.

d) At this site where the proposed well locations are all in a very busy, heavily trafficked area, the air inlet wells would have to be installed below grade. Underground piping would be used to allow air inlet from a remote location where an aboveground riser can be installed. To eliminate additional wells and reduce the amount of piping that would be required to install dedicated air inlet wells, the SVE extraction wells will be designed to serve both applications. The wells are designed such that closing the valve to the SVE system and removing the threaded end cap will allow the SVE wells to function as air inlet wells. Occasionally varying which wells function as extraction or inlet wells should allow the entire extent of contamination to be treated.

4) **Vacuum Monitoring Points**

a) Vacuum monitoring points typically are used to verify that the extraction wells are maintaining a sufficient vacuum across the area designated for treatment. These monitors are most useful during the initial startup and balancing of the system, and following any subsequent adjustments to the system.

At this site, considering the conservative spacing of the extraction wells, there is little question as to whether the SVE system will provide adequate coverage, so vacuum monitoring points would not provide much useful information. Therefore, only six vacuum monitoring points are proposed as shown on the Contract Drawings. The vacuum monitors are located around all of the treatment areas, just outside the areas targeted for treatment. Vacuum measurements from these monitors will provide a good indication of the actual extent of the vacuum zone.

5) Piping Design

a) Prior to determining the size of the system piping, it is necessary to know how much air will be flowing through the system. The pilot study (Ref. 4) determined that a flow rate of 35 to 45 cfm should be achieved from each extraction well. To be conservative for the purpose of pipe selection, a flow rate of 50 cfm from each well is assumed.

b) It is assumed that there will be a separate manifold from each of the three source areas into the treatment system. Assuming equal flow from each of the wells, and using the quantity of wells determined above, the total air flow from each area is projected to be:

Source Area 1 -	10 wells @ 50 cfm =	500 cfm
Source Area 2 -	3 wells @ 50 cfm =	150 cfm
Source Area 3 -	2 wells @ 50 cfm =	100 cfm
Total -	15 wells @ 50 cfm =	750 cfm

c) In order to maximize the vacuum at the extraction wells, the pipe is sized so that the pressure drop between the blowers and the wells is minimized. Ref. 5 includes a figure that shows the velocity and pressure drop for the flow of air through various round ducts. Pipe diameters were chosen for each of the flow rates that so that the pressure drop will be minimal; i.e., less than 1 inch of drop per 100 linear feet of pipe.

Based on this criteria, pipe for each of the expected air flow rates was selected as shown below:

Pipe Diameter Selection

Flow Rate (cfm)	Pipe Diameter (inch)	Velocity (fpm)	Pressure Drop (in./100 ft)
50	4	575	0.18
100	4	1150	0.64
150	6	775	0.18
500	8	1450	0.4
750	8	2150	0.9

The above table will be used as a general guideline for the selection of pipe. Pipe for any flow rates not shown on the table above will be selected using the same criteria. For short lengths of pipe, a diameter smaller than shown on the table may be selected if it is more convenient, as long as the total pressure drop is still minimal.

6) Blower Design

a) Flow Rate: The SVE Pilot Test (Ref. 4) recommended an extraction rate of 35 to 45 cfm per well. Assuming a total of 15 extraction wells, this equates to a blower system designed for (35 x 15 =) 525 to (45 x 15 =) 675 cfm.

Conservatively allowing for 50 cfm per well, and assuming a total of 15 wells, the blower system will be designed for a **total capacity of 750 cfm**.

b) Pore Volumes: One method to check adequacy of the air flow rate for the SVE system is to determine the rate at which the system can remove one pore volume of air.

The attached Figure 2 shows an approximate determination of the area that will be affected by SVE (based on a 50-foot radius of influence). The total area was roughly estimated to be 87,000 square feet. Assuming a 10 foot unsaturated zone, and an porosity in the unsaturated zone of 35%

(consistent with the assumptions of the pilot test, Ref. 4), the total pore volume in the affected area is:

$$(87{,}000 \text{ ft}^2 \times 10 \text{ ft.} \times 0.35) = 304{,}500 \text{ ft}^3$$

Based on an extraction rate of 750 cfm, the total time to extract one pore volume would be:

$$(304{,}500 \text{ ft}^3) / (750 \text{ ft}^3 / \text{min}) / (60 \text{ min} / \text{hr}) = 6.8 \text{ hours.}$$

Therefore, operating a maximum capacity, the system would be able to remove approximately 3½ pore volumes per day.

Ref. 6 recommends that at least one pore volume should be extracted per day for effective remedial progress; so removing 3½ volumes per day should be more than adequate.

c) Blower Quantity: While it would be possible to select one blower capable of achieving a 750 cfm flow rate, it is assumed that three blower units installed in parallel will be used. Using multiple blowers will allow for more flexibility and efficiency for operating the system, especially if the quantity of operating wells is reduced over time. Using multiple blowers also allows the system to continue operating at a reduced rate if there are mechanical problems with any of the blowers. **Each of the three blowers will be designed to provide 250 cfm.**

d) Vacuum: As recommended by the pilot test (Ref. 4), it is assumed that the blower will be selected to maintain a pressure of 40 to 45 inches water column (in. wc) at each extraction well. For the purpose of selecting the blower, a vacuum of 40 in. wc column is assumed at the extraction well.

e) Pressure Drop: To achieve the desired vacuum at the extraction wells, the blower must include additional vacuum to account for the pressure drop in the pipe and valve system.

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i) Piping Losses: Due to the different pipe diameters and distances between the extraction wells and the blower, the pressure drop will vary significantly among the various well locations. The pressure drop will be determined only for the "worst case" of all the well locations. Once the blower is designed for the worst case, it will have excess vacuum at all other well locations. Control valves at each well head will be used to balance the vacuum and flow among the wells.

Pressure drops for the various diameters of pipe and flow rates are shown on the table in Section 5 of this calculation. Assuming that the SVE system is located to the south of the existing building, the worst case pressure drop will be to either Source Area 2 or 3, since these wells will be located the furthest from the extraction system and use the smaller diameters of pipe. Figure 3 shows the approximate length and routing of the pipe from these areas. As calculated in the table below, the total pressure drop to Source Area 3 turns out to be the largest pressure drop.

Pipe Friction Losses

Location	Pipe Diameter (inch)	Pressure Drop (in./100 ft)	Approximate Pipe Length (ft)	Total Pressure Drop (in)
Source Area 2	6	0.18	490	0.88
Source Area 3	4	0.64	360	2.3

ii) Valves and Fittings Losses: Additional pressure drop will also occur due to the control valves and due to bends and joints in the piping manifold. Ref. 7 includes assumptions regarding equivalent lengths of pipes for air flow. Estimated quantities of fittings and the associated equivalent length of pipe are outlined below. All valves and fittings are assumed to be 4 inch diameter.

JOB NO.: 11171611

MADE BY: D. McCall TOW DATE: 10.29.02
CHECKED BY: CWP DATE: 10/29/02

PROJECT: **West Side Corporation Site Remedial Design**
SUBJECT: **SVE System Design**

Valve and Fitting Losses

Fitting	Estimated Quantity	Equivalent Length (Ref. 7) (ft)	Total Equivalent Length (ft)
90° Elbow	10	10	100
Tee (through)	3	7	21
Tee (branch)	1	20	20
Valve	2	3	6
Total			**147 ft**

Now, taking the total equivalent length and multiplying by the friction factor from the previous section:

(147 ft) x (0.64 in. / 100 ft) = 0.94 in. wc. friction loss for fittings and valves.

iii) Knockout Tank (Liquid Separator): Ref. 9 presents a chart to determine the pressure drop from the knockout tank that will be located before the blowers. Assuming that the total flow is 750 cfm, the lowest pressure drop will be obtained from an Ametek Model MS1000BS (Ref. 9) unit. (Other manufacturers may present different alternatives as far as the size and capacity of units available). The pressure drop across the Ametek unit is estimated to be approximately 3 in. wc based on their literature.

iv) Minor Sources: Other minor sources of pressure drop will include any inlet filters, miscellaneous fittings located directly at the blower, etc. Allow a total of say 2 in. wc. to account for these additional minor sources.

v) Total Pressure Drop:

Piping:	2.3
Fittings and Valves:	0.94
Knockout Tank:	3
Minor Sources:	2
Total:	8.24 say 9 in. wc.

vi) Total Blower Vacuum

40 in. wc + 9 in. wc = 49, say 50 in. wc. to allow for a small safety factor.

f) Blower Design Summary: As outlined above, the criteria for the selection of the blowers is as follows:

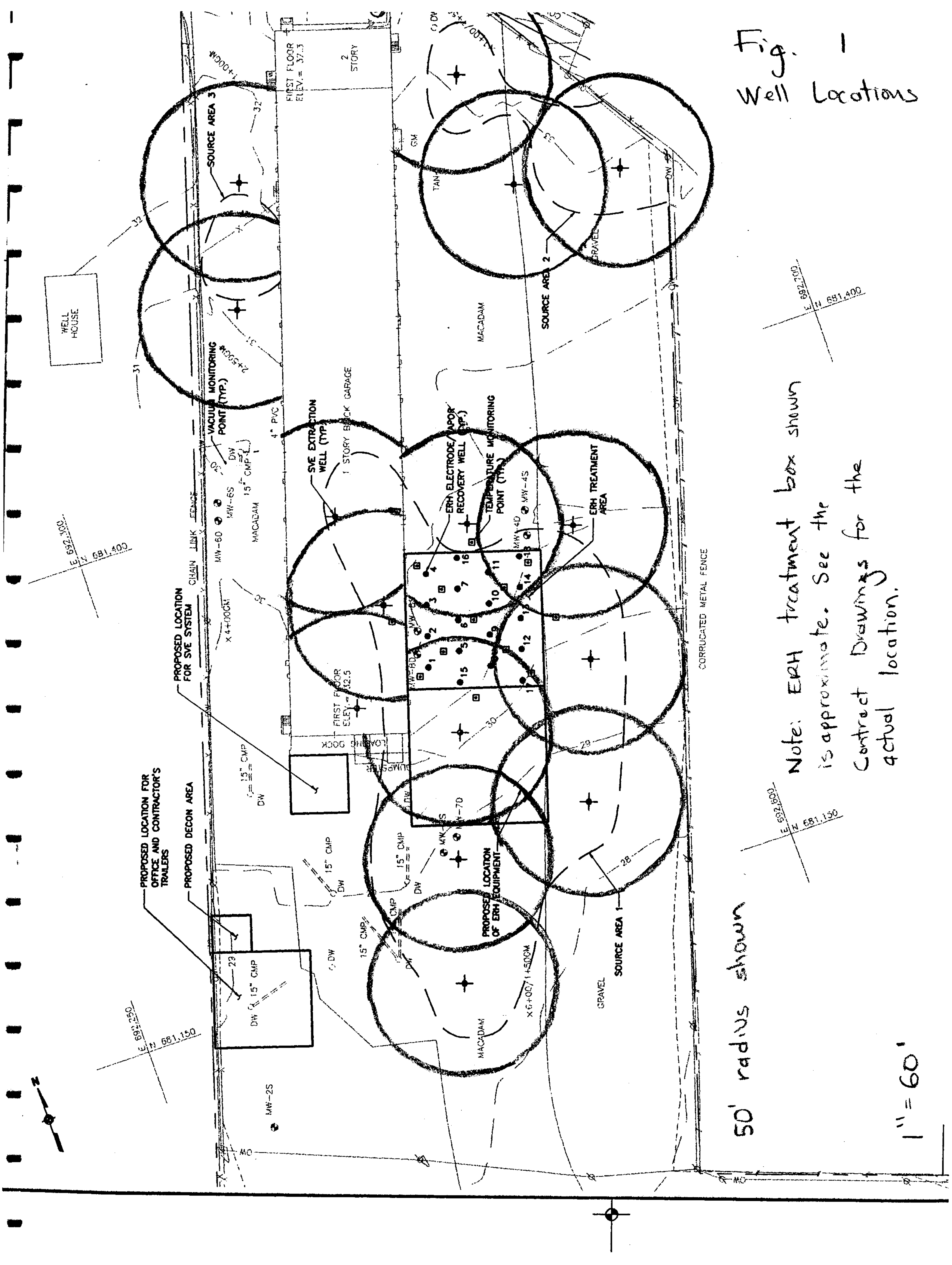
Quantity:	3
Air Flow:	250 cfm each
Vacuum:	50 in. wc.

Ref. 9 shows a typical blower that meets this requirement.

7) Air Treatment

a) Air treatment will be a significant component of the SVE system as well as other components of the remedial actions at the site. Comprehensive air treatment is evaluated separately in Appendix 4A of this DAR.

Fig. 1
Well Locations



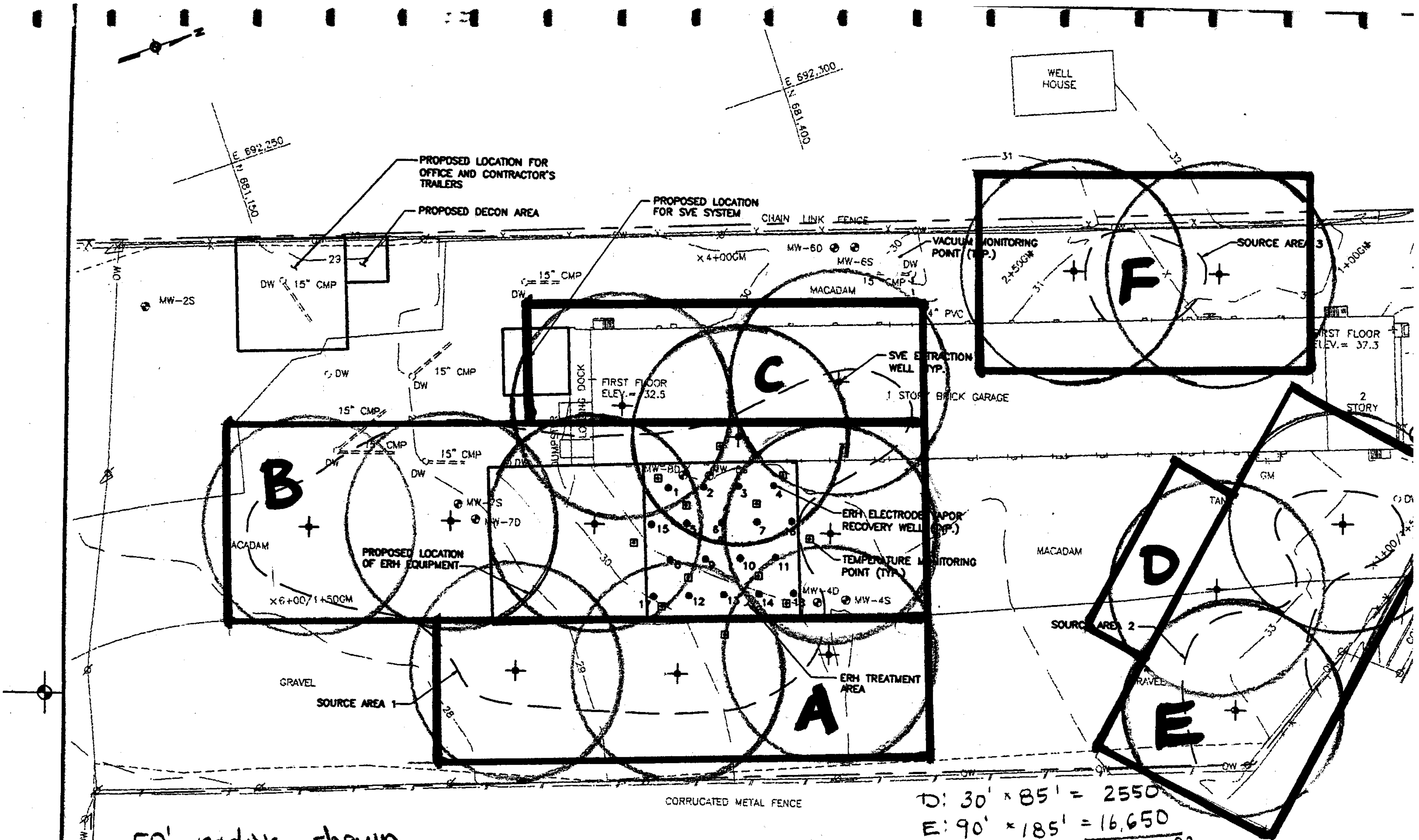
Note: ERH treatment box shown is approximate. See the Contract Drawings for the actual location.

50' radius shown

1" = 60'

Fig. 2

Approx. Volumes of Treatment Areas



D: 30' × 85' = 2550
E: 90' × 185' = 16,650
19,200 f²

50' radius shown

A: 65' × 230' = 14,950
B: 90' × 325' = 29,250
C: 55' × 180' = 9,900
54,100 f²

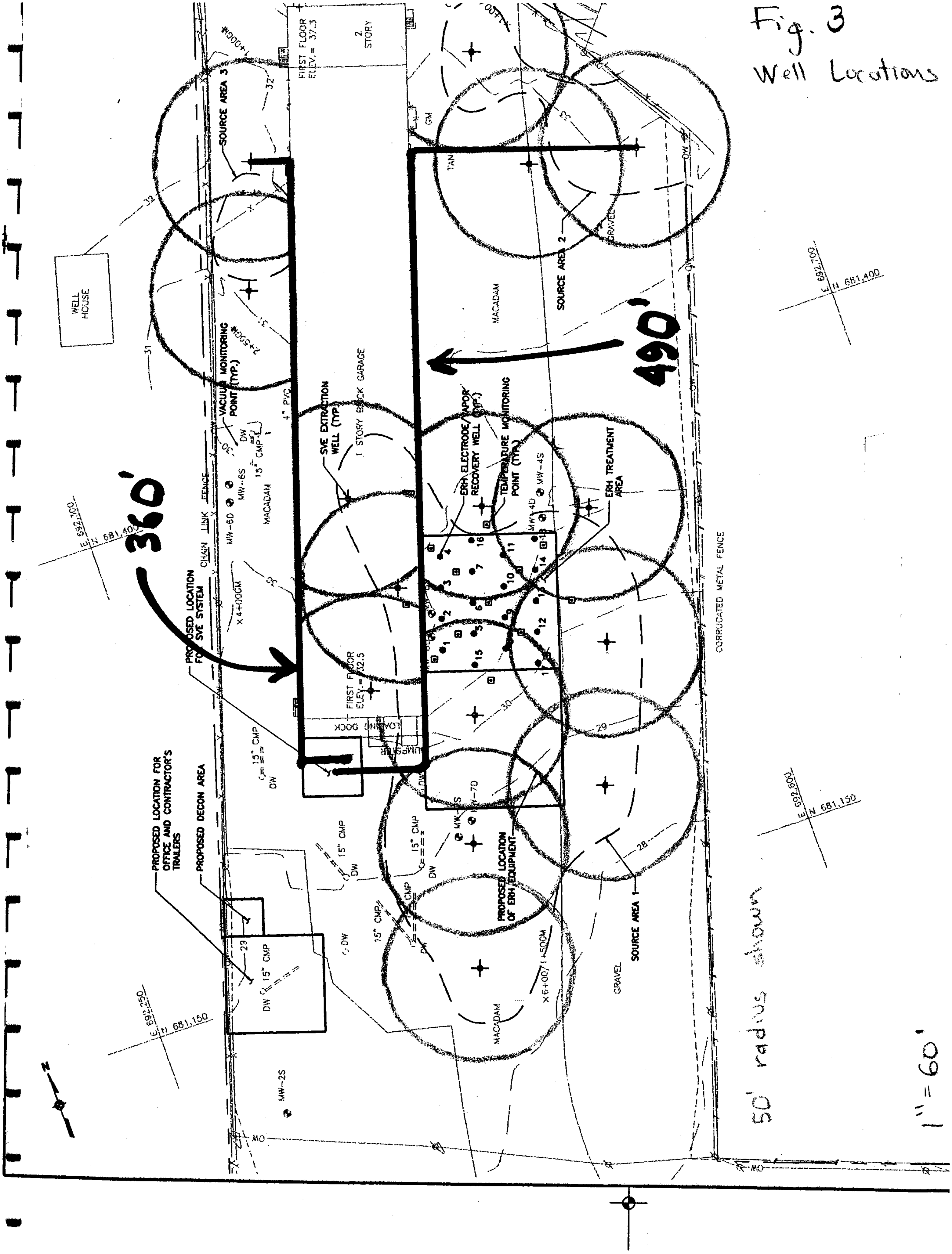
1" = 60'

Note: For the purpose of determining volumes of treatment, the radii were assumed to extend beyond the building foundations.

F: 150' × 90' = 13,500 f²

Total area = 86,800, say 87,000 f².

Fig. 3
Well Locations



50' radius shown

1" = 60'

Ref. 2

SUPERFUND STANDBY PROGRAM
New York State
Department of Environmental Conservation
50 Wolf Road
Albany, New York 12233-7010

ON SITE

REMEDIAL INVESTIGATION WEST SIDE CORPORATION SITE
Site No. 2-41-026

Volume 1
Work Assignment Number
D003060-24

Prepared by:

TAMS Consultants, Inc.
300 Broadacres Drive
Bloomfield, NJ 07003-3153

and

GZA GeoEnvironmental of New York
364 Nagel Drive
Buffalo, NY 14225

July 2000

Ref. 3

SUPERFUND STANDBY PROGRAM
New York State
Department of Environmental Conservation
50 Wolf Road
Albany, New York 12233-7010

ON-SITE

FEASIBILITY STUDY
WEST SIDE CORPORATION SITE
Site No. 2-41-026

Work Assignment Number
D003060-24

Prepared by:

TAMS Consultants, Inc.
300 Broadacres Drive
Bloomfield, NJ 07003-3153

and

GZA GeoEnvironmental of New York
364 Nagel Drive
Buffalo, NY 14225

July 2000

Ref. 5

INDUSTRIAL VENTILATION

A Manual of Recommended Practice

1980

COMMITTEE ON INDUSTRIAL VENTILATION
P.O. BOX 16153
LANSING, MICHIGAN, 48901, U.S.A.

American Conference of Governmental Industrial Hygienists

Manual

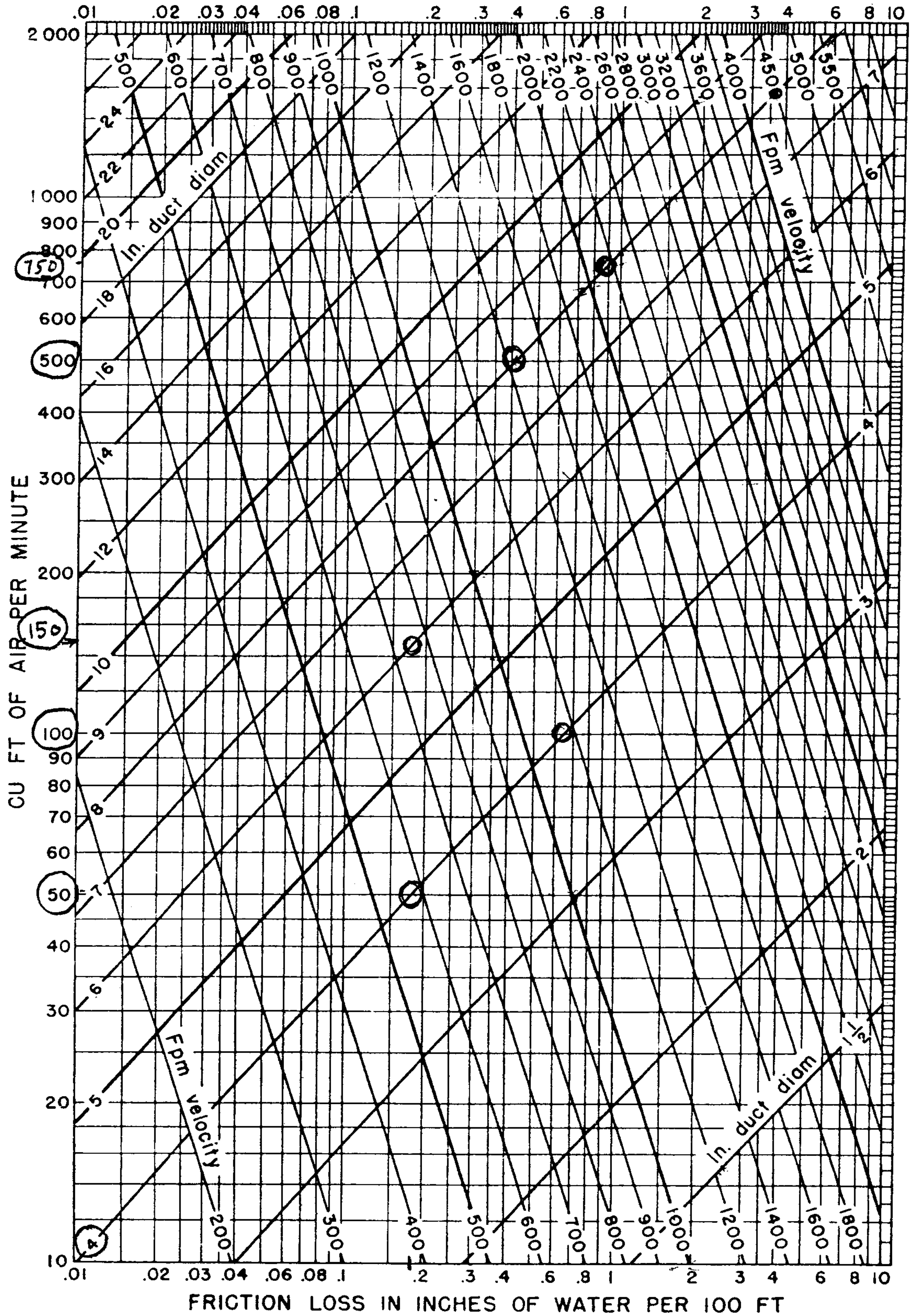
U.S.A.
$10.00—copy
7.50—15 or more copies
Contact us for prices in quantities of 100 or more

Orders must be accompanied by a check or bank draft in U.S. currency
Prices subject to change without notice.

Calculation Sheets

$2.00 — 25 copies
4.00 — 100 copies

Ref. 5



(Based on Standard Air of 0.075 lb per cu ft density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft.)
Caution: Do not extrapolate below chart.

For proprietary duct, obtain data from manufacturer. Friction of Air in Straight Ducts for Volumes of 10 to 2000 Cfm

$$\text{Friction Loss}/100' = \frac{2.74\left[\frac{V_{\text{fpm}}}{1000}\right]^{1.9}}{\left[D_{\text{inches}}\right]^{1.22}}$$

(Ref. 130)

Note: Both "1.9" and "1.22" are exponents.

Fig. 6-15A

United States
Environmental Protection
Agency

Solid Waste And
Emergency Response
5403W

EPA 510-B-95-007
May 1995

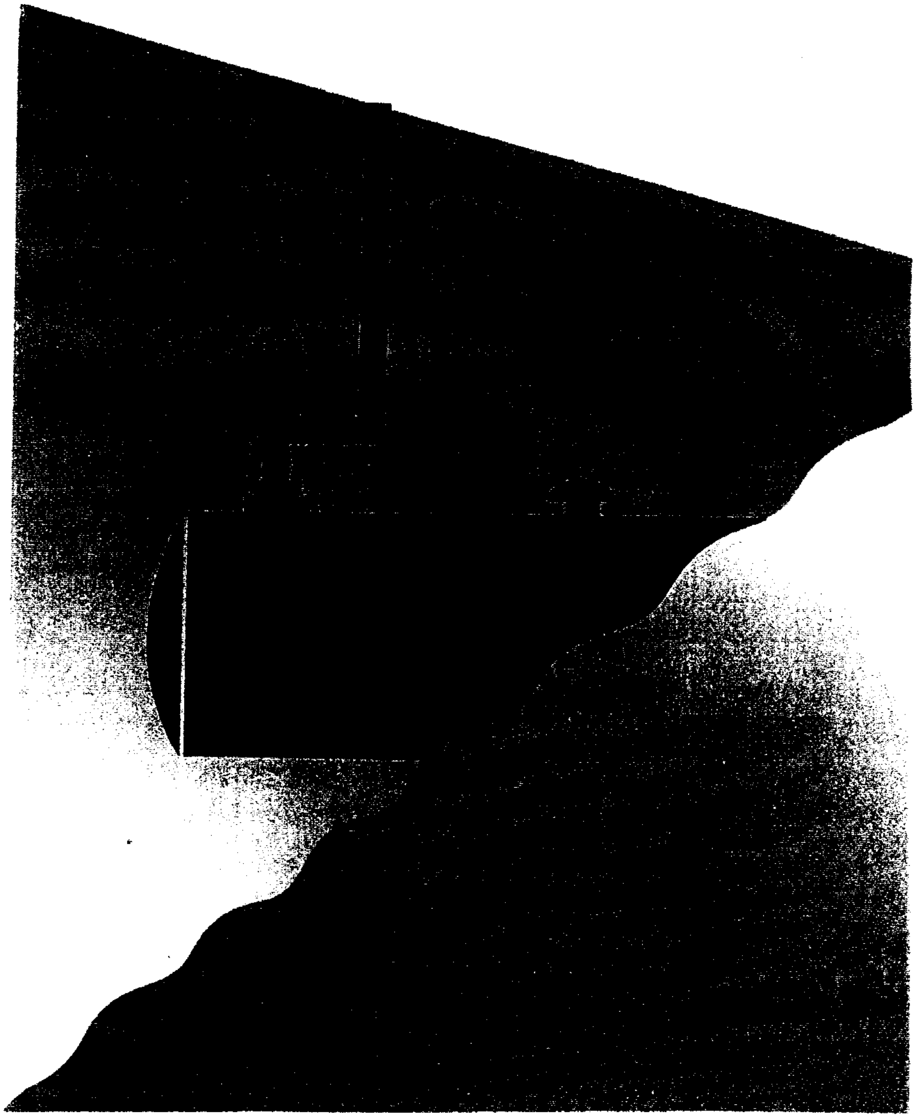
McCALL

EPA

How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites

Ref. 6

A Guide for Corrective Action Plan Reviewers



Ref. 6

volume of soil to be treated. Some literature suggests that one pore volume of soil vapor should be extracted at least daily for effective remedial progress.

You can calculate the time required to exchange one pore volume of soil vapor using the following equation:

$$E = \frac{(m^3 \text{ vapor} / m^3 \text{ soil}) \cdot (m^3 \text{ soil})}{(m^3 \text{ vapor} / hr)} = hr$$

where: E = pore volume exchange time (hr)
ε = soil porosity (m^3 vapor/m^3 soil)
V = volume of soil to be treated (m^3 soil)
Q = total vapor extraction flowrate (m^3 vapor/hr)

$$E = \frac{\varepsilon V}{Q}$$

- *Discharge Limitations And Monitoring Requirements* are usually established by state regulations but must be considered by designers of an SVE system to ensure that monitoring ports are included in the system hardware. Discharge limitations imposed by state air quality regulations will determine whether offgas treatment is required.

- *Site Construction Limitations* such as building locations, utilities, buried objects, residences, and the like must be identified and considered in the design process.

Components Of An SVE System

Once the rationale for the design is defined, the actual design of the SVE system can be developed. A typical SVE system design will include the following components and information:

- Extraction wells
- Well orientation, placement, and construction details
- Manifold piping
- Vapor pretreatment design
- Blower selection
- Instrumentation and control design
- Optional SVE components
  - Injection wells
  - Surface seals
  - Groundwater depression pumps
  - Vapor treatment systems

Exhibit II-11 is a schematic diagram of an SVE system.

Ref. 7

CALCULATING SYSTEM FRICTION LOSS

Friction causes pressure loss in all systems. Plumbing design and length affect this loss in air flow.

1. Determine total straight pipe equivalent.
List number of each fitting in system. Circle the column under the supply pipe size. Multiply the number of each item by the pipe size conversion factor to find the equivalent amount of straight pipe. Add equivalent figures to actual straight pipe figures.

Friction loss in pipe fittings equivalent length of straight pipe

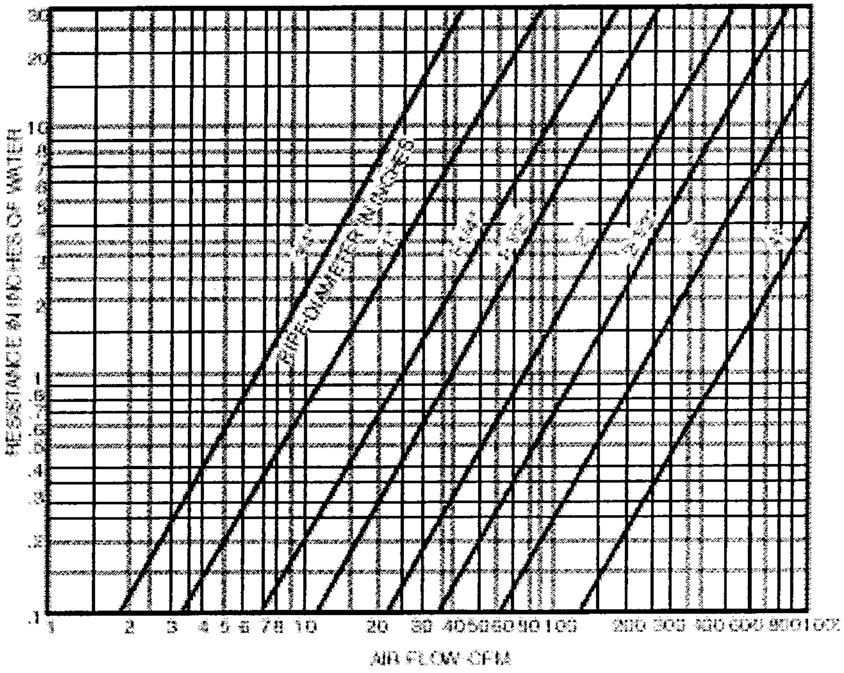
Fitting	#	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"	↓ 4"	Equivalent Feet
90° Elbows	10 x	2.0	3.0	3.5	4.0	5.0	6.0	8.0	10.0	=_____
Std. through tees	3 x	1.5	2.0	2.5	3.0	3.5	4.0	5.0	7.0	=_____
Std. branch tees	1 x	4.0	5.0	7.0	8.0	10.5	12.5	15.5	20.0	=_____
Check valves	___x	7.0	9.0	11.5	13.5	17.0	20.5	25.5	34.0	=_____
Gate valves	2 x	0.55	0.7	0.9	1.0	1.5	2.0	2.0	3.0	=_____

Total length of straight pipe =_____ft.

Total straight pipe equivalent =_____ft.

2. Determine total friction loss in pipe system.
On bottom line of the pipe friction loss chart, mark the air flow needed. Using a ruler, scan vertically from the CFM figure to the diagonal line for the proper pipe size. Mark the intersection and then scan to the left (vertical) axis to find the friction loss figure.

PIPE FRICTION LOSS/10' of pipe



3. Divide the Total straight pipe equivalent from step 1 by 10; multiply by friction loss figure just determined to get the total friction loss in the pipe system.

_________________ ÷ 10 x _________________ = _______________________

Total feet of pipe in system

Friction loss factor

Total friction loss in system in H₂O"

Gast Mfg.

Ref. 9

Blower Model Reference Key	
A = SPIRAL	E = DR/EN/CP 656, 6, 623, S7
B = DR/EN/CP 068, 083, 101, 202	F = DR/EN/CP 707, 808, 858, S9, P9 (Inlet Only)
C = DR/EN/CP 303, 312, 313, 353	G = DR/EN/CP 823, S13, P13 (Inlet Only)
D = DR/EN/CP 404, 454, 513, 505, 555, 523	H = DR/EN/CP 909, 979, 1223, 14, S15, P15 (Inlet Only)

Filtration Accessories

2.0 Moisture Separator™ Specifications

2.1 DUTY

The moisture separator shall be designed for use in a soil vapor extraction system capable of continuous operation with a pressure drop of less than six inches of water at the rated flow of _____ SCFM. The separator shall be capable of operation under various inlet conditions ranging from a fine mist to slugs of water with high efficiency.

2.2 PRINCIPLE OF OPERATION

The moisture separator shall incorporate cyclonic separation to remove entrained water. The separator must protect against an overflow by fail safe mechanical means. An electrical switch or contact(s) alone is not an acceptable means of protection against overflow, but is a good backup.

2.3 CONSTRUCTION

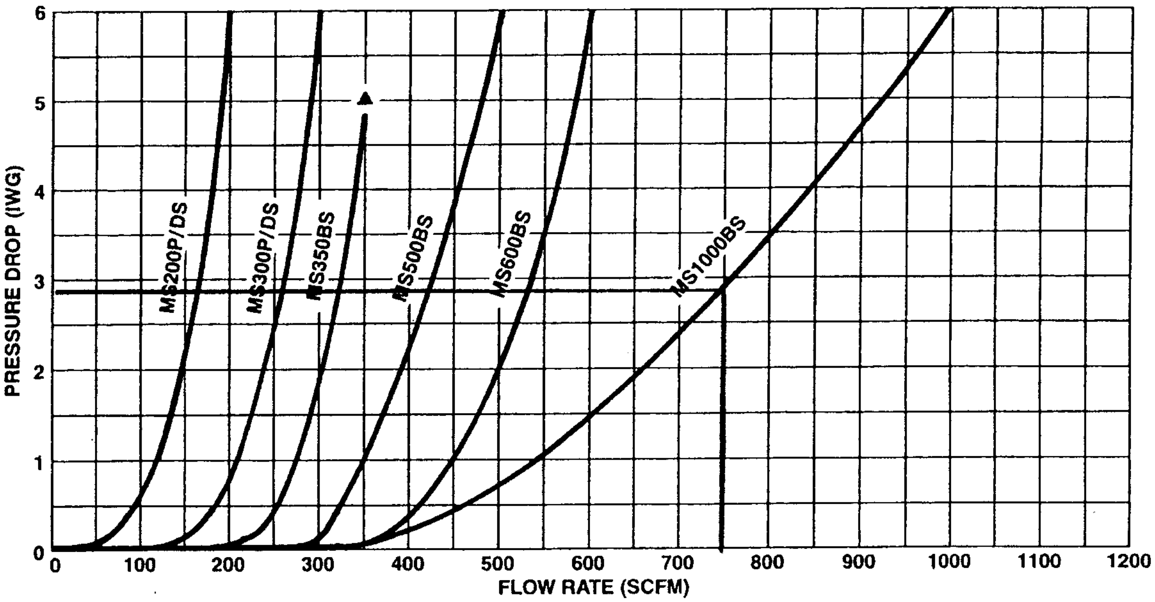
The body of the moisture separator shall be constructed of heavy wall plastic or heavy gauge cold rolled steel. The steel interior and exterior shall be epoxy (powder) coated to resist abrasion, corrosion, and chipping that might expose the surface. The inlet shall be tangentially located and welded to the body. The outlet port shall be constructed of PVC or cast aluminum alloy, flanged and sealed to the center of the top of the separator. The separator shall incorporate a non-sparking copper float ball and an adjustable relief valve to protect against overflow and overheating the blower.

2.4 CAPACITY AND DIMENSIONS

The moisture separator must have a liquid capacity of _____ gallons. The inlet shall be _____ inch OD slip-on type. The outlet shall be _____ inch OD slip-on type.

For DR/EN/CP Blower Model	Selector Moisture Separator Model	Liquid-holding Capacity (gallons)	Inlet (OD)	Outlet	Max Vacuum Allowed (IHg)
404 454 505 513	MS200PS	7	2.38	4.5" OD	12
523 555 623 823	MS200DS	10	2.0		22
656 6 707	MS300PS	7	2.88		12
	MS300DS	10	2.5		22
808	MS350BS	40	3.25		
858 1223	MS500BS			6.63" ID	
909	MS600BS		4.0"		
979 14	MS1000BS		6.0"	8.62" OD	

2.5 PRESSURE DROP



Rev. 2/01

Ref. 9

Filtration Accessories

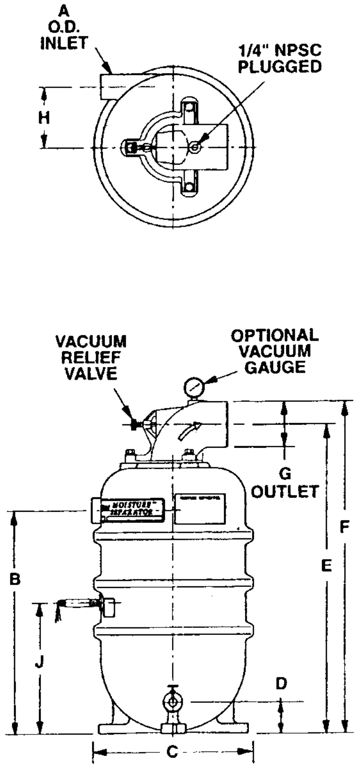
Blower Connection Key
NPT – American National Standard Taper Pipe Thread (Male)
NPSC – American National Standard Straight Pipe Thread for Coupling (Female)
SO – Slip On (Smooth – No Threads)

Moisture Separator™

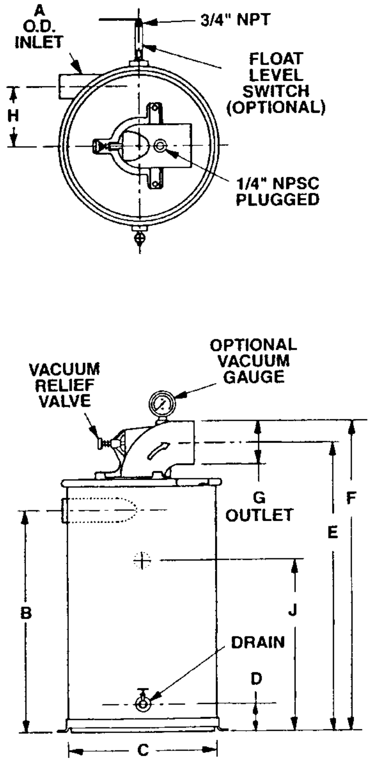
By separating and containing entrained liquids, Rotron's moisture separator helps protect our regenerative blowers and the end treatment system from corrosion and mineralization damage. Recommended for all soil vacuum extraction applications.

SPECIFICATIONS:

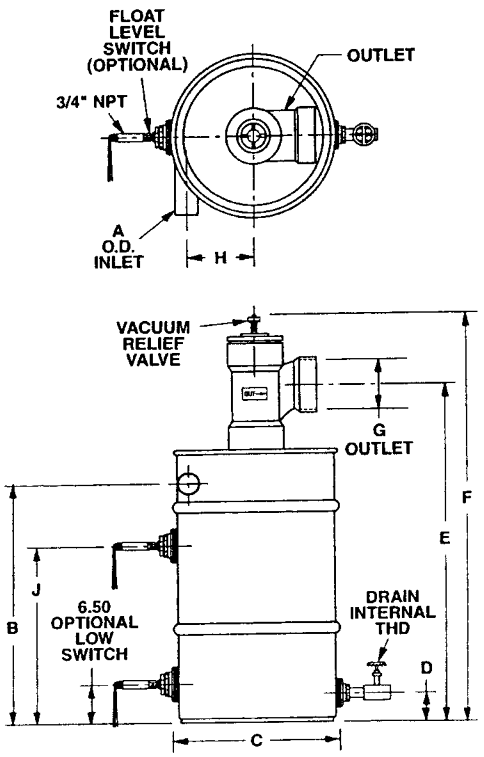
SEPARATION METHOD – High Efficiency Cyclonic
RELIEF VALVE MATERIAL – Brass & Stainless Steel
FLOAT MATERIAL – Copper
FLOAT SWITCH – SPDT, Explosion-proof
NEMA 7&9, 5 Amp max.



PLASTIC "P" DESIGN



METAL "D" DESIGN



METAL "B" DESIGN

Model	Part No.	CFM Max.	A Dia.	B	C Dia.	D	E	F	G Dia.	H	J Switch	Drain Internal THD	Shipping Weight
MS200PS	038519	200	2.38	22.46	16.00	3.25	31.05	33.30	4.50 OD	6.00	13.25	3/4" NPT	42 lb.
MS300PS	038520	300	2.88										
MS200DS	080086	200	2.00	22.12	16.75	2.75	27.92	30.17		6.56	12.62		
MS300DS	080087	300	2.50							6.81			
MS350BS	038357	350	3.25	28.00	23.00	4.00	37.25	39.50		9.75	17.50	1" NPT	82 lb.
MS500BS	080660	500					37.37	54.50	6.63 ID				95 lb.
MS600BS	080659	600	4.00	27.00						9.25			96 lb.
→ MS1000BS	038914	1000	6.00	31.00	27.00		47.32	51.70	8.62 OD	10.00	19.88		150 lb.

Models without float switch available. Metal MS200/300DS models are not the standard stocked, but are available.

Rev. 2/01

AMETEK® Rotron® Industrial Products

DR 858 & CP 858 Regenerative Blower

Ref. 9

FEATURES

- Manufactured in the USA – ISO 9001 compliant
- CE compliant – Declaration of Conformity on file
- Maximum flow: 405 SCFM
- Maximum pressure: 110 IWG
- Maximum vacuum: 7.7" Hg (104.8 IWG)
- Standard motor: 10 HP, TEFC
- Cast aluminum blower housing, impeller & cover; cast iron flanges (threaded)
- UL & CSA approved motor with permanently sealed ball bearings
- Inlet & outlet internal muffling
- Quiet operation within OSHA standards

MOTOR OPTIONS

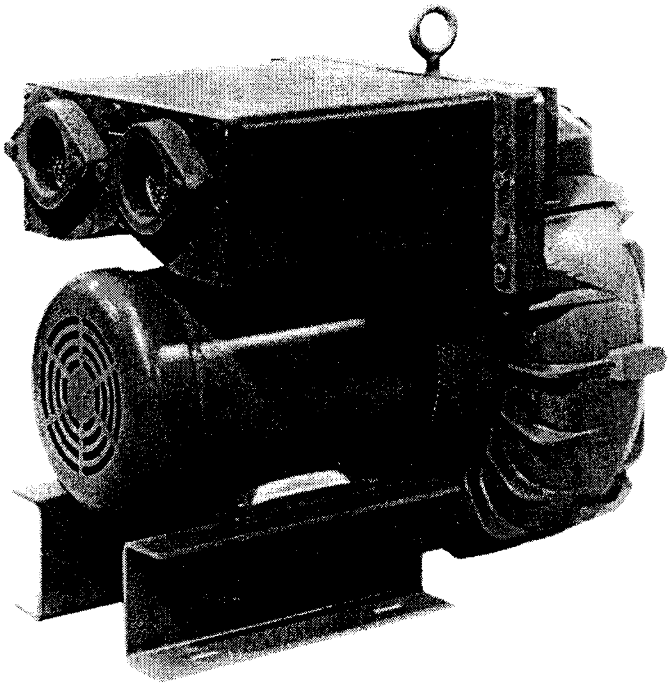
- International voltage & frequency (Hz)
- Chemical duty, high efficiency, inverter duty or industry-specific designs
- Various horsepowers for application-specific needs

BLOWER OPTIONS

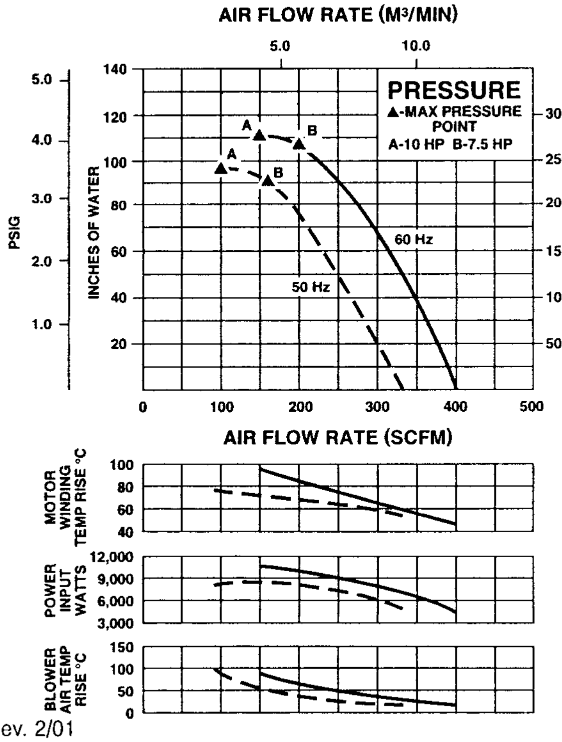
- Corrosion resistant surface treatments & sealing options
- Remote drive (motorless) models
- Slip-on or face flanges for application-specific needs

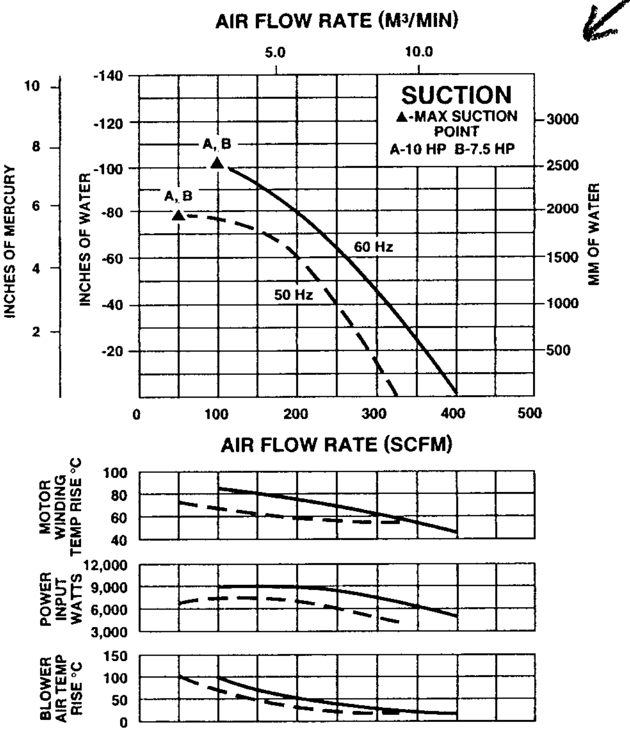
ACCESSORIES (See Catalog Accessory Section)

- Flowmeters reading in SCFM
- Filters & moisture separators
- Pressure gauges, vacuum gauges & relief valves
- Switches – air flow, pressure, vacuum or temperature
- External mufflers for additional silencing
- Air knives (used on blow-off applications)
- Variable frequency drive package



BLOWER PERFORMANCE AT STANDARD CONDITIONS





Rev. 2/01

APPENDIX 3A

ELECTRICAL RESISTANCE HEATING DESIGN

URS

EXHIBIT 4.7-2

CALCULATION COVER SHEET

Client: NYSDEC

Project Name: West Side Corp

Project/Calculation Number: 11172744

Title: ERH System Design

Total Number of Pages (including cover sheet): 23

Total Number of Computer Runs: 0

Prepared by: Donald A. McCall DAM Date: 10.17.02

Checked by: Craig W. Pawlewski CWP Date: 10/18/02

Description and Purpose:

Design major components of the ERH system

Design Basis/References/Assumptions

See Attached

Remarks/Conclusions/Results:

See Attached

Calculation Approved by: ______________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:
		Project Manager/Date

JOB NO.: 11172744

MADE BY: D. McCall DATE: 3.13.03

CHECKED BY: CWP DATE: 3/13/03

PROJECT: **West Side Corporation Site Remedial Design**

SUBJECT: **ERH System Design**

Problem: Outline the basis for design for the major Electrical Resistance Heating (ERH) system components including:

- Electrode spacing and layout
- Electrode / extraction well construction
- Temperature monitoring points
- Power control unit(s) (PCUs)
- Blower sizing
- Condenser sizing
- Cooling water flow rate
- Cooling tower design
- Air treatment

References:

1. *In-Situ Thermal Treatment Feasibility Evaluation - West Side Corporation Site,* URS Corporation, August 2002.

2. *Record of Decision - West Side Corporation Site Operable Unit No. 1,* New York State Department of Environmental Conservation, July 2000.

3. Thermal Remediation Services, Inc. (www.thermalrs.com), Mr. Greg Beyke, phone calls, website, and quote.

4. *SVE Pilot Test Report - West Side Corporation Site,* URS Corporation, December 2001.

5. *Perry's Chemical Engineers' Handbook - Sixth Edition*, Don W. Green, McGraw-Hill, Inc., 1984.

6. Baltimore Air Coil, Vendor Information (www.baltimoreaircoil.com)

MADE BY: D. McCall DATE: 3.13.03
CHECKED BY: CWP DATE: 3/13/03

PROJECT: **West Side Corporation Site Remedial Design**
SUBJECT: **ERH System Design**

General Assumptions:

1. ERH remediation will be conducted prior to the implementation of SVE for the remainder of the contaminated areas at the site. The ERH system will be completely separate from the other systems (although the same air treatment system may be used for both).

2. The SVE system for the remainder of the site is discussed in a separate appendix. When SVE is discussed in the following sections, it refers only to the SVE system that is part of, and used in conjunction with, the ERH system.

3. The ERH system will be rented equipment, provided by the ERH contractor. The calculations below outline only the minimum requirements for an ERH system. The ERH contractor may revise or refine the design based on their knowledge and past experience, assuming that the design meets the minimum requirements of the contract documents.

4. When reference is made to a "vendor" in the following sections, it refers to one particular company that provides thermal remediation. Other vendors may make different recommendations and/or use different criteria in their design. The contract documents will be structured to allow leeway for other vendors to provide the thermal remediation services.

5. Other assumptions regarding the design of the ERH system are outlined below in the applicable section.

---

1) Electrode Spacing and Layout

a) The area for the application of ERH is shown on the attached Figure 1. This is an area approximately 60 foot by 60 foot square that was originally indicated in the ROD (Ref. 2) for in-situ chemical oxidation. The ERH system will be designed to target this entire area to the extent practicable.

b) Based on Ref. 3, and as outlined in Ref. 1, the electrodes are assumed to be located approximately 16 feet apart, in a triangular pattern. Sixteen feet is the maximum spacing recommended by one vendor, who would possibly recommend an even closer spacing of say 15 feet. Other vendors have suggested that the electrodes may be spaced up to 20 feet apart.

Figure 2 shows one potential layout of the electrodes. Based on the assumed 16 foot spacing, the minimum quantity of electrodes required is fourteen. Four additional electrodes are shown (nos. 15 through 18). These optional electrodes, shown just outside the treatment area, would be required to ensure that the entire 60' by 60' extent of the contaminated area is addressed, based on a 6-foot zone of heating beyond the electrodes as suggested by the same vendor. If the electrodes were installed in a 15-foot spacing, these four extra electrodes would fall within the 60' by 60' area.

The contract documents will be structured such that the contractor is required to install a minimum of 12 electrodes for remediation, based on the 20-foot spacing. Each of the electrodes will conduct electricity and generate heat with up to six surrounding electrodes.

c) Electrode locations shown on Figure 2 are approximate. The actual locations may be adjusted based on specific site conditions, such as subsurface obstructions.

2) **Electrode / Extraction Well Construction**

a) Upper Electrode: as outlined in the ROD (Ref. 2) the purpose of the ERH system (which replaced the Fenton's reagent system referred to in the ROD) is to reduce the volume of highly contaminated tetrachloroethylene (PCE) saturated soil and groundwater in a select area of Source Area 1. The ROD shows that most of the PCE is located in the upper 45 feet of the sandy soils in the area proposed for treatment. Although deeper contamination has been detected, it is not the target of the ERH activities.

MADE BY: D. McCall DATE: 3-13-03
CHECKED BY: CWP DATE: 3/13/03

PROJECT: **West Side Corporation Site Remedial Design**
SUBJECT: **ERH System Design**

Based on information from Ref. 3, by constructing the upper electrode from slotted steel, the electrode can serve both as the electrode in the saturated zone as well as a conduit for steam/vapor collection in the vadose zone.

b) Lower Electrode: Ref. 1 describes the conceptual implementation of the ERH. As described, a thermal barrier will be formed below the actual depth of treatment. The thermal barrier is simply a deep zone that is heated to temperature prior to heating the intended zone of treatment. The thermal barrier prevents the downward mobilization of contaminants from the upper heating zone. Any contaminants that migrate downward will hit the thermal barrier where they will be vaporized.

The zone for the thermal barrier is proposed to be 10 feet thick, from say 45 to 55 feet below ground surface.

c) Boring Depth: the depth of boring required is just to the bottom of the lower electrode; i.e., 55 feet.

d) Vapor Extraction: each electrode location will also function as a soil vapor extraction location for the vadose zone. As described above, the upper electrode will be constructed of slotted steel. The slotted portion will extend from approximately 3 feet below ground surface to the depth of the electrode at 45 feet, for a total length of 42 feet. The diameter of this vent is assumed to be 4 inches, consistent with typical SVE design.

e) Well Diameter: the boring for the electrode well must be large enough for the installation of the electrodes and the extraction piping. The diameter of the electrode boring is assumed to be 10 inches OD, based on Ref. 3.

f) Well Completion: because the area for ERH will be fenced due to safety concerns, all of the ERH electrode and associated vapor extraction piping will be installed above ground in conduit. Due to the high temperature of the vapor to be extracted, all conduit will be constructed of CPVC, rated for a long-term temperature of approximately 90°C, and a short-term exposure up to 110°C.

3) **Temperature Monitoring Points (TMPs)**

a) To monitor the operation of the ERH system and determine its effectiveness in achieving the remediation goals for the site, temperature monitoring points will be installed at various locations throughout the treatment area. The temperature transmitters will include an electrical isolation system to protect them from the damaging voltages in the treatment area. It is assumed that the transmitters will be connected to a data acquisition computer, supplied by the Contractor.

b) Depth: Each probe location will monitor the temperature at varying depths. For the purpose of this design, it is assumed that the depth will be monitored in approximately 5-foot intervals along the depth of the electrodes, for a total of say 11 temperature monitors per location.

c) Quantity and Location: as described elsewhere in this DAR, a total of 13 TMPs are proposed:

- 5 inside the treatment area
- 4 at the corners of the treatment area
- 4 located 10 feet away from the treatment area

d) Temperature Goals:

The 4 TMPs located outside the treatment area are installed only to provide information and monitoring of the surrounding area during remediation.

The 9 probes located in the treatment area will be used to determine whether the ERH system has met its intended goals for remediation. As described elsewhere in this DAR, the intended goal is that the an average of 95% of the theoretical boiling point at each location must be achieved.

e) TMP Construction: The temperature transmitters (thermocouples) will be housed in a 1-inch diameter pipe. One pipe will house all of the thermocouples. The annular space between the thermocouples and the boring will be backfilled with cement grout / bentonite up to the level of the existing water table. The vadose zone area will be backfilled with sand, up to approximately 4 feet from the surface, which will be filled with a cement grout / bentonite seal.

f) Vacuum Monitoring: The temperature monitoring point locations will also serve as locations to monitor the subsurface vacuum and vapor concentrations. Small diameter tubing or hose will be installed into the vadose zone sand layer. The top of the tubing will be fitted with a small valve and hose barb. Subsurface vacuum will be measured using a portable pressure gauge. Contaminant concentrations will be determined using a photoionization detector (PID).

g) Boring Diameter: the boring diameter required to house the equipment for the TMPs is small, and will be installed using a 3.25-inch ID hollow stem auger.

h) Well Completion: unlike the electrodes that will be completed as aboveground structures, the TMPs will be completed at grade in a small road-box suitable for traffic loading. This will allow for the continued monitoring of the subsurface temperature and vapor concentrations during the cooldown period following the completion of the ERH.

4) **Power Control Unit(s) (PCUs)**

a) The power control unit(s) (PCUs) are used to condition the electrical power for optimum subsurface heating. The power control unit will most likely be a large trailer or other container that houses a set of 60 hertz transformers for power output in the range of 1,000 kW total, although the average usage will be lower. As these units are typically supplied by the vendor and are not readily available, the exact specifications of the unit will be up to the vendor and what is available at the time of the remediation activities.

b) As shown in Appendix 5D, the minimum power input from the PCU was calculated to be 800 kW.

c) For reasons of safety, the PCU will be equipped with numerous automatic shutoff controls. Emergency stop buttons also will be installed to shut down the unit in the event that a problem or potential hazard is identified.

5) Blower Sizing

a) The blower is used to extract the soil vapors and steam from the subsurface of the site. Because the ERH generates an appreciable quantity of steam, the blower must be sized larger than would be chosen for an SVE system. This helps to ensure adequate collection of the steam contaminant vapors.

b) Ref. 3 recommended a total blower flow rate of 460 scfm. This refers to the flow rate into the blower only, and does not account for the volume of steam that will condense as it passes through the condenser. The vendor estimates that the total flow volume from the wells, including the steam, will be up to 1800 scfm.

c) As compared to the results of the SVE pilot test, this is a significantly higher extraction rate. The SVE pilot test (Ref. 4) showed a flow rate of approximately 45 cfm per well, with a radius of influence of 50 feet. This equates to a flow rate per area of:

$$(45\text{ cfm}) / [\pi \times (50\text{ft})^2] = 5.73\times10^{-3}\text{ cfm/ft}^2$$

Based on the 60 foot square dimension of the treatment area, the flow rate per area for the ERH, considering just the soil vapor (not steam) is:

$$(460\text{ cfm}) / (60\text{ ft})^2 = 1.28\times10^{-1}\text{ cfm/ft}^2$$

Thus, the flow rate for the ERH is approximately:

(1.28×10^{-1} cfm/ft^2) / (5.73×10^{-3} cfm/ft^2) = 22 times greater than the flow rate of the SVE system used to remediate the remainder of the site.

6) **Condenser Sizing**

a) The purpose of the condenser is to cool the steam / soil vapor that is collected by the ERH system. The cooling load for the condenser will consist of both steam and soil vapor.

b) Steam Cooling Load: The temperature of the vapor into the condenser is assumed to be 200°F. The temperature of the vapor at the outlet of the condenser is assumed to be 77°F (an average ambient temperature). It is assumed that all of the steam condenses.

Most of the duty for the condenser will be in condensing steam. As shown in Appendix 5B, a condensate flow rate of 4 gpm was determined. The actual condensate rate, allowing for some additional safety factor that may be needed to obtain uniform heating, may be as high as 7 - 9 gpm as water. Assuming the higher end of the range, and converting this to a mass flow rate:

(9 gal/min) x (8.34 lb/gal) = 75.06 lb/min of steam to be cooled from 200°F to 77°F.

The enthalpy (H) of steam at 200°F = 1146 BTU/lb
The enthalpy of water at 77°F = 45 BTU/lb

The total cooling load (Q) to achieve the ΔH is then calculated:

(75.06 lb/min) x [(1146 - 45) BTU/lb] x (60 min/hr) =
= 4.96×10^6 BTU/hr for steam cooling

c) Soil Vapor Cooling Load: The non-condensable soil vapor also will be cooled by the condenser from 200°F to 77°F. Once the system is up to the heating temperature, a large portion of the cooling load will be for steam condensing. However, there will still be 460 scfm of soil vapor. First, determining the density of air at 77°F:

From Ref. 5, the density of air at 0°C = $0.0808\ \text{lb/ft}^3$

$$(0.0808\ \text{lb/ft}^3) \times [(32°\text{F} + 460) / (77°\text{F} + 460)] = 0.074\ \text{lb/ft}^3$$

Now, determining the mass flow rate of the soil vapor:

$$(460\ \text{scfm}) \times (0.074\ \text{lb/ft}^3) = 34.04\ \text{lb/min of air}$$

Since there is no change in phase, the cooling load for the air is determined from $Q = mc_p\Delta T$

Now using a heat capacity for air of 0.25 BTU/lb·°F (from Ref. 5), and substituting into the equation:

$$\begin{aligned} Q &= (34.04\ \text{lb/min})(0.25\ \text{BTU/lb}\cdot°\text{F})(200° - 77°\text{F}) \\ &= 1{,}047\ \text{BTU/min} \times (60\ \text{min/hr}) \\ &= 62{,}804\ \text{BTU/hr or } 0.063\ \text{MMBTU/hr for air cooling} \end{aligned}$$

d) Total Cooling Load: Adding the total cooling load from the steam and the air yields a total cooling load of:

$$4.96\times10^6\ \text{BTU/hr} + 62{,}804\ \text{BTU/hr} = 5\times10^6\ \text{BTU/hr}$$

7) Cooling Water Flow Rate

a) The cooling load calculated for the condenser above will be achieved with cooling water. A conservative temperature rise for cooling water used in a condenser is 20°F; e.g., the water will flow into the condenser at say 85°F and flow out at 105°F. If a higher temperature rise in acceptable, then the flow rate of the water can be reduced proportionately.

b) Cooling rate for water: the amount of heat absorbed by the cooling water is determined from the equation:

$$Q = mc_p\Delta T,$$

The heat capacity for water is approximately 1.0 BTU/lb·°F. The cooling load will be determined on a basis of 1 lb of water, so:

$$Q = (1\ \text{lb}) \times (1.0\ \text{BTU/lb}\cdot{}^\circ\text{F}) \times (105^\circ - 85^\circ\text{F}) = 20\ \text{BTU/lb water}.$$

Now, knowing the total cooling load required, the flow rate of cooling water is determined:

$$\frac{5x10^6\,BTU}{hr}\,x\,\frac{1lb_{water}}{20BTU}\,x\,\frac{1gal_{water}}{8.34lb}\,x\,\frac{1hr}{60\min} = 500gpm$$

Based on information from the vendor, 500 gpm is somewhat higher than typically used. Estimating a condensate rate of approximately 7 gpm, and assuming a 30° temperature rise in the cooling water, a flow rate of 250 was estimated. Therefore, the actual cooling water flow rate is assumed to be in the range of 250 to 500 gpm.

8) **Cooling Tower Design**

a) The cooling tower will be designed to remove the heat from the cooling water used in the steam condenser. As assumed above for the condenser, the hot water will flow into the cooling tower at say 105°F and exit at say 85°F. A fan is used to blow ambient air up through the cooling tower as the water flows down through the unit.

b) Using a vendor supplied selection program (Ref. 6), a typical cooling tower was selected. Based on this preliminary unit, a single cooling tower with a 25 HP fan was chosen.

PROJECT: West Side Corporation Site Remedial Design
SUBJECT: ERH System Design

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9) **Air Treatment**

a) Air treatment will be a significant component of the ERH system as well as other components of the remedial actions at the site. Comprehensive air treatment is evaluated separately in this DAR.

APPENDIX 3B

CALCULATION OF PCE VAPOR/LIQUID DISTRIBUTION AT CONDENSER

URS
282 Delaware Avenue
Buffalo, New York 14202
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CALCULATION COVER SHEET

Client: NYSDEC　Project Name: West Side Corporation

Project/Calculation Number: 11172744

Title: Calculation of PCE vapor / liquid distribution at condenser

Total number of pages (including cover sheet): 16

Total number of computer runs: one spreadsheet

Prepared by: Jon Sundquist　Date: 4/3/03

Checked by:　Date: 4/3/03

Description and Purpose: Confirm that no free-phase PCE will be present in the liquid phase leaving the condenser

Design bases/references/assumptions: See calculations

Remarks/conclusions: At design vapor recovery air flow rate, PCE concentration in condensate water would be only ~4 mg/L, with the vast majority of PCE remaining in vapor phase. Air removal rates would have to reduce to ~0.28 ft³/min in order to get PCE free liquid condensate

Calculation Approved by: ____________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:

Project Manager/Date

URSF-124/1 OF 1/CCS/gcm

URS

Page 1 of 15

Job West Side Corp

Project No. 11172244

Sheet ____ of ____

Description Calculation of PCE vapor/liquid distribution at Condenser.

Computed by Jon Sundquist

Date 12/5/02

Checked by

Date 4/3/03

Reference

Problem : Calculate whether PCE will mainly be in the vapor phase or liquid phase following condensation.

Assumptions:

Vapor recovery process recovers:

- water at $\left(\frac{3.5\ \text{gal}}{\text{min}}\right)\left(\frac{3.785\ \text{L}}{\text{gal}}\right)\left(\frac{1000\ \text{mL}}{\text{L}}\right)\left(\frac{1\ \text{g}}{\text{mL}}\right) = 13,250\ \frac{\text{g}}{\text{min}}$

- PCE ~ assume 90% is removed in first month (conservative) and that 5000 lb of PCE will be removed overall

Condenser temperature is 77° F

Calculations:

PCE average recovery rate:

$$(90\%)\left(\frac{5000\ \text{lb}}{30\ \text{days}}\right)\left(\frac{453.6\ \text{g}}{\text{lb}}\right)\left(\frac{\text{day}}{24\ \text{hr}}\right)\left(\frac{\text{hr}}{60\ \text{min}}\right) = \frac{47.25\ \text{g}}{\text{min}}$$

First, if <u>all</u> was condensed (no vapor remaining)

$$\frac{47.25\ \text{g}}{13,25\ \text{L}} = \frac{3,566\ \text{mg}}{\text{L}}$$

This is above solubility of PCE which is ~150 mg/L

However not all PCE will condense

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Job West Side Corporation

Project No. 11172744

Sheet ____ of ____

Description Calculation of PCE vapor/liquid distribution at condenser

Computed by Jon Sundquist

Date 12/5/02

Checked by

Date 4/3/03

Reference

Assume Henry's Law applies.

Henry's Law constant = $0.0153 \frac{\text{atm-m}^3}{\text{mol}}$ (ref 1)

or = $0.023 \frac{\text{atm-m}^3}{\text{mol}}$ (ref 2)

assume $0.02 \frac{\text{atm-m}^3}{\text{mol}}$

$$\frac{\text{Partial pressure (atm)}}{\text{liquid concentration } \left(\frac{\text{mol}}{\text{m}^3}\right)} = 0.02 \frac{\text{atm-m}^3}{\text{mol}}$$

Vapor phase would be combination of air, water, & PCE, can't do a mass balance strictly on Water + PCE

Calculate amount of gas coming in

PCE MW = (2)(12) + (4)(35.45) = 165.8

H_2O MW = 18

so 47 g/min of PCE = $\left(\frac{47 \text{ g}}{\text{min}}\right)\left(\frac{\text{mol}}{165.8 \text{ g}}\right) = 0.285 \frac{\text{mol}}{\text{min}}$

$13{,}250 \frac{\text{g}}{\text{min}}$ of H_2O = $\left(\frac{13{,}250 \text{ g}}{\text{min}}\right)\left(\frac{\text{mol}}{18 \text{ g}}\right) = 736 \frac{\text{mol}}{\text{min}}$

or almost entirely water from a mole basis.

Total gas flow rate = 460 ft³/min following condenser (~25°C)

density calculation: $\frac{n}{V} = \frac{P}{RT} = \frac{1 \text{ atm}}{(298 \text{ °K})\left(0.082 \frac{\text{L-atm}}{\text{mol-°K}}\right)} = 0.041 \frac{\text{mol}}{\text{L}}$

so $460 \frac{\text{ft}^3}{\text{min}} = \left(460 \frac{\text{ft}^3}{\text{min}}\right)\left(\frac{0.041 \text{ mol}}{\text{L}}\right)\left(\frac{\text{L}}{1000 \text{ cm}^3}\right)\left(\frac{30.48 \text{ cm}}{\text{ft}}\right)^3 = 534 \frac{\text{mol}}{\text{min}}$

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Job West Side Corporation

Description Calculation of PCE Vapor/liquid distribution at condenser

Project No. 11177744

Sheet ___ of ___

Computed by Jon Sundquist

Date 12/5/02

Checked by E Dursin

Date 4/3/03

Reference

Mass balance calculation (basis: 1 minute)

Mass PCE in vapor + Mass PCE dissolved = 47 g = 0.285 mole

Mass Water in vapor + Mass Water condensed = 13,250 g = 736 mole

Assume most water is condensed, or at least water vapor contributes negligibly to total volume of headspace (which is mostly air)

Define "y" as # of moles in gas phase and "x" as # of moles in dissolved phase

then: partial pressure of PCE = $\left[\frac{y \text{ mole PCE}}{534 \text{ mole Air}}\right] 1 \text{ atm}$

Concentration of PCE in water = $\frac{x \text{ mole PCE}}{[13{,}250 \text{ cm}^3 \text{ water}]\left[\frac{\text{m}^3}{10^6 \text{ cm}^3}\right]} = (75.47)x \frac{\text{mol}}{\text{m}^3}$

So $H = 0.02 \frac{\text{atm-m}^3}{\text{mol}} = \frac{(y/534) \text{ atm}}{(75.47x) \text{ mol/m}^3} = 2.48 \times 10^{-5} \frac{y}{x} \frac{\text{atm-m}^3}{\text{mol}}$

and $x + y = 0.285$ mole (total moles of PCE for 1-minute basis)

Since $\frac{y}{x} = \frac{0.02}{2.48 \times 10^{-5}} = 806$

$y = 806x$

so $x + (806)x = 0.285$ mole

$x = 3.59 \times 10^{-4}$ moles

$y = 0.285$ moles

Conclusion → virtually none of PCE is in condensate

Calculate resultant PCE liquid concentration:

$$\frac{(3.59 \times 10^{-4} \text{ mole})(165.83 \text{ g/mole})}{(13{,}250 \text{ g})(1 \text{ mL/g})}\left[\frac{10^3 \text{ mL}}{\text{L}}\right]\left[\frac{10^3 \text{ mg}}{\text{g}}\right] = 4.5 \frac{\text{mg}}{\text{L}}$$

This is well below solubility

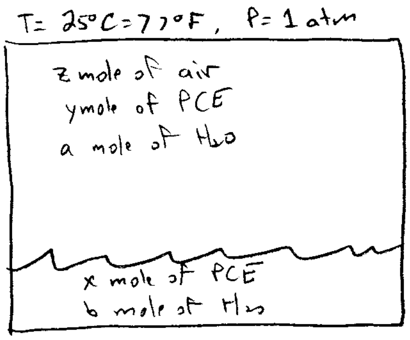
The calculation above assumed that air was the major component of the gas phase due to the amount that is withdrawn through by the vapor recovery program. We will perform one more calculation that looks at how low an airflow is needed before PCE condensation (free product) occurs.

Basis: one minute

In one minute, we collect, according to our assumptions above, we get

0.29 mole or 47 g PCE
736 mole or 13,250 g water
z mole or (29.1)(z) g air
└ MW of air (21% O_2, 79% N_2)

This is the 1-minute basis "snapshot" we need to solve:



Here we introduce

a for # of H_2O moles as vapor
b for # of H_2O moles as liquid

At 25°C = 77°F,

~~Vapor pressure of PCE ≈ 19 mm Hg~~ don't need
Vapor pressure of H_2O ≈ 23.8 mm Hg

Because solubility of PCE ≈ 150 mg/L (i.e. is low)

partial pressure of H_2O ≈ vapor pressure = 23.8 mm Hg (Ref 3)

(i.e., not appreciably decreased by Raoult's Law)

cont'd →

URS

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Job West Side Corp.

Project No. 11172744

Sheet ___ of ___

Description Calculation of PCE vapor / liquid distribution

Computed by Jon Sundquist

Date 4/15/02

Checked by

Date 4/3/03

Reference

Mass balances:

$a + b = 736$ mole water

$x + y = 0.285$ mole PCE

$\boxed{\text{so } y = 0.285 - x}$

Since we assumed H_2O partial pressure ≈ vapor pressure

$$\frac{\text{partial pressure water}}{\text{total pressure}} = \frac{a}{a+y+z} = \frac{23.8}{760} = 3.13 \times 10^{-2}$$

$$31.9\,a = a + y + z$$

$$30.9\,a = y + z = 0.285 - x + z$$

$$\boxed{a = 9.22 \times 10^{-3} - (3.24 \times 10^{-2})x + (3.24 \times 10^{-2})z}$$

$$\text{Concentration of PCE in water} = \frac{x \text{ mole PCE}}{(b \text{ mole } H_2O)(18 \frac{g}{mole})(1 \, {}^{cm^3}/{}_{g})({}^{m}/{}_{100\,cm})^3}$$

$$= \left(\frac{x}{b}\right) 55{,}556 \ \frac{mole}{m^3}$$

since $b = 736 - a$

and $a =$ (defined above)

$$\boxed{b = 736 - (3.24 \times 10^{-2})x + (3.24 \times 10^{-2})z}$$

using Henry's Law for PCE

$$\frac{\text{partial pressure of PCE}}{\text{molar concentration of PCE}} = 0.2 \ \frac{atm-mole}{m^3}$$

$$= \frac{\left[\frac{y}{(a+y+z)}\right] atm}{\left(\frac{x}{b}\right)\left(55{,}556 \ \frac{mol}{m^3}\right)}$$

cont'd ⇒

URS

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Job West Side Corp.

Project No. 11172744

Sheet ____ of ____

Description Calculation of PCE vapor / liquid distribution

Computed by Jon Sundquist

Date ____

Checked by

Date 4/3/03

Reference

$$0.2 = \frac{\left\{\dfrac{(0.285-x)}{[9.22\times10^{-3}-(3.24\times10^{-2})x+(3.24\times10^{-2})z]+[0.285-x]+z}\right\}}{\left[\dfrac{x}{736-(3.24\times10^{-2})x+(3.24\times10^{-2})z}\right][55{,}556]}$$

$$\frac{(11{,}111)x}{736-(3.24\times10^{-2})x+(3.24\times10^{-2})z}$$

$$= \frac{0.285-x}{[9.22\times10^{-3}-(3.24\times10^{-2})x+(3.24\times10^{-2})z+[0.285-x]+z}$$

$$(102.4)x-(360)x^2+(360z)x+(3{,}167)x-(11{,}111)x^2+(11{,}111z)x$$

$$= 209.8-(9.23\times10^{-2})x+(9.23\times10^{-2})z-(736)x+(3.24\times10^{-2})x^2-(3.24\times10^{-2})(z)(x)$$

$$(-360-11{,}111-3.24\times10^{-2})x^2+(102.4+360z+3{,}167+11{,}111z+9.23\times10^{-2}+736+(3.24\times10^{-2}z))x$$

$$= 213.4+(9.23\times10^{-2})z$$

$$(11{,}471)x^2-(4{,}005+11{,}471(z))x+(213.4+(9.23\times10^{-2})z)=0$$

$$x = \frac{4{,}005+(11{,}471)z \pm \left[(4{,}005+(11{,}471)z)^2-(4)(11{,}471)(213.4+(9.23\times10^{-2})z)\right]^{1/2}}{22{,}942}$$

PCE concentration in water is

$$\frac{(x\text{ moles PCE})(165.8\,\text{g/mole})(10^3\,\text{mg/g})}{\underbrace{(736-(3.24\times10^{-2})x+(3.24\times10^{-2})z)}_{b\text{ moles}}(18\,\text{g/mole})(1\,\text{mL/g})}\left(\frac{10^3\,\text{mL}}{\text{L}}\right)$$

$$= \frac{(9.2\times10^{6})\,x}{736-(3.24\times10^{-2})x+(3.24\times10^{-2})z} \qquad \frac{\text{mg}}{\text{L}}$$

These equations solved by spread sheet

Job West Side Corp.

Project No. 1172744

Sheet ____ of ____

Description Calculation of PCE vapor / liquid distribution

Computed by Jon Sundquist

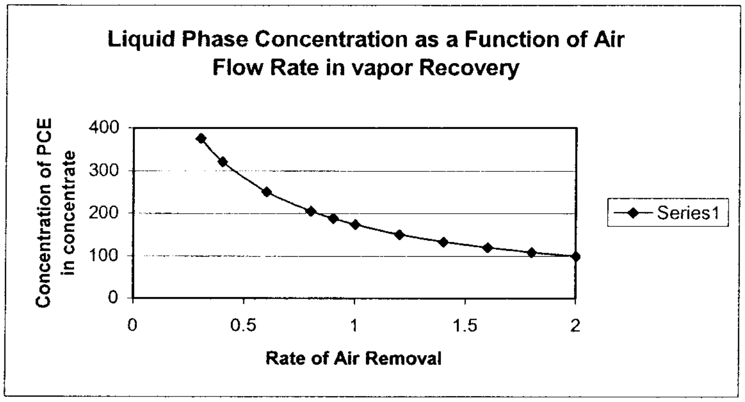
Date 4/3/02

Checked by

Date 4/3/03

Reference

Quadratic equation solution		(z:) 0.3	0.4	0.6	0.8	0.9	1	1.2	1.4	1.6	1.8	2
x moles	"+"	0.619091	0.723425	0.929118	1.132717	1.234066	1.335208	1.537037	1.738439	1.939549	2.140449	2.341194
	"-"	0.03005	0.025716	0.020023	0.016424	0.015075	0.013934	0.012104	0.010702	0.009592	0.008692	0.007947
mg/L	"+"	7738.75	9042.942	11614.14	14159.17	15426.05	16690.34	19213.25	21730.82	24244.73	26756.02	29265.37
	"-"	375.6202	321.4474	250.2836	205.2966	188.4364	174.1623	151.2929	133.7653	119.8953	108.642	99.3265



Of the solutions to the quadratic equation, the "+" solution provides a value of x that is greater than 0.285 so is not the proper solution.

This solution shows that a minimum air flow rate of ~1.2 mole/min is required

$$\left(\frac{1.2\ \text{mole}}{\text{min}}\right)\left(\frac{\text{L}}{0.041\ \text{mole}}\right)\left(\frac{\text{gal}}{3.785\ \text{L}}\right)\left(\frac{\text{ft}^3}{7.48\ \text{gal}}\right) = 1.06\ \frac{\text{ft}^3}{\text{min}}$$

So long as stay above 1.06 ft³/min air flow rate, will not condense free phase PCE.

ref(1)

Papers & Information

Papers, Articles & Information

"Performance Testing of Conventional and Innovative Down Samplers and Pumps for VOC's in a Laboratory Monitoring V

by:
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ABSTRACT

Concentrations of groundwater contaminants in samples that differ from concentrations in the aquifer can lead to incorrect conclusio extent and severity of contamination and the effectiveness of remedial measures. Sample collection and storage techniques affect me concentrations in samples, particularly of organic compounds that are subject to loss by sorption or volatilization. Both commerciall VOC samplers and prototypes still under development were evaluated under controlled conditions in a laboratory setting using a vert steel pipe located in a stairwell, which simulates a monitoring well. Samplers were lowered inside the pipe to the bottom and activate samples, while control samples were collected from a stopcock at the base of the well. Comparison of concentrations in samples coll VOC samplers to concentrations in the control samples was used as a measure of the quality of samples provided by various VOC sa

INTRODUCTION

This paper describes preliminary results of an ongoing project. Several commercially available and prototype downhole water sample tested under laboratory conditions to evaluate their ability to provide samples for VOC analysis that are representative of the water fr samples were collected. The laboratory facility includes a simulated well that consists of a 5 3/4 inch (14.6 cm) diameter stainless stee (9.75 m) tall, which is located in a stairwell. The simulated well is completely above ground, and the stairs provide convenient access vertical height of the well. The well was filled to about 3.5 metres below the top with simulated groundwater spiked with a mixture of v compounds. Water samples were collected by lowering samplers to the bottom of the laboratory well and operating the sampler as if well was an actual well in the field. These samples were compared against a suite of control samples collected from the bottom of the well by opening a sample port, which allowed water to flow out of the well due to gravity and through stainless steel tubing to an EPA ml glass vial. A sampling head allowed the vial to be filled and then flushed with any desired volume of water, which was not exposed phase after initial filling of the vial.

The mean concentration of the control samples was taken as the true concentration in the well, and a difference between the mean co the control set and the downhole water sampler data set indicates that the sampler produces samples that are not representative of t sampled.

The major loss mechanisms for dissolved VOCs from groundwater samples are thought to be sorption onto organic components of s storage containers, such as plastic or rubber, and volatilization into the gas phase. Volatilization can occur whenever the aqueous sa exposed to a gas phase, such as bubbles or a head space in a sampler or sample container, or exposed to the atmosphere while bein from a sampler to a storage container

To evaluate the potential for losses by these mechanisms, the water used in the laboratory experiments was spiked with compounds range of tendency to sorb or volatilize. The octanol - water partitioning coefficient, Kow, is a measure of the tendency of a compound by organic materials, with higher values corresponding to greater tendency to sorb. The Henry's Law constant describes the tendenc compound to partition from the aqueous phase to the gas phase, with higher values corresponding to a greater tendency to partition phase. Table 1 lists the values of the octanol - water partitioning coefficient and the Henry's law constant for the compounds used in work.

Table 1
Properties of Compounds Used in Laboratory Evaluation of Water Samplers

Compound	Abbreviation	Log Kow	Henry's Law Constant (atm m3/mol)

Att 1, cont'd

9 , 15

methylene chloride	MeCl	1.30	0.0020
carbon tetrachloride	CTET	2.40	0.023
trichloroethylene	TCE	2.60	0.0091
tetrachloride	PCE	2.83	0.0153

Concentrations in the spiked water in the well were in a convenient range for analysis to maximize the precision and accuracy of the
results, and were well above drinking water limits (Table 2).

Table 2
Drinking Water Limits

Compound	Drinking Water Limit
DCE	7
MeCl	NA
CTET	5
TCE	5
PCE	0.5

Several commercially available and prototype samplers have been evaluated to date in this project, and others are currently being ev
samplers evaluated and reported here are listed in Table 3

Table 3
Samplers Evaluated

Sampler	Supplier
Stainless steel bailer	Solinst Canada Ltd.
Teflon bailer	Norwell
VOA trap sampler	Solinst Canada Ltd.
Canister sampler	Prototype
Bladder Pump	QED
Double valve sampler	Solinst Canada Ltd.
Peristaltic pump & sampling head	Prototype
Inertial pump (Solinst Canada Ltd.)	WaTerra

Both the Solinst and Norwell bailers have check valves at the top and bottom to facilitate collecting a sample from a discrete depth.
transferred from the bailers into a separate sample container by opening a valve at the bottom of the bailer and directing a stream of
sample vial, which exposes the water to the atmosphere. The Solinst VOA trap sampler is basically a syringe that is lowered to the de
sampling depth. The piston retracts in the cylinder due to the hydrostatic pressure in the well as the syringe fills with water, and a ch
the piston allows additional water to flush through the syringe cylinder after the piston is fully retracted. The sampler is withdrawn fr
and the syringe is transported to the laboratory for analysis, without transferring the sample into a separate container. The canister s
prototype developed at the University of Waterloo, is designed for use in narrow diameter multilevel sampling systems or convention
requires a diameter of only one half inch. It consists of a length of stainless steel pipe fitted with manually operated valves at each en
are opened, and a separate check valve is attached to the bottom. The canister is lowered to the desired depth in the well, the check v
opened to allow water to fill the canister and continue to flush it after initial filling. The check valve is closed, the sampler is removed
and the manual valves are closed. The check valve is removed and the sealed canister is shipped to the laboratory for analysis. The
a bladder pump, the operating principles of which are well known and are not repeated here. The Solinst Double Valve Pump is some
operation to a bladder pump except that there is no bladder. Hence, there is some contact between the water sample and a gas phase
peristaltic pump and sampling head system consists of a sampling head that allows a glass vial to be placed in line on the suction (u
of a peristaltic pump. A suction hose is lowered to the desired sampling depth in the well, and any required volume of water can be p
through the vial to flush it without exposing the water to a headspace, after the vial is initially filled. The inertial pump is the WaTerra
operating principles are well known and not repeated here. The procedure for filling sample vials recommended by the supplier was
involves placing a Teflon tube into the polyethylene riser pipe to direct water from the riser pipe into sample vials to minimize expos
atmosphere.

RESULTS AND DISCUSSION

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Appendix B
Properties of Common Organic Pollutants

B-1. Introduction

Appendix B consists of 13 tables, each presenting physical and/or chemical properties of compounds and fuel products. This information, including, for example, molecular weights, boiling points, Henry's Law Constants, vapor pressures, and vapor densities may prove helpful in evaluating whether a given site with its contaminants of concern is amenable to SVE/BV. In addition, this information may be needed in calculating various operating parameters or outcomes of an SVE/BV system at a given site with a given suite of contaminants of concern.

B-2. List of Tables

B-1: Selected Compounds and Their Chemical Properties. Lists molecular weight, compound boiling point, vapor pressure, and equilibrium vapor concentration.

B-2: Physicochemical Properties of PCE and Associated Compounds. Lists molecular weight, liquid density, melting point, boiling point, vapor pressure, water solubility, log octanol-water coefficient, soil sorption coefficient, and Henry's Law constant for PCE; TCE; 1,1-DCE; 1,2-DCE; and vinyl chloride.

B-3: Physicochemical Properties of TCA and Associated Compounds. Lists same properties as Table B-2 for 1,1,1-TCA; 1,1-DCA; and CA.

B-4: Physical Properties of Fuel Components. Lists molecular weight, solubility, soil sorption coefficient, log octanol-water coefficient, and vapor pressure for n-alkanes, isoalkanes, cycloalkanes, alkenes, aromatics, and PAHs.

B-5: Selected Specification Properties of Aviation Gas Turbine Fuels. Lists data on composition, volatility, fluidity and combustion for Jet Fuels A and B and JP-4, -5, -7, and -8.

B-6: Detectable Hydrocarbons Found in U.S. Finished Gasolines at a Concentration of 1% or more. Lists constituents and estimated ranges of weight percentages of each.

B-7: Major Component Streams of European Automotive Diesel Oil (Diesel Fuel No. 2) and Distillate Marine Diesel Fuel (Diesel Fuel No. 4). Lists nonspecific components by Toxic Substances Control Act (TSCA) inventory name and identification number, as well as volumetric percentages of each in both automotive diesel oil and distillate marine diesel fuel.

B-8: Henry's Law Constants for Selected Organic Compounds. Lists values of H at 20-25 C for chlorinated nonaromatics, chlorinated ethers, monocyclic aromatics, pesticides, PCBs, and polycyclic aromatics.

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Table B-2

Physiochemical Properties of PCE and Associated Compounds*

Formula	PCE C_2Cl_4	TCE C_2HCl_3	1,1-DCE $C_2H_2Cl_2$	t-1,2-DCE $C_2H_2Cl_2$	c-1,2-DCE $C_2H_2Cl_2$	V C C_2H_3Cl
Molecular weight (g/mol)	165.85	131.40	96.95	96.95	96.95	62.5
Liquid density (g/cm^3)	1.625	1.46	1.214	1.257	1.284	0.9121#
Melting point (K)	250.6	200	150.4	223.6	191.5	119.2
Boiling point (K)	394	360	304.6	320.7	333.2	259.6
Vapor pressure (mmHg)	14	69$^{\circ 1}$	500	5.3	2.7	2300
Water solubility (mg/l)	150	1100[1]	400	6300	3500	1100
Log octanol - water coefficient (K_{OW})	3.14	2.42	2.13	2.09	1.86	1.23
Soil sorption coefficient (K_{OC}) (l/kg)	665	160[2]	65	59	35	8.2
Henry's Law constant (atm. m^3/mol)	0.023	.0103[1]	0.154	0.0066[1]	0.0075[1]	0.695

Arthur D. Little, Inc. (1987). *The installation restoration program toxicology guide, Volume 1.* Section 2:1-16.

All values are at 293 K, unless otherwise indicated.
#Value is a specific gravity measurement.
[1] At 298 K.
[2] From Lyman et al.(1982) Handbook of Chemical Property Estimation Methods

reference (3)

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CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data

1981—1982
62nd
EDITION

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CRC Press, Inc.
Boca Raton, Florida

VAPOR PRESSURE OF WATER BELOW 100°C

Pressure of aqueous vapor over water in mm of Hg for temperatures from −15.8 to 100°C. Values for fractional degrees between 50 and 89 were obtained by interpolation.

Temp. °C	0.0	0.2	0.4	0.6	0.8
−15	1.436	1.414	1.390	1.368	1.345
−14	1.560	1.534	1.511	1.485	1.460
−13	1.691	1.665	1.637	1.611	1.585
−12	1.834	1.804	1.776	1.748	1.720
−11	1.987	1.955	1.924	1.893	1.863
−10	2.149	2.116	2.084	2.050	2.018
− 9	2.326	2.289	2.254	2.219	2.184
− 8	2.514	2.475	2.437	2.399	2.362
− 7	2.715	2.674	2.633	2.593	2.553
− 6	2.931	2.887	2.843	2.800	2.757
− 5	3.163	3.115	3.069	3.022	2.976
− 4	3.410	3.359	3.309	3.259	3.211
− 3	3.673	3.620	3.567	3.514	3.461
− 2	3.956	3.898	3.841	3.785	3.730
− 1	4.258	4.196	4.135	4.075	4.016
− 0	4.579	4.513	4.448	4.385	4.320
0	4.579	4.647	4.715	4.785	4.855
1	4.926	4.998	5.070	5.144	5.219
2	5.294	5.370	5.447	5.525	5.605
3	5.685	5.766	5.848	5.931	6.015
4	6.101	6.187	6.274	6.363	6.453
5	6.543	6.635	6.728	6.822	6.917
6	7.013	7.111	7.209	7.309	7.411
7	7.513	7.617	7.722	7.828	7.936
8	8.045	8.155	8.267	8.380	8.494
9	8.609	8.727	8.845	8.965	9.086
10	9.209	9.333	9.458	9.585	9.714
11	9.844	9.976	10.109	10.244	10.380
12	10.518	10.658	10.799	10.941	11.085
13	11.231	11.379	11.528	11.680	11.833
14	11.987	12.144	12.302	12.462	12.624
15	12.788	12.953	13.121	13.290	13.461
16	13.634	13.809	13.987	14.166	14.347
17	14.530	14.715	14.903	15.092	15.284
18	15.477	15.673	15.871	16.071	16.272
19	16.477	16.685	16.894	17.105	17.319
20	17.535	17.753	17.974	18.197	18.422
21	18.650	18.880	19.113	19.349	19.587
22	19.827	20.070	20.316	20.565	20.815
23	21.068	21.324	21.583	21.845	22.110
24	22.377	22.648	22.922	23.198	23.476
25	23.756	24.039	24.326	24.617	24.912
26	25.209	25.509	25.812	26.117	26.426
27	26.739	27.055	27.374	27.696	28.021
28	28.349	28.680	29.015	29.354	29.697
29	30.043	30.392	30.745	31.102	31.461
30	31.824	32.191	32.561	32.934	33.312
31	33.695	34.082	34.471	34.864	35.261
32	35.663	36.068	36.477	36.891	37.308
33	37.729	38.155	38.584	39.018	39.457
34	39.898	40.344	40.796	41.251	41.710
35	42.175	42.644	43.117	43.595	44.078
36	44.563	45.054	45.549	46.050	46.556
37	47.067	47.582	48.102	48.627	49.157
38	49.692	50.231	50.774	51.323	51.879
39	52.442	53.009	53.580	54.156	54.737
40	55.324	55.91	56.51	57.11	57.72
41	58.34	58.96	59.58	60.22	60.86

Temp. °C	0.0	0.2	0.4	0.6	0.8
42	61.50	62.14	62.80	63.46	64.12
43	64.80	65.48	66.16	66.86	67.56
44	68.26	68.97	69.69	70.41	71.14
45	71.88	72.62	73.36	74.12	74.88
46	75.65	76.43	77.21	78.00	78.80
47	79.60	80.41	81.23	82.05	82.87
48	83.71	84.56	85.42	86.28	87.14
49	88.02	88.90	89.79	90.69	91.59
50	92.51	93.5	94.4	95.3	96.3
51	97.20	98.2	99.1	100.1	101.1
52	102.09	103.1	104.1	105.1	106.2
53	107.20	108.2	109.3	110.4	111.4
54	112.51	113.6	114.7	115.8	116.9
55	118.04	119.1	120.3	121.5	122.6
56	123.80	125.0	126.2	127.4	128.6
57	129.82	131.0	132.3	133.5	134.7
58	136.08	137.3	138.5	139.9	141.2
59	142.60	143.9	145.2	146.6	148.0
60	149.38	150.7	152.1	153.5	155.0
61	156.43	157.8	159.3	160.8	162.3
62	163.77	165.2	166.8	168.3	169.8
63	171.38	172.9	174.5	176.1	177.7
64	179.31	180.9	182.5	184.2	185.8
65	187.54	189.2	190.9	192.6	194.3
66	196.09	197.8	199.5	201.3	203.1
67	204.96	206.8	208.6	210.5	212.3
68	214.17	216.0	218.0	219.9	221.8
69	223.73	225.7	227.7	229.7	231.7
70	233.7	235.7	237.7	239.7	241.8
71	243.9	246.0	248.2	250.3	252.4
72	254.6	256.8	259.0	261.2	263.4
73	265.7	268.0	270.2	272.6	274.8
74	277.2	279.4	281.8	284.2	286.6
75	289.1	291.5	294.0	296.4	298.8
76	301.4	303.8	306.4	308.9	311.4
77	314.1	316.6	319.2	322.0	324.6
78	327.3	330.0	332.8	335.6	338.2
79	341.0	343.8	346.6	349.4	352.2
80	355.1	358.0	361.0	363.8	366.8
81	369.7	372.6	375.6	378.8	381.8
82	384.9	388.0	391.2	394.4	397.4
83	400.6	403.8	407.0	410.2	413.6
84	416.8	420.2	423.6	426.8	430.2
85	433.6	437.0	440.4	444.0	447.5
86	450.9	454.4	458.0	461.6	465.2
87	468.7	472.4	476.0	479.8	483.4
88	487.1	491.0	494.7	498.5	502.2
89	506.1	510.0	513.9	517.8	521.8
90	525.76	529.77	533.80	537.86	541.95
91	546.05	550.18	554.35	558.53	562.75
92	566.99	571.26	575.55	579.87	584.22
93	588.60	593.00	597.43	601.89	606.38
94	610.90	615.44	620.01	624.61	629.24
95	633.90	638.59	643.30	648.05	652.82
96	657.62	662.45	667.31	672.20	677.12
97	682.07	687.04	692.05	697.10	702.17
98	707.27	712.40	717.56	722.75	727.98
99	733.24	738.53	743.85	749.20	754.58
100	760.00	765.45	770.93	776.44	782.00
101	787.57	793.18	798.82	804.50	810.21

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Temp. °C	m
100	760
101	787
102	815
103	845
104	875
105	906
106	937
107	970
108	1004
109	1038
110	1074
111	1111
112	1148.
113	1187.
114	1227.
115	1267.
116	1309.
117	1352.
118	1397.
119	1442.
120	1489.
121	1536.
122	1586.
123	1636.
124	1687.
125	1740.
126	1795.
127	1850.
128	1907.
129	1966.
130	2026.
131	2087.
132	2150.
133	2214.
134	2280.
135	2347.
136	2416.
137	2488.
138	2560.
139	2634.
140	2710.
141	2788.
142	2867.
143	2948.
144	3031
145	3116
146	3203.
147	3292.
148	3382.
149	3476.
150	3570.
151	3667.
152	3766.
153	3866.
154	3970.
155	4075.
156	4183.
157	4293.
158	4404.
159	4519.
160	4636.
161	4755.
162	4876.
163	5000.
164	5126.
165	5256.
166	5386.
167	5521.
168	5658.
169	5798.

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VAPOR PRESSURE OF WATER ABOVE 100° C.

Based on values given by Keyes in the International Critical Tables.

Temp. °C	Pressure		Temp. °F	Temp. °C	Pressure		Temp. °F	Temp °C	Pressure		Temp. °F	Temp. °C	Pressure		Temp. °F
	mm	Pounds per sq. in.			mm	Pounds per sq. in.			mm	Pounds per sq. in.			mm	Pounds per sq. in.	
100	760.	14.696	212.0	170	5940.92	114.879	338.0	240	25100.52	485.365	464.0	310	74024.00	1431.390	590.0
101	787.51	15.228	213.8	171	6085.32	117.671	339.8	241	25543.60	493.933	465.8	311	75042.40	1451.083	591.8
102	815.86	15.776	215.6	172	6233.52	120.537	341.6	242	25994.28	502.647	467.6	312	76076.00	1471.070	593.6
103	845.12	16.342	217.4	173	6383.24	123.432	343.4	243	26449.52	511.450	469.4	313	77117.20	1491.203	595.4
104	875.06	16.921	219.2	174	6538.28	126.430	345.2	244	26912.36	520.400	471.2	314	78166.00	1511.484	597.2
105	906.07	17.521	221.0	175	6694.08	129.442	347.0	245	27381.28	529.467	473.0	315	79230.00	1532.058	599.0
106	937.92	18.136	222.8	176	6852.92	132.514	348.8	246	27855.52	538.638	474.8	316	80294.00	1552.632	600.8
107	970.60	18.768	224.6	177	7015.56	135.659	350.6	247	28335.84	547.926	476.6	317	81373.20	1573.501	602.6
108	1004.42	19.422	226.4	178	7180.48	138.848	352.4	248	28823.76	557.360	478.4	318	82467.60	1594.663	604.4
109	1038.92	20.089	228.2	179	7349.20	142.110	354.2	249	29317.00	566.898	480.2	319	83569.60	1615.972	606.2
110	1074.56	20.779	230.0	180	7520.20	145.417	356.0	250	29817.84	576.583	482.0	320	84686.80	1637.575	608.0
111	1111.20	21.487	231.8	181	7694.24	148.782	357.8	251	30324.00	586.370	483.8	321	85819.20	1659.472	609.8
112	1148.74	22.213	233.6	182	7872.08	152.221	359.6	252	30837.76	596.305	485.6	322	86959.20	1681.516	611.6
113	1187.42	22.961	235.4	183	8052.96	155.719	361.4	253	31356.84	606.342	487.4	323	88114.40	1703.854	613.4
114	1227.25	23.731	237.2	184	8236.88	159.275	363.2	254	31885.04	616.556	489.2	324	89277.20	1726.339	615.2
115	1267.98	24.519	239.0	185	8423.84	162.890	365.0	255	32417.80	626.858	491.0	325	90447.60	1748.971	617.0
116	1309.94	25.330	240.8	186	8616.12	166.609	366.8	256	32957.40	637.292	492.8	326	91633.20	1771.897	618.8
117	1352.95	26.162	242.6	187	8809.92	170.356	368.6	257	33505.36	647.888	494.6	327	92826.40	1794.969	620.6
118	1397.18	27.017	244.4	188	9007.52	174.177	370.4	258	34059.40	658.601	496.4	328	94042.40	1818.483	622.4
119	1442.63	27.896	246.2	189	9208.16	178.057	372.2	259	34618.76	669.417	498.2	329	95273.60	1842.291	624.2
120	1489.14	28.795	248.0	190	9413.36	182.025	374.0	260	35188.00	680.425	500.0	330	96512.40	1866.245	626.0
121	1536.80	29.717	249.8	191	9620.08	186.022	375.8	261	35761.80	691.520	501.8	331	97758.80	1890.346	627.8
122	1586.04	30.669	251.6	192	9831.36	190.107	377.6	262	36343.20	702.763	503.6	332	99020.40	1914.742	629.6
123	1636.36	31.642	253.4	193	10047.20	194.281	379.4	263	36932.20	714.152	505.4	333	100297.20	1939.431	631.4
124	1687.81	32.637	255.2	194	10265.32	198.499	381.2	264	37529.56	725.703	507.2	334	101581.60	1964.267	633.2
125	1740.93	33.664	257.0	195	10488.76	202.819	383.0	265	38133.00	737.372	509.0	335	102881.20	1989.398	635.0
126	1795.12	34.712	258.8	196	10715.24	207.199	384.8	266	38742.52	749.158	510.8	336	104196.00	2014.822	636.8
127	1850.83	35.789	260.6	197	10944.76	211.637	386.6	267	39361.92	761.135	512.6	337	105526.00	2040.540	638.6
128	1907.83	36.891	262.4	198	11179.60	216.178	388.4	268	39986.64	773.215	514.4	338	106871.20	2066.552	640.4
129	1966.35	38.023	264.2	199	11417.48	220.778	390.2	269	40619.72	785.457	516.2	339	108224.00	2092.710	642.2
130	2026.16	39.180	266.0	200	11659.16	225.451	392.0	270	41261.16	797.861	518.0	340	109592.00	2119.163	644.0
131	2087.42	40.364	267.8	201	11905.40	230.213	393.8	271	41910.20	810.411	519.8	341	110967.60	2145.763	645.8
132	2150.42	41.582	269.6	202	12155.44	235.048	395.6	272	42566.08	823.094	521.6	342	112358.40	2172.657	647.6
133	2214.64	42.824	271.4	203	12408.52	239.942	397.4	273	43229.56	835.923	523.4	343	113749.20	2199.550	649.4
134	2280.76	44.103	273.2	204	12666.16	244.924	399.2	274	43902.16	848.929	525.2	344	115178.00	2227.179	651.2
135	2347.26	45.389	275.0	205	12929.12	250.008	401.0	275	44580.84	862.053	527.0	345	116614.40	2254.954	653.0
136	2416.34	46.724	276.8	206	13197.40	255.196	402.8	276	45269.40	875.367	528.8	346	118073.60	2283.171	654.8
137	2488.16	48.113	278.6	207	13467.96	260.428	404.6	277	45964.04	888.799	530.6	347	119532.80	2311.387	656.6
138	2560.67	49.515	280.4	208	13742.32	265.733	406.4	278	46669.32	902.437	532.4	348	121014.80	2340.044	658.4
139	2634.84	50.950	282.2	209	14022.76	271.156	408.2	279	47382.20	916.222	534.2	349	122504.40	2368.848	660.2
140	2710.92	52.421	284.0	210	14305.48	276.623	410.0	280	48104.20	930.183	536.0	350	124001.60	2397.799	662.0
141	2788.44	53.920	285.8	211	14595.04	282.222	411.8	281	48833.80	944.291	537.8	351	125521.60	2427.191	663.8
142	2867.48	55.448	287.6	212	14888.40	287.895	413.6	282	49570.24	958.532	539.6	352	127049.20	2456.730	665.6
143	2948.80	57.020	289.4	213	15184.80	293.626	415.4	283	50316.56	972.963	541.4	353	128599.60	2486.710	667.4
144	3031.64	58.622	291.2	214	15488.04	299.490	417.2	284	51072.76	987.586	543.2	354	130157.60	2516.837	669.2
145	3116.76	60.268	293.0	215	15792.80	305.383	419.0	285	51838.08	1002.385	545.0	355	131730.80	2547.258	671.0
146	3203.40	61.944	294.8	216	16104.40	311.408	420.8	286	52611.76	1017.345	546.8	356	133326.80	2578.119	672.8
147	3292.32	63.663	296.6	217	16420.56	317.522	422.6	287	53395.32	1032.497	548.6	357	134945.60	2609.422	674.6
148	3382.76	65.412	298.4	218	16742.04	323.738	424.4	288	54187.24	1047.810	550.4	358	136579.60	2641.018	676.4
149	3476.24	67.220	300.2	219	17067.32	330.028	426.2	289	54989.04	1063.314	552.2	359	138228.80	2672.908	678.2
150	3570.48	69.042	302.0	220	17395.64	336.377	428.0	290	55799.20	1078.980	554.0	360	139893.20	2705.093	680.0
151	3667.00	70.908	303.8	221	17731.56	342.872	429.8	291	56612.40	1094.705	555.8	361	141572.80	2737.571	681.8
152	3766.56	72.833	305.6	222	18072.80	349.471	431.6	292	57448.40	1110.871	557.6	362	143275.20	2770.490	683.6
153	3866.88	74.773	307.4	223	18417.84	356.143	433.4	293	58284.40	1127.036	559.4	363	144992.80	2803.703	685.4
154	3970.24	76.772	309.2	224	18766.68	362.888	435.2	294	59135.60	1143.496	561.2	364	146733.20	2837.357	687.2
155	4075.88	78.815	311.0	225	19123.12	369.781	437.0	295	59994.40	1160.102	563.0	365	148519.20	2871.892	689.0
156	4183.80	80.901	312.8	226	19482.60	376.732	438.8	296	60860.80	1176.856	564.8	366	150320.40	2906.722	690.8
157	4293.24	83.018	314.6	227	19848.92	383.815	440.6	297	61742.40	1193.903	566.6	367	152129.20	2941.698	692.6
158	4404.96	85.178	316.4	228	20219.80	390.987	442.4	298	62624.00	1210.950	568.4	368	153960.80	2977.116	694.4
159	4519.72	87.397	318.2	229	20596.76	398.276	444.2	299	63528.40	1228.439	570.2	369	155815.20	3012.974	696.2
160	4636.00	89.646	320.0	230	20978.28	405.654	446.0	300	64432.80	1245.927	572.0	370	157692.40	3049.273	698.0
161	4755.32	91.953	321.8	231	21365.12	413.134	447.8	301	65352.40	1263.709	573.8	371	159584.80	3085.866	699.8
162	4876.92	94.304	323.6	232	21757.28	420.717	449.6	302	66279.60	1281.638	575.6	372	161507.60	3123.047	701.6
163	5000.04	96.685	325.4	233	22154.00	428.388	451.4	303	67214.40	1299.714	577.4	373	163468.40	3160.963	703.4
164	5126.96	99.139	327.2	234	22558.32	436.207	453.2	304	68156.80	1317.937	579.2	374	165467.20	3199.613	705.2
165	5256.16	101.638	329.0	235	22967.96	444.128	455.0	305	69114.40	1336.454	581.0				
166	5386.88	104.165	330.8	236	23382.92	452.152	456.8	306	70072.00	1354.971	582.8				
167	5521.40	106.766	332.6	237	23802.44	460.264	458.6	307	71052.40	1373.929	584.6				
168	5658.20	109.412	334.4	238	24229.56	468.523	460.4	308	72048.00	1393.181	586.4				
169	5798.04	112.116	336.2	239	24661.24	476.871	462.2	309	73028.40	1412.139	588.2				

Page [illegible] of [illegible]
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ORGANIC COMPOUNDS

Pressures Less than One Atmosphere (Continued)

Name	Formula	Temperature °C						M.P.
		1 mm	10 mm	40 mm	100 mm	400 mm	760 mm	
2-Methyldisilazane	CH_7NSi_2	−76.3	−50.1	−29.6	−13.1	+17.2	34.0	—
Cyanogen iodide	CIN	25.2s	57.7s	80.3s	97.6s	126.1s	141.1s	—
Tetranitromethane	CN_4O_8	s	22.7	48.4	68.9	105.9	125.7d	13
Carbon monoxide	CO	−222.0s	−215.0s	−210.0s	−205.7s	−196.3	−191.3	−205.0
Carbonyl sulfide	COS	−132.4	−113.3	−98.3	−85.9	−62.7	−49.9	−138.8
Carbonyl selenide	$COSe$	−117.1	−95.0	−76.4	−61.7	−35.6	−21.9	—
Carbon dioxide	CO_2	−134.3s	−119.5s	−108.6s	−100.2s	−85.7s	−78.2s	−57.5
Carbon Selenosulfide	$CSSe$	−47.3	−16.0	+8.6	28.3	65.2	85.6	−75.2
Carbon disulfide	CS_2	−73.8	−44.7	−22.5	−5.1	+28.0	46.5	−110.8
Trichloroacetyl bromide	C_2BrCl_3O	−7.4	+29.3	57.2	79.5	120.2	143.0	—
1-Chloro-1,2,2-trifluoroethylene	C_2ClF_3	−116.0	−95.9	−79.7	−66.7	−41.7	−27.9	−157.5
1,2-Dichloro-1,2-difluoroethylene	$C_2Cl_2F_2$	−82.0	−57.3	−38.2	−23.0	+5.0	20.9	−112
1,2-Dichloro-1,1,2,2-tetrafluoroethane	$C_2Cl_2F_4$	−95.4	−72.3	−53.7	−39.1	−12.0	+3.5	−94
1,1,2-Trichloro-1,2,2-trifluoroethane	$C_2Cl_3F_3$	−68.0s	40.3s	−18.5	−1.7	+30.2	47.6	−35
→Tetrachloroethylene	C_2Cl_4	−20.6s	+13.8	40.1	61.3	100.0	120.8	−19.0
1,1,2,2-Tetrachloro-1,2-difluoroethane	$C_2Cl_4F_2$	−37.5s	−5.0s	+19.8s	38.6	73.1	92.0	26.5
Hexachloroethane	C_2Cl_6	32.7s	73.5s	102.3s	124.2s	163.8s	185.6s	186.6
Tribromoacetaldehyde	C_2HBr_3O	18.5	58.0	87.8	110.2	151.6	174.0d	—
Trichloroethylene	C_2HCl_3	−43.8	−12.4	+11.9	31.4	67.0	86.7	−73
Trichloroacetaldehyde	C_2HCl_3O	−37.8	−5.0	20.2	40.2	77.5	97.7	−57
Trichloroacetic acid	$C_2HCl_3O_2$	51.0s	88.2	116.3	137.8	175.2	195.6	57
Pentachloroethane	C_2HCl_5	+1.0	39.8	69.9	93.5	137.2	160.5	−22
Acetylene	C_2H_2	−142.9s	−128.2s	−116.7s	−2107.9s	−92.0s	−84.0s	−81.5
1,1,1,2-Tetrabomoethane	$C_2H_2Br_4$	58.0	95.7	123.2	144.0	181.0	200.0d	—
1,1,2,2-Tetrabromoethane	$C_2H_2Br_4$	65.0	110.0	144.0	170.0	217.5	243.5	—
cis-1,2-Dichloroethylene	$C_2H_2Cl_2$	−58.4	−29.9	−7.9	+9.5	41.0	59.0	−80.5
trans-1,2-Dichloroethylene	$C_2H_2Cl_2$	−65.4s	−38.0	−17.0	−0.2	+30.8	47.8	−50.0
1,1-Dichloroethane	$C_2H_2Cl_2$	−77.2	−51.2	−31.1	−15.0	+14.8	31.7	−122.5
Dichloroacetic acid	$C_2H_2Cl_2O_2$	44.0	82.6	111.8	134.0	173.7	194.4	9.7
1,1,1,2-Tetrachloroethane	$C_2H_2Cl_4$	−16.3	+19.3	46.7	68.0	108.2	130.5	−68.7
1,1,2,2-Tetrachloroethane	$C_2H_2Cl_4$	−3.8	+33.0	60.8	83.2	124.0	145.9	−36
1-Bromoethylene	C_2H_3Br	−95.4	−68.8	−48.1	−31.9	−1.1	+15.8	−138
Bromoacetic acid	$C_2H_3BrO_2$	54.7	94.1	124.0	146.3	186.7	208.0	49.5
1,1,2-Tribromoethane	$C_2H_3Br_3$	32.6	70.6	100.0	123.5	165.4	188.4	−26
1-Chloroethylene	C_2H_3Cl	−105.6	−83.7	−66.8	−53.2	−28.0	−13.8	−153.7
Chloroacetic acid	$C_2H_3ClO_2$	43.0s	81.0	109.2	130.7	169.0	189.5	61.2
1,1,1-Trichloroethane	$C_2H_3Cl_3$	−52.0	−21.9	+1.6	20.0	54.6	74.1	−30.6
1,1,2-Trichloroethane	$C_2H_3Cl_3$	−24.0	+8.3	35.2	55.7	93.0	113.9	−36.7
Trichloroacetaldehyde hydrate	$C_2H_3Cl_3O_2$	−9.8s	+19.5s	39.7s	55.0	82.1	96.2d	51.7
1-Fluoroethylene	C_2H_3F	−149.3	−132.2	−118.0	−106.2	−84.0	−72.2	−160.5
Acetonitrile	C_2H_3N	−47.0s	−16.3	+7.7	27.0	62.5	81.8	−41
Methyl thiocyanate	C_2H_3NS	−14.0	+21.6	49.0	70.4	110.8	132.9	−51
Methyl isothiocyanate	C_2H_3NS	−34.7s	+5.4s	38.2	59.3	97.8	119.0	35.5
Ethylene	C_2H_4	−168.3	−153.2	−141.3	−131.8	−113.9	−103.7	−169
1-Bromo-1-chloroethane	C_2H_4BrCl	−36.0s	−9.4s	+10.4s	28.0	63.4	82.7	16.6
1-Bromo-2-chloroethane	C_2H_4BrCl	−28.8s	+4.1	29.7	49.5	86.0	106.7	−16.6
1,2-Dibromoethane	$C_2H_4Br_2$	−27.0s	+18.6	48.0	70.4	110.1	131.5	10
1,1-Dichloroethane	$C_2H_4Cl_2$	−60.7	−32.3	−10.2	+7.2	39.8	57.4	−96.7
1,2-Dichloroethane	$C_2H_4Cl_2$	−44.5s	−13.6	+10.0	29.4	64.0	82.4	−35.3
1,1-Difluoroethane	$C_2H_4F_2$	−112.5	−91.7	−75.8	−63.2	−39.5	−26.5	−117
Acetaldehyde	C_2H_4O	−81.5	−56.8	−37.8	−22.6	+4.9	20.2	−123.5
Ethylene oxide	C_2H_4O	−89.7	−65.7	−46.9	−32.1	−4.9	+10.7	−111.3
Acetic acid	$C_2H_4O_2$	−17.2s	+17.5	43.0	63.0	99.0	118.1	16.7
Methyl formate	$C_2H_4O_2$	−74.2	−48.6	−28.7	−12.9	16.0	32.0	−99.8
Mercaptoacetic acid	$C_2H_4O_2S$	−60.0	101.5	131.8	154.0d	—	—	−16.5
Ethyl bromide	C_2H_5Br	−74.3	−47.5	−26.7	−10.0	+21.0	38.4	−117.8
Ethyl chloride	C_2H_5Cl	−89.8	−65.8	−47.0	−32.0	−3.9	+12.3	−139
2-Chloroethanol	C_2H_5ClO	−4.0	+30.3	56.0	75.0	110.0	128.8	−69
Trichloroethylsilane	$C_2H_5Cl_3Si$	−27.9	+3.6	27.9	46.3	80.3	99.5	−40
Trichloroethyoxysilane	$C_2H_5Cl_3OSi$	−32.4	0.0	+25.3	45.2	82.2	102.4	—
Ethyl fluoride	C_2H_5F	−117.0	−97.7	−81.8	−69.3	−45.5	−32.0	—
Ethyltrifluorosilane	$C_2H_5F_3Si$	−95.4	−73.7	−56.8	−43.6	−19.1	−5.4	—
Ethyl Iodide	C_2H_5I	−54.4	−24.3	−0.9	+18.0	52.3	72.4	−105
Acetamide	C_2H_5NO	65.0s	105.0	135.8	158.0	200.0	222.0	81
Acetaldoxime	C_2H_5NO	−5.8s	+25.8	48.6	66.2	98.0	115.0	47
Nitroethane	$C_2H_5NO_2$	−21.0	+12.5	38.0	57.8	94.0	114.0	−90
Di(nitrosomethyl)amine	$C_2H_5N_3O_2$	+3.2	40.0	68.2	90.3	131.3	153.0	—
Ethane	C_2H_6	−159.5	−142.9	−129.8	−119.3	−99.7	−88.6	−183.2
Dichlorodimethylsilane	$C_2H_6Cl_2Si$	−53.5	−23.8	−0.4	+17.5	51.9	70.3	−86.0
Ethanol	C_2H_6O	−31.3	−2.3	+19.0	34.9	63.5	78.4	−112
Dimethyl ether	C_2H_6O	−115.7	−93.3	−76.2	−62.7	−37.8	−23.7	−138.5
1,2-Ethanediol	$C_2H_6O_2$	53.0	92.1	120.0	141.8	178.5	197.3	−15.6
Dimethyl sulfide	C_2H_6S	−75.6	−49.2	−28.4	−12.0	+18.7	36.0	−83.2
Ethanethiol	C_2H_6S	−76.7	−50.2	−29.8	−13.0	+17.7	35.5	−121
Dimethylantimony	C_2H_6Sb	44.0	86.0	118.3	143.5	187.2	211.0	—
Ethylamine	C_2H_7N	−82.3s	−58.3	−39.8	−25.1	+2.0	16.6	−80.6
Dimethylamine	C_2H_7N	−87.7	−64.6	−46.7	−32.6	−7.1	+7.4	−96
1,2-Ethanediamine	$C_2H_8N_2$	−11.0s	+21.5	45.8	62.5	99.0	117.2	8.5
Dimethylsilane	C_2H_8Si	−115.0	−93.1	−75.7	−61.4	−35.0	−20.1	—
Dimethyldiborane	$C_2H_{10}B_2$	−106.5	−82.1	−62.4	−47.0	−18.8	−2.6	−150.2
2-Ethyldisilazane	$C_2H_{11}NSi_2$	−62.0	−32.2	−8.3	+10.4	45.9	65.9	−127

APPENDIX 4A

AIR EMISSIONS CONTROL DESIGN

URS **EXHIBIT 4.7-2**

CALCULATION COVER SHEET

Client: NYSDEC Project Name: West Side Corp.

Project/Calculation Number: 11171611

Title: Off-gas Treatment

Total Number of Pages (including cover sheet): 13

Total Number of Computer Runs: 0

Prepared by: Donald A. McColl Date: 10.21.02

Checked by: Craig W. Pawlewski CWP Date: 10/22/02

Description and Purpose:

Outline the basis of off-gas treatment for SVE and ERH

Design Basis/References/Assumptions

See Attached

Remarks/Conclusions/Results:

See Attached.

Calculation Approved by: ____________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:
		Project Manager/Date

URS

Page 1 of 6
JOB NO.: 11172744
MADE BY: D. McCall DATE: 10.22.02
CHECKED BY: CWP DATE: 10/29/02

PROJECT: **West Side Corporation Site Remedial Design**
SUBJECT: **Off-gas Treatment**

Problem: Outline the basis for treatment of the off-gas from the Electrical Resistance Heating (ERH) and the Soil Vapor Extraction (SVE) Systems

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References:

1. *In-Situ Thermal Treatment Feasibility Evaluation - West Side Corporation Site,* URS Corporation, August 2002.
2. *SVE Pilot Test Report - West Side Corporation Site,* URS Corporation, December 2001.
3. Global Technologies, Inc., Vendor information, www.globaltechnologiesinc.com
4. *NIOSH Pocket Guide to Chemical Hazards,* URS SoURSe website, www.oklink.com/safety/nioshdbs/npg/
5. *Design Issues - Memo #2,* URS Corporation, Inc., October 9, 2002.

General Assumptions:

1. ERH remediation will be conducted prior to the implementation of SVE for the remainder of the contaminated areas at the site. This is a different conclusion than was reached in the Thermal Feasibility Evaluation (Ref. 1), where it was assumed that both systems would operate concurrently. Additional information on the construction sequencing for these two systems is included in Ref. 5.
2. The same type of off-gas treatment system will be used for both the ERH and the SVE off-gas treatment systems. Depending on whether the off-gas system is purchased or rented, it will be modified or replaced to treat the off-gas from the SVE system following the completion of ERH.
3. Other assumptions regarding the design of the off-gas treatment system are outlined below in the applicable sections.

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1) Off-gas Streams

a) Flow Rates: The two major criteria for the treatment of off-gas are the flow rate and the organic loading rate. Flow rates for the off-gas for the two streams have been estimated as:

ERH: 460 scfm
SVE: 750 scfm

The flow rate for the SVE system is higher than was assumed in Ref. 1, because some additional allowance has been included as a factor of safety.

b) Loading Rates - ERH: determination of loading rates for both the ERH and the SVE systems is difficult due to the nature of these remediation processes. Contaminant loading rates for ERH are even more difficult to determine than for SVE. Loading rates for the ERH will vary as the subsurface is heated, and as different pockets of DNAPL are liberated. The loading rate is expected to be moderate (similar to SVE) and then increase to a peak after the soil reaches the design temperature. As with the SVE, the ERH concentrations are then expected to decrease exponentially.

For the purpose of this DAR, an **average** loading rate of **50 pounds per day** will be assumed, based on the same number that was used in Ref. 1.

Assuming that all of the contamination consists of PCE, the concentration in the air stream (ppmv) can be determined:

$$\frac{50 lb}{day} x \frac{day}{1440 \min} x \frac{1 \min}{460 ft^3} x \frac{1 ft^3}{2.832 x 10^{-2} m^3} x \frac{454 g}{lb} x \frac{1000 mg}{1 g} x \frac{24.45 L / mol}{165.8 g / mol (MW)} =$$

= 178 ppmv as PCE

c) Loading Rates - SVE: With SVE, the contaminant concentrations in the off-gas stream will initially be very high, but will probably drop at an exponential rate as the soil is remediated. A sample of the SVE vapor was collected and analyzed during the SVE Pilot test (Ref. 2, attached). The total VOC concentration indicated in this sample was 1,622 ppmv, or 0.16% VOCs. Based on that concentration, and a total flow rate of 600 scfm, Ref. 1 estimated a daily VOC loading of 518 pounds.

For the purpose of this DAR, **500 pounds per day** is considered to be a conservative **peak** loading rate. Even though a higher flow rate is now assumed, 500 lb/day is conservative, considering that a large portion of the soil vapor will be extracted from areas of the site less contaminated than the area used for the pilot test. Additionally, as stated above, the soil vapor concentration will drop exponentially as the remediation progresses. The average loading rate is more difficult to determine, and will depend upon the duration of the remediation. However, given than the area of SVE is much larger, but will not involve any heat, 50 pounds per day is also considered to be a reasonable estimate for the average loading rate from SVE.

2) Selected Treatment Unit

a) Selected Unit: Based on the information presented in Ref. 1, as well as other vendor information, a catalytic oxidizer or "Catox" unit was selected as the best alternative for treating the off-gas emissions from this site. As shown in Ref. 3, a Global Model 10 Chloro-Cat would be required to treat a flow stream of up to 1,000 scfm. The maximum flow rate from the SVE is estimated to be only 750 scfm, so the system will have some excess capacity. This unit has a fuel consumption of up to 440,000 BTU/hour, and is equipped with a 10 hp fan blower.

As the name implies, these units are specifically designed for the treatment of vapor streams including chlorinated VOCs. Note that this unit is selected only for the purpose of this DAR evaluation. Other vendors may supply units with different flow rates and/or other characteristics.

MADE BY: D. McCall DM DATE: 10·22·02
CHECKED BY: CWP DATE: 10/29/02

PROJECT: West Side Corporation Site Remedial Design
SUBJECT: Off-gas Treatment

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b) Potential Limitations: although the flow rate is probably the major factor in selecting a catox unit, the vapor concentration is also an important consideration. As shown in Ref. 3, the chloro-cat unit will automatically shut down if the incoming vapor concentration exceeds 25% of the lower explosive limit (LEL) for the air stream. This is a safety consideration to avoid overheating the unit. Considering that each 1% of the LEL leads to a 25°F temperature rise (Ref. 3), at 25% LEL, there will be a 625°F temperature increase.

LELs for the major contaminants in the air stream are shown below (as reported in Ref. 4):

1,2-Dichloroethene	5.6%
Methylene Chloride	13%
Tetrachloroethene	NA
Trichloroethene	8%
Vinyl Chloride	3.6%

The lowest LEL is for vinyl chloride at 3.6%. 25% of that concentration would be $\frac{1}{4} \times 3.6 = 0.9\%$. Considering that the total VOC concentration detected in the sample from SVE was only 0.16% (Ref. 2), the off-gas from SVE should be well below the limitations and acceptable for treatment.

c) As described above, the off-gas concentrations from ERH may be higher than was estimated for SVE. However, one benefit to the sequential operation of the ERH and SVE systems, is that the system will have excess capacity for the ERH. The proposed unit catox is rated for 1,000 scfm, while the expected flow rate from ERH is only 460 scfm. Thus, if the off-gas from the ERH system is too rich in VOCs, up to 540 scfm of dilution air can be introduced to cut the contaminant concentrations.

In the unlikely event that the contaminant concentrations still exceed 25% LEL, the operation of the ERH system would have to be temporarily scaled back until the concentrations decreased.

3) Ancillary Treatment

a) Combustion of chlorinated organic compounds yields carbon dioxide (CO_2) and hydrochloric acid (HCl). In cases where the emissions levels of HCl are unacceptable, a scrubber is included as part of the catox unit package. The scrubber uses caustic to neutralize the acid gases in the exhaust from the catox.

Considering that this site is located in an urban area, with residential homes in the immediate vicinity, it is possible that treatment for the acid emissions may be required.

The need for an acid scrubber, as well as the actual limitations to discharge, will be determined by the NYSDEC based on an air permit application prepared for this site.

4) Basis of Catox Operation and Options

a) Regardless of how the contract is structured, the off-gas treatment will comprise a significant portion of the total cost for both initial installation and for routine operation. As outlined in Ref. 1, one consideration may be to replace the catox system with a vapor phase carbon adsorption system once the contaminant concentrations have decreased.

b) As stated previously, the off-gas contaminant concentrations are expected to be very high during the initial operation of both remediation systems. However, over time the concentrations will drop significantly. At some point, it may be more cost effective to switch to carbon adsorption instead of catox for treatment. There are many factors that make predicting the most cost-effective method for off-gas treatment very difficult.

c) Given the basic framework of the remediation program (i.e., that ERH will be conducted for the first three months, followed by long-term operation of an SVE system), it is assumed that only catox will be considered for the ERH system. The short-term nature of the ERH operation would not justify the additional capital expense for the installation of a vapor phase carbon system. Therefore, the only consideration for switching the type of off-gas treatment will be for operation of the SVE system.

It is assumed that the catox system will also be used during the first three months of SVE operation. After the first three months, there should be enough operating data available to more accurately predict the trend of the contaminant concentrations and to prepare a more accurate estimate of the duration of the remediation.

Ref. 1

WEST SIDE CORPORATION
SITE NO. 2-41-026
REVISED
IN SITU THERMAL TREATMENT
FEASIBILITY EVALUATION

AUGUST, 2002

Prepared for

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 BROADWAY
ALBANY, NY 12233

Prepared by

URS CORPORATION
282 DELAWARE AVENUE
BUFFALO, NY 14202

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8/9/02 2:01 PM

Ref. 2

MITKEM CORPORATION

Client Sample ID: EW-1

GC/MS Volatiles

Lot-Sample #...: H1J010107-001	**Work Order #...:** ELC911AA	**Matrix.........:** AIR	
Date Sampled...: 09/28/01	**Date Received..:** 10/01/01		
Prep Date......: 10/04/01	**Analysis Date..:** 10/04/01		
Prep Batch #...: 1277284			
Dilution Factor: 144684	**Method.........:** EPA-19 TO-14		

PARAMETER	RESULT	REPORTING LIMIT	UNITS
Acetone	ND	720000	ppb(v/v)
Benzene	ND	29000	ppb(v/v)
Bromodichloromethane	ND	29000	ppb(v/v)
Bromoform	ND	29000	ppb(v/v)
Bromomethane	ND	29000	ppb(v/v)
Carbon disulfide	ND	29000	ppb(v/v)
Carbon tetrachloride	ND	29000	ppb(v/v)
Chlorobenzene	ND	29000	ppb(v/v)
Dibromochloromethane	ND	29000	ppb(v/v)
Chloroethane	ND	29000	ppb(v/v)
Chloroform	ND	29000	ppb(v/v)
Chloromethane	ND	72000	ppb(v/v)
1,1-Dichloroethane	ND	29000	ppb(v/v)
1,2-Dichloroethane	ND	29000	ppb(v/v)
1,1-Dichloroethene	ND	29000	ppb(v/v)
cis-1,2-Dichloroethene	**170000**	**29000**	**ppb(v/v)**
trans-1,2-Dichloroethene	ND	29000	ppb(v/v)
1,2-Dichloropropane	ND	29000	ppb(v/v)
cis-1,3-Dichloropropene	ND	29000	ppb(v/v)
trans-1,3-Dichloropropene	ND	29000	ppb(v/v)
Ethylbenzene	ND	29000	ppb(v/v)
2-Hexanone	ND	72000	ppb(v/v)
Methylene chloride	**23000 J,B**	**29000**	**ppb(v/v)**
Styrene	ND	29000	ppb(v/v)
1,1,2,2-Tetrachloroethane	ND	29000	ppb(v/v)
Tetrachloroethene	**1300000**	**29000**	**ppb(v/v)**
Toluene	ND	29000	ppb(v/v)
1,1,1-Trichloroethane	ND	29000	ppb(v/v)
1,1,2-Trichloroethane	ND	29000	ppb(v/v)
Trichloroethene	**39000**	**29000**	**ppb(v/v)**
Vinyl chloride	**90000**	**29000**	**ppb(v/v)**
o-Xylene	ND	29000	ppb(v/v)
m-Xylene & p-Xylene	ND	29000	ppb(v/v)
2-Butanone (MEK)	ND	72000	ppb(v/v)
4-Methyl-2-pentanone (MIBK)	ND	72000	ppb(v/v)

SURROGATE	PERCENT RECOVERY	RECOVERY LIMITS
1,2-Dichloroethane-d4	101	(70 - 130)
Toluene-d8	100	(70 - 130)
4-Bromofluorobenzene	99	(70 - 130)

(Continued on next page)

URS

Ref. 2

December 21, 2001

Shive Mittal
NYSDEC, Bureau of Western Remedial Action
625 Broadway
Albany, NY 12233

RE: WEST SIDE CORP. SITE #2-41-026
W.A. D003825-31
SVE PILOT TEST REPORT

Dear Mr. Mittal:

Please find attached the report on the SVE pilot test conducted at the above-referenced site on September 26 and 27, 2001.

If you have any questions, please contact me at 716-856-5636.

Sincerely yours,

URS Corporation

Jon Sundquist, Ph.D.
Project Manager

cc: Daniel W. Rothman, P.E.
File: 05-000-35897.01 (C-1)

URS Corporation
282 Delaware Avenue
Buffalo, NY 14202-1805
Tel: 716.856.5636
Fax: 716.856.2545

J:\35987.01\word\cor\SVE report cover letter

Ref. 3

Global Technologies

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Products

More info

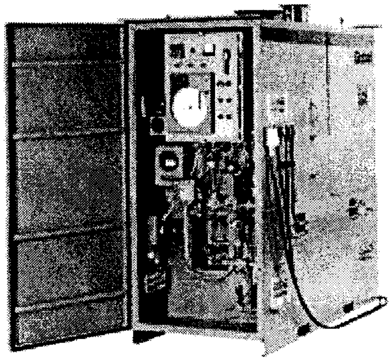
Have a project? Get faster budget quotes with **Quick Quote** or view our **Rental** availability.

Chlorinated cleanup? Read about a recent **solution**.

Do you already own a Global Chloro-Cat? Extend the life and profitability of the unit with Global **Service**.

Ask the Engineers a question or find other FAQs.

Chloro-Cat™
Catalytic Oxidizer



Global Technologies' Chloro-Cat™ catalytic oxidizer destroys halogenated or mixed organic vapor contaminants that are discharged from soil vapor extraction and groundwater treatment systems, such as airstrippers, during site remediation.

How the Chloro-Cat™ Works

The Chloro-Cat model is selected based on volume of airflow, contaminant type and desired destruction efficiency. During operation, VOC-laden air is drawn through the Chloro-Cat's fan and is discharged into the system's heat exchanger. The air passes through the tube side of the heat exchanger and into the burner, where the contaminated air is raised to the catalyzing temperature. When the VOC-laden air passes through the specialty catalyst, an exothermic reaction takes place. The VOC's in the air stream are converted to carbon dioxide, water vapor, and inorganic acids.

The hot, purified air then passes on the shell side of the heat exchanger where the energy released by the reaction is used to preheat the incoming air. This minimizes the system's fuel costs; in many cases the Chloro-Cat is self-sustaining. Finally, the contaminant-free air is exhausted into the atmosphere. In some cases, a Global scrubber module may be required to neutralize the inorganic acids.

Global's Fully Integrated Approach

The Therm-Cat was designed as part of Global's entire line of soil and groundwater remediation products. The Global line of products, which includes Vapor Liquid Separators (Knockout Pots), Extraction Blower Packages, Oxidizers, and Acid Gas Scrubbers, is technologically advanced as well as user-friendly. Each module interfaces easily and is constructed for optimum performance and trouble-free operation.

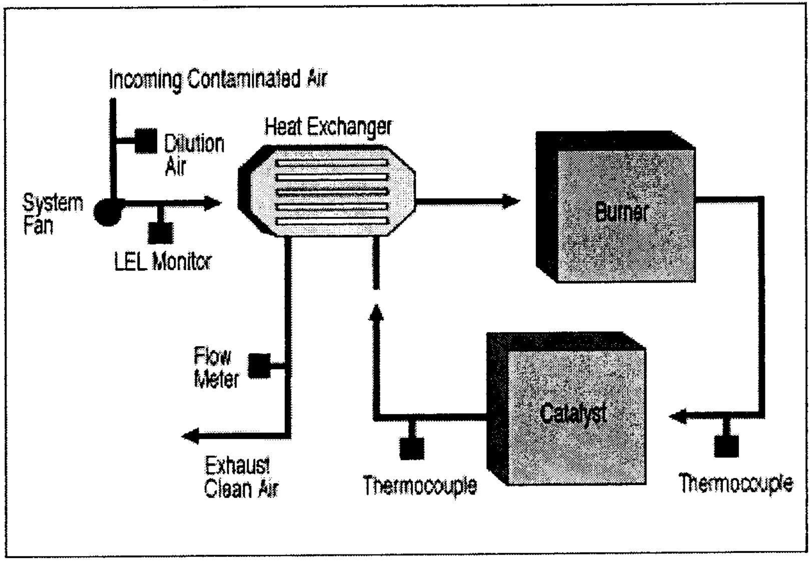
When networked, the Global modules form a comprehensive subsurface remediation system that works continuously and automatically to achieve site closure quickly. In addition, Global's modular approach allows rapid deployment and provides the flexibility necessary to successfully perform site remediation under a wide variety of conditions.

System Components

Standard Chloro-Cat systems include a shell and tube heat exchanger, modulating burner, fuel train, catalyst bed, fan, motor, fresh air dilution valves, flanged inlet and outlet, system controls, LEL monitor, temperature recorder, first-out shutdown detector, flame arrestor and exhaust stack. The system's components are housed in a weatherproof, insulated steel cabinet with three access doors that allow service to all internal parts.

Ref. 3

Chloro-Cat System Schematic



Safety Shutdowns

The system will shut down safely and automatically if any of the following occur:

- Electrical power loss to the control panel.
- Loss of proper airflow.
- High/low temperature or gas pressure.
- Flame out of the burner.
- System operation above 25% LEL.
- High level in Vapor Liquid Separator.

The PLC-driven, first-out shutdown detector will indicate the cause of a shutdown on a liquid crystal display.

Options

- Remote monitoring/communication package.
- Acid gas scrubber.
- Integrated extraction blower.
- Trailer-mounted.
- Exhaust stack extensions.
- U.L. labeled panel.
- NFPA Class 1 Division 2 explosion-proof design.
- Larger or custom systems available.
- Flame arrestor.

SPECIFICATIONS	**Model 1.5 Chloro-Cat**	**Model 5 Chloro-Cat**	**Model 10 Chloro-Cat**	**Model 20 Chloro-Cat**
Unit Weight	3,400 lbs	4,200 lbs	5,500 lbs	7,500 lbs
	4'W x 8'H	4'3"W x	6.5'W x	7'W x 9'H

Ref. 3

Overall Dimensions	x 7'5"L	8'5"'H x 8'5"L	9'H x 13'L	x 15'5"L
Airflow	50-165 SCFM	100-500 SCFM	100-1,000 SCFM	100-2,000 SCFM
Fuel Consumption (maximum VOC loading)	13,000 BTU/hour	26,000 BTU/hour	52,000 BTU/hour	103,000 BTU/hour
Fuel Consumption (no VOC loading)	75,000 BTU/hour	220,000 BTU/hour	440,000 BTU/hour	880,000 BTU/hour
Standard Power Requirements	230V/ 60Hz/1ph	230V/ 60Hz/1ph	230-460V/ 60Hz/3ph	230-460V/ 60Hz/3ph
Inlet Pipe	6" diameter, 150# flange	6" diameter, 150# flange	8" diameter, 150# flange	10" diameter, 150# flange
Heat Exchanger Efficiency	50% nominal	50% nominal	50% nominal	50% nominal
Fan	3 hp	3 hp	10 hp	20 hp

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Global Technologies, Division of Anguil Environmental Systems, Inc.
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In addition to the explosive aspects of the LEL, another issue is the heat energy given off during oxidation. An estimate of the exotherm is that there will be a 25° F rise per 1% LEL in the stream. Hence, if the process air enters the oxidiser at a given temperature, and if the stream has a concentration of 2% LEL, then a 50° F rise in process stream temperature is expected after oxidation. If the process stream were running at a 10% LEL, then a 250° F temperature rise would be predicted. A maximum LEL of 25%, yields a 625° F temperature rise of the process stream.

Ref. 3

The concentration that is required to yield 100% LEL varies with the characteristics of the identified organics. For example, ethanol has a 20,000 PPM by volume concentration whereas benzene has a 12,000 ppmv.

Not only do different organics have different LELs but every time a pound of a different organic is oxidised, a different amount of heat will be given off. An example that demonstrates this energy release is the catalytic muffler in an automobile. When mufflers were initially installed, the high level of unburned gasoline which went through the muffler caused excessive heating and subsequently caused fires if the auto had been parked on leaves. The reason for the excessive heat was that for each pound of gasoline being oxidised 20,000 BTU's were being released.

Chlorinated organics are hydrocarbons that have one or many chlorine atoms. Oxidation of chlorinated hydrocarbons yield CO_2, water vapour and hydrogen chloride (HCl) gas. Some typical chlorinated organics are TCE and PCE. These organics have calorific values as low as 5,000 BTU/lb.

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CATALYST

The characteristics of oxidation catalyst are many and varied. Fundamentally, if an airstream containing organics is heated and passed across catalyst, the organics will be converted to carbon dioxide and water vapour. However, the percent conversion happens at different temperatures for different organics and for different catalysts. (See Figure 8.4.4 and 8.4.5)

Consider the compound - Toluene. To destroy 25% of the Toluene in an air stream, the chart is entered on the y axis at 25%, come over to the toluene line, and down to the Fahrenheit line, and it is seen that a temperature of about 300° F is required. However, the EPA does not require 25% destruction, but 95-99% destruction. In order to destroy 95% of the Toluene, enter the graph at 95% destruction, come over to the Toluene line, down vertically and it is seen that 500-550 degree range is required in order to destroy the Toluene. Some organics require higher temperatures to be destroyed than others, catalytically. Alcohols, isopropyl alcohol and ethanol, can be destroyed relatively simply whereas the Acetates, particularly the ethyl acetates and propyl acetates, may require temperatures in the 750° F range in order to achieve adequate destruction. Depending on the process stream, either a single organic may be present as found in the chemical industry, or in printing operations, a multiplicity of organics exists. Having a multiplicity of organics imposes the requirement of focusing on the ability to destroy the most difficult organic

Some organics can not be effectively destroyed by catalyst. For example: heptane and hexane, can be destroyed at temperatures of 600-700 degrees. Whereas propane, ethane and methane require temperatures beyond a reasonable temperature range. Since methane is not a smog producing organic, a guarantee to destroy 95% of the organics means that the methane is not considered and is removed from that stream in the computation process. However, if propane is the auxiliary fuel, that is if the burners are being driven by LPG or by propane directly, it means that there will be contribution to the VOC at the end of the stack.

Catalyst samples are shown in Figure 8.4.6. Some catalyst is deposited on a ceramic substrate. These ceramics are extruded in a malleable state and then fired in ovens. The process consists of starting with a ceramic and depositing an aluminum oxide coating. The aluminum oxide makes the ceramic, which is fairly smooth, have a number of bumps. On those bumps a noble metal catalyst, such as platinum, palladium or rubidium, is deposited. The active sited, wherever the noble metal is deposited, is where the conversion will actually take place.

APPENDIX 4B

ESTIMATE OF AIR EMISSIONS FOR AIR PERMIT

URS **EXHIBIT 4.7-2**

CALCULATION COVER SHEET

Client: NYSDEC Project Name: West Side Corp

Project/Calculation Number: 11172744

Title: Estimate of Emissions for Air Permit

Total Number of Pages (including cover sheet): 33

Total Number of Computer Runs: 0

Prepared by: Donald A. McCall DAM Date: 1.30.03

Checked by: Craig W. Pawlowski CWP Date: 2/6/03

Description and Purpose:

See Attached

Design Basis/References/Assumptions

See Attached

Remarks/Conclusions/Results:

See Attached

Calculation Approved by: ______________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:
1	added HCl evaluation	
		Project Manager/Date

URS

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JOB NO.: 11172744
MADE BY: D. McCall DATE: 2.4.03
CHECKED BY: GWP DATE: 2/6/03

PROJECT: **NYSDEC - West Side Corporation Site**
SUBJECT: **Estimate of Emissions for Air Permits**

Problem: For the purpose of completing an air permit application, estimate the emissions from the remedial activities at the West Side site. The emission sources will consist of the electrical resistance heating (ERH) and the soil vapor extraction (SVE) systems.

References:

1. *In Situ Thermal Treatment Feasibility Evaluation, West Side Corporation,* URS, August 2002.
2. *Chemical Oxidation Pilot Test Report, West Side Corporation,* URS, January 2002.
3. *Perry's Chemical Engineers' Handbook, Sixth Edition*, Robert H. Perry and Don W. Green, McGraw-Hill Inc., 1984.
4. *Global Technologies, Inc.*, Vendor Information.
5. *SVE Pilot Test Report, West Side Corporation*, URS, December 21, 2001.
6. *Record of Decision, West Side Corporation Site, OU#1*, New York State Department of Environmental Conservation, July 2000.

General Assumptions:

1. The two remedial activities considered at this site are the ERH application and the operation of an SVE system.
2. The two remediation technologies be operated sequentially (ERH followed by SVE), using the same air treatment system for both.
3. In general, the contaminant emissions from the SVE system will decrease as the remediation progresses. In the case of the ERH, the contaminant emissions will

initially be low, increase as the temperature of the treatment area increases, and then decrease again. However, for the purpose of these calculations, the emissions from both of these systems are assumed to be linear.

4. Only one air permit application will be submitted. Annual emissions will be the total emissions for the first year, i.e., 3 months of the ERH emissions plus 9 months of SVE system emissions. For the purpose of completing the permit, the hourly emissions rate will be a weighted average of the emissions from the ERH and the SVE systems.

5. Although there will be a period of time between the completion of ERH and initiation of SVE where there are no air emissions, this has not been accounted for in any of the emissions estimates. Thus, the annual emissions numbers presented are somewhat conservative.

6. This permit is being completed on the basis of the first year of operation. The emissions estimated for the first year will be substantially higher than the emissions from any of the following years.

1) ERH Emissions

To estimate the emissions from the ERH system, the total quantity of contamination in the ERH treatment area will first be determined, and then divided by the duration of operation to determine the emission rate.

a) Total Mass of PCE Contamination in the ERH Area

The dimensions of the area targeted for ERH treatment are 60' by 60', to a depth of 45 feet bgs. Although the treatment will actually extend somewhat beyond and below these dimensions, only the most highly contaminated area is being considered. The total volume of the contaminated soil is therefore:

$$60 \text{ ft} \times 60 \text{ ft} \times 45 \text{ ft} = \mathbf{162{,}000 \text{ ft}^3}$$

Multiplying the soil volume by its density provides the total mass of the contaminated soil in the ERH zone. Based on Ref. 3, a density of say 120 lb/ft^3 is assumed for the soil (assumed to be sand).

162,000 ft^3 x 120 lb/ft^3 x 0.454 kg/lb = 8,825,760 kg of soil

As outlined in Ref. 1, an average PCE concentration of **200 mg/kg** was assumed, based on the data collected during the chemical oxidation pilot test. Multiplying by the total mass of contaminated soil, and converting back to pounds gives:

(8,825,760 kg) x (200 mg/kg) x (1g / 1000 mg) x (1 lb / 454 g) = 3888, say **4,000 lbs of PCE** in the ERH area.

b) Total Mass of Other Contaminants in the ERH Area

Using only the data from the post-chemical oxidation testing, the only other contaminants detected in the soil were cis-1,2-dichloroethene, acetone, and methyl acetate. Of these, acetone is a common laboratory contaminant, and therefore assumed to not actually be present in the soil.

Out of the 40 post-oxidation soil samples collected, methyl acetate was detected in only four, at concentrations of 2, 6, 9, and 2 µg/Kg. For the purpose of this calculation, a conservative average calculation of **1 µg/kg** will be assumed.

Cis-1,2-dichloroethene was detected in only 1 post-oxidation sample at a concentration of 2 µg/kg. For the purpose of this calculation, a conservative average calculation of **0.5 µg/kg** will be assumed.

Multiplying by the average concentrations by the total mass of contaminated soil, and converting back to pounds gives:

Methyl Acetate:
(8,825,760 kg) x (1 μg/kg) x (1g / 1,000,000 μg) x (1 lb / 454 g) = 0.019, say **0.02 lbs of methyl acetate** in the ERH area.

Similarly for cis-1,2-dichloroethene yields **0.01 lbs of 1,2-DCE** in the ERH area.

c) Contaminants Not Included

Comparing the pre- and post-oxidation samples shows that the contaminants detected and their concentrations were very similar.

However, several contaminants were detected in the soil during the RI/FS that were not detected in the post-oxidation soil samples nor in the vapor sample collected for the SVE pilot test. These contaminants were: chloromethane, carbon disulfide, 1,1-dichloroethene, chloroform, 2-butanone, 1,1,1-trichloroethane, 1,3-dichloropropene, 1,1,2-trichloroethane, benzene, 4-methyl-2-pentanone, toluene, chlorobenzene, ethylbenzene, styrene, and xylene. It is expected that these contaminants may occasionally be detected in monitoring for the site remediation, but only at trace concentrations. These contaminants are not included in the air permit submittal.

d) Duration of Operation

As outlined in Ref. 1, the expected duration of the ERH treatment is 3 months, or say 90 days.

e) Hourly Emission Rate (Uncontrolled)

Dividing the total mass of contamination by the duration of operation:

PCE:
(4,000 lbs PCE) / (90 days x (24 hr / day)) = **1.85 lb/hr**

Similarly, for the other contaminants:

Methyl acetate:
(0.02 lbs MeAcetate) / (90 days x (24 hr / day)) = **9.3×10^{-6} lb/hr**

cis-1,2-Dichloroethene:
(0.01 lbs DCE) / (90 days x (24 hr / day)) = **4.6×10^{-6} lb/hr**

f) Controlled Emissions

It is assumed that the air emissions from the ERH system will be passed through a thermal oxidation unit. Based on Ref. 4, these units are capable of destruction efficiencies of 99% and higher. However, to be conservative, and based on the guaranteed efficiency of the unit installed at the Robeson site, a destruction efficiency of 95% will conservatively be assumed.

Controlled emissions therefore would be:

PCE:	1.85 lb/hr x 0.05 =	**0.093lb/hr**
Methyl Acetate:	9.3×10^{-6} lb/hr x 0.05 =	**4.7×10^{-7} lb/hr**
Cis-1,2-Dichloroethene:	4.6×10^{-6} lb/hr x 0.05 =	**2.3×10^{-7} lb/hr**

g) Fuel Usage

Per Ref. 4, the maximum fuel usage for a Chloro-Cat™ Catalytic Oxidizer is 440,000 BTU/hr.

Assuming that the heating value for the natural gas is approximately 1,000 BTU/scf (Ref. 3), the gas flow rate for the unit will be on the order of:

(440,000 BTU/hr) / (1,000 BTU/scf) = 440 scf/hr.

2) SVE Emissions

Even if it were possible to reasonably estimate of the total mass of contamination present in soil, it is impossible to accurately predict the rate at which an SVE system will extract the contaminants over time. Therefore, it was decided that it would be more reasonable to estimate the emissions based on the vapor sample collected during the SVE pilot study.

a) Initial Contaminant Concentrations

One sample of the soil vapor was collected and analyzed as part of the SVE Pilot Test that was conducted in September 2001. The results of this sample are summarized below:

Tetrachloroethene	1,300,000 ppbv
Trichloroethene	39,000 ppbv
Cis-1,2-Dichloroethene	170,000 ppbv
Vinyl Chloride	90,000 ppbv

Although methylene chloride also was detected in this sample (at 23,000 ppbv), it is a common laboratory contaminant that also was detected in the blank sample. Therefore, it is not considered for the purpose of this calculation or completing the air permit application.

b) Long-term Average Concentrations

There are two factors that will greatly affect that contaminant concentrations actually collected by the SVE system. One is that the concentrations collected by an SVE system will drop exponentially as the remediation progresses. Significant decreases are observed during the first days and weeks of operation once the initial pore volume from the soil is extracted. Secondly, most of the soil to be treated by SVE is much less contaminated than the area chosen for the pilot test. Each of these factors is evaluated below.

MADE BY: D. McCall DATE: 2.4.03
CHECKED BY: CMP DATE: 2/6/03

PROJECT: NYSDEC - West Side Corporation Site
SUBJECT: Estimate of Emissions for Air Permits

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i) Exponential Drop in Concentration

Due to the short duration (<1 day) of the pilot test conducted at this site, there is insufficient information to determine the rate at which the concentrations will decrease. As such, it was decided to base the estimate on data from a similar site (the Robeson site in Castile, NY).

As shown on the attached graph of the date from that site, after one week of operation the soil gas concentrations were less than ½ the concentrations detected during the pilot study. After the first month, the concentrations were approximately 11% of the pilot test concentrations for the next 6 months, and then dropped to about 4% for the next 12 months.

To be conservative, for this site it is assumed that the concentrations for the first year will average approximately 15% of the concentrations detected in the sample from the pilot test.

ii) Soil Contaminant Concentrations

The attached figure from Ref. 6 shows the three source areas to be treated via SVE. Also shown in the location where the pilot study was conducted. As shown on this figure, the pilot test was located in a zone of higher soil contaminant concentrations. However, a large portion of the soil to be treated with SVE had soil concentrations much less than the pilot test area. All of Source Area 3, most of Source Area 2, and at least 2/3 of Source Area 1 should have soil concentrations significantly lower than the pilot study area. Based on this rough analysis, it was conservatively assumed that the contaminants collected by the SVE system will be reduced another 2/3.

iii) Calculated Average Concentrations

Based on the above assumptions, the average contaminant concentrations in the SVE air stream for the first year are assumed to be:

Tetrachloroethene	1,300,000 (0.15)(1/3) = 65,000 ppbv
Trichloroethene	39,000 (0.15)(1/3) = 1,950 ppbv
Cis-1,2-Dichloroethene	170,000 (0.15)(1/3) = 8,500 ppbv

Vinyl Chloride 90,000 (0.15)(1/3) = 4,500 ppbv

c) SVE Air Flow Rate

The total flow rate for the SVE system is assumed to be 750 scfm, based on a conservative flow rate of 50 scfm per well.

d) Hourly Emission Rate lb/h (Uncontrolled)

First, converting ppbv to mg/m^3 using the gram MW and standard molar volume:

Tetrachloroethene 6500 ppbv x (1 ppmv/1000 ppbv) x (165.9 g/gmol) / (24.45 L/mol) = **44.1 mg/m^3**

Trichloroethene 1950 ppbv x (1 ppmv/1000 ppbv) x (131.4 g/gmol) / (24.45 L/mol) = **10.5 mg/m^3**

Cis-1,2-Dichloroethene 8500 ppbv x (1 ppmv/1000 ppbv) x (96.9 g/gmol) / (24.45 L/mol) = **33.7 mg/m^3**

Vinyl Chloride 4500 ppbv x (1 ppmv/1000 ppbv) x (62.5 g/gmol) / (24.45 L/mol) = **11.5 mg/m^3**

Now, multiplying concentration by the flow rate to get the total emissions:

Tetrachloroethene 44.1 mg/m^3 x (2.832×10^{-2} m^3/ft^3) x (750 ft^3/min) x (60 min/hr) x (1 g / 1000 mg) x (1 lb / 454 g) = **0.124 lb/h**

Trichloroethene 10.5 mg/m^3 x (2.832×10^{-2} m^3/ft^3) x (750 ft^3/min) x (60 min/hr) x (1 g / 1000 mg) x (1 lb / 454 g) = **0.0295 lb/h**

Cis-1,2-Dichloroethene 33.7 mg/m^3 x (2.832×10^{-2} m^3/ft^3) x (750 ft^3/min) x (60 min/hr) x (1 g / 1000 mg) x (1 lb / 454 g) = **0.0946 lb/h**

Vinyl Chloride $11.5\ mg/m^3 \times (2.832\times10^{-2}\ m^3/ft^3) \times (750\ ft^3/min) \times (60\ min/hr) \times (1\ g / 1000\ mg) \times (1\ lb / 454\ g) =$ **0.0323 lb/h**

e) Controlled Emissions

It is assumed that the air emissions from the SVE system will be passed through a thermal oxidation unit. Based on Ref. 4, these units are capable of destruction efficiencies of 99% and higher. However, to be conservative, and based on the guaranteed efficiency of the unit installed at the Robeson site, a destruction efficiency of 95% will conservatively be assumed.

Controlled emissions therefore would be:

Tetrachloroethylene:	0.124 lb/hr x 0.05 = **0.0062 lb/hr**
Trichloroethylene:	0.0295 lb/hr x 0.05 = **0.00148 lb/hr**
Cis-1,2-Dichloroethene:	0.0946 lb/hr x 0.05 = **0.00473 lb/hr**
Vinyl Chloride:	0.0323 lb/hr x 0.05 = **0.00162 lb/hr**

Total Controlled Emissions = 0.014 lb/hr

3) Combined Emissions

For the purpose of completing the air permit, the emissions from the ERH and the SVE system will be totaled to determine the annual and the hourly emissions. Calculations from this section are summarized on Table 1, attached.

a) Potential Annual Emissions (lb/yr)

Total uncontrolled emissions from the ERH system were determined above in Section 1 and are summarized on Table 1. These are the total emissions assumed for the first three months of the air discharge from the site.

To determine the mass removed during the remaining 9 months of the first year, the hourly emissions rates from the SVE system were calculated and totaled as follows:

Example for PCE:

Avg. PCE emissions from SVE = 0.124 lb/h (Section 2d, above)

(0.124 lb/hr) x (24 hr/day) x (365 day/yr) x (9/12 months) = 815 lb/yr.

SVE emissions for all contaminants are summarized on Table 1.

To determine the total emissions for the first year, the numbers from the ERH and the SVE were summed together. As shown on Table 1, total uncontrolled emissions for the first year are estimated to be 5,842 lb/yr, say **5,840 lb/yr**.

b) Actual Annual Emissions (lb/yr)

Using the same control treatment efficiency (95%) as outlined in the sections above, the total emissions after the catalytic oxidizer are estimated to be:

5,842 lb/yr x 0.05 = 292 lb/yr, say **300 lb/yr**

c) Potential Hourly Emissions (lb/h)

To determine the potential hourly emissions (uncontrolled), the annual emissions were simply divided by the total hours per year:

(5,842 lb/yr) / (365 day/yr) / (24 hr/day) = **0.67 lb/hr**

Calculations for the individual contaminants are shown on Table 1.

JOB NO.: 11172744

MADE BY: D. McCall DATE: 2-4-03

CHECKED BY: DATE: 2/6/03

PROJECT: NYSDEC - West Side Corporation Site

SUBJECT: Estimate of Emissions for Air Permits

---

d) *Actual Hourly Emissions (lb/h)*

Again based on the assumed 95% efficiency of the air control system, the actual annual emissions were estimated to be:

0.67 lb/hr x 0.05 = **0.034 lb/hr**

Calculations for the individual contaminants are shown on Table 1.

---

4) Hydrochloric Acid Emissions

One product from the combustion of chlorinated organic compounds is hydrochloric acid (HCl). If emissions of HCl from the catalytic oxidation unit exceed a limit of 4 lbs/hour, scrubbing of the acid will be required in order to meet the air emissions limitations. For the purpose of this estimate, it is assumed that all of the emissions will be in the form of PCE.

The molecular weight of PCE (C_2Cl_4) = 165.9
The molecular weight of HCl = 36.5

a) Combustion Equation

The equation for the combustion of the chlorinated organics, based on PCE, is as follows:

$$C_2Cl_4 + 2CH_4 + 5O_2 \rightarrow 4CO_2 + 2H_2O + 4HCl$$

Thus, 4 moles of HCl are produced for every mole of PCE combusted.

b) Emissions Estimate

Conservatively assuming that the entire 0.67 lb/hr of emissions as determined above are PCE, the corresponding emissions of HCl following combustion would be:

0.67 lb/hr PCE x (1 lb mol PCE / 165.9 lb) x (4 mol HCl / 1 mol PCE) x (36.5 lb/lb mol HCl) = **0.59 lb HCl/hour**.

Since the estimated HCl emissions are much lower than the limit of 4 lbs/hr, it is not expected that acid scrubbing will be a required component of the catalytic system.

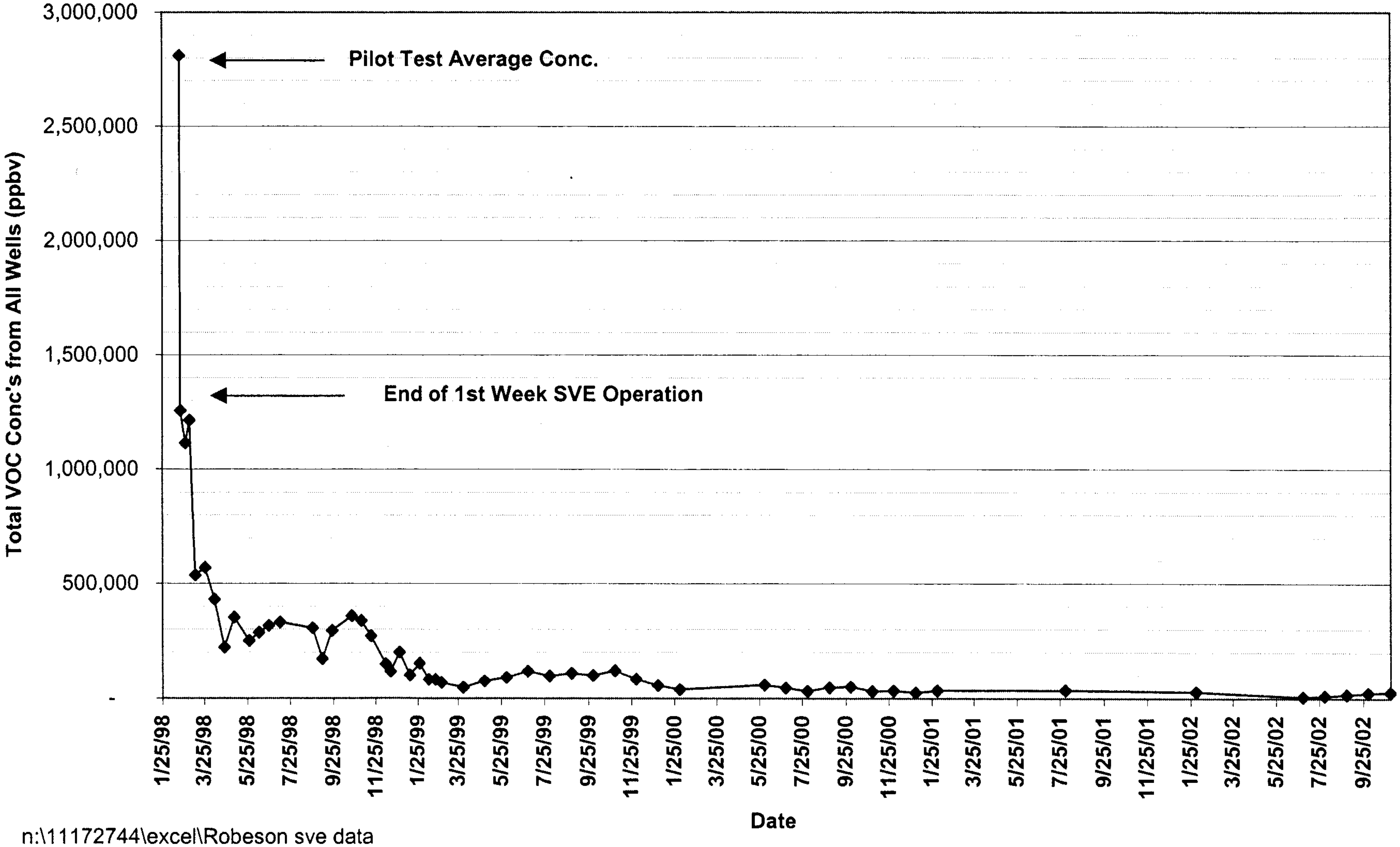
Table 1

West Side Corporation Site Air Emissions Estimate

Contaminant	Annual Emissions					Hourly Emissions	
	ERH Total Emissions	SVE Emissions		Total Uncontrolled	Total Controlled	Total Uncontrolled	Total Controlled
	lb	lb/h	lb	lb/yr	lb/yr	lb/h	lb/h
Tetrachloroethylene	4,000	0.1240	815	4,815	240.7	0.55	0.0275
Methyl Acetate	0.02	-	-	0	0.001	2.28E-06	1.14E-07
cis-1,2-Dichloroethene	0.01	0.0946	622	622	31.1	0.07	0.0035
Trichloroethene	-	0.0295	194	194	9.7	0.02	0.0011
Vinyl Chloride	-	0.0323	212	212	10.6	0.02	0.0012
Total	4,000.03	0.2804	1,842	5,842	292.1	0.67	0.0333

N:\11172744.00000\WORD\DRAFT\[air emissions calcs.xls]Sheet1

Robeson Site
Collected VOC Concentrations



n:\11172744\excel\Robeson sve data

Ref. 1

WEST SIDE CORPORATION
SITE NO. 2-41-026
REVISED
IN SITU THERMAL TREATMENT
FEASIBILITY EVALUATION

AUGUST, 2002

Prepared for

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 BROADWAY
ALBANY, NY 12233

Prepared by

URS CORPORATION
282 DELAWARE AVENUE
BUFFALO, NY 14202

Ref. 1

rate of removal will decline. A decision to terminate operations will be made when the removal rates are trending to an asymptotic low point. Soil samples would also be taken at the point of completion (as determined by diminishing returns in the vapor recovery process) to confirm reduction in source mass.

Table 1-1 presents a statistical summary of the contamination as measured in a 10 × 12 foot subsection of the 60 × 60 foot main source area that was sampled as part of the oxidation study:

TABLE 1-1
STATISTICAL SUMMARY OF SOIL SAMPLE ANALYSES
BEFORE AND AFTER CHEMICAL OXIDATION TREATMENT
PCE (μG/KG)

	Vadose		**Saturated**		**Combined**	
	Before	**After**	**Before**	**After**	**Before**	**After**
No. of Samples	9	10	30	30	39	40
Max. PCE conc. (μg/kg)	6,100,000	10,000,000	320,000	6,600,000	6,100,000	10,000,000
Min. PCE conc. (μg/kg)	ND	5	ND	1	ND	1
Arithmetic mean (μg/kg)	615,320	1,014,728	21,602	237,664	174,391	431,930
Geometric mean (μg/kg)	419	639	152	228	191	295
Median (μg/kg)	38	45	44	96	43	96
	key: μg/kg: micrograms per kilogram ND: Not detected					

Although additional sampling was conducted during the RI, this data set represents the most intensive investigation of the zone that would be treated in situ. Especially considering the limited number of RI samples taken in this source zone were consistent with the levels observed during the chemical oxidation pilot testing, the pilot test data set is used as the basis of the thermal treatment valuation calculations. Based on the arithmetic mean from these data, we may assume an average concentration of about 200 mg/kg. This value was arrived at by taking a value at the lower end of the "combined" arithmetic means yet at the upper end of the arithmetic mean of the saturated zone, since more treatment would be directed towards the saturated zone (the vadose zone is presumed to be readily treated by the vapor recovery portion of these

Ref. 1

technologies). Based on a 200 mg/kg basis, approximately 4,000 pounds of PCE may be present in the 60 ft × 60 ft (area) × 45 ft (depth) source zone. However, experience has shown that using such estimates for the purposes of remediation planning can be inaccurate. Therefore, remediation progress will be monitored to determine when the removal rates are trending toward an asymptotic low point, followed by a soil sampling program similar to the one used during chemical oxidation pilot testing to confirm reduction in contaminant mass.

1.2.3 General Implementation Overview

Both steam injection and ERH work by heating up the subsurface, however recovery operations are significantly different for each. Using steam injection, recovery is made as both vapor and liquid. Steam injection involves the propagation of a heating front from the steam injection well. PCE is mobilized as a "solvent bank" ahead of the heating front. As more steam is injected, the heating front and hence the solvent bank propagates outwards from the steam injection well. It is this pressure/heating front that allows for the collection of separate phase DNAPL from wells during steam injection, making fluid (groundwater plus DNAPL) pumping an integral part of a steam injection remediation approach. Behind the solvent bank, volatilization is the dominant removal mechanism for the PCE.

Using ERH, there is no fluid pumping beyond vapor recovery, which also contains entrained water. Heating the groundwater to steam results in significant volume changes. The conversion of water to steam increases the water volume 1,700 fold at standard pressure, which in porous media will result in an apparent raising of the water table in the heating zone. The water table in the treatment zone is not truly elevated, as the steam bubbles rise, water is forced to the surface. As a result, the vapor recovery system will also recover significant entrained water. To compensate, vapor recovery for ERH is oversized in comparison to conventional vapor recovery to accommodate the removal of entrained water. With the vapor recovery system in operation removing vapors and entrained water, an inward hydraulic gradient to the treatment zone is maintained, hydraulically containing the area being treated. When ERH is applied, there is some initial preferential heating of the subsurface through areas of higher total dissolved solids (TDS) and through colloidal material. As these zones heat up, the lower TDS zones also heat up until the entire treatment zone is heated to the boiling point of water (which will vary with depth). As

Ref. 1

5.0 OFF GAS TREATMENT OPTIONS

Gas treatment is needed for both the SVE system and the vapor recovery system of the thermal treatment units. The contributions from each of these systems would be similar both in quantity and contaminant load. The SVE pilot test results suggest that an extraction rate of 40 scfm per well would be appropriate to capture vapors within a 50-foot radius, and that about 37 pounds of PCE per day would be recovered per well at the start of SVE operation. The thermal treatment systems would be expected to generate about 460 scfm and up to 50 pounds of PCE per day on average. The main difference between the two systems is that in situ thermal treatment would operate over a shorter time period than the SVE system. SVE would operate for more than a year. Thermal treatment is expected to treat the soil over a period of about three months. Also the PCE concentrations in the SVE system would be expected to drop more quickly than the thermal treatment-generated volatiles. PCE generation rates from in situ thermal treatment would be expected to ramp up as the subsurface is heated up, reach a maximum generation rate, and then tail off asymptotically.

Despite the disparity in operating durations and concentration vs. time profiles, URS recommends that the two gas streams be treated together. This will reduce costs and make operation easier. The shorter duration of the gas stream from in situ thermal treatment would not be a problem. Off gas would be treated by either carbon or catalytic oxidation, as discussed below. If carbon is used, then a reduced air flow at the end of soil treatment would not impact operation or cost effectiveness, as the carbon could continue to be used until its capacity is reached. Catalytic oxidation may not be appropriate or economical when only SVE offgas is treated due to lower flow rates and that fact that concentrations of PCE in the SVE offgas after several months of treatment will likely be much lower than at the start of operation. Furthermore, the remediation operators would have a much better estimate of the long-term concentrations in the extracted gas stream. So at that point, a carbon system appropriately sized for long term operation could be installed.

Because of the relatively high gas flow rates and predicted mass fluxes (at least at the start of operation), a cost comparison of carbon adsorption versus catalytic oxidation were considered. Catalytic oxidation was evaluated over thermal oxidation because of the advances in catalyst formulation that have allowed effective chlorinated organic oxidation, and that therefore

Ref. 2

WEST SIDE CORPORATION
SITE NO. 2-41-026
CHEMICAL OXIDATION
PILOT TEST REPORT

JANUARY 21, 2002

Prepared for

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 BROADWAY
ALBANY, NY 12233

Prepared by

URS CORPORATION
282 DELAWARE AVENUE
BUFFALO, NY 14202

Ref. 2

POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		**SB-01**	**SB-01**	**SB-01**	**SB-01**	**SB-02**
Sample ID		**SB1-8**	**SB1-15**	**SB1-31**	**SB1-42**	**SB2-7**
Matrix		**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
Depth Interval (ft)		**8.0-8.0**	**15.0-15.0**	**31.0-31.0**	**42.0-42.0**	**7.0-7.0**
Date Sampled		**11/15/01**	**11/15/01**	**11/15/01**	**11/15/01**	**11/15/01**
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG					
Methyl acetate	UG/KG					
Tetrachloroethene	UG/KG	9 J	18	13,000	360,000	72,000

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

Ref. 2

POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		SB-02	SB-02	SB-02	SB-03	SB-03
Sample ID		SB2-21	SB2-27	SB2-35	SB3-8	SB3-18
Matrix		Soil	Soil	Soil	Soil	Soil
Depth Interval (ft)		21.0-21.0	27.0-27.0	35.0-35.0	8.0-8.0	18.0-18.0
Date Sampled		11/15/01	11/15/01	11/15/01	11/15/01	11/15/01
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG					
Methyl acetate	UG/KG					
Tetrachloroethene	UG/KG	6,600,000	35 J	7 J	11	13

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

Ref. 2

POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		SB-03	SB-03	SB-04	SB-04	SB-04
Sample ID		SB3-24	SB3-40	SB4-11	SB4-19	SB4-28
Matrix		Soil	Soil	Soil	Soil	Soil
Depth Interval (ft)		24.0-24.0	40.0-40.0	11.0-11.0	19.0-19.0	28.0-28.0
Date Sampled		11/15/01	11/15/01	11/14/01	11/14/01	11/14/01
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG					
Methyl acetate	UG/KG			2 J		
Tetrachloroethene	UG/KG	60	140,000	45	9,700	700 J

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

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POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		SB-04	SB-05	SB-05	SB-05	SB-05
Sample ID		SB4-33	SB5-9	SB5-19	SB5-27	SB5-34
Matrix		Soil	Soil	Soil	Soil	Soil
Depth Interval (ft)		33.0-33.0	9.0-9.0	19.0-19.0	27.0-27.0	34.0-34.0
Date Sampled		11/14/01	11/14/01	11/14/01	11/14/01	11/14/01
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG					
Methyl acetate	UG/KG		6 J			9 J
Tetrachloroethene	UG/KG	510 J	10 J	2,900	20	14

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

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POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		**SB-06**	**SB-06**	**SB-06**	**SB-06**	**SB-07**
Sample ID		**SB6-6**	**SB6-16**	**SB6-23**	**SB6-42**	**SB7-11**
Matrix		**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
Depth Interval (ft)		**6.0-6.0**	**16.0-16.0**	**23.0-23.0**	**42.0-42.0**	**11.0-11.0**
Date Sampled		**11/14/01**	**11/14/01**	**11/14/01**	**11/14/01**	**11/14/01**
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG			5 J		
Methyl acetate	UG/KG					2 J
Tetrachloroethene	UG/KG	11,000	460 J	38 J		

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

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POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		SB-07	SB-07	SB-07	SB-08	SB-08
Sample ID		SB7-18	SB7-26	SB7-42	SB8-10	SB8-17
Matrix		Soil	Soil	Soil	Soil	Soil
Depth Interval (ft)		18.0-18.0	26.0-26.0	42.0-42.0	10.0-10.0	17.0-17.0
Date Sampled		11/14/01	11/14/01	11/14/01	11/13/01	11/13/01
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG	4 J				
Methyl acetate	UG/KG					
Tetrachloroethene	UG/KG	20	570 J	230 J	10,000,000 J	320 J

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

Ref. 2

POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		SB-08	SB-08	SB-09	SB-09	SB-09
Sample ID		SB8-23	SB8-34	SB9-9	SB9-17	SB9-26
Matrix		Soil	Soil	Soil	Soil	Soil
Depth Interval (ft)		23.0-23.0	34.0-34.0	9.0-9.0	17.0-17.0	26.0-26.0
Date Sampled		11/13/01	11/13/01	11/13/01	11/13/01	11/13/01
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG					
Acetone	UG/KG					
Methyl acetate	UG/KG					
Tetrachloroethene	UG/KG	35 J		64,000	600 J	430 J

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

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POST-TREATMENT SOIL
WEST SIDE CORPORATION

Location ID		SB-09	SB-10	SB-10	SB-10	SB-10
Sample ID		SB9-41	SB10-9	SB10-12	SB10-22	SB10-37
Matrix		Soil	Soil	Soil	Soil	Soil
Depth Interval (ft)		41.0-41.0	9.0-9.0	12.0-12.0	22.0-22.0	37.0-37.0
Date Sampled		11/13/01	11/13/01	11/13/01	11/13/01	11/13/01
Parameter	**Units**					
Volatiles Organic Compounds						
1,2-Dichloroethene (cis)	UG/KG		2 J			
Acetone	UG/KG		10 J	4 J		5 J
Methyl acetate	UG/KG					
Tetrachloroethene	UG/KG	130 J	200	6 J	22	61

Flags assigned during chemistry validation are shown.

J - The reported concentration is an estimated value.

Only Detected Results Reported.

Ref. 3

PERRY'S CHEMICAL ENGINEERS' HANDBOOK

SIXTH EDITION

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Ref 3

DENSITIES OF MISCELLANEOUS MATERIALS

TABLE 3-118 Approximate Specific Gravities and Densities of Miscellaneous Solids and Liquids*

Water at 4°C and normal atmospheric pressure taken as unity. For more detailed data on any material, see the section dealing with the properties of that material.

Substance	Sp. gr.	Aver. weight lb./cu. ft.
Metals, Alloys, Ores		
Aluminum, cast-hammered	2.55–2.80	165
bronze	7.7	481
Brass, cast-rolled	8.4–8.7	534
Bronze, 7.9 to 14% Sn	7.4–8.9	509
phosphor	8.88	554
Copper, cast-rolled	8.8–8.95	556
ore, pyrites	4.1–4.3	262
German silver	8.58	536
Gold, cast-hammered	19.25–19.35	1205
coin (U.S.)	17.18–17.2	1073
Iridium	21.78–22.42	1383
Iron, gray cast	7.03–7.13	442
cast, pig	7.2	450
wrought	7.6–7.9	485
spiegeleisen	7.5	468
ferro-silicon	6.7–7.3	437
ore, hematite	5.2	325
ore, limonite	3.6–4.0	237
ore, magnetite	4.9–5.2	315
slag	2.5–3.0	172
Lead	11.34	710
ore, galena	7.3–7.6	465
Manganese	7.42	475
ore, pyrolusite	3.7–4.6	259
Mercury	13.6	849
Monel metal, rolled	8.97	555
Nickel	8.9	537
Platinum, cast-hammered	21.5	1330
Silver, cast-hammered	10.4–10.6	656
Steel, cold-drawn	7.83	489
machine	7.80	487
tool	7.70–7.73	481
Tin, cast-hammered	7.2–7.5	459
cassiterite	6.4–7.0	418
Tungsten	19.22	1200
Zinc, cast-rolled	6.9–7.2	440
blende	3.9–4.2	253
Various Solids		
Cereals, oats, bulk	0.51	26
barley, bulk	0.62	39
corn, rye, bulk	0.73	45
wheat, bulk	0.77	48
Cork	0.22–0.26	15
Cotton, flax, hemp	1.47–1.50	93
Fats	0.90–0.97	58
Flour, loose	0.40–0.50	28
pressed	0.70–0.80	47
Glass, common	2.40–2.80	162
plate or crown	2.45–2.72	161
crystal	2.90–3.00	184
flint	3.2–4.7	247
Hay and straw, bales	0.32	20
Leather	0.86–1.02	59
Paper	0.70–1.15	58
Potatoes, piled	0.67	44
Rubber, caoutchouc	0.92–0.96	59
goods	1.0–2.0	94
Salt, granulated, piled	0.77	48
Saltpeter	1.07	67
Starch	1.53	96
Sulfur	1.93–2.07	125
Wool	1.32	82

Subetance	Sp. gr.	Aver. weight lb./cu. ft.
Timber, Air-dry		
Apple	0.66–0.74	44
Ash, black	0.55	34
white	0.64–0.71	42
Birch, sweet, yellow	0.71–0.72	44
Cedar, white, red	0.35	22
Cherry, wild red	0.43	27
Chestnut	0.48	30
Cypress	0.45–0.48	29
Elm, white	0.56	35
Fir, Douglas	0.48–0.55	32
balsam	0.40	25
Hemlock	0.45–0.50	29
Hickory	0.74–0.80	48
Locust	0.67–0.77	45
Mahogany	0.56–0.85	44
Maple, sugar	0.68	43
white	0.53	33
Oak, chestnut	0.74	46
live	0.87	54
red, black	0.64–0.71	42
white	0.77	48
Pine, Norway	0.55	34
Oregon	0.51	32
red	0.48	30
Southern	0.61–0.67	38–42
white	0.43	27
Poplar	0.43	27
Redwood, California	0.42	26
Spruce, white, red	0.45	28
Teak, African	0.99	62
Indian	0.66–0.88	48
Walnut, black	0.59	37
Willow	0.42–0.50	28
Various Liquids		
Alcohol, ethyl (100%)	0.789	49
methyl (100%)	0.796	50
Acid, muriatic, 40%	1.20	75
nitric, 91%	1.50	94
sulfuric, 87%	1.80	112
Chloroform	1.500	95
Ether	0.736	46
Lye, soda, 66%	1.70	106
Oils, vegetable	0.91–0.94	58
mineral, lubricants	0.88–0.94	57
Turpentine	0.861–0.867	54
Water, 4°C. max. density	1.0	62.428
100°C	0.9584	59.830
ice	0.88–0.92	56
snow, fresh fallen	0.125	8
sea water	1.02–1.03	64
Ashlar Masonry		
Bluestone	2.3–2.6	153
Granite, syenite, gneiss	2.4–2.7	159
Limestone	2.1–2.8	153
Marble	2.4–2.8	162
Sandstone	2.0–2.6	143
Rubble Masonry		
Bluestone	2.2–2.5	147
Granite, syenite, gneiss	2.3–2.6	153
Limestone	2.0–2.7	147
Marble	2.3–2.7	156
Sandstone	1.9–2.5	137

Substance	Sp. gr.	Aver. weight lb./cu. ft.
Dry Rubble Masonry		
Granite, syenite, gneiss	1.9–2.3	130
Limestone, marble	1.9–2.1	125
Sandstone, bluestone	1.8–1.9	110
Brick Masonry		
Hard brick	1.8–2.3	128
Medium brick	1.6–2.0	112
Soft brick	1.4–1.9	103
Sand-lime brick	1.4–2.2	112
Concrete Masonry		
Cement, stone, sand	2.2–2.4	144
slag, etc	1.9–2.3	130
cinder, etc	1.5–1.7	100
Various Building Materials		
Ashes, cinders	0.64–0.72	40–45
Cement, Portland, loose	1.5	94
Lime, gypsum, loose	0.85–1.00	53–64
Mortar, lime, set	1.4–1.9	103
Portland cement	2.08–2.25	94–135
Portland cement	3.1–3.2	196
Slags, bank slag	1.1–1.2	67–72
bank screenings	1.5–1.9	98–117
machine slag	1.5	96
slag sand	0.8–0.9	49–55
Earth, etc., Excavated		
Clay, dry	1.0	63
damp plastic	1.76	110
and gravel, dry	1.6	100
Earth, dry, loose	1.2	76
dry, packed	1.5	95
moist, loose	1.3	78
moist, packed	1.6	96
mud, flowing	1.7	108
mud, packed	1.8	115
Riprap, limestone	1.3–1.4	80–85
Riprap, sandstone	1.4	90
Riprap, shale	1.7	105
Sand, gravel, dry, loose	1.4–1.7	90–105
gravel, dry, packed	1.6–1.9	100–120
gravel, wet	1.89–2.16	126
Excavations in Water		
Clay	1.28	80
River mud	1.44	90
Sand or gravel	0.96	60
and clay	1.00	65
Soil	1.12	70
Stone riprap	1.00	65
Minerals		
Asbestos	2.1–2.8	153
Barytes	4.50	281
Basalt	2.7–3.2	184
Bauxite	2.55	159
Bluestone	2.5–2.6	159
Borax	1.7–1.8	109
Chalk	1.8–2.8	143
Clay, marl	1.8–2.6	137
Dolomite	2.9	181
Feldspar, orthoclase	2.5–2.7	162
Gneiss	2.7–2.9	175
Granite	2.6–2.7	165
Greenstone, trap	2.8–3.2	187
Gypsum, alabaster	2.3–2.8	159
Hornblende	3.0	187
Limestone	2.1–2.86	155
Marble	2.6–2.86	170
Magnesite	3.0	187
Phosphate rock, apatite	3.2	200
Porphyry	2.6–2.9	172

---

* From Marks, "Mechanical Engineers' Handbook," McGraw-Hill.

Ref. 3

TABLE 9-12 Characteristics of Typical Nonpetroleum Fuels

	Conventional coal-tar fuels from retorting[a]		Typical coal-derived fuels with different levels of hydrogenation[b]					Synthetic crude oils, by hydrogenation	
	CTF 50	CTF 400	Minimal		Mild	Mild[c]	Severe	Oil shale	Tar sands[d]
Distillation range, °C			175–280	280–500	160–415	175–400	125–495		
Density, kg/m^3, 15°C	1.018	1.234	.974	1.072	0.964	0.9607	0.914	0.817	0.864
lb/U.S. gal, 60°F	8.5	10.3	8.1	8.9	8.0	8.0	7.6	6.8	7.2
Viscosity, mm^2/s	2–9	9–18	3.1–3.4	50–90	3.6	....	2.18		
	At 38°C	At 121°C	At 38°C	At 38°C	At 38°C	....	At 38°C		
Ultimate analysis, %									
Carbon	87.4	90.1	86.0	89.1	87.8	89.6	89.0	86.1	87.1
Hydrogen	7.9	5.4	9.1	7.5	9.7	10.1	11.1	13.84	12.69
Oxygen	3.6	2.4	3.6–4.3	1.4–1.8	2.4	0.3	0.5	0.12	0.04
Nitrogen	0.9	1.4	0.9–1.1	1.2–1.4	0.6	0.04	0.09	0.01	0.07
Sulfur	0.2	0.7	<0.2	0.4–0.5	0.07	0.004	0.04	0.02	0.10
Ash[e]	Trace	0.15	<0.001	[f]					
C/H ratio, weight	11.0	16.5	9.4	11.9	9.1	8.9	8.0	6.2	6.9
Gross calorific value, MJ/kg	38.4–40.7	36.8–37.9							
Btu/lb	16,500 to 17,500	15,800 to 16,300							

[a] CTF 50, 100, etc., indicate approximate preheat temperature, °F, for atomization of fuel in burners (terminology used in British Standard B.S. 1469).

[b] Properties depend on distillation range, as shown, and to a lesser extent on coal source.

[c] Using recycle-solvent process.

[d] Tar sands, although a form of petroleum, are included in this table for comparison.

[e] Inorganic mineral constituents of coal tar fuel:
5 to 50 ppm: Ca, Fe, Pb, Zn (Na, in tar treated with soda ash)
0.05 to 5 ppm: Al, Bi, Cu, Mg, Mn, K, Si, Na, Sn
Less than 0.05 ppm: As, B, Cr, Ge, Ti, V, Mo
Not detected: Sb, Ba, Be, Cd, Co, Ni, Sr, W, Zr

[f] Inherent ash is "trace" or "<0.1%," although entrainment in distillation has given values as high as 0.03 to 0.1%.

TABLE 9-13 Physical Properties of Light Hydrocarbons*

	Methane	Ethane	Propane	Isobutane	Butane	Pentane
Molecular volume of gas, cu. ft.†	378.7	375.8	372.7	366.7	365.4	
Molecular weight of gas	16.04	30.07	44.09	58.12	58.12	72.15
Gal./lb.-mole at 60°F	6.4‡	9.64	10.41	12.38	11.94	13.71
Weight:						
% carbon	74.88	79.88	81.72	82.66		
% hydrogen	25.12	20.12	18.28	17.34	17.34	
Specific gravity:						
Of liquid (water = 1)	0.248	0.377	0.508	0.563	0.584	0.631
Of liquid, °A.P.I.	340†	247	147	120	111	93
Of gas (air = 1)	0.555	1.048	1.550	2.077	2.084	2.490
Weights and volumes:						
Lb./gal. liquid	2.5†	3.145	4.235	4.694	4.873	5.250
Cu. ft. gas/gal. liquid	59.0†	39.69	36.28	30.65	31.46	27.67
Cu. ft. gas/lb. liquid	24.8	12.50	8.55	6.50		
Ratio, gas volume to liquid volume§	443†	293.4	272.7	229.3	237.8	207.0
Initial boiling point (atmospheric pressure)	−259	−128.2	−43.7	10.9	31.1	97
Heat value (gross):						
B.t.u./cu. ft. gas	1,012	1,786	2,522	3,163	3,261	4,023
B.t.u./lb. liquid	23,885	22,323	21,560	20,732	21,180	21,110
B.t.u./gal. liquid		70,210	91,500	103,750	102,600	110,800
Vapor pressure, lb./sq. in. abs						
At −44°F		88	0	−9	−12	−14
At 0°F		206	38	12	−7	−13
At 33°F		343	54	17	0	−11
At 70°F		563	124	45	31	−6
At 90°F		710	165	62	44	
At 100°F			189	72	52	4
At 130°F			275	110	81	11
At 150°F			346	138	87	21
Latent heat of vaporization at boiling point:						
B.t.u./lb.	221	211	185	158	167	153
B.t.u./gal.	553	664	785	742	808	802
Specific heat:						
Of liquid, at C_p and 60°F., B.t.u./(lb.)(°F.)		0.780	0.588	0.560	0.549	
Of gas, at C_p and 60°F., B.t.u./(lb.)(°F.)	0.526	0.413	0.390	0.406	0.396	0.402
Of gas, at C_v and 60°F., B.t.u./(lb.)(°F.)	0.402	0.347	0.346	0.373	0.363	0.376

*Johnson and Auth (eds.), *Fuels and Combustion Handbook*, McGraw-Hill, New York, 1951. To convert British thermal units per cubic foot to megajoules per cubic meter, multiply by 0.0373; to convert British thermal units per pound to megajoules per kilogram, multiply by 0.00232; to convert British thermal units per gallon to megajoules per cubic meter, multiply by 0.277; and to convert cubic feet to cubic meters, multiply by 0.0283. Gal/(lb·mol)(at 60°F) × 0.008 = m^3/(kg·mol)(at 16°C).

†Ideal gas = 379.5 ft^3.

‡Apparent values for dissolved methane at 60°F.

§Based on "perfect gas."

Ref. 4

Global Technologies

home products | services | resources | company | contact

Products

More info

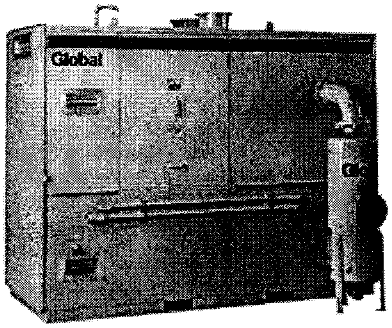
Have a project? Get faster budget quotes with **Quick Quote** or look at **Rental** availability.

Read about the Integrated Vapor Treatment system **in action**.

Do you already own a Global Integrated Vapor Treatment Module? Extend the life and profitability of the unit with Global **Service**.

Ask the Engineers a question or find other FAQs.

Integrated Vapor Treatment Module



Global Technologies' Integrated Vapor Treatment Module (VTM) destroys organic vapor contaminants that are extracted from soil vapor extraction wells or air scrubber towers. The system is integrated with a Vapor Liquid Seperator (knockout pot), blower and vapor treatment module. The Remedi-Cat™ model is designed for hydrocarbon contamination; the Chloro-Cat™ model is designed for halogenated or mixed organic vapor contaminants.

How the Remedi-Cat Works

The Remedi-Cat or Chloro-Cat will provide 99% destruction efficiency of VOC's (higher destruction efficiencies are possible with additional catalyst). During operation, VOC-laden air is drawn by the VTM regenerative system blower from vacuum extraction wells and diluted to the appropriate concentration using an automatic valve. The blower discharges the contaminated air into the tube side of the primary heat exchanger, where it is preheated prior to the gas burner. Within the burner/reactor section the contaminated air is raised to oxidizing temperature by the burner prior to entering the catalyst module. When the vapor-laden air passes through the catalyst, an exothermic reaction takes place. The hot purified air then passes through the shell side of the heat exchanger where the energy released by the reaction is used to preheat the incoming air. The cooler, vapor-free air is exhausted to the outside atmosphere.

The Model 7 Integrated Unit has a 20 h.p. regenerative blower which allows vapor extraction at up to 10" hg vacuum from vapor extraction wells. No additional blowers are needed.

Global's Fully Integrated Approach

The Therm-Cat was designed as part of Global's entire line of soil and groundwater remediation products. The Global line of products, which includes Vapor Liquid Separators (Knockout Pots), Extraction Blower Packages, Oxidizers, and Acid Gas Scrubbers, is technologically advanced as well as user-friendly. Each module interfaces easily and is constructed for optimum performance and trouble-free operation.

When networked, the Global modules form a comprehensive subsurface remediation system that works continuously and automatically to achieve site closure quickly. In addition, Global's modular approach allows rapid deployment and provides the flexibility necessary to successfully perform site remediation under a wide variety of conditions.

System Components

The Integrated System includes a Vapor Liquid Separator Module, 300 series stainless steel shell and tube heat exchanger, reactor vessel with catalyst, modulating burner, gas train, regenerative blower with 20 h.p. motor, system controls, flowmeter, automatic fresh air dilution valves, first-out shutdown

Ref. 4

CATALYTIC OXIDIZER UNIT MACRO SPECIFICATIONS

Tyree Organization Ltd.

Unit CC-5311

OPERATING SPECIFICATIONS	(All values established for required VOC destruction efficiency)
Nominal Process Stream VOC Content	Air Stripper Discharge
Guaranteed VOC Destruction Efficiency	95 %
Maximum Process Air Stream	600 SCFM
Inlet Temperature Control Set Point	Field set to Achieve 845°F at Outlet (600°F min.)
Catalyst Required Operating Temperature	845°F
Temperature Control Method	Modulating firing rate valve controlled via temperature PI loop controller
Temperature High Limit Safety Set Point	1,050°F
Catalyst Inlet High Temp. Safety Set Point	900°F

Ref. 4

MACRO SPECIFICATIONS - Unit CC-5311

BURNER & ASSOCIATED EQUIPMENT

Manufacturer	Eclipse
Model	40 AHMA
Type	Air Heat
Maximum Nominal Firing Rate	400,000 BTU/Hr.
Minimum Firing Rate	10,000 BTU/Hr.
Fuel Train	1"
Required Gas Pressure to Fuel Train	2 psig to 5 psig
Gas Pressure Regulated To Approximately	12" to 14" water column (Nominal value only. Must be adjusted by qualified technician)

FLAME SAFETY EQUIPMENT

Flame Safeguard Primary Control	Honeywell RM7895
Flame Sensor Type	Rectifying Flame Rod
High Temperature Limit Control	Honeywell DC100L

URS

Ref. 5

December 21, 2001

Shive Mittal
NYSDEC, Bureau of Western Remedial Action
625 Broadway
Albany, NY 12233

RE: WEST SIDE CORP. SITE #2-41-026
W.A. D003825-31
SVE PILOT TEST REPORT

Dear Mr. Mittal:

Please find attached the report on the SVE pilot test conducted at the above-referenced site on September 26 and 27, 2001.

If you have any questions, please contact me at 716-856-5636.

Sincerely yours,

URS Corporation

Jon Sundquist, Ph.D.
Project Manager

cc: Daniel W. Rothman, P.E.
File: 05-000-35897.01 (C-1)

URS Corporation
282 Delaware Avenue
Buffalo, NY 14202-1805
Tel: 716.856.5636
Fax: 716.856.2545

J:\35987.01\word\cor\SVE report cover letter

Ref. 5

MITKEM CORPORATION

Client Sample ID: EW-1

GC/MS Volatiles

Lot-Sample #...:	H1J010107-001	**Work Order #...:**	ELC911AA	**Matrix.........:**	AIR
Date Sampled...:	09/28/01	**Date Received..:**	10/01/01		
Prep Date......:	10/04/01	**Analysis Date..:**	10/04/01		
Prep Batch #...:	1277284				
Dilution Factor:	144684	**Method.........:**	EPA-19 TO-14		

PARAMETER	RESULT	REPORTING LIMIT	UNITS
Acetone	ND	720000	ppb (v/v)
Benzene	ND	29000	ppb (v/v)
Bromodichloromethane	ND	29000	ppb (v/v)
Bromoform	ND	29000	ppb (v/v)
Bromomethane	ND	29000	ppb (v/v)
Carbon disulfide	ND	29000	ppb (v/v)
Carbon tetrachloride	ND	29000	ppb (v/v)
Chlorobenzene	ND	29000	ppb (v/v)
Dibromochloromethane	ND	29000	ppb (v/v)
Chloroethane	ND	29000	ppb (v/v)
Chloroform	ND	29000	ppb (v/v)
Chloromethane	ND	72000	ppb (v/v)
1,1-Dichloroethane	ND	29000	ppb (v/v)
1,2-Dichloroethane	ND	29000	ppb (v/v)
1,1-Dichloroethene	ND	29000	ppb (v/v)
cis-1,2-Dichloroethene	**170000**	**29000**	**ppb (v/v)**
trans-1,2-Dichloroethene	ND	29000	ppb (v/v)
1,2-Dichloropropane	ND	29000	ppb (v/v)
cis-1,3-Dichloropropene	ND	29000	ppb (v/v)
trans-1,3-Dichloropropene	ND	29000	ppb (v/v)
Ethylbenzene	ND	29000	ppb (v/v)
2-Hexanone	ND	72000	ppb (v/v)
Methylene chloride	**23000 J,B**	**29000**	**ppb (v/v)**
Styrene	ND	29000	ppb (v/v)
1,1,2,2-Tetrachloroethane	ND	29000	ppb (v/v)
Tetrachloroethene	**1300000**	**29000**	**ppb (v/v)**
Toluene	ND	29000	ppb (v/v)
1,1,1-Trichloroethane	ND	29000	ppb (v/v)
1,1,2-Trichloroethane	ND	29000	ppb (v/v)
Trichloroethene	**39000**	**29000**	**ppb (v/v)**
Vinyl chloride	**90000**	**29000**	**ppb (v/v)**
o-Xylene	ND	29000	ppb (v/v)
m-Xylene & p-Xylene	ND	29000	ppb (v/v)
2-Butanone (MEK)	ND	72000	ppb (v/v)
4-Methyl-2-pentanone (MIBK)	ND	72000	ppb (v/v)

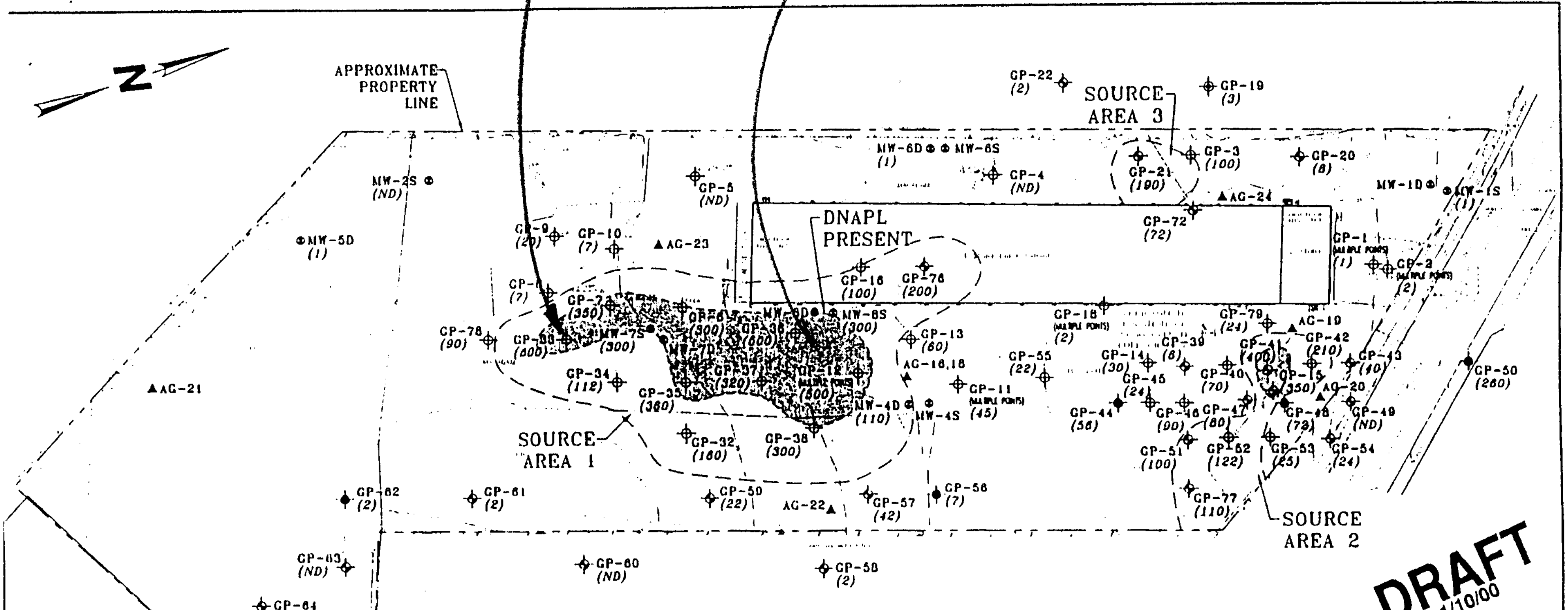
SURROGATE	PERCENT RECOVERY	RECOVERY LIMITS
1,2-Dichloroethane-d4	101	(70 - 130)
Toluene-d8	100	(70 - 130)
4-Bromofluorobenzene	99	(70 - 130)

(Continued on next page)

Ref. 6

Approx. location of SVE pilot test well

ERH treatment area



LEGEND

☐	INDICATES APPROXIMATE AREA WHERE OVM READINGS WERE >100ppm
▨	INDICATES APPROXIMATE AREA WHERE OVM READINGS WERE >300ppm
GP-62 (2)	GEOPROBE SOIL BORING (SOIL AND SHALLOW & DEEP GROUNDWATER SAMPLING), WITH OVM READING IN ppm (SEE NOTE 4)
GP-55 (22)	GEOPROBE SOIL BORING (SOIL SAMPLING ONLY), WITH OVM READING IN ppm (SEE NOTE 4)
GP-61 (2)	GEOPROBE SOIL BORING (SOIL AND SHALLOW GROUNDWATER SAMPLING), WITH OVM READING IN ppm (SEE NOTE 4)
GP-10 (3)	GEOPROBE SOIL BORING (SOIL AND DEEP GROUNDWATER SAMPLING), WITH OVM READING IN ppm (SEE NOTE 4)
MW-4D (110)	MONITORING WELL, WITH OVM READING IN ppm (SEE NOTE 4)
(ND)	INDICATES ORGANIC VAPOR NOT DETECTED
▲ AG-22	SUBSURFACE SOIL SAMPLING POINT LOCATION

NOTES:

1. BASE MAP ADAPTED FROM A PLAN PROVIDED BY YEC, INC. IN AUTOCAD FORMAT DATED DECEMBER 1999. DATE OF SURVEY, OCTOBER 6, 1999, PERFORMED BY YEC, INC.
2. HORIZONTAL DATUM: NAD 83-96 STATE PLANE COORDINATE SYSTEM, EAST ZONE. VERTICAL DATUM: NGVD 1929
3. THE SIZE AND LOCATION OF EXISTING SITE FEATURES AND EXPLORATIONS SHOULD BE CONSIDERED APPROXIMATE.
4. OVM CONTOURS DEVELOPED BY INTERPOLATING SOIL SAMPLE HEAD SPACE SCREENING RESULTS IN WIDELY SPACED BORINGS AND ARE PRESENTED ON THIS FIGURE FOR CONCEPTUAL PURPOSES ONLY. THESE RESULTS ARE BASED ON PHASE 1 AND 2 FIELD ACTIVITIES

WEST SIDE CORPORATION
JAMAICA, NEW YORK

REMEDIAL INVESTIGATION/FEASIBILITY STUDY

CONCEPTUAL HOT SPOT/ SOURCE AREA LOCATION PLAN

REV No.	DESCRIPTION	BY	DATE

SCALE IN FEET
0 30 60 120

GZA
GZA GeoEnvironmental of New York

DRAWN BY: DEW
DATE: JANUARY 2000
PROJECT No.
55265
FIGURE No.
4

APPENDIX 5A

BOILING POINT CALCULATIONS FOR WATER/PCE MIXTURE

URS
282 Delaware Avenue
Buffalo, New York 14202
(716) 856-5636

CALCULATION COVER SHEET

Client: NYSDEC
Project Name: West Side Corporation
Project/Calculation Number: 1117 2744
Title: Calculation of boiling point of Water/PCE mixture
Total number of pages (including cover sheet): 8
Total number of computer runs: 0
Prepared by: Jon Sundquist
Date: 10/3/02
Checked by: Donald A. McCall
Date: 10.23.02

Description and Purpose: This calculation calculates the boiling temperatures of two-liquid-phase mixtures of PCE and water at various pressures

Design bases/references/assumptions: Vapor pressure data as supplied by CRC handbook of Chemistry and Physics. These data were used to develop a correlation in the format of $\log_{10} P = m\left(\frac{1}{T}\right) + b$ in accordance with the Clausius-Clapeyron equation.

Remarks/conclusions: Boiling points of the two-liquid-phase system range from 88°C at atmospheric pressure to 105°C at the hydrostatic pressure found at 28 feet of water head.

Calculation Approved by: ______________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:

Project Manager/Date

URS

Job West Side Corp
Description Calculation of boiling point of Water / PCE mixture.
Project No. 1117 2744
Computed by Jon Sundquist
Checked by D. McCall
Page 1 of 7
Sheet ___ of ___
Date Oct 3 /02
Date 10.23.02
Reference

Problem Statement : Calculate temperature at which a mixture of PCE and water vapors equal one atmosphere, and temperature at which combined vapor pressures equal hydrostatic pressure of water at varying depths

Assumptions:

Both liquids are pure liquids.

Reference: 1) CRC Handbook of Chemistry and Physics, 62nd edition

1st Calculation: (for water table depth, pressure = 760 mmHg)

From reference (1), p. D-175 & D-168

For C_2Cl_4:

	Temperature °C	Temperature °K	Vapor pressure (mmHg)
For C_2Cl_4	40.1	313.1	40
	61.3	334.3	100
	100.0	373	400
	120.8	393.8	760
For water:	40.0	313	55.3
	61.2	334.2	157.8
	100.0	373	760
	121.0	394	1537

Assume fits equation $\log_{10} P = \frac{m}{T_{°K}} + b$

For C_2Cl_4: $\log_{10} P = \frac{-1,951}{T} + 7.83$

For Water $\log_{10} P = \frac{-2,199}{T} + 8.77$

URS

Job West Side Corp
Description Calculation of boiling point of water/PCE mixture
Project No. 11172744
Computed by Jan Sandquist
Checked by D. McCall
Page 2 of 7
Sheet ___ of ___
Date Oct. 3, 2002
Date 10.23.02
Reference

so, $P_{PCE} = 10^{\left(\frac{-1{,}951}{T} + 7.83\right)}$ $\quad P_{water} = 10^{\left(\frac{-2{,}199}{T} + 8.77\right)}$

$$P_{PCE} + P_{water} = 760_{mm} = 10^{\left(\frac{-1{,}951}{T} + 7.83\right)} + 10^{\left(\frac{-2{,}199}{T} + 8.77\right)}$$

iteratively solve for T = 88.6 °C

but this over estimate since at 88.6 °C
water is 500 mmHg from Ref (1)
where as formula gives 488 mm Hg

so is more like $\underline{\underline{88\ °C}}$

2nd calculation

at 55 feet, we are 43 feet below water table
at 43 feet, pressure of water = $\rho g h$ =

$$\left(\frac{1\ \cancel{g}}{cm^3}\right)\left(\frac{980.7\ cm}{\cancel{sec^2}}\right)(43\ \cancel{ft})\left(\frac{30.48\ cm}{\cancel{ft}}\right)\left(\frac{dyne}{cm\text{-}\cancel{g}/sec^2}\right) =$$

$$= 1{,}644 \times 10^6\ \frac{dyne}{cm^2} \times \frac{7.5 \times 10^{-4}\ mmHg}{dyne/cm^3}$$

$$= 964\ mm\ Hg$$

plus atmospheric pressure of 760 → 1,724 mmHg

Using above formula, T = 112.1 °C,

say $\underline{T = 112\ °C}$

equation check: at 112, correlation gives water v.p. of 1147
ref (1) gives " " " 1149.

URS

Page 3 of 7

Job West Side Corp.

Project No. 1117 2744

Sheet ____ of ____

Description Calculation of boiling point of Water/PCE mixture

Computed by Jon Sundquist

Date 10/21/02

Checked by D. McColl

Date 10.23.02

Reference

3rd Calculation

Calculate temperature @ 5-foot interval, starting at 15 feet bgs, which we will define as 3 feet below water table.

Hydrostatic pressure will be calculated as linear to the pressure calculated on page 2 for 43 feet. Specifically

$$\text{Pressure at depth "x" below water table} = \left(\frac{x}{43}\right)(964) + 760$$

For each calculation, qualitative rounding adjustments are made based on comparison of calculated water vapor pressure to that presented in ref (1)

Depth bgs (ft)	Depth below watertable (ft)	Hydro-static Pressure	Predicted 2-phase boiling temperature (°C)	Predicted Water Vapor pressure (mmHg)	Actual (ref 1) Water VP (mmHg)	Adjusted 2 phase boiling Temp °C
15	3	827	90.9	533.5	~543	90
20	8	939	94.4	609.1	620	94
25	13	1051	97.5	682.1	~689	97
30	18	1164	100.5	762.9	~768	100
35	23	1276	103.1	834.5	~848	103
40	28	1388	105.5	908.2	~921	105

Note, because derived water vapor correlation tends to underestimate water vapor pressure in this particular range, it is justifiable to round down.

4th "Calculation"

Need to know single-phase (water-only) boiling points at depths below the DNAPL zone. We do not need the correlation for this → can read from tables in ref (1)

Depth bgs	Depth below water table	Pressure	Water boiling point
45	33	1,500	120.2
50	38	1,612	122.5
55	43	1,724	124.7

reference (1)

Page 4.F7

CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data

1981—1982

62nd EDITION

Editor

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and
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In collaboration with a large number of professional chemists and physicists whose assistance is acknowledged in the list of general collaborators and in connection with the particular tables or sections involved.

CRC Press, Inc.
Boca Raton, Florida

VAPOR PRESSURE OF WATER BELOW 100°C

Pressure of aqueous vapor over water in mm of Hg for temperatures from −15.8 to 100°C. Values for fractional degrees between 50 and 89 were obtained by interpolation.

Temp. °C	0.0	0.2	0.4	0.6	0.8
−15	1.436	1.414	1.390	1.368	1.345
−14	1.560	1.534	1.511	1.485	1.460
−13	1.691	1.665	1.637	1.611	1.585
−12	1.834	1.804	1.776	1.748	1.720
−11	1.987	1.955	1.924	1.893	1.863
−10	2.149	2.116	2.084	2.050	2.018
− 9	2.326	2.289	2.254	2.219	2.184
− 8	2.514	2.475	2.437	2.399	2.362
− 7	2.715	2.674	2.633	2.593	2.553
− 6	2.931	2.887	2.843	2.800	2.757
− 5	3.163	3.115	3.069	3.022	2.976
− 4	3.410	3.359	3.309	3.259	3.211
− 3	3.673	3.620	3.567	3.514	3.461
− 2	3.956	3.898	3.841	3.785	3.730
− 1	4.258	4.196	4.135	4.075	4.016
− 0	4.579	4.513	4.448	4.385	4.320
0	4.579	4.647	4.715	4.785	4.855
1	4.926	4.998	5.070	5.144	5.219
2	5.294	5.370	5.447	5.525	5.605
3	5.685	5.766	5.848	5.931	6.015
4	6.101	6.187	6.274	6.363	6.453
5	6.543	6.635	6.728	6.822	6.917
6	7.013	7.111	7.209	7.309	7.411
7	7.513	7.617	7.722	7.828	7.936
8	8.045	8.155	8.267	8.380	8.494
9	8.609	8.727	8.845	8.965	9.086
10	9.209	9.333	9.458	9.585	9.714
11	9.844	9.976	10.109	10.244	10.380
12	10.518	10.658	10.799	10.941	11.085
13	11.231	11.379	11.528	11.680	11.833
14	11.987	12.144	12.302	12.462	12.624
15	12.788	12.953	13.121	13.290	13.461
16	13.634	13.809	13.987	14.166	14.347
17	14.530	14.715	14.903	15.092	15.284
18	15.477	15.673	15.871	16.071	16.272
19	16.477	16.685	16.894	17.105	17.319
20	17.535	17.753	17.974	18.197	18.422
21	18.650	18.880	19.113	19.349	19.587
22	19.827	20.070	20.316	20.565	20.815
23	21.068	21.324	21.583	21.845	22.110
24	22.377	22.648	22.922	23.198	23.476
25	23.756	24.039	24.326	24.617	24.912
26	25.209	25.509	25.812	26.117	26.426
27	26.739	27.055	27.374	27.696	28.021
28	28.349	28.680	29.015	29.354	29.697
29	30.043	30.392	30.745	31.102	31.461
30	31.824	32.191	32.561	32.934	33.312
31	33.695	34.082	34.471	34.864	35.261
32	35.663	36.068	36.477	36.891	37.308
33	37.729	38.155	38.584	39.018	39.457
34	39.898	40.344	40.796	41.251	41.710
35	42.175	42.644	43.117	43.595	44.078
36	44.563	45.054	45.549	46.050	46.556
37	47.067	47.582	48.102	48.627	49.157
38	49.692	50.231	50.774	51.323	51.879
39	52.442	53.009	53.580	54.156	54.737
40	55.324	55.91	56.51	57.11	57.72
41	58.34	58.96	59.58	60.22	60.86
42	61.50	62.14	62.80	63.46	64.12
43	64.80	65.48	66.16	66.86	67.56
44	68.26	68.97	69.69	70.41	71.14
45	71.88	72.62	73.36	74.12	74.88
46	75.65	76.43	77.21	78.00	78.80
47	79.60	80.41	81.23	82.05	82.87
48	83.71	84.56	85.42	86.28	87.14
49	88.02	88.90	89.79	90.69	91.59
50	92.51	93.5	94.4	95.3	96.3
51	97.20	98.2	99.1	100.1	101.1
52	102.09	103.1	104.1	105.1	106.2
53	107.20	108.2	109.3	110.4	111.4
54	112.51	113.6	114.7	115.8	116.9
55	118.04	119.1	120.3	121.5	122.6
56	123.80	125.0	126.2	127.4	128.6
57	129.82	131.0	132.3	133.5	134.7
58	136.08	137.3	138.5	139.9	141.2
59	142.60	143.9	145.2	146.6	148.0
60	149.38	150.7	152.1	153.5	155.0
61	156.43	157.8	159.3	160.8	162.3
62	163.77	165.2	166.8	168.3	169.8
63	171.38	172.9	174.5	176.1	177.7
64	179.31	180.9	182.5	184.2	185.8
65	187.54	189.2	190.9	192.6	194.3
66	196.09	197.8	199.5	201.3	203.1
67	204.96	206.8	208.6	210.5	212.3
68	214.17	216.0	218.0	219.9	221.8
69	223.73	225.7	227.7	229.7	231.7
70	233.7	235.7	237.7	239.7	241.8
71	243.9	246.0	248.2	250.3	252.4
72	254.6	256.8	259.0	261.2	263.4
73	265.7	268.0	270.2	272.6	274.8
74	277.2	279.4	281.8	284.2	286.6
75	289.1	291.5	294.0	296.4	298.8
76	301.4	303.8	306.4	308.9	311.4
77	314.1	316.6	319.2	322.0	324.6
78	327.3	330.0	332.8	335.6	338.2
79	341.0	343.8	346.6	349.4	352.2
80	355.1	358.0	361.0	363.8	366.8
81	369.7	372.6	375.6	378.8	381.8
82	384.9	388.0	391.2	394.4	397.4
83	400.6	403.8	407.0	410.2	413.6
84	416.8	420.2	423.6	426.8	430.2
85	433.6	437.0	440.4	444.0	447.5
86	450.9	454.4	458.0	461.6	465.2
87	468.7	472.4	476.0	479.8	483.4
88	487.1	491.0	494.7	498.5	502.2
89	506.1	510.0	513.9	517.8	521.8
90	525.76	529.77	533.80	537.86	541.95
91	546.05	550.18	554.35	558.53	562.75
92	566.99	571.26	575.55	579.87	584.22
93	588.60	593.00	597.43	601.89	606.38
94	610.90	615.44	620.01	624.61	629.24
95	633.90	638.59	643.30	648.05	652.82
96	657.62	662.45	667.31	672.20	677.12
97	682.07	687.04	692.05	697.10	702.17
98	707.27	712.40	717.56	722.75	727.98
99	733.24	738.53	743.85	749.20	754.58
100	760.00	765.45	770.93	776.44	782.00
101	787.57	793.18	798.82	804.50	810.21

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Temp. °C	m
100	760
101	787
102	815
103	845
104	875
105	906
106	937
107	970
108	1004.
109	1038.
110	1074.
111	1111.
112	1148.
113	1187.
114	1227.
115	1267.
116	1309.
117	1352.
118	1397.
119	1442.
120	1489.
121	1536.
122	1586.
123	1636.
124	1687.
125	1740.
126	1795.
127	1850.
128	1907.
129	1966.
130	2026.
131	2087.
132	2150.
133	2214.
134	2280.
135	2347.
136	2416.
137	2488.
138	2560.
139	2634.
140	2710.
141	2788.
142	2867.
143	2948
144	3031.
145	3116.
146	3203.
147	3292.
148	3382.
149	3476.
150	3570.
151	3667.
152	3766.
153	3866.
154	3970.
155	4075.
156	4183.
157	4293.
158	4404.
159	4519.
160	4636.
161	4755.
162	4876.
163	5000.
164	5126.
165	5256.
166	5386.
167	5521.
168	5658.
169	5798.

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VAPOR PRESSURE OF WATER ABOVE 100° C.

Based on values given by Keyes in the International Critical Tables.

Temp. °C	Pressure		Temp. °F	Temp. °C	Pressure		Temp. °F	Temp °C	Pressure		Temp. °F	Temp. °C	Pressure		Temp. °F
	mm	Pounds per sq. in.			mm	Pounds per sq. in.			mm	Pounds per sq. in.			mm	Pounds per sq. in.	
100	760.	14.696	212.0	170	5940.92	114.879	338.0	240	25100.52	485.365	464.0	310	74024.00	1431.390	590.0
101	787.51	15.228	213.8	171	6085.32	117.671	339.8	241	25543.60	493.933	465.8	311	75042.40	1451.083	591.8
102	815.86	15.776	215.6	172	6233.52	120.537	341.6	242	25994.28	502.647	467.6	312	76076.00	1471.070	593.6
103	845.12	16.342	217.4	173	6383.24	123.432	343.4	243	26449.52	511.450	469.4	313	77117.20	1491.203	595.4
104	875.06	16.921	219.2	174	6538.28	126.430	345.2	244	26912.36	520.400	471.2	314	78166.00	1511.484	597.2
105	906.07	17.521	221.0	175	6694.08	129.442	347.0	245	27381.28	529.467	473.0	315	79230.00	1532.058	599.0
106	937.92	18.136	222.8	176	6852.92	132.514	348.8	246	27855.52	538.638	474.8	316	80294.00	1552.632	600.8
107	970.60	18.768	224.6	177	7015.56	135.659	350.6	247	28335.84	547.926	476.6	317	81373.20	1573.501	602.6
108	1004.42	19.422	226.4	178	7180.48	138.848	352.4	248	28823.76	557.360	478.4	318	82467.60	1594.663	604.4
109	1038.92	20.089	228.2	179	7349.20	142.110	354.2	249	29317.00	566.898	480.2	319	83569.60	1615.972	606.2
110	1074.56	20.779	230.0	180	7520.20	145.417	356.0	250	29817.84	576.583	482.0	320	84686.80	1637.575	608.0
111	1111.20	21.487	231.8	181	7694.24	148.782	357.8	251	30324.00	586.370	483.8	321	85819.20	1659.472	609.8
112	1148.74	22.213	233.6	182	7872.08	152.221	359.6	252	30837.76	596.305	485.6	322	86959.20	1681.516	611.6
113	1187.42	22.961	235.4	183	8052.96	155.719	361.4	253	31356.84	606.342	487.4	323	88114.40	1703.854	613.4
114	1227.25	23.731	237.2	184	8236.88	159.275	363.2	254	31885.04	616.556	489.2	324	89277.20	1726.339	615.2
115	1267.98	24.519	239.0	185	8423.84	162.890	365.0	255	32417.80	626.858	491.0	325	90447.60	1748.971	617.0
116	1309.94	25.330	240.8	186	8616.12	166.609	366.8	256	32957.40	637.292	492.8	326	91633.20	1771.897	618.8
117	1352.95	26.162	242.6	187	8809.92	170.356	368.6	257	33505.36	647.888	494.6	327	92826.40	1794.969	620.6
118	1397.18	27.017	244.4	188	9007.52	174.177	370.4	258	34059.40	658.601	496.4	328	94042.40	1818.483	622.4
119	1442.63	27.896	246.2	189	9208.16	178.057	372.2	259	34618.76	669.417	498.2	329	95273.60	1842.291	624.2
120	1489.14	28.795	248.0	190	9413.36	182.025	374.0	260	35188.00	680.425	500.0	330	96512.40	1866.245	626.0
121	1536.80	29.717	249.8	191	9620.08	186.022	375.8	261	35761.80	691.520	501.8	331	97758.80	1890.346	627.8
122	1586.04	30.669	251.6	192	9831.36	190.107	377.6	262	36343.20	702.763	503.6	332	99020.40	1914.742	629.6
123	1636.36	31.642	253.4	193	10047.20	194.281	379.4	263	36932.20	714.152	505.4	333	100297.20	1939.431	631.4
124	1687.81	32.637	255.2	194	10265.32	198.499	381.2	264	37529.56	725.703	507.2	334	101581.60	1964.267	633.2
125	1740.93	33.664	257.0	195	10488.76	202.819	383.0	265	38133.00	737.372	509.0	335	102881.20	1989.398	635.0
126	1795.12	34.712	258.8	196	10715.24	207.199	384.8	266	38742.52	749.158	510.8	336	104196.00	2014.822	636.8
127	1850.83	35.789	260.6	197	10944.76	211.637	386.6	267	39361.92	761.135	512.6	337	105526.00	2040.540	638.6
128	1907.83	36.891	262.4	198	11179.60	216.178	388.4	268	39986.64	773.215	514.4	338	106871.20	2066.552	640.4
129	1966.35	38.023	264.2	199	11417.48	220.778	390.2	269	40619.72	785.457	516.2	339	108224.00	2092.710	642.2
130	2026.16	39.180	266.0	200	11659.16	225.451	392.0	270	41261.16	797.861	518.0	340	109592.00	2119.163	644.0
131	2087.42	40.364	267.8	201	11905.40	230.213	393.8	271	41910.20	810.411	519.8	341	110967.60	2145.763	645.8
132	2150.42	41.582	269.6	202	12155.44	235.048	395.6	272	42566.08	823.094	521.6	342	112358.40	2172.657	647.6
133	2214.64	42.824	271.4	203	12408.52	239.942	397.4	273	43229.56	835.923	523.4	343	113749.20	2199.550	649.4
134	2280.76	44.103	273.2	204	12666.16	244.924	399.2	274	43902.16	848.929	525.2	344	115178.00	2227.179	651.2
135	2347.26	45.389	275.0	205	12929.12	250.008	401.0	275	44580.84	862.053	527.0	345	116614.40	2254.954	653.0
136	2416.34	46.724	276.8	206	13197.40	255.196	402.8	276	45269.40	875.367	528.8	346	118073.60	2283.171	654.8
137	2488.16	48.113	278.6	207	13467.96	260.428	404.6	277	45964.04	888.799	530.6	347	119532.80	2311.387	656.6
138	2560.67	49.515	280.4	208	13742.32	265.733	406.4	278	46669.32	902.437	532.4	348	121014.80	2340.044	658.4
139	2634.84	50.950	282.2	209	14022.76	271.156	408.2	279	47382.20	916.222	534.2	349	122504.40	2368.848	660.2
140	2710.92	52.421	284.0	210	14305.48	276.623	410.0	280	48104.20	930.183	536.0	350	124001.60	2397.799	662.0
141	2788.44	53.920	285.8	211	14595.04	282.222	411.8	281	48833.80	944.291	537.8	351	125521.60	2427.191	663.8
142	2867.48	55.448	287.6	212	14888.40	287.895	413.6	282	49570.24	958.532	539.6	352	127049.20	2456.730	665.6
143	2948.80	57.020	289.4	213	15184.80	293.626	415.4	283	50316.56	972.963	541.4	353	128599.60	2486.710	667.4
144	3031.64	58.622	291.2	214	15488.04	299.490	417.2	284	51072.76	987.586	543.2	354	130157.60	2516.837	669.2
145	3116.76	60.268	293.0	215	15792.80	305.383	419.0	285	51838.08	1002.385	545.0	355	131730.80	2547.258	671.0
146	3203.40	61.944	294.8	216	16104.40	311.408	420.8	286	52611.76	1017.345	546.8	356	133326.80	2578.119	672.8
147	3292.32	63.663	296.6	217	16420.56	317.522	422.6	287	53395.32	1032.497	548.6	357	134945.60	2609.422	674.6
148	3382.76	65.412	298.4	218	16742.04	323.738	424.4	288	54187.24	1047.810	550.4	358	136579.60	2641.018	676.4
149	3476.24	67.220	300.2	219	17067.32	330.028	426.2	289	54989.04	1063.314	552.2	359	138228.80	2672.908	678.2
150	3570.48	69.042	302.0	220	17395.64	336.377	428.0	290	55799.20	1078.980	554.0	360	139893.20	2705.093	680.0
151	3667.00	70.908	303.8	221	17731.56	342.872	429.8	291	56612.40	1094.705	555.8	361	141572.80	2737.571	681.8
152	3766.56	72.833	305.6	222	18072.80	349.471	431.6	292	57448.40	1110.871	557.6	362	143275.20	2770.490	683.6
153	3866.88	74.773	307.4	223	18417.84	356.143	433.4	293	58284.40	1127.036	559.4	363	144992.80	2803.703	685.4
154	3970.24	76.772	309.2	224	18766.68	362.888	435.2	294	59135.60	1143.496	561.2	364	146733.20	2837.357	687.2
155	4075.88	78.815	311.0	225	19123.12	369.781	437.0	295	59994.40	1160.102	563.0	365	148519.20	2871.892	689.0
156	4183.80	80.901	312.8	226	19482.60	376.732	438.8	296	60860.80	1176.836	564.8	366	150320.40	2906.722	690.8
157	4293.24	83.018	314.6	227	19848.92	383.815	440.6	297	61742.40	1193.903	566.6	367	152129.20	2941.698	692.6
158	4404.96	85.178	316.4	228	20219.80	390.987	442.4	298	62624.00	1210.950	568.4	368	153960.80	2977.116	694.4
159	4519.72	87.397	318.2	229	20596.76	398.276	444.2	299	63528.40	1228.439	570.2	369	155815.20	3012.974	696.2
160	4636.00	89.646	320.0	230	20978.28	405.654	446.0	300	64432.80	1245.927	572.0	370	157692.40	3049.273	698.0
161	4755.32	91.953	321.8	231	21365.12	413.134	447.8	301	65352.40	1263.709	573.8	371	159584.80	3085.866	699.8
162	4876.92	94.304	323.6	232	21757.28	420.717	449.6	302	66279.60	1281.638	575.6	372	161507.60	3123.047	701.6
163	5000.04	96.685	325.4	233	22154.00	428.388	451.4	303	67214.40	1299.714	577.4	373	163468.40	3160.963	703.4
164	5126.96	99.139	327.2	234	22558.32	436.207	453.2	304	68156.80	1317.937	579.2	374	165467.20	3199.613	705.2
165	5256.16	101.638	329.0	235	22967.96	444.128	455.0	305	69114.40	1336.454	581.0				
166	5386.88	104.165	330.8	236	23382.92	452.152	456.8	306	70072.00	1354.971	582.8				
167	5521.40	106.766	332.6	237	23802.44	460.264	458.6	307	71052.40	1373.929	584.6				
168	5658.20	109.412	334.4	238	24229.56	468.523	460.4	308	72048.00	1393.181	586.4				
169	5798.04	112.116	336.2	239	24661.24	476.871	462.2	309	73028.40	1412.139	588.2				

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ORGANIC COMPOUNDS
Pressures Less than One Atmosphere (Continued)

Name	Formula	Temperature °C						M.P.
		1 mm	10 mm	40 mm	100 mm	400 mm	760 mm	
2-Methyldisilazane	CH_9NSi_2	−76.3	−50.1	−29.6	−13.1	+17.2	34.0	—
Cyanogen iodide	CIN	25.2s	57.7s	80.3s	97.6s	126.1s	141.1s	—
Tetranitromethane	CN_4O_8	s	22.7	48.4	68.9	105.9	125.7d	13
Carbon monoxide	CO	−222.0s	−215.0s	−210.0s	−205.7s	−196.3	−191.3	−205.0
Carbonyl sulfide	COS	−132.4	−113.3	−98.3	−85.9	−62.7	−49.9	−138.8
Carbonyl selenide	COSe	−117.1	−95.0	−76.4	−61.7	−35.6	−21.9	—
Carbon dioxide	CO_2	−134.3s	−119.5s	−108.6s	−100.2s	−85.7s	−78.2s	−57.5
Carbon Selenosulfide	CSSe	−47.3	−16.0	+8.6	28.3	65.2	85.6	−75.2
Carbon disulfide	CS_2	−73.8	−44.7	−22.5	−5.1	+28.0	46.5	−110.8
Trichloroacetyl bromide	C_2BrCl_3O	−7.4	+29.3	57.2	79.5	120.2	143.0	—
1-Chloro-1,2,2-trifluoroethylene	C_2ClF_3	−116.0	−95.9	−79.7	−66.7	−41.7	−27.9	−157.5
1,2-Dichloro-1,2-difluoroethylene	$C_2Cl_2F_2$	−82.0	−57.3	−38.2	−23.0	+5.0	20.9	−112
1,2-Dichloro-1,1,2,2-tetrafluoroethane	$C_2Cl_2F_4$	−95.4	−72.3	−53.7	−39.1	−12.0	+3.5	−94
1,1,2-Trichloro-1,2,2-trifluoroethane	$C_2Cl_3F_3$	−68.0s	40.3s	−18.5	−1.7	+30.2	47.6	−35
Tetrachloroethylene	C_2Cl_4	−20.6s	+13.8	40.1	61.3	100.0	120.8	−19.0
1,1,2,2-Tetrachloro-1,2-difluoroethane	$C_2Cl_4F_2$	−37.5s	−5.0s	+19.8s	38.6	73.1	92.0	26.5
Hexachloroethane	C_2Cl_6	32.7s	73.5s	102.3s	124.2s	163.8s	185.6s	186.6
Tribromoacetaldehyde	C_2HBr_3O	18.5	58.0	87.8	110.2	151.6	174.0d	—
Trichloroethylene	C_2HCl_3	−43.8	−12.4	+11.9	31.4	67.0	86.7	−73
Trichloroacetaldehyde	C_2HCl_3O	−37.8	−5.0	20.2	40.2	77.5	97.7	−57
Trichloroacetic acid	$C_2HCl_3O_2$	51.0s	88.2	116.3	137.8	175.2	195.6	57
Pentachloroethane	C_2HCl_5	+1.0	39.8	69.9	93.5	137.2	160.5	−22
Acetylene	C_2H_2	−142.9s	−128.2s	−116.7s	−2107.9s	−92.0s	−84.0s	−81.5
1,1,1,2-Tetrabomoethane	$C_2H_2Br_4$	58.0	95.7	123.2	144.0	181.0	200.0d	—
1,1,2,2-Tetrabromoethane	$C_2H_2Br_4$	65.0	110.0	144.0	170.0	217.5	243.5	—
cis-1,2-Dichloroethylene	$C_2H_2Cl_2$	−58.4	−29.9	−7.9	+9.5	41.0	59.0	−80.5
trans-1,2-Dichloroethylene	$C_3H_2Cl_2$	−65.4s	−38.0	−17.0	−0.2	+30.8	47.8	−50.0
1,1-Dichloroethane	$C_2H_2Cl_2$	−77.2	−51.2	−31.1	−15.0	+14.8	31.7	−122.5
Dichloroacetic acid	$C_2H_2Cl_2O_2$	44.0	82.6	111.8	134.0	173.7	194.4	9.7
1,1,1,2-Tetrachloroethane	$C_2H_2Cl_4$	−16.3	+19.3	46.7	68.0	108.2	130.5	−68.7
1,1,2,2-Tetrachloroethane	$C_2H_2\ Cl_4$	−3.8	+33.0	60.8	83.2	124.0	145.9	−36
1-Bromoethylene	C_2H_3Br	−95.4	−68.8	−48.1	−31.9	−1.1	+15.8	−138
Bromoacetic acid	$C_2H_3BrO_2$	54.7	94.1	124.0	146.3	186.7	208.0	49.5
1,1,2-Tribromoethane	$C_2H_3Br_3$	32.6	70.6	100.0	123.5	165.4	188.4	−26
1-Chloroethylene	C_2H_3Cl	−105.6	−83.7	−66.8	−53.2	−28.0	−13.8	−153.7
Chloroacetic acid	$C_2H_3ClO_2$	43.0s	81.0	109.2	130.7	169.0	189.5	61.2
1,1,1-Trichloroethane	$C_2H_3Cl_3$	−52.0	−21.9	+1.6	20.0	54.6	74.1	−30.6
1,1,2-Trichloroethane	$C_2H_3Cl_3$	−24.0	+8.3	35.2	55.7	93.0	113.9	−36.7
Trichloroacetaldehyde hydrate	$C_2H_3Cl_3O_2$	−9.8s	+19.5s	39.7s	55.0	82.1	96.2d	51.7
1-Fluoroethylene	C_2H_3F	−149.3	−132.2	−118.0	−106.2	−84.0	−72.2	−160.5
Acetonitrile	C_2H_3N	−47.0s	−16.3	+7.7	27.0	62.5	81.8	−41
Methyl thiocyanate	C_2H_3NS	−14.0	+21.6	49.0	70.4	110.8	132.9	−51
Methyl isothiocyanate	C_2H_3NS	−34.7s	+5.4s	38.2	59.3	97.8	119.0	35.5
Ethylene	C_2H_4	−168.3	−153.2	−141.3	−131.8	−113.9	−103.7	−169
1-Bromo-1-chloroethane	C_2H_4BrCl	−36.0s	−9.4s	+10.4s	28.0	63.4	82.7	16.6
1-Bromo-2-chloroethane	C_2H_4BrCl	−28.8s	+4.1	29.7	49.5	86.0	106.7	−16.6
1,2-Dibromoethane	$C_2H_4Br_2$	−27.0s	+18.6	48.0	70.4	110.1	131.5	10
1,1-Dichloroethane	$C_2H_4Cl_2$	−60.7	−32.3	−10.2	+7.2	39.8	57.4	−96.7
1,2-Dichloroethane	$C_2H_4Cl_2$	−44.5s	−13.6	+10.0	29.4	64.0	82.4	−35.3
1,1-Difluoroethane	$C_2H_4F_2$	−112.5	−91.7	−75.8	−63.2	−39.5	−26.5	−117
Acetaldehyde	C_2H_4O	−81.5	−56.8	−37.8	−22.6	+4.9	20.2	−123.5
Ethylene oxide	C_2H_4O	−89.7	−65.7	−46.9	−32.1	−4.9	+10.7	−111.3
Acetic acid	$C_2H_4O_2$	−17.2s	+17.5	43.0	63.0	99.0	118.1	16.7
Methyl formate	$C_2H_4O_2$	−74.2	−48.6	−28.7	−12.9	16.0	32.0	−99.8
Mercaptoacetic acid	$C_2H_4O_2S$	−60.0	101.5	131.8	154.0d	—	—	−16.5
Ethyl bromide	C_2H_5Br	−74.3	−47.5	−26.7	−10.0	+21.0	38.4	−117.8
Ethyl chloride	C_2H_5Cl	−89.8	−65.8	−47.0	−32.0	−3.9	+12.3	−139
2-Chloroethanol	C_2H_5ClO	−4.0	+30.3	56.0	75.0	110.0	128.8	−69
Trichloroethylsilane	$C_2H_5Cl_3Si$	−27.9	+3.6	27.9	46.3	80.3	99.5	−40
Trichloroethyoxysilane	$C_2H_5Cl_3OSi$	−32.4	0.0	+25.3	45.2	82.2	102.4	—
Ethyl fluoride	C_2H_5F	−117.0	−97.7	−81.8	−69.3	−45.5	−32.0	—
Ethyltrifluorosilane	$C_2H_5F_3Si$	−95.4	−73.7	−56.8	−43.6	−19.1	−5.4	—
Ethyl Iodide	C_2H_5I	−54.4	−24.3	−0.9	+18.0	52.3	72.4	−105
Acetamide	C_2H_5NO	65.0s	105.0	135.8	158.0	200.0	222.0	81
Acetaldoxime	C_2H_5NO	−5.8s	+25.8	48.6	66.2	98.0	115.0	47
Nitroethane	$C_2H_5NO_2$	−21.0	+12.5	38.0	57.8	94.0	114.0	−90
Di(nitrosomethyl)amine	$C_2H_5N_3O_2$	+3.2	40.0	68.2	90.3	131.3	153.0	—
Ethane	C_2H_6	−159.5	−142.9	−129.8	−119.3	−99.7	−88.6	−183.2
Dichlorodimethylsilane	$C_2H_6Cl_2Si$	−53.5	−23.8	−0.4	+17.5	51.9	70.3	−86.0
Ethanol	C_2H_6O	−31.3	−2.3	+19.0	34.9	63.5	78.4	−112
Dimethyl ether	C_2H_6O	−115.7	−93.3	−76.2	−62.7	−37.8	−23.7	−138.5
1,2-Ethanediol	$C_2H_6O_2$	53.0	92.1	120.0	141.8	178.5	197.3	−15.6
Dimethyl sulfide	C_2H_6S	−75.6	−49.2	−28.4	−12.0	+18.7	36.0	−83.2
Ethanethiol	C_2H_6S	−76.7	−50.2	−29.8	−13.0	+17.7	35.5	−121
Dimethylantimony	C_2H_6Sb	44.0	86.0	118.3	143.5	187.2	211.0	—
Ethylamine	C_2H_7N	−82.3s	−58.3	−39.8	−25.1	+2.0	16.6	−80.6
Dimethylamine	C_2H_7N	−87.7	−64.6	−46.7	−32.6	−7.1	+7.4	−96
1,2-Ethanediamine	$C_2H_8N_2$	−11.0s	+21.5	45.8	62.5	99.0	117.2	8.5
Dimethylsilane	C_2H_8Si	−115.0	−93.1	−75.7	−61.4	−35.0	−20.1	—
Dimethyldiborane	$C_2H_{10}B_2$	−106.5	−82.1	−62.4	−47.0	−18.8	−2.6	−150.2
2-Ethyldisilazane	$C_2H_{11}NSi_2$	−62.0	−32.2	−8.3	+10.4	45.9	65.9	−127

APPENDIX 5B

THERMAL EXPANSION AND RECOVERY

URS
282 Delaware Avenue
Buffalo, New York 14202
(716) 856-5636

CALCULATION COVER SHEET

Client: NYSDEC Project Name: West Side Corporation

Project/Calculation Number: 11172744

Title: Thermal Expansion and Recovery

Total number of pages (including cover sheet): 14

Total number of computer runs: 0

Prepared by: Jon Sundquist Date: 1/10/03 – 1/12/03

Checked by: Date: 1/21/03

Description and Purpose: Evaluate the effects of thermal expansion, and mass removal as steam, have on the flow patterns of groundwater in the vicinity of treatment zone

Design bases/references/assumptions: see calculations

Remarks/conclusions: Thermal expansion would not cause a significant difference in rates of contaminated groundwater migration. While release rates may increase by 16% during heatup, release rates would be reduced (possibly capturing earlier releases) during steam generation / removal

Calculation Approved by: ________________
Project Manager/Date

Revision No.:	Description of Revision:	Approved by:

Project Manager/Date

6R

URS

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Description Thermal Expansion and recovery	Computed by Jon Sundquist	Date 1/10/03	
	Checked by	Date 1/21/03	
		Reference	

Sheet ____ of ____

Problem Statement

Estimate volume expansion from heating and impact this has compared to recovery (as steam) rate and natural plume convection

References:

(1) CRC Handbook of Chemistry and Physics
(2) Remedial Investigation, West Side Corporation, GZA, 2000
(3)

Calculation

density of water at 10°C 0.99973 gm/cm³
density of water at 100°C 0.95838 gm/cm³
} reference (1)

Thus increase in volume is 4.3%

Assume porosity of medium does not change (this assumes negligable increase in volume of sand material, which is not entirely correct)

For heating a (55 - 12) = 43 foot column of water, this would result in a 1.86 foot increase in head.

Of course, would not really see an increase in head, rather an outflow.

Outflow Calculation. Conservatively assume porosity is 0.40

$$1.86 \text{ foot} \times 60 \text{ ft} \times 60 \text{ ft} \times 0.40 = 2{,}678 \text{ ft}^3$$

$$= 20{,}000 \text{ gallons}$$

(note, reference (2) suggests porosity of 0.35, so this is a high estimate)

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Time to recover 20,000 gallon displacement as a function of steam recovery rate:

Steam recovery rate (gal condensate/min)	Time to recover 20,000 gallon (hr)
1	333
2	167
3	111
4	83
5	67
6	56
7	48
8	42
9	37
10	33

Calculation of flow velocity for inflow or outflow vs. existing natural flow velocity

Assume water flows out of "cube" at the same rate along all five of its non-vadose edges. In reality flow will be less uniform.

Total area of "cube" is

$$\underbrace{(4)(55-12)(60)}_{\text{sides}} + \underbrace{(60)}_{\text{bottom}}{}^2 = 13{,}920 \text{ ft}^3$$

For calculation basis, use a 1 gpm inflow/outflow $= 0.134 \text{ ft}^3/\text{min}$

Thus velocity is calculated as:

$$\left(v \frac{\text{ft}}{\text{day}}\right)\left(\frac{\text{day}}{1440 \text{ min}}\right)\left(\frac{13{,}920 \text{ ft}^2}{}\right)\left(0.4 \text{ porosity}\right) = \frac{0.134 \text{ ft}^3}{\text{min}}$$

So out flow velocity $\underline{v = 0.035 \text{ ft/day}}$

Compare this value to natural flow gradient of 0.24 ft/day (reference 2). This suggests that flows induced by expansion are negligable compared to "natural" plume migration

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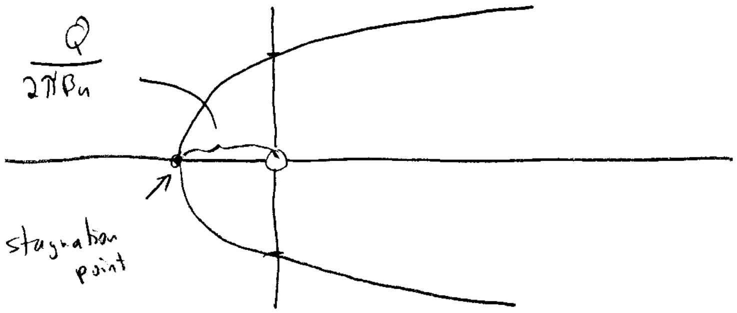
On downgradient side, flow at most would be 0.24 ft/day plus 0.035 ft/day addition. Assuming a 50% retardation, mobilized contaminant, if any, would move

$$\left(\frac{0.24\ \text{ft}}{\text{day}} + \frac{0.035\ \text{ft}}{\text{day}}\right)(50\%)(14\ \text{day}) = 1.92\ \text{feet} \approx 2\ \text{feet}$$

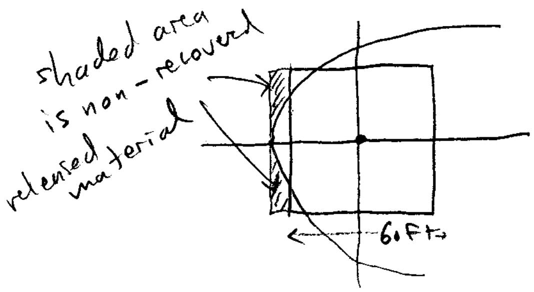
This assumes 14 days of heating before boiling

Now, once "extraction" (steam recovery starts) then we could envision it as an extraction well, at least for a first approximation



From reference (3)
Q = Extraction rate
B = thickness of aquifer
u = groundwater velocity

To capture contaminants that were released from the center of the treatment square, stagnation point must be ½ the square distance plus 2 feet as shown below:



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Performing Calculation

$$\frac{Q}{2\pi Bu} = \frac{60}{2} + 2 = 32$$

$B = 55-12$ feet for this calculation
(ignore the 55' to 65' bgs not "screened")

$u = 0.24$ ft/day

so $Q = (32 \text{ ft})(2)(\pi)(55-12 \text{ ft})(0.24 \text{ ft/day})$
$= 2{,}075 \text{ ft}^3/\text{day}$

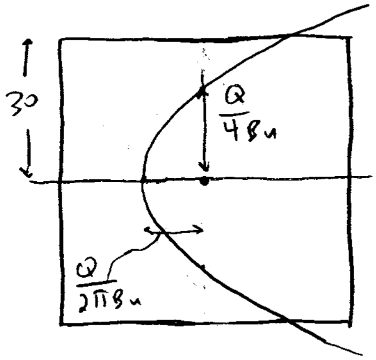
or

$$\left(\frac{2{,}075 \text{ ft}^3}{\text{day}}\right)\left(\frac{7.48 \text{ gal}}{\text{ft}^3}\right)\left(\frac{\text{day}}{24 \text{ hr}}\right)\left(\frac{\text{hr}}{60 \text{ min}}\right) = 10.8 \ \frac{\text{gal}}{\text{min}}$$

For comparison purposes:
shape of curve with 4 gpm

$$\frac{Q}{2\pi Bu} = \frac{\left(4 \frac{\text{gal}}{\text{min}}\right)\left(\frac{\text{ft}^3}{7.48 \text{ gal}}\right)\left(\frac{60 \text{ min}}{\text{hr}}\right)\left(\frac{24 \text{ hr}}{\text{day}}\right)}{(2)(\pi)(55-12 \text{ ft})(0.24 \text{ ft/day})} = 11.9 \text{ ft}$$

and $\frac{Q}{4Bu} = \left(\frac{Q}{2\pi Bu}\right)\left(\frac{\pi}{2}\right) = 18.7$ ft



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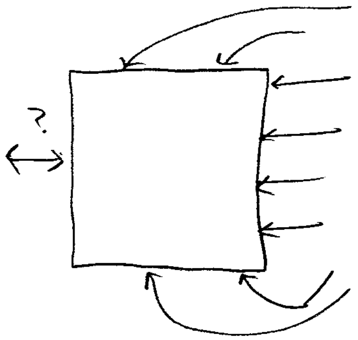
However, this is not the best way to model extraction since groundwater is being withdrawn throughout the entire square area rather than just at a point in the middle. Actual flow would look like this (plan view)



The question is, is there water exiting the downgradient side while steam is being removed?

Assumption scenario A: Under this assumed scenario the cube (or at least the five sides not facing the vadose zone) all affect the rate of water through these planes (compared to "natural" conditions) at a velocity of (0.035)(x) ft/day where (x) is the condensate/steam removal rate in gallons per minute, and 0.035 ft/day was calculated on page 2.

In this case, we would continue to see water exit the downgradient face since the "natural" velocity is only reduced from 0.24 $\frac{\text{ft}}{\text{day}}$ to ~0.205 ft/day

As a check, calculate mass balance:

influent = effluent

$$\underbrace{\left(\frac{0.035\text{ ft}}{\text{day}}\right)(60^2)}_{\text{bottom}}(0.4) + \left(\underbrace{\frac{0.24+0.035\text{ ft}}{\text{day}}\right)\left(\frac{55-12\text{ ft}}{1}\right)\left(\frac{60\text{ ft}}{1}\right)}_{\text{upgradient}}(0.4)\Big) + \underbrace{(2)\left(\frac{0.035\text{ ft}}{\text{day}}\right)\left(\frac{55-12}{1}\right)\left(\frac{60\text{ ft}}{1}\right)}_{\text{sides}}(0.4)\Big)$$

$$\overset{?}{=} \underbrace{\left(\frac{0.24-0.035\text{ ft}}{\text{day}}\right)\left(\frac{55-12\text{ ft}}{}\right)\left(\frac{60\text{ ft}}{1}\right)(0.4)}_{\text{downgradient}} + \underbrace{\left(\frac{1\text{ gal}}{\text{min}}\right)\left(\frac{\text{ft}^3}{7.48\text{ gal}}\right)\left(\frac{1440\text{ min}}{\text{day}}\right)}_{\text{steam}}$$

$$\frac{406\text{ ft}^3}{\text{day}} \approx\!\checkmark \frac{404\text{ ft}^3}{\text{day}}$$

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Reference

Assumption scenario A, cont'd....

This scenario indicates contaminated water would continue to flow from the "cube" during boiling

<u>Assumption</u> <u>Scenario</u> <u>B</u>: Under this assumed scenario, water would flow into the cube only on the up gradient side, and not from the side-gradient sides, nor from the bottom. Now calculate whether this scenario predicts inflow or out flow on down gradient side:

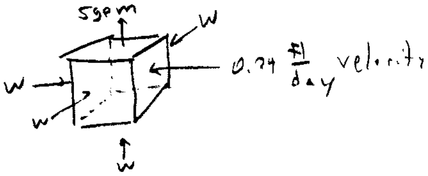
Water entering on upgradient side due solely to natural groundwater flow:

$$\left(\frac{0.24\ \text{ft}}{\text{day}}\right)\left(55.12\ \text{ft}\right)\left(60\ \text{ft}\right)(0.4)\left(\frac{7.48\ \text{gal}}{\text{ft}^3}\right)\left(\frac{\text{day}}{1440\ \text{min}}\right) = 1.29\ \frac{\text{gal}}{\text{min}}$$

Thus under this assumed scenario, with anything greater than 1.29 gal/min of steam removal (i.e. condensate removal) then there would be <u>no</u> out flow on the down gradient side.

For example, let's calculate velocity <u>in</u> on other 4 sides under a condensate rate of 4 gpm.

<u>Assume</u> flow rate uniform over all four sides (For simplicity, as before)



$$(0.4)\left[\underbrace{(3)\left(\frac{w\ \text{ft}}{\text{day}}\right)(55.12\ \text{ft})(60\ \text{ft})}_{\text{sides}} + \underbrace{\left(\frac{w\ \text{ft}}{\text{day}}\right)(60\ \text{ft})^2}_{\text{bottom}}\right]\left(\frac{7.48\ \text{gal}}{\text{ft}^3}\right)\left(\frac{\text{day}}{1440\ \text{min}}\right) + \underbrace{1.29\ \frac{\text{gal}}{\text{min}}}_{\text{upgradient}} = \underbrace{4\ \frac{\text{gal}}{\text{min}}}_{\text{steam}}$$

$w = 0.12$ ft/day

This is on same order of magnitude as natural flow velocity

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The rate of steam generation needs to also be evaluated against typical experience-based maximum energy densities that are typically observed during application of ERH. Introduction of too much energy through a network of electrodes may result in excessive steam generation immediately adjacent to the electrodes. This would result in drying of the soil in these areas, and thus reducing electrical conductivity, reducing further the ability to achieve uniform or near-uniform energy distributions

Discussions with one vendor suggested that a typical energy density for ERH is about 150 w/yd^3. For this application of 6,000 yd^3 treatment zone, this is 900 KW. Based on calculations shown in Appendix 5D, this would correspond to a steam generation rate of 3.6 to 4.8 gpm, depending on rates of conduction losses.

Discussions with a second vendor suggest that for an application such as the West Side site, condensate generation as low as 3 gpm may be reasonable while still allowing for adequate boiling

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Conclusions from this analysis

- Thermal expansion will increase the rate at which contaminated groundwater flows out of the source zone "box". Based on some simplifying assumptions (actual flow geometry would be much more complex), the increase of removal compared to actual, existing migration from source area would be about 16%.

- Assuming a condensate collection rate of the range of 1 to 10 gpm, the time required to remove the volume of water "added" by thermal expansion (an estimated 20,000 gallons) would range from 1.4 to 14 days. However, it is not clear if the recovered water would come from just upgradient and side gradient flows, or from the downgradient side as well

- Using a single well extraction point approximation (which is not the most appropriate) about 10 gpm removal would provide a capture zone that would capture most of the treatment square. However this is not the best way to model the steam removal

- Alternatively, can do a mass balance on the treatment "cube" to see what the effect of steam removal has on migration of water from the cube. Two extreme scenarios were considered - one where contributions to steam removal were equal on all sides, but natural flow was factored in on upgradient & downgradient sides. And - two, where all inflow on upgradient side was contributed to steam generation, and flows from other faces depended on rate of steam removal.

- Actual behavior of flows probably will lie in between the 2 mass balance scenario extremes. Taking into consideration the operational experience of ERH vendors and typical condensate rates achieved, apply a design condensation rate of 3 to 4 gpm.

Reference (1)

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CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data

1981—1982

62nd

EDITION

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In collaboration with a large number of professional chemists and physicists whose assistance is acknowledged in the list of general collaborators and in connection with the particular tables or sections involved.

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pf. 1, cont'd

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DENSITY OF DRY AIR

At the Temperature t, and under the Pressure H cm of Mercury the Density of Air

$$= \frac{0.001293}{1 + 0.00367\,t}\,\frac{H}{76}.$$

Units of this table are grams per milliliter
(From Miller's Laboratory Physics, Ginn & Co., publishers, by permission.)

t	Pressure H in Centimeters						Proportional Parts	
	72.0	73.0	74.0	75.0	76.0	77.0		
°								17
10	0.001182	0.001198	0.001215	0.001231	0.001247	0.001264	cm	
11	178	193	210	227	243	259	0.1	2
12	173	190	206	222	239	255	0.2	3
13	169	186	202	218	234	251	0.3	5
14	165	181	198	214	230	246	0.4	7
							0.5	8
							0.6	10
							0.7	12
15	0.001161	0.001177	0.001193	0.001210	0.001226	0.001242	0.8	14
16	157	173	189	205	221	238	0.9	15
17	153	169	185	201	217	233		16
18	149	165	181	197	213	229	cm	
19	145	161	177	193	209	225	0.1	2
							0.2	3
							0.3	5
							0.4	6
20	0.001141	0.001157	0.001173	0.001189	0.001205	0.001221	0.5	8
21	137	153	169	185	201	216	0.6	10
22	134	149	165	181	197	212	0.7	11
23	130	145	161	177	193	208	0.8	13
24	126	142	157	173	189	204	0.9	14
								15
							cm	
25	0.001122	0.001138	0.001153	0.001169	0.001185	0.001200	0.1	1
26	118	134	149	165	181	196	0.2	3
27	115	130	146	161	177	192	0.3	4
28	111	126	142	157	173	188	0.4	6
29	107	123	138	153	169	184	0.5	7
							0.6	9
							0.7	10
							0.8	12
30	0.001104	0.001119	0.001134	0.001150	0.001165	0.001180	0.9	13

Density of dry air at 20C and 760mm Hg = 1.204 mg/cm^3. (*Rev. Mod. Phys.*, 52, Part II, S33, 1980.)

DENSITY OF WATER

The temperature of maximum density for pure water, free from air = 3.98C (277.13K)

t, °C	d, gm/ml
0	0.99987
3.98	1.00000
5	0.99999
10	0.99973
15	0.99913
18	0.99862
20	0.99823
25	0.99707
30	0.99567
35	0.99406
38	0.99299
40	0.99224
45	0.99025
50	0.98807
55	0.98573
60	0.98324
65	0.98059
70	0.97781
75	0.97489
80	0.97183
85	0.96865
90	0.96534
95	0.96192
100	0.95838

THERMODYNAMIC AND TRANSPORT PROPERTIES OF AIR

From NASA Technical Note D-7488 by David J. Poferl and Roger Svehla (1973). The following three tables list the thermodynamic and transport properties of air over the temperature range of 300-2800K at pressures of 20, 30, and 40 atm. Factors for converting viscosity, specific heat at constant pressure, thermal conductivity, and enthalpy from cgs units to SI and English units are

Viscosity:

$$1\,\frac{\text{g}}{(\text{cm})(\text{sec})} = 0.1\,\frac{(\text{N})(\text{sec})}{\text{m}^2}$$

$$= 6.72\text{x}10^{-2}\,\frac{\text{lbm}}{(\text{ft})(\text{sec})}$$

$$= 241.9\,\frac{\text{lbm}}{(\text{ft})(\text{hr})}$$

$$= 2.089\text{x}10^{-3}\,\frac{(\text{lbf})(\text{sec})}{\text{ft}^2}$$

Thermal conductivity:

$$1\,\frac{\text{cal}}{(\text{cm})(\text{sec})(\text{K})} = 418.4\,\frac{\text{W}}{(\text{m})(\text{K})}$$

$$= 0.8064\,\frac{\text{Btu}}{(\text{ft})^2(\text{sec})(^\circ\text{F/in.})}$$

$$= 6.72\text{x}10^{-2}\,\frac{\text{Btu}}{(\text{ft}^2)(\text{sec})(^\circ\text{F/ft})}$$

$$= 241.9\,\frac{\text{Btu}}{(\text{ft})^2(\text{hr})(^\circ\text{F/ft})}$$

Specific heat at constant pressure:

$$1\,\frac{\text{cal}}{(\text{g})(\text{K})} = 4.184\,\frac{\text{J}}{(\text{g})(\text{K})}$$

$$= 1\,\frac{\text{Btu}}{(\text{lbm})(^\circ\text{F})}$$

Enthalpy:

$$1\,\frac{\text{cal}}{\text{g}} = 4.184\,\frac{\text{J}}{\text{g}}$$

$$= 1.8\,\frac{\text{Btu}}{\text{lbm}}$$

Reference (2)

10 of 13

SUPERFUND STANDBY PROGRAM
New York State
Department of Environmental Conservation
50 Wolf Road
Albany, New York 12233-7010

ON-SITE

REMEDIAL INVESTIGATION
WEST SIDE CORPORATION SITE
Site No. 2-41-026

Volume 1

Work Assignment Number
D003060-24

Prepared by:

TAMS Consultants, Inc.
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and

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July 2000

ref(2), cont'd

11 of 12

3.7.1 Hydraulic Conductivity and Soil Porosity

Estimated hydraulic conductivity values were calculated from field permeability test data. The hydraulic conductivities of the seven shallow wells were calculated to range from 66 to 150 feet per day (fpd) with an average of approximately 114 fpd. Five deep wells had hydraulic conductivity values that were calculated to range from 8 to 71 fpd, with an average of 39 fpd. However, two of the seven deep wells had significantly higher calculated hydraulic conductivities relative to the other wells at the Site: monitoring wells MW-3D and MW-7D had calculated hydraulic conductivities of 610 and 800 fpd, respectively. Due to the nature of this glacial outwash deposition, it is probable that areas or zones of fluctuating permeability exist throughout the Site.

The aquifer thickness is anticipated to vary at different locations of the study area; however, the thickness was measured at the deep locations drilled to average approximately 55 feet. The transmissivity of the upper glacial aquifer, considering an average depth of 55 feet, ranges from 445 to 8340 ft^2/day with an estimated average of 4615 ft^2/day.

The effective porosity for gravelly sand was estimated to be 0.35, based on published values for this type of soil (gravelly sand).

3.7.2 Groundwater Flow Patterns and Velocities

A groundwater contour map, presenting groundwater elevations (Figure 8) recorded during this study, was prepared based on the water elevations measured in the shallow groundwater monitoring wells on September 24, 1999.

The groundwater flow direction in the study area is southerly based on the groundwater contour map prepared. As discussed in Section 2.10, the groundwater flow direction may have been affected by the former JWS supply wells located adjacent to the Site during periods of operation. During times of water pumping, these wells could have skewed the groundwater in an easterly, westerly and/or northerly direction depending on which well was pumping and the amount of water pumped at a given time.

The calculated average horizontal hydraulic gradient at the Site is 0.001 based on the September 24, 1999 groundwater elevation data.

The groundwater velocity at the Site study area was calculated to range from 0.02 to 0.43 fpd, or 7.0 to 160 feet per year (fpy), with an average of 0.24 fpd or 88 fpy.

Reference (3)

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PRACTICAL DESIGN CALCULATIONS

for Groundwater and Soil Remediation

JEFF KUO, PH.D., P.E.
Civil and Environmental Engineering
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LEWIS PUBLISHERS
Boca Raton London New York Washington, D.C.

should be strategically located to create a capture zone that encloses the entire contaminant plume. If two or more wells are used, the general interest is to find the maximum distance between any two wells such that no contaminants can escape through the interval between the wells. Once such distances are determined, one can depict the capture zone of these wells from the rest of the aquifer.

To delineate the capture zone of a groundwater pumping system in an actual aquifer can be a very complicated task. To allow for a theoretical approach, let us consider a homogeneous and isotropic aquifer with a uniform thickness and assume the groundwater flow is uniform and steady. The theoretical treatment of this subject starts from one single well and expands to multiple wells. The discussions are mainly based on the work by Javandel and Tsang.[2]

One groundwater extraction well

For easier presentation, let the extraction well be located at the origin of an x-y coordinate system (Figure VI.1.A). The equation of the dividing streamlines that separate the capture zone of this well from the rest of the aquifer (sometimes referred to as the "envelope") is

$$y = \pm \frac{Q}{2Bu} - \frac{Q}{2\pi Bu} \tan^{-1} \frac{y}{x} \qquad \text{[Eq. VI.1.3]}$$

where B = aquifer thickness (ft or m), Q = groundwater extraction rate (ft^3/s or m^3/s), and u = regional groundwater velocity (ft/s or m/s) = Ki.

Figure VI.1.A illustrates the capture zone of a single pumping well. The larger the Q/Bu value is (i.e., larger groundwater extraction rate, slower groundwater velocity, or shallower aquifer thickness), the larger the capture zone. Three interesting sets of x and y values of the capture zone:

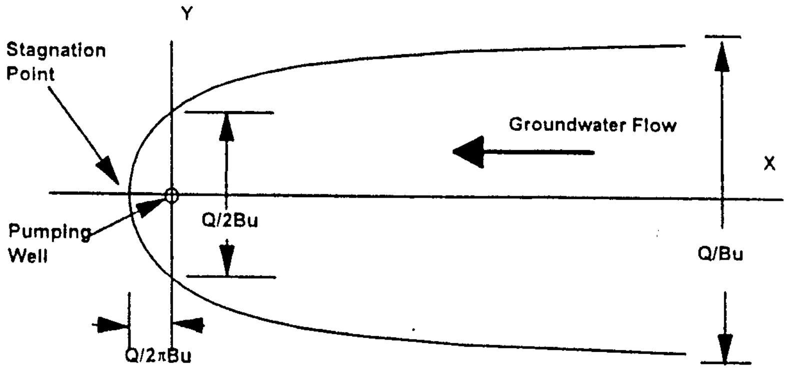

Figure VI.1.A Capture zone of a single well.

1. The stagnation point, where y is approaching zero,
2. The sidestream distance at the line of the extraction well, where 0, and
3. The asymptotic values of y, where $x = \infty$.

If these three sets of data are determined, the rough shape of the captu zone can be depicted. At the stagnation point (where y is approaching zer the distance between the stagnation point and the pumping well is equal $Q/2\pi Bu$, which represents the farthest downstream distance that the pum ing well can reach. At $x = 0$, the maximum sidestream distance from t extraction well is equal to $\pm Q/4Bu$. In other words, the distance between t dividing streamlines at the line of the well is equal to $Q/2Bu$. The asympto value of y (where $x = \infty$) is equal to $\pm Q/2Bu$. Thus, the distance between t streamlines far upstream from the pumping well is Q/Bu.

Note that the parameter in Eq. VI.1.3 (Q/Bu) has a dimension of lengt To draw the envelope of the capture zone, Eq. VI.1.3 can be rearranged a

$$x = \frac{y}{\tan\left\langle \left[+1 - \left(\frac{2Bu}{Q} \right) y \right] \pi \right\rangle} \quad \text{for positive } y \text{ values} \quad \text{[Eq. VI.1.4}$$

$$x = \frac{y}{\tan\left\langle \left[-1 - \left(\frac{2Bu}{Q} \right) y \right] \pi \right\rangle} \quad \text{for negative } y \text{ values} \quad \text{[Eq. VI.1.4}$$

A set of (x, y) values can be obtained from these equations by fir specifying a value of y. The envelope is symmetrical about the x-axis.

Example VI.1.2A *Draw the envelope of a capture zone of a groundwater pumping well*

Delineate the capture zone of a groundwater recovery well with the follo ing information:

Q = 60 gpm
Hydraulic conductivity = 2000 gpd/ft^2
Groundwater gradient = 0.01
Aquifer thickness = 50 ft

Solution:

a. Determine the groundwater velocity, u:

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APPENDIX 5C

EVALUATION OF REPORTED STEAM GENERATION RATE

URS

JOB NO.: 11172744

MADE BY: Jon Sundquist **DATE:** 1/21/03

CHECKED BY: **DATE:** 3/24/03

PROJECT: NYSDEC - West Side Corporation Site

SUBJECT: Evaluation of Reported Steam Generation Rates

Problem: Evaluate rates of steam generation (condensate collection) at two completed ERH projects where these data were reported.

References:

1. *Six-Phase Soil Heating for Enhanced Removal of Contaminants: Volatile Organic Compounds in Non-Arid Soils Integrated Demonstration, Savannah River Site,* Pacific Northwest National Laboratory, October 1997.
2. *Applications Analysis Report: Six-Phase Heating of the Saturated Zone Dover Air Force Base, Delaware,* Pacific Northwest National Laboratory, October 1994.

General Assumptions:

1. Assume rates of condensate collection can be scaled with volume of soil treated.
2. For Savannah River application, assume steam generated only during operation phase, not heat-up phase.
3. West Side treatment volume is $60 \times 60 \times 45 /(27 ft^3/yd^3) = 6,000\ yd^3$

---

1) Condensate Collection at Savannah River (Ref. 1)

Reference (1) indicates 19,000 gallons of water were collected during this remediation. Operation phase for this project was 17 days long, so average rate of collection is 1,100 gal/day or 0.8 gal/min. The volume of soil treated was 1,430 yd^3.

Scaling the rate of condensate collection to the volume of soil treated from 1,430 yd^3 to 6,000 yd^3 produces this extrapolated condensate volume:

$$\left[0.8\,\frac{gal}{\min}\right]\left[\frac{6{,}000}{1{,}430}\right]=3.4\,\frac{gal}{\min}$$

2) Condensate Collection at Dover Air Force base (Ref. 2)

Reference (2) indicates 29,000 gallons of condensate were collected in the first 21 days of operation, and 21,000 more gallons were collected in the last 9 days.

For the first 21 days:

$$\left[\frac{29{,}000\,gal}{21\,days}\right]\left[\frac{1\,day}{24\,hr}\right]\left[\frac{1\,hr}{60\min}\right]=0.96\,\frac{gal}{\min}$$

Treatment volume was 600 m^3 or 800 yd^3. Scaling up to 6,000 yd^3 treatment volume:

$$\left[0.96\,\frac{gal}{\min}\right]\left[\frac{6{,}000}{800}\right]=7.2\,\frac{gal}{\min}$$

For the last 9 days:

$$\left[\frac{21{,}000\,gal}{9\,days}\right]\left[\frac{1\,day}{24\,hr}\right]\left[\frac{1\,hr}{60\min}\right]=1.62\,\frac{gal}{\min}$$

Scaling up to 6,000 yd^3 treatment volume:

$$\left[1.62\,\frac{gal}{\min}\right]\left[\frac{6{,}000}{800}\right]=12.2\,\frac{gal}{\min}$$

MADE BY: Jon Sundquist **DATE:** 1/21/03
CHECKED BY: **DATE:** 3/24/03

PROJECT: NYSDEC - West Side Corporation Site
SUBJECT: Evaluation of Reported Steam Generation Rates

Summary:

Condensate collection rate data are not published for many of the sites where ERH has been implemented. Although these summaries represent only two sites and both were smaller than West Side Corp. site, these examples are useful for determining the range and order of magnitude of condensate collection rates that represent sufficient steam stripping rates. The rates presented by these examples range from 3.4 to 12.2 gpm, when scaled to treatment of 6,000 yd^3.

However in both these cases, the volume of treatment was much smaller than 6,000 yd^3 and the thickness of the contaminated groundwater was less. Thus, the assumption of linear scaling from these smaller, thinner applications to the larger, thicker application at West Side may result in an overestimate of comparable condensate generation. With a thicker contaminated groundwater zone, steam bubbles have a greater residence time within the groundwater, achieving a greater degree of stripping compared to thinner aquifers.

ref. (1) 4 of 10

Six-Phase Soil Heating for Enhanced Removal of Contaminants:

Volatile Organic Compounds in Non-Arid Soils Integrated Demonstration, Savannah River Site

October 1994

Prepared for the Office of Technology Development and the U.S. Department of Energy under Contract DE-AC06-76RLO 1830

rf (1)

r.f.b

Executive Summary

During November 1993, Pacific Northwest Laboratory (PNL) and Savannah River Site (SRS) personnel completed a field demonstration of six-phase soil heating (SPSH) at the Savannah River Site, Aiken, South Carolina. This demonstration was directed by the U.S. Department of Energy (DOE) Volatile Organic Compounds in Non-Arid Soils Integrated Demonstration (VOCs in Non-Arid Soils ID). Pacific Northwest Laboratory designed the SPSH systems for this demonstration, and Westinghouse Savannah River Company (WSRC) conducted drilling, soil sampling, construction, off-gas treatment, and contaminant analyses. The purpose of the project was to demonstrate a soil heating system that uses electricity to cost effectively heat soil and enhance the performance of conventional soil-venting techniques.

Soils at the integrated demonstration site are contaminated with perchloroethylene (PCE) and trichloroethylene (TCE); the highest soil contamination occurs in clay-rich zones that are ineffectively treated by conventional soil vapor extraction (SVE) because of the very low permeability of the clay. Specific objectives for the demonstration were to:

Demonstrate that SPSH accelerates the removal of TCE and PCE from the SRS clay soils compared with conventional SVE techniques

Quantify the areal and vertical distribution of heating as a result of SPSH under soil conditions experienced at the SRS

Provide a functional soil electrode and vent design for SPSH

Collect sufficient data to project the economic feasibility of commercial application of SPSH technology for soils and contaminants similar to those at the SRS

To quantify the accelerated VOC removal using SPSH, pre-and post-demonstration soil characterization and monitoring activities were conducted. Testing and monitoring support was provided by the VOCs in Non-Arid Soils ID. To record soil temperature changes, thermocouples at 30 locations were installed to quantify the areal and vertical heating within the treated zone. Soil samples were collected before and after heating to

rf (1)

quantify the efficacy of heat-enhanced vapor extraction of PCE and TCE from the clay soil. Samples were taken [essentially every one-third meter (foot)] from six wells before heating and adjacent to these wells after heating for direct comparison of soil parameters and changes.

The results of the SRS field demonstration indicate that SPSH is a technology capable of heating and remediating low-permeability soils containing volatile organic contaminants. Comparison of pre-and post-test soil samples show that contaminants removal from the clay zone was 99.7% (median) within the electrode array. Outside the array where the soil was heated, but to only 50^0C, the removal efficiency was 93%, showing that heating accelerated removal of VOCs from the clay soil. The accelerated remediation resulted from effective heating of the contaminated clay zone by SPSH.

Soil temperature profiles show that SPSH was successful in heating the targeted clay zone that contained the higher levels of soil contamination. The clay-zone temperatures increased to 100^0C after 8 days of heating and were maintained near 100^0C for 17 days. In addition, the electrical heating removed 72,000 L (19,000 gal) of water from the soil as steam, with peak removal rate of 5,700 L per day [1,500 gallons per day (gpd)] of condensed steam. Process automation allowed unattended operation following an initial start-up period.

The total energy applied to the soil during the demonstration was approximately 100,00 kWh. After the initial start-up, electrical power was applied to the heating pattern at an average rate of 200 kW. The volume of soil heated to above 70^0C is estimated to be 1100m^3, giving an energy input of 90 kWh/m^3 (70 kWh/yd^3). The average voltage (line to neutral) applied to the soil was 1000 V. The voltages began at 250 V (L-N) during start-up and increased to 2400 V (L-N) at the end of the test. Based on this demonstration experience, the SPSH energy use is estimated to be approximately $7 per cubic meter of soil at $0.07/kWh.

The success of the SPSH technology at the Savannah River Site has resulted in the planned use of SPSH at the Rocky Flats Plant and consideration by several potential commercial partners for use at private industrial sites.

ref (2)

7 of 6

APPLICATIONS ANALYSIS REPORT:

SIX-PHASE SOIL HEATING
OF THE SATURATED ZONE
DOVER AIR FORCE BASE,
DELAWARE

October 1997

Prepared by:

L.M. Peurrung and T.M. Bergsman

Pacific Northwest National Laboratory

ref(2)

EXECUTIVE SUMMARY

A. Background:

In August 1995, Armstrong Laboratory's Environics Directorate selected Six-Phase Soil Heating (SPSH) as part of their program to identify technologies for treating Dense Non-Aqueous-Phase liquids (DNAPLs) in the saturated zone. An expert panel reviewed various technologies, and SPSH was identified as a promising technology for further evaluation. Six-Phase Soil Heating uses electrical resistive heating to raise the temperature of soil and groundwater to boiling, creating an in-situ source of steam to strip contaminants. A field test was performed at the Groundwater Remediation Field Laboratory (GRFL) at Dover Air Force Base, Delaware, to determine the effectiveness of SPSH for heating the aquifer sufficiently to remove target DNAPL contaminants. This field test was conducted in an uncontaminated aquifer using tracer compounds to mimic DNAPLs commonly found at Air Force sites.

B. DESCRIPTION OF DEMONSTRATION:

A single, six-electrode array was installed into the aquifer at the GRFL site. The stratigraphy at the site consisted of sand, gravel, thin clay layers and silt to a depth of 33.5 to 34 feet below ground surface (bgs) and an underlayer of dense clay containing thin laminations of silt and fine sand. The water table was located at approximately 25 feet bgs and extended to the clay layer, forming an aquifer with a total thickness of about 5 to 7 feet in the upper high permeability region. Electrodes were installed to a depth of 35 feet bgs, and the active heated region extended from 20 feet bgs to 35 feet bgs. This design allowed heating of not only the aquifer but also approximately 5 feet of the vadose zone above the aquifer to assist in steam collection. The diameter of the electrode array was 30 feet, creating a heated zone roughly 42 feet in diameter and 15 feet thick for a total heated soil volume of about 800 yd^3 ($600m^3$). Non-hazardous organic tracers mimicking DNAPLs were added to the heated region to study their migration and to test the effectiveness of the vapor extraction system in removing DNAPL mobilized by SPSH. The vapor extraction system used for this demonstration was designed as part of the electrode array to collect both steam and mobilized contaminants from each electrode and from a central vent.

The above-surface equipment included a transformer to convert standard three-phase line power into six phases, a collection header, a vacuum blower, a condenser and knockout box, and granulated activated carbon drums to treat both the off gas and condensate. A water addition system was also installed in case additional moisture was needed to maintain conduction at the electrodes; however, this system was never needed.

C. RESULTS:

Power was applied to the array beginning on February 7, 1997. Over 12-17 days, temperature in the saturated zone rose to boiling. Heating and boiling of the aquifer continued for another 13 days while sampling for the tracers proceeded. The total duration of the heating operation was 30 days, during which 50,000 gallons of condensate were removed from the site, an amount roughly equal to all the subsurface moisture initially in that region. The energy used over 30 days was 200,000 kW-hrs. Most of the tracer removed over 21 days. The energy used up to that time was 136,000 kW-hrs, and the condensate removed was 29,000 gallons.

Tracer sampling results showed no significant migration of tracers in the groundwater, some migration of tracers in the unsaturated zone, full recovery of the perfluoromethylcyclohexane (PMCH) in the extracted off gas, and 35% recovery of the perfluorotrimethylcyclohexane (PTMCH). The fate of the remaining PTMCH is uncertain. Its appearance in the off gas may have been missed during an outage of the analytical system. Moreover, soil vapor and off-gas analyses at the end of the operation were consistent with the view that a negligible amount of the PTMCH remained in the subsurface.

D. CONCLUSIONS:

Six-Phase Soil Heating was successful in heating the aquifer to levels sufficient to remove target DNAPL contaminants. Temperatures within the heated region exceeded the target heating temperatures, and boiling occurred throughout the aquifer.

A significant portion of the injected tracers was removed during treatment, indicating that SPSH has the potential to treat DNAPL. The apparent lower recovery of PTMCH may be due to loss of data between sampling events.

Soil vapor samples suggest that the tracer compounds migrated outward through the vadose zone when steam was first generated, indicating incomplete control of vapor by the off-gas collection system. However, the high recovery of PMCH (the tracer placed at the edge of heating) indicates that an increase in the vacuum applied to the soil during the operation enabled overall high capture efficiency for the system.

Groundwater samples showed no measurable tracer at any time during the demonstration.

rf (2)

Energy requirements for SPSH treatment of an aquifer were roughly as predicted. At 20 percent of the total cost, energy costs are an important part, but not a majority of the overall treatment cost. For the 30-day test, 200,000 kW-hrs were used and 50,000 gallons of condensate were collected. Most of the tracer was removed during the first 21 days of heating. During that period, 136,000 kW-hrs were used and 29,000 gallons of condensate were collected. At $0.07 per kW-hr, this represents an energy cost $9,500 or approximately $16 per cubic meter heated.

E. RECOMMENDATIONS:

Six-Phase Soil Heating is applicable for full-scale deployment at a DNAPL site. The GRFL demonstration was successful at showing that the technology can be used to heat a flowing aquifer to temperatures sufficient to remove targeted DNAPL compounds. The technology has also been deployed, full-scale, at a saturated, tight-soil DNAPL site in Chicago where it was successful in removing over 12,000 pounds of perchloroethylene contaminants in six months. The success of the GRFL demonstration and the Chicago deployment support moving forward with a full-scale demonstration or deployment of this technology.

The six-phase transformer, vacuum blower, and condenser operated well; however, the condensate collection system had numerous problems. The condensate collection system should be modified for future demonstrations. This will also allow continuous operation of the vapor collection system at higher vacuums, improving vapor collections.

APPENDIX 5D

ENERGY BALANCE

URS
282 Delaware Avenue
Buffalo, New York 14202
(716) 856-5636

CALCULATION COVER SHEET

Client: NYSDEC Project Name: West Side Corporation

Project/Calculation Number: 11172744

Title: Energy Balance

Total number of pages (including cover sheet): 31

Total number of computer runs: 0

Prepared by: Jon Sundquist Date: 1/10/03 - 1/15/03

Checked by: Date: 1/21/03

Description and Purpose: Estimate:

- Amount of Energy needed to raise temperature of treatment area to boiling
- Amount of Energy needed to provide nominal level of volatilization/steam stripping
- Amount of Energy lost through conduction/convection losses

The last two items added together are used to estimate a minimum power input

Design bases/references/assumptions: See calculations

Remarks/conclusions:

- A total of $\sim 1.6 \times 10^9$ BTU are needed to heat treatment zone to boiling, exclusive of conduction losses
- 800 KW of power needs to be added to maintain boiling, including consideration of conduction/convection losses

Calculation Approved by:
Project Manager/Date

Revision No.: Description of Revision: Approved by:

Project Manager/Date

URSF-124/1 OF 1/CCS/gcm

URS

Page 1 of 30

Job West Side Corporation

Project No. 1172744

Sheet ___ of ___

Description Energy Balance

Computed by Jon Sundquist

Date 1/10/02

Checked by

Date 1/21/03

Reference

Problem Statement

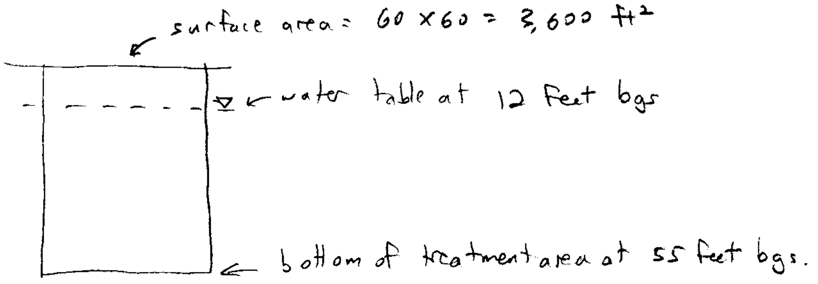
Estimate :

- Amount of energy needed to raise temperature of treatment area to boiling
- Amount of energy needed to provide nominal level of volatilization / steam stripping
- Amount of energy lost through conductive / convective heat losses

References – at end

Calculation

Basis:



First, look at most conservative (least energy) requirement of heating only from water table to 55 feet bgs

Volume of area to be heated = 60 x 60 x (55 - 12) = 154,800 ft^3

Specific gravity of soils from saturated zone, based on samples taken during chemical oxidation testing (reference 1) ≈ 2.7 g/cm^3

Also from reference (1), water content of saturated samples (average) =

$$\frac{20.7 + 22.4 + 25.4}{3} = 22.8\ \%$$

$$\text{So Mass of water} = \left(154{,}800\ \text{ft}^3\right)\left(\frac{2.7\ \text{g}}{\text{cm}^3}\right)\left(\frac{30.48\ \text{cm}}{\text{ft}}\right)^3\left(\frac{\text{kg}}{1000\ \text{g}}\right)\left(0.228\right) = 2.70 \times 10^6\ \text{kg}$$

$$\text{Mass of Soil} = \left(\frac{1 - 0.228}{0.228}\right)\left(2.7 \times 10^6\right) = 9.15 \times 10^6\ \text{kg}$$

Specific heat of sand: Approximately 800 Joules/kg-k
per reference (2) and (3)

Assume initial temperature of subsurface of 10°C

therefore energy required to heat saturated cube (only), sand (only) to 100C is

$$\left(9.15 \times 10^{6} \text{ kg}\right)\left(\frac{800 \text{ Joules}}{\text{kg-K}}\right)\left(90 \text{ K}\right) = 6.59 \times 10^{11} \text{ Joule}$$

Energy required to heat the water →

specific heat averages around 4200 J/kg-k (reference 2)

$$\left(2.70 \times 10^{6} \text{ kg}\right)\left(\frac{4200 \text{ Joule}}{\text{kg-K}}\right)\left(90 \text{ K}\right) = 1.02 \times 10^{12} \text{ Joule}$$

Total Energy needed = 1.68×10^{12} Joule = $\underline{\underline{1.59 \times 10^{9} \text{ BTU}}}$

Energy to provide volatilization

As a basis, consider a water removal rate of 3.5 gallons per minute

Required heat is (1) heat required to volatilize 3.5 gpm
plus (2) heat required to heat up water that flows back to treatment zone to replace it.

So essentially total heat is heat needed to bring from 10°C to 100° vapor.

Heat of vaporization of water: 970 Btu/lb (reference 4)

or 2,255 KJ/kg

URS

Page 3 of 30
Job West Side Corporation
Project No. 11172744
Sheet ___ of ___
Description Energy Balance
Computed by Jon Sundquist
Date 1/10/03
Checked by
Date 1/21/03
Reference

So, for a nominal 3.5 gal/min, heat required to vaporize is

$$\left(\frac{3.5\text{ gal}}{\text{min}}\right)\left(\frac{3.785\text{ L}}{\text{gal}}\right)\left(\frac{1\text{ kg}}{\text{L}}\right)\left(2{,}255\,\frac{\text{kJ}}{\text{kg}} + \frac{4.2\text{ kJ}}{\text{kg-K}}\times 90\text{ K}\right)$$

$$= 34{,}900\ \text{kJ/min}$$

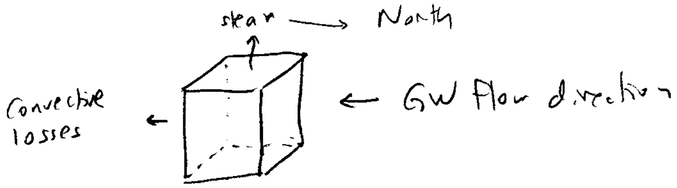
$$= 2.1\times 10^{6}\ \text{kJ/hr}$$

$$= 2.0\times 10^{6}\ \text{Btu/hr}$$

$$= 580\ \underline{\text{KW}}$$

Convective losses.

Will estimate convective losses this way:



Will simplify mass/energy balance by assuming water enters from upgradient side (north), and exits either as steam or as heated liquid on downgradient side

Previously, we have estimated the amount of energy lost as steam. Now calculate amount of energy lost in exiting hot water

Darcy velocity of groundwater from reference (5) is ~ 0.24 ft/day so water entering cube is

$$\underbrace{\left(\frac{0.24\text{ ft}}{\text{day}}\right)}_{\text{velocity}}\underbrace{\left(55-12\text{ ft}\right)\left(60\text{ ft}\right)}_{\text{area of north side}}\underbrace{\left(0.4\right)}_{\text{porosity (assumed)}} = 248\ \frac{\text{ft}^3}{\text{day}}$$

URS

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Job West Side Corporation

Project No. 11172744

Sheet ____ of ____

Description Energy Balance

Computed by Jon Sundquist

Date 1/12/03

Checked by

Date 1/21/03

Reference

Now <u>assume</u> a 5 gpm water removal as steam

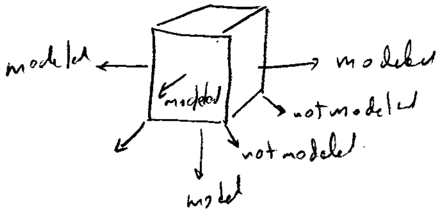
$$\left(\frac{5\text{ gal}}{\text{min}}\right)\left(\frac{\text{ft}^3}{7.48\text{ gal}}\right)\left(\frac{60\text{ min}}{\text{hr}}\right)\left(\frac{24\text{ hr}}{\text{day}}\right) = 963\ \frac{\text{ft}^3}{\text{day}}$$

This suggests there are no convective losses, since the steam removal rate is greater than influent rate. Because inflow from the sides and bottom may more than make up the 963-248 difference, there may still be some convective loss on the downgradient edge of the "cube", but it would be minimal.

Energy lost by Conduction

Conduction loss is a time-dependent three-dimensional problem. Will approach it with the following <u>assumptions</u>

a) Will model heat loss only orthogonal to each of the five faces that touch water. The vadose zone is assumed to be at the same temperature as the "cube" and thus will not conduct heat. Heat loss in the "diagonal directions" from the cube is not modeled (this thus underestimates heat rate loss



b) Since convective heat loss is not significant, heat loss would be modeled as conduction into a semi infinite slab.

cont'd....

URS

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Job West Side Corporation

Project No. 1117 2744

Sheet ___ of ___

Description Energy Balance

Computed by Jon Sundquist

Date 1/14/03

Checked by

Date 1/21/03

Reference

c) Conduction losses occur in two phases → first during heatup when the temperature along the faces of the "cube" vary and increase from ~10°C to ~100°C, and second when boiling occurs where temperatures along the faces of the cube are fixed at ~106°C (actually vary with depth, at bottom, can use 125°C). The first phase is more difficult to model. Rather than model this, we will calculate the heat loss rate assuming the temperature of the cube is suddenly/instaneously brought to 106° (or 125°C for bottom). However, the very high heat fluxes during the first week of this situation will not be considered when identifying "2nd phase" conduction heat loss rates.

Calculation

From reference (6), the heat flux for conduction into a semi-infinite slab is given by

$$q = \frac{k}{\sqrt{\pi \alpha t}} (T_1 - T_0)$$

where q = heat flux

k = thermal conductivity of saturated soil

α = thermal diffusivity = $\frac{k}{\rho C_p}$

ρ = density of saturated soil

C_p = specific heat of saturated soil

t = time

T_1 = Temperature of cube face (106° for sides, 125° for bottom)

T_0 = ambient water temperature far from cube. (assume 10°C)

(note, temperature along sides varies from 88° to 125° with depth, thus average temp of 106 selected.

Of these parameters, values were already identified for all in preceding calculations except for thermal conductivity of soil

Although several correlations exist for estimating thermal conductivity of soil, these correlations typically require more data about the composition of the soil than is available. Thermal conductivity of soil is strongly influenced by the moisture content. Soils in this application are saturated so thermal conductivity is higher. According to reference (7) k can vary from 0.3 to 3.0 w/m-k depending on soil moisture. Based on a review of data presented in references (8) and (9), a k value of 1.5 w/m-k is selected.

To perform this calculation, we first calculate α, the thermal diffusivity

$$\alpha = \frac{k}{\rho C_p} = \left[\frac{1.5 \frac{w}{m\text{-}K}}{(2.7\ g/cm^3)(800\ \frac{Joule}{Kg\cdot K})}\right]\left[\frac{Joule}{w\text{-}sec}\right]\left[\frac{m}{100\ cm}\right]^3\left[\frac{1000\ g}{kg}\right] = 6.94 \times 10^{-7}\ \frac{m^2}{sec}$$

Now we can calculate q, which is a function of time t (in seconds):

$$q = \frac{k}{\sqrt{\pi \alpha t}}(T_1 - T_0)$$

For heat transfer from the sides, we will assume an average Temperature of 106°C

$$q_{(sides)} = \frac{1.5\ \frac{W}{m\text{-}K}}{\sqrt{(\pi)(6.94 \times 10^{-7} \frac{m^2}{sec})(t)}}(106-10\text{K}) = 97{,}500 \times t^{-1/2}\ \frac{W}{m^2}$$

t is time in seconds.

For heat transfer from bottom, T = 125°C

$$q_{(bottom)} = \frac{1.5}{\sqrt{(\pi)(6.94 \times 10^{-7})t}}(125-10) = 116{,}830 \times t^{-1/2}\ \frac{W}{m^2}$$

URS

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Job West Side Corporation

Project No. 1117274 4

Sheet ____ of ____

Description Energy Balance

Computed by Jon Sundquist

Date 1/15/03

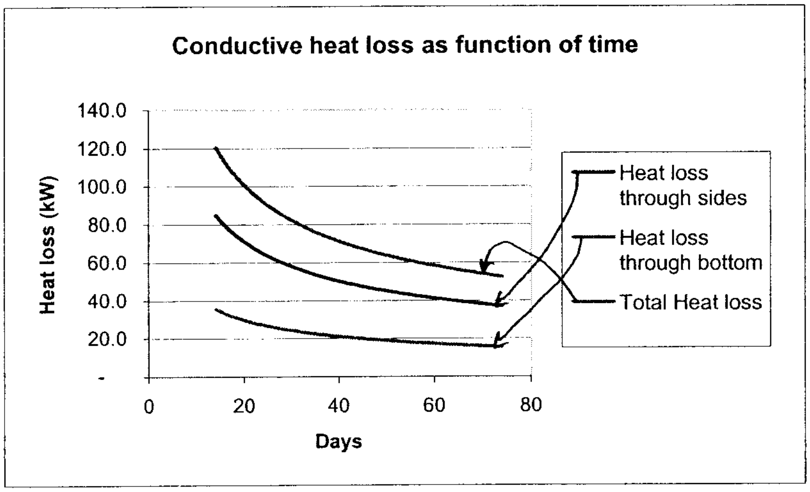
Checked by

Date 1/21/03

Reference

To (under) estimate total heat flux from the "cube", we apply the side heat fluxes to the four sides of the "cube" and the bottom flux to the bottom side of the "cube". This is a function of time as shown on following graph:-

k:	(W/m-K)	1.5	
rho:	(g/cm³)	2.7	
Cp:	(J/kg-K)	800	
alpha:	(m²/sec)	6.944E-07	
T-side:	(C)	106	
T-bottom:	(C)	125	
T-distance:	(C)	10	
q (sides):	(W/m²)	97,492	/ SQRT(t)
q (bottom):	(W/m²)	116,787	/ SQRT(t)
t:	(day)	14	
t:	(sec)	1209600	
each side	(m²)	240	
bottom	(m²)	334	
Loss through sides:	kW	85.0	
Loss through bottom:	kW	35.5	
Total losses:		120.5	



It is important to revisit some of the simplifying assumptions that go into this calculation

- This does not model early stages of heat up, In the early stages, Temperature is rising slowly. This model, if extended towards time zero, shows infinite heat flux at first with the "cube" being instantly raised to target temperatures. The unsteady state heat up period was not modeled here. Going with this simplification will <u>underestimate</u> the heat flux later in the process because it assumes more heat had been transferred to the area surrounding the cube than actually will have been transferred. With more heat there, temperature gradients would be less, and thus heat fluxes (losses) are underestimated by this approach

- This looks at heat losses in the direction of the cube corners. Heat will not exit through these points, but rather be conducted from the "semi infinite slabs" opposite each side. Since heat would have to flow from these "slabs" to the "point areas, heat in the "slabs" would be reduced, thus their temperature would be reduced, and thus temperature gradients would be higher. Thus heat fluxes are again <u>underestimated</u>

Since the simplifying assumptions tend to underestimate heat flux, we need to add a significant safety factor to setting the minimum amount of energy that needs to be added to counteract heat losses.

We will choose a design heat conduction loss of 200-250 KW total. This represents approximately 2X to 3X the theoretical requirements, although these requirements decrease as time increases. However, for contracting purposes, the energy requirement will remain the same. The net effect of this is increased removal efficiency as time goes on, which is beneficial because concentrations will decrease with time and added energy would be useful for removing these residual contaminants

Summary / Conclusions

Energy requirements for heat up (not used for a basis of contract): ~10^9 BTU ≈ 320,000 KWhr

Energy rate required for boiling 3.5 gpm of groundwater:	580 KW
Energy rate for replacing convective losses:	~ 0
Energy rate for replacing conductive losses:	~225 KW
Total energy requirements	~805 KW
	say 800 KW

Reference:

(1) Data report for samples collected for chemical oxidation testing, Fall, 2001
(2) hypertextbook.com
(3) Laboratory data summary
(4) Steam Tables, from CRC Handbook of Chemistry & Physics 62nd edition, CRC Press
(5) GZA, 2000 "Remedial Investigation, West Side Corporation Site"
(6) Bird, Stewart, and Lightfoot (1960) "Transport Phenomena"
(7) Hans Dresler, 2000 "District Heating, an Objective Choice" Bois/Holz Energy
(8) Oliver Fuhrer, 2000 "Inverse heat Conduction in Soils", Diploma Thesis, ETH Zürich, Dept. Physics
(9) "Engineering Properties of Materials"

Reference (1)

Copies: 9 of 30
~~3587~~ (AD-1)
Sandquist

GEOTECHNICAL LABORATORY TESTING DATA SUMMARY

PROJECT NAME: WESTSIDE CORPORATION
LOCATION: JAMAICA, NEW YORK
PROJECT NO. 55529.10

CLIENT: URS CORPORATION

MATERIAL SOURCE: TEST BORINGS (BUCKET)
DATE REPORTED: OCTOBER 12, 2001

WORK ORDER NO. 4126

IDENTIFICATION			WATER CONTENT	ATTERBERG LIMITS			SPECIFIC GRAVITY	GRAIN SIZE ANALYSIS		MOISTURE-DENSITY RELATIONSHIP (LOOSE/DENSE STATE)		PERMEABILITY TEST					LABORATORY LOG AND SOIL DESCRIPTION
SAMPLE TYPE	SAMPLE NUMBER	DEPTH ft.	%	LL %	PL %	PI	G_s	SIEVE -200 %	HYD. -2μ %	DRY DENSITY pcf	WATER CONTENT %	PERME-ABILITY cm/sec.	TYPE OF TEST	$\bar{\sigma}_c$ psf	DRY UNIT WT pcf	WATER CONTENT %	
BULK	MW-9S	-	4.4				2.72			113.4 119.0	0.6 4.2						
BULK	MW-9D	~2.0	8.4				2.68			113.7 128.0	2.9 8.3						
BULK	MW-9D	~11.0	4.7				2.69			117.0 125.9	4.7 10.6						
BULK	MW-9D	~15.0	4.8				2.70			112.6 117.5	0.6 4.9						
BULK	MW-9D	~20.0	20.7				2.70			118.1 119.4	0.4 8.3						
BULK	MW-9D	~40.0	22.4				2.69			114.5 117.0	0.3 8.5						
BULK	MW-9D	~55.0	25.4				2.68			109.9 114.8	1.0 13.7						
BULK	MW-88S	~3.5	8.8				2.71			117.1 120.0	8.0 14.2						
BULK	MW-88S	~8.0	7.9				2.67			112.6 118.8	1.2 9.2						
BULK	MW-88S	~13.0	6.1				2.69			112.2 117.8	0.7 6.8						
BULK	MW-88S	~18.0	8.0				2.70			112.9 117.9	0.7 10.9						

GZA GeoEnvironmental of New York
Engineers and Scientists

Reference (2)

Sensible Heat

The Physics Hypertextbook™

prev | up | next

Discussion

introduction

Heat that results in a temperature change is said to be "sensible" (although this term is falling out of favor).

1781 Wilcke comes up with the concept of specific heats.

1819 Objects have a heat capacity, while materials have a specific heat capacity (often just called specific heat) was first defined by Pierre-Louis Dulong and Alexis-Thérèse Petit, France, 1819.

- The specific heat of a material is the amount of heat required to change a unit mass of a substance by one unit of temperature.

continue

Specific heat capacity at constant pressure for selected materials
(~300 K and ~100 kPa except where otherwise indicated).

material	c_p (J/kg·K)	material	c_p (J/kg·K)
air, 0200 K	1650	mica	880
air, 0300 K	1158	neon	1030
air, 0500 K	1073	nickel	444
air, 1000 K	1151	nitrogen (N_2)	1040
alcohol, methyl (wood)	2530	oil, olive	1790
alcohol, ethyl (grain)	2440	oxygen (O_2)	918
aluminum	897	perlite	387
ammonia, liquid	4700	platinum	133
ammonia, gas	2060	plutonium	140
argon	520	porcelain	1085
asphalt	920	salt	880
bone	440	sand	835
brass	375	scandium	568
brick	840	silicon	705
concrete	880	silver	235
carbon, diamond	516	soil, dry	800
carbon, graphite	717	soil, wet	1480
copper	385	snow	2090

ref(2), cont'd

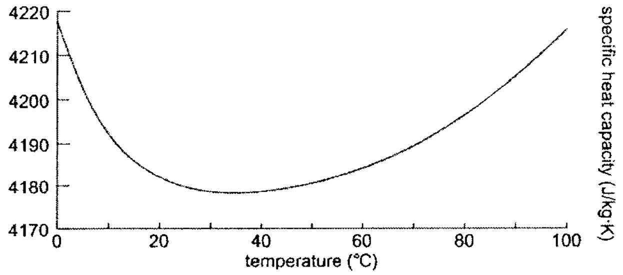
freon 12, liquid	????	teflon	1172
freon 12, vapor	600	tin	228
glass, crown	670	titanium	523
glass, flint	503	tungsten	132
glass, pyrex	753	uranium	116
gold	129	water, ice, -5 °C	2090
granite	790	water, liquid, 000 °C	4217.6
gypsum	1090	water, liquid, 020 °C	4181.8
hydrogen (H_2)	14,304	water, liquid, 040 °C	4178.5
helium	5193	water, liquid, 080 °C	4196.3
iron	449	water, liquid, 100 °C	4215.9
lead	129	water, vapor, 000 °C	3909.2
lithium	3582	water, vapor, 027°C	3984.6
lucite	1460	water, vapor, 100 °C	4039.2
marble	880	wood	1700
mercury	140	zinc	388

water has an unusually high specific heat, the only natural substance with a higher specific heat is liquid ammonia

- our bodies can lose or absorb significant amounts of heat without becoming dangerously hot or cold
- large bodies of water moderate climate

calories

A calorie is the energy needed to raise the temperature of one gram of water by one celsius degree. This turns out to be a terrible definition as the heat required to raise the temperature of any substance varies with temperature itself.



The specific heat of liquid water varies with temperature. (See water.txt for the numerical values.)

Thus, there are at least five different units that are called calories. Three of them are now defined in terms of the SI unit of energy, the joule.

There is more than one kind of calorie.

type of calorie	joule equivalent	SI status
thermochemical	4.18400	defined
International Table	4.18680	defined
at 15 °C	4.18550	defined
at 20 °C	4.18180	approximate
mean	4.19092	approximate

Reference (3)

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Module 3 Lab Data
14-Oct-02

Group	Specific heat of Sand (J/g C)	Enthalpy of reaction (KJ/mol) A	B	C
Theoretical	0.795	-43.991	-99.851	-55.86
Josh/David/Aaron	0.7236	-34.6003	-76.88	-50.208
Ali/Michelle/Jasmine		-45.38	-104.58	-50.208
Josh/Colin	0.8081	-44.2624	-64.982	
Zeke/David	0.72	-55.1	-100.4	-56.9
Andrea/Jen	0.7451	-35.92	-100.46	-60.249

*The data from the Monday lab is on a computer that is no longer in the lab. Sorry.

Reference (4)

13 of 30 4

CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data

HANDBOOK OF CHEMISTRY AND PHYSICS
1981—1982
62nd
EDITION
CRC PRESS, INC.

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In collaboration with a large number of professional chemists and physicists whose assistance is acknowledged in the list of general collaborators and in connection with the particular tables or sections involved.

CRC Press, Inc.
Boca Raton, Florida

mf(4), cont'd

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STEAM TABLES (Continued)

Properties of Saturated Steam and Saturated Water

Temp. F	Press. psia	Volume, ft³/lbm Water v_f	Volume, ft³/lbm Evap. v_{fg}	Volume, ft³/lbm Steam v_g	Enthalpy, Btu/lbm Water h_f	Enthalpy, Btu/lbm Evap. h_{fg}	Enthalpy, Btu/lbm Steam h_g	Entropy, Btu/lbm × F Water s_f	Entropy, Btu/lbm × F Evap. s_{fg}	Entropy, Btu/lbm × F Steam s_g	Temp. F
280.0	49.200	0.017264	8.627	8.644	249.17	924.6	1173.8	0.4098	1.2501	1.6599	280.0
278.0	47.653	0.017246	8.890	8.907	247.13	926.0	1173.2	0.4071	1.2554	1.6625	278.0
276.0	46.147	0.017228	9.162	9.180	245.08	927.5	1172.5	0.4043	1.2607	1.6650	276.0
274.0	44.678	0.017210	9.445	9.462	243.03	928.9	1171.9	0.4015	1.2661	1.6676	274.0
272.0	43.249	0.017193	9.738	9.755	240.99	930.3	1171.3	0.3987	1.2715	1.6702	272.0
270.0	41.856	0.017175	10.042	10.060	238.95	931.7	1170.6	0.3960	1.2769	1.6729	270.0
268.0	40.500	0.017157	10.358	10.375	236.91	933.1	1170.0	0.3932	1.2823	1.6755	268.0
266.0	39.179	0.017140	10.685	10.703	234.87	934.5	1169.3	0.3904	1.2878	1.6781	266.0
264.0	37.894	0.017123	11.025	11.042	232.83	935.9	1168.7	0.3876	1.2933	1.6808	264.0
262.0	36.644	0.017106	11.378	11.395	230.79	937.3	1168.0	0.3847	1.2988	1.6835	262.0
260.0	35.427	0.017089	11.745	11.762	228.76	938.6	1167.4	0.3819	1.3043	1.6862	260.0
258.0	34.243	0.017072	12.125	12.142	226.72	940.0	1166.7	0.3791	1.3098	1.6889	258.0
256.0	33.091	0.017055	12.520	12.538	224.69	941.4	1166.1	0.3763	1.3154	1.6917	256.0
254.0	31.972	0.017039	12.931	12.948	222.65	942.7	1165.4	0.3734	1.3210	1.6944	254.0
252.0	30.883	0.017022	13.358	13.375	220.62	944.1	1164.7	0.3706	1.3266	1.6972	252.0
250.0	29.825	0.017006	13.802	13.819	218.59	945.4	1164.0	0.3677	1.3323	1.7000	250.0
248.0	28.796	0.016990	14.264	14.281	216.56	946.8	1163.4	0.3649	1.3379	1.7028	248.0
246.0	27.797	0.016974	14.744	14.761	214.53	948.1	1162.7	0.3620	1.3436	1.7056	246.0
244.0	26.826	0.016958	15.243	15.260	212.50	949.5	1162.0	0.3591	1.3494	1.7085	244.0
242.0	25.883	0.016942	15.763	15.780	210.48	950.8	1161.3	0.3562	1.3551	1.7113	242.0
240.0	24.968	0.016926	16.304	16.321	208.45	952.1	1160.6	0.3533	1.3609	1.7142	240.0
238.0	24.079	0.016910	16.867	16.884	206.42	953.5	1159.9	0.3505	1.3667	1.7171	238.0
236.0	23.216	0.016895	17.454	17.471	204.40	954.8	1159.2	0.3476	1.3725	1.7201	236.0
234.0	22.379	0.016880	18.065	18.082	202.38	956.1	1158.5	0.3446	1.3784	1.7230	234.0
232.0	21.567	0.016864	18.701	18.718	200.35	957.4	1157.8	0.3417	1.3842	1.7260	232.0
230.0	20.779	0.016849	19.364	19.381	198.33	958.7	1157.1	0.3388	1.3902	1.7290	230.0
229.0	20.394	0.016842	19.707	19.723	197.32	959.4	1156.7	0.3373	1.3931	1.7305	229.0
228.0	20.015	0.016834	20.056	20.073	196.31	960.0	1156.3	0.3359	1.3961	1.7320	228.0
227.0	19.642	0.016827	20.413	20.429	195.30	960.7	1156.0	0.3344	1.3991	1.7335	227.0
226.0	19.274	0.016819	20.777	20.794	194.29	961.3	1155.6	0.3329	1.4021	1.7350	226.0
225.0	18.912	0.016812	21.149	21.166	193.28	962.0	1155.3	0.3315	1.4051	1.7365	225.0
224.0	18.556	0.016805	21.529	21.545	192.27	962.6	1154.9	0.3300	1.4081	1.7380	224.0
223.0	18.206	0.016797	21.917	21.933	191.26	963.3	1154.5	0.3285	1.4111	1.7396	223.0
222.0	17.860	0.016790	22.313	22.330	190.25	963.9	1154.2	0.3270	1.4141	1.7411	222.0
221.0	17.521	0.016783	22.718	22.735	189.24	964.6	1153.8	0.3255	1.4171	1.7427	221.0
220.0	17.186	0.016775	23.131	23.148	188.23	965.2	1153.4	0.3241	1.4201	1.7442	220.0
219.0	16.857	0.016768	23.554	23.571	187.22	965.8	1153.1	0.3226	1.4232	1.7458	219.0
218.0	16.533	0.016761	23.986	24.002	186.21	966.5	1152.7	0.3211	1.4262	1.7473	218.0
217.0	16.214	0.016754	24.427	24.444	185.21	967.1	1152.3	0.3196	1.4293	1.7489	217.0
216.0	15.901	0.016747	24.878	24.894	184.20	967.8	1152.0	0.3181	1.4323	1.7505	216.0
215.0	15.592	0.016740	25.338	25.355	183.19	968.4	1151.6	0.3166	1.4354	1.7520	215.0
214.0	15.289	0.016733	25.809	25.826	182.18	969.0	1151.2	0.3151	1.4385	1.7536	214.0
213.0	14.990	0.016726	26.290	26.307	181.17	969.7	1150.8	0.3136	1.4416	1.7552	213.0
212.0	14.696	0.016719	26.782	26.799	180.17	970.3	1150.5	0.3121	1.4447	1.7568	212.0
211.0	14.407	0.016712	27.285	27.302	179.16	970.9	1150.1	0.3106	1.4478	1.7584	211.0
210.0	14.123	0.016705	27.799	27.816	178.15	971.6	1149.7	0.3091	1.4509	1.7600	210.0
209.0	13.843	0.016698	28.324	28.341	177.14	972.2	1149.4	0.3076	1.4540	1.7616	209.0
208.0	13.568	0.016691	28.862	28.878	176.14	972.8	1149.0	0.3061	1.4571	1.7632	208.0
207.0	13.297	0.016684	29.411	29.428	175.13	973.5	1148.6	0.3046	1.4602	1.7649	207.0
206.0	13.031	0.016677	29.973	29.989	174.12	974.1	1148.2	0.3031	1.4634	1.7665	206.0
205.0	12.770	0.016670	30.547	30.564	173.12	974.7	1147.9	0.3016	1.4665	1.7681	205.0
204.0	12.512	0.016664	31.135	31.151	172.11	975.4	1147.5	0.3001	1.4697	1.7698	204.0
203.0	12.259	0.016657	31.736	31.752	171.10	976.0	1147.1	0.2986	1.4728	1.7714	203.0
202.0	12.011	0.016650	32.350	32.367	170.10	976.6	1146.7	0.2971	1.4760	1.7731	202.0
201.0	11.766	0.016643	32.979	32.996	169.09	977.2	1146.3	0.2955	1.4792	1.7747	201.0
200.0	11.526	0.016637	33.622	33.639	168.09	977.9	1146.0	0.2940	1.4824	1.7764	200.0
199.0	11.290	0.016630	34.280	34.297	167.08	978.5	1145.6	0.2925	1.4856	1.7781	199.0
198.0	11.058	0.016624	34.954	34.970	166.08	979.1	1145.2	0.2910	1.4888	1.7798	198.0
197.0	10.830	0.016617	35.643	35.659	165.07	979.7	1144.8	0.2894	1.4920	1.7814	197.0
196.0	10.605	0.016611	36.348	36.364	164.06	980.4	1144.4	0.2879	1.4952	1.7831	196.0
195.0	10.385	0.016604	37.069	37.086	163.06	981.0	1144.0	0.2864	1.4985	1.7848	195.0
194.0	10.168	0.016598	37.808	37.824	162.05	981.6	1143.7	0.2848	1.5017	1.7865	194.0
193.0	9.956	0.016591	38.564	38.580	161.05	982.2	1143.3	0.2833	1.5050	1.7882	193.0
192.0	9.747	0.016585	39.337	39.354	160.05	982.8	1142.9	0.2818	1.5082	1.7900	192.0
191.0	9.541	0.016578	40.130	40.146	159.04	983.5	1142.5	0.2802	1.5115	1.7917	191.0
190.0	9.340	0.016572	40.941	40.957	158.04	984.1	1142.1	0.2787	1.5148	1.7934	190.0
189.0	9.141	0.016566	41.771	41.787	157.03	984.7	1141.7	0.2771	1.5180	1.7952	189.0
188.0	8.947	0.016559	42.621	42.638	156.03	985.3	1141.3	0.2756	1.5213	1.7969	188.0
187.0	8.756	0.016553	43.492	43.508	155.02	985.9	1140.9	0.2740	1.5246	1.7987	187.0
186.0	8.568	0.016547	44.383	44.400	154.02	986.5	1140.5	0.2725	1.5279	1.8004	186.0
185.0	8.384	0.016541	45.297	45.313	153.02	987.1	1140.2	0.2709	1.5313	1.8022	185.0
184.0	8.203	0.016534	46.232	46.249	152.01	987.8	1139.8	0.2694	1.5346	1.8040	184.0
183.0	8.025	0.016528	47.190	47.207	151.01	988.4	1139.4	0.2678	1.5379	1.8057	183.0
182.0	7.850	0.016522	48.172	48.189	150.01	989.0	1139.0	0.2662	1.5413	1.8075	182.0
181.0	7.679	0.016516	49.178	49.194	149.00	989.6	1138.6	0.2647	1.5446	1.8093	181.0
180.0	7.511	0.016510	50.208	50.225	148.00	990.2	1138.2	0.2631	1.5480	1.8111	180.0

Reference (5)

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SUPERFUND STANDBY PROGRAM
New York State
Department of Environmental Conservation
50 Wolf Road
Albany, New York 12233-7010

ON-SITE

REMEDIAL INVESTIGATION WEST SIDE CORPORATION SITE
Site No. 2-41-026

Volume 1
Work Assignment Number
D003060-24

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July 2000

ref(2), cont'd

3.7.1 Hydraulic Conductivity and Soil Porosity

Estimated hydraulic conductivity values were calculated from field permeability test data. The hydraulic conductivities of the seven shallow wells were calculated to range from 66 to 150 feet per day (fpd) with an average of approximately 114 fpd. Five deep wells had hydraulic conductivity values that were calculated to range from 8 to 71 fpd, with an average of 39 fpd. However, two of the seven deep wells had significantly higher calculated hydraulic conductivities relative to the other wells at the Site: monitoring wells MW-3D and MW-7D had calculated hydraulic conductivities of 610 and 800 fpd, respectively. Due to the nature of this glacial outwash deposition, it is probable that areas or zones of fluctuating permeability exist throughout the Site.

✓ The aquifer thickness is anticipated to vary at different locations of the study area; however, the thickness was measured at the deep locations drilled to average approximately 55 feet. The transmissivity of the upper glacial aquifer, considering an average depth of 55 feet, ranges from 445 to 8340 ft^2/day with an estimated average of 4615 ft^2/day.

The effective porosity for gravelly sand was estimated to be 0.35, based on published values for this type of soil (gravelly sand).

3.7.2 Groundwater Flow Patterns and Velocities

A groundwater contour map, presenting groundwater elevations (Figure 8) recorded during this study, was prepared based on the water elevations measured in the shallow groundwater monitoring wells on September 24, 1999.

The groundwater flow direction in the study area is southerly based on the groundwater contour map prepared. As discussed in Section 2.10, the groundwater flow direction may have been affected by the former JWS supply wells located adjacent to the Site during periods of operation. During times of water pumping, these wells could have skewed the groundwater in an easterly, westerly and/or northerly direction depending on which well was pumping and the amount of water pumped at a given time.

The calculated average horizontal hydraulic gradient at the Site is 0.001 based on the September 24, 1999 groundwater elevation data.

The groundwater velocity at the Site study area was calculated to range from 0.02 to 0.43 fpd, or 7.0 to 160 feet per year (fpy), with an average of 0.24 fpd or 88 fpy.

reference (6)

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TRANSPORT PHENOMENA

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Temperature Distributions with More than One Independent Variable

In Chapter 9 it was shown how a number of simple heat-flow problems can be solved by means of shell energy balances. In Chapter 10 the energy equation for flow systems was developed, which in principle describes heat-transfer processes in more complex situations. Just to illustrate the usefulness of the energy equation, we presented in §10.5 a series of examples, most of which required no knowledge of partial differential equations. In this chapter we discuss several classes of heat-transfer problems which involve more than one independent variable: unsteady heat conduction in solids, steady heat conduction in viscous flow, steady two-dimensional heat conduction in solids, and heat flow in laminar boundary layers. These topics roughly parallel those given in Chapter 4 both in physical processes and mathematical techniques.

§11.1 UNSTEADY HEAT CONDUCTION IN SOLIDS

For solids, the energy equation of Eq. 10.1–19, after insertion of Fourier's law of heat conduction, becomes

$$\rho \hat{C}_p \frac{\partial T}{\partial t} = (\nabla \cdot k\nabla T) \qquad (11.1\text{–}1)$$

If the thermal conductivity is independent of the temperature or position, then Eq. 11.1–1 becomes

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T \qquad (11.1\text{–}2)$$

in which $\alpha = k/\rho\hat{C}_p$ is the thermal diffusivity of the solid. Equation 11.1–2 is one of the most worked-over equations of theoretical physics. The treatise of Carslaw and Jaeger[1] is devoted entirely to methods of solution of this equation; their book should be familiar to all engineers and applied scientists because of its extensive tabulation of solutions to Eq. 11.1–2 for an enormous number of boundary and initial conditions. Many frequently encountered heat-conduction problems may be solved simply by looking up the solution in Carslaw and Jaeger's reference work.

In this section we begin by giving two of the very simplest unsteady-state solutions to Eq. 11.1–2 to introduce beginners to the subject. These solutions illustrate the method of combination of variables and the method of separation of variables, which were also used in §4.1. Then we give one example of a problem solved by means of Laplace transform, a technique that is of great importance in solving unsteady-state problems. Readers desiring more elaborate examples will have no trouble finding them in Carslaw and Jaeger.

Example 11.1-1. Heating of a Semi-Infinite Slab[2]

A solid body occupying the space from $y = 0$ to $y = \infty$ is initially at temperature T_0. At time $t = 0$, the surface at $y = 0$ is suddenly raised to temperature T_1 and maintained at that temperature for $t > 0$. Find the time-dependent temperature profiles $T(y, t)$.

Solution. For this problem, Eq. 11.1–2 becomes

$$\frac{\partial \Theta}{\partial t} = \alpha \frac{\partial^2 \Theta}{\partial y^2} \qquad (11.1\text{–}3)$$

in which we have introduced a dimensionless temperature $\Theta = (T - T_0)/(T_1 - T_0)$. With this dimensionless temperature, the initial and boundary conditions assume this simple form:

I.C.: at $t \leqslant 0$, $\Theta = 0$ for all y (11.1–4)

B.C. 1: at $y = 0$, $\Theta = 1$ for all $t > 0$ (11.1–5)

B.C. 2: at $y = \infty$, $\Theta = 0$ for all $t > 0$ (11.1–6)

This problem is mathematically analogous to that formulated in Eqs. 4.1–1 through

---

[1] H. S. Carslaw and J. C. Jaeger, *Conduction of Heat in Solids*, Oxford University Press, (1959), Second Edition.

[2] See K. T. Yang, *J. Appl. Mechanics*, **25**, 146–147 (1958) for a solution with variable thermal conductivity.

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4; hence the solution in Eq. 4.1–13 can be taken over directly by appropriate change in notation.

$$\Theta = 1 - \frac{2}{\sqrt{\pi}} \int_0^{y/\sqrt{4\alpha t}} e^{-\eta^2}\, d\eta \tag{11.1–7}$$

or

$$\frac{T - T_0}{T_1 - T_0} = 1 - \operatorname{erf} \frac{y}{\sqrt{4\alpha t}} \tag{11.1–8}$$

The graphical solution in Fig. 4.1–2 for $n = 1$ describes the temperature profiles when the ordinate is labeled $(T - T_0)/(T_1 - T_0)$ and the abscissa, $y/\sqrt{4\alpha t}$.

Because the error function reaches a value of 0.99 when the argument is about 2, the "thermal penetration thickness" δ_T is

$$\delta_T \doteq 4\sqrt{\alpha t} \tag{11.1–9}$$

That is, for distances $y > \delta_T$, the temperature has changed by less than 1 per cent of the difference $(T_1 - T_0)$. If it is necessary to calculate the temperature in a slab of finite thickness, the solution in Eq. 11.1–8 will be a good approximation when δ_T is small with respect to the slab thickness. When δ_T is of the order of magnitude of the slab thickness, then the series solution of Example 11.1–2 has to be used.

The wall heat flux can be calculated from Eq. 11.1–8:

$$q_y\big|_{y=0} = -k \left.\frac{\partial T}{\partial y}\right|_{y=0} = \frac{k}{\sqrt{\pi \alpha t}} (T_1 - T_0) \tag{11.1–10}$$

Hence the penetration thickness varies as $t^{1/2}$ and the wall heat flux as $t^{-1/2}$.

Example 11.1–2. Heating of a Finite Slab

A slab occupying the space between $y = -b$ and $y = +b$ is initially at temperature T_0. At time $t = 0$ the surfaces at $y = \pm b$ are suddenly raised to T_1 and maintained there. Find $T(y, t)$.

Solution. For this problem we introduce the following dimensionless quantities:

$$\Theta = \frac{T_1 - T}{T_1 - T_0} = \begin{array}{l}\text{dimensionless temperature} \\ \text{(different from } \Theta \text{ in Example 11.1–1)}\end{array} \tag{11.1–11}$$

$$\eta = \frac{y}{b} = \text{dimensionless length} \tag{11.1–12}$$

$$\tau = \frac{\alpha t}{b^2} = \text{dimensionless time} \tag{11.1–13}$$

Experience teaches us that it is convenient to introduce such dimensionless quantities so that the differential equations and boundary conditions assume a simpler form:

$$\frac{\partial \Theta}{\partial \tau} = \frac{\partial^2 \Theta}{\partial \eta^2} \tag{11.1–14}$$

I.C.: at $\tau = 0$, $\Theta = 1$ (11.1–15)

B.C.'s 1 and 2: at $\eta = \pm 1$, $\Theta = 0$ (11.1–16)

We present here the classical solution by the method of separation of variables. We anticipate that a solution of the following product form can be found:

$$\Theta(\eta, \tau) = f(\eta) g(\tau) \tag{11.1–17}$$

Substitution of this trial function into Eq. 11.1–14 gives, after division by fg,

$$\frac{1}{g}\frac{dg}{d\tau} = \frac{1}{f}\frac{d^2 f}{d\eta^2} \tag{11.1–18}$$

The left side is a function of τ alone, and the right side is a function of η alone. This can be true only if both sides equal a constant, which we call $-c^2$. The problem then becomes one of solving the two ordinary differential equations:

$$\frac{dg}{d\tau} = -c^2 g \tag{11.1–19}$$

$$\frac{d^2 f}{d\eta^2} = -c^2 f \tag{11.1–20}$$

These may be integrated to give

$$g = A \exp(-c^2 \tau) \tag{11.1–21}$$

$$f = B \sin c\eta + C \cos c\eta \tag{11.1–22}$$

in which A, B, and C are constants.

We note that Θ, hence f, must be even functions of η by virtue of the symmetry of the problem. Therefore we must set B equal to zero. Use of either one of the boundary conditions gives

$$C \cos c = 0 \tag{11.1–23}$$

Clearly, C cannot be zero because this choice would lead to a physically inadmissable solution. Consequently, we are forced to let

$$c = (n + \tfrac{1}{2})\pi \qquad n = 0, \pm 1, \pm 2, \cdots \pm \infty \tag{11.1–24}$$

The foregoing choices for C and c lead then to the fact that

$$\Theta_n = A_n C_n e^{-(n+\frac{1}{2})^2 \pi^2 \tau} \cos (n + \tfrac{1}{2})\pi\eta \tag{11.1–25}$$

is an admissable solution. The subscripts n remind us that A and C may be different for each n. The most general solution of this form is obtained by adding the solutions of the form of Eq. 11.1–25 for all integral n from $n = -\infty$ to $n = +\infty$:

$$\Theta = \sum_{n=0}^{\infty} D_n e^{-(n+\frac{1}{2})^2 \pi^2 \tau} \cos (n + \tfrac{1}{2})\pi\eta \tag{11.1–26}$$

in which $D_n = A_n C_n + A_{-(n+1)} C_{-(n+1)}$.

The set of D_n are now determined by using the initial condition, which states that

$$1 = \sum_{n=0}^{\infty} D_n \cos (n + \tfrac{1}{2})\pi\eta \tag{11.1–27}$$

Multiplication by $\cos (m + \frac{1}{2})\pi\eta\, d\eta$ and integrating from $\eta = -1$ to $\eta = +1$ gives

$$\int_{-1}^{+1} \cos (m + \tfrac{1}{2})\pi\eta\, d\eta = \sum_{n=0}^{\infty} D_n \int_{-1}^{+1} \cos (m + \tfrac{1}{2})\pi\eta \cos (n + \tfrac{1}{2})\pi\eta\, d\eta \tag{11.1–28}$$

Reference (7)

The idea of a buried network of preinsulated tubing includes the difficult choice of the material to be used. To achieve the right choice, both technical and economic considerations must be carefully evaluated with respect particularly to the working environment of the systems. This choice is basically dependent on catalogues, brochures and price lists published by the manufacturers of preinsulated tubing. Only a well-informed consulting engineer can see immediately that some documents cannot be compared with each other and this does not make the final choice any easier!

La conception d'un réseau enterré de tuyauteries préisolées inclut le difficile choix du produit à prescrire. Pour y parvenir, les arguments techniques et commerciaux doivent être correctement comparés, notamment en fonction des conditions de service des réseaux. Les catalogues, brochures et listes de prix édités par les fabricants de tuyauteries préisolées, constituent la base de ces comparatifs. Seul un ingénieur conseil averti peut immédiatement déceler que certains documents ne peuvent être comparés entre eux, ce qui ne facilite pas la décision!

District heating, an Objective Choice

Réseaux de chaleur, *un choix objectif*

Hans Dresler

E One has to consider the price of the product, the installation cost as well as the technical characteristics of the installation with their impact on future running costs. While it is easy to look at price lists and work out the installation cost, the technical data derived from the manufacturers' documents are often published in such a way as to render useful comparative evaluation impossible. For example, the extracts from two catalogues cited below in a table from BRUGG (CALPEX) (table 1) and a chart from FLEXALEN (table 2), who specialise in long distance distribution networks.

Whereas CALPEX talks about total heat loss from the tube (on flow and return), FLEXALEN charts give the heat loss per buried tube per run, treating flow and return as separate problems. This is logical, as the two tubes are never at the same temperature. As the presentation and the data are different, it is useful to bring the two together as in the table 3.

As the basic data are so different one can have an idea of the difficulties encountered in making a comparative evaluation which is still the principal tool for making a decision.
In order to give to the decision makers (consulting engineers, users) an easy way of evaluating heat loss in different systems of preinsulated tubing, we will set up a common database able

Heat loss q [W/m] for a UNO tube
Pertes de chaleur q [W/m] pour un tube UNO

Type	Average working temperature TB(°C) Température moyenne de service TB(°C)					
CALPEX UNO	40°C	50°C	60°C	70°C	80°C	90°C
25/92 PLUS	4,4	5,9	7,4	8,8	10,3	11,8
32/76	6,2	8,3	10,4	12,5	14,6	16,6
32/111 PLUS	4,5	6,0	7,6	9,1	10,6	12,1
40/91	6,7	9,0	11,2	13,4	15,7	17,9
40/126 PLUS	4,9	6,5	8,2	9,8	11,4	13,0
50/111	6,8	9,1	11,4	13,7	16,0	18,2
50/126 PLUS	5,9	7,9	9,9	11,9	13,9	15,8
63/126	7,7	10,3	12,9	15,4	18,0	20,6
63/142 PLUS	6,8	9,0	11,3	13,6	15,8	18,1
75/142	8,4	11,2	14,1	16,9	19,7	22,5
75/162 PLUS	7,1	9,4	11,8	14,2	16,5	18,9
90/162	9,0	12,0	15,0	17,9	20,9	23,9
110/162	12,8	17,1	21,4	25,7	30,0	34,2

Methode of laying UNO tube / Mode de pose du tube UNO : 2 burried tubes
Depth of tubing / Hauteur de couverture : 60 cm
Ground temperature / Température du terrain : 10°C
Soil conductivity / Conductibilité du sol : 1.2 W/mK
PUR foam conductivity / Conductibilité de la mousse PUR: 0.032 W/mK
PEX tube conductivity / Conductibilité du tube en PEX : 0.38 W/mK
PE tube conductivity / Conductibilité du tube en PE : 0.43 W/mK

Table 1 / Tableau 1

ref (1), cont'd

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to produce a valid comparison.

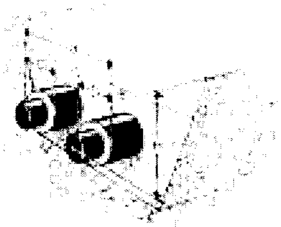
Heat loss is calculated using a chart software which applies the resistance constants of Mr. DI Ziegler of the Munich University Thermal Insulation Research Institute as well as the formulae derived from the work. Mr DI Ziegler puts forward his calculations both for traditional solutions with underground preinsulated tubing, but also for solutions such as FLEXALEN whose technology depends on individual insulating segments either for single or double runs of tubing.

To see in more detail what happens inside a trench we shall use the following formula.

$$m_E = \frac{1}{2 * \pi * \lambda_E} \ln\left(\frac{2U}{d_a} + \sqrt{\left(\frac{2U}{d_a}\right)^2 - 1}\right)$$

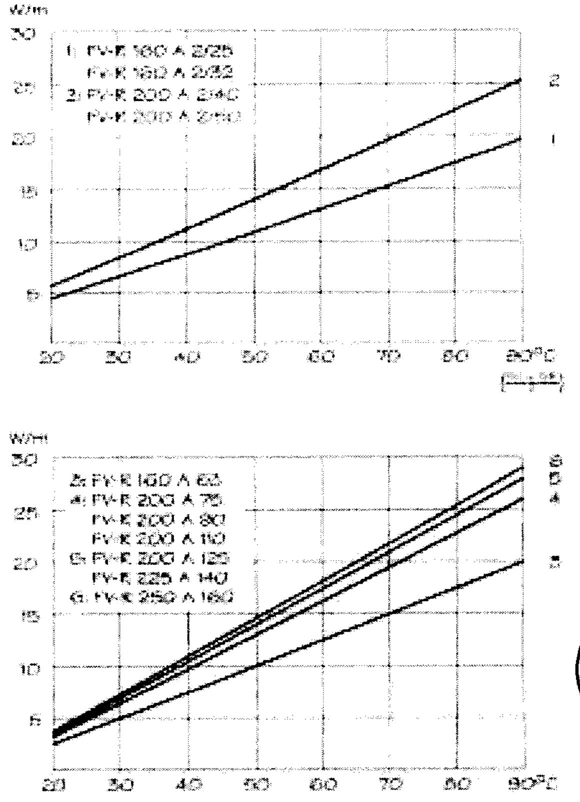
m_E = *Soil thermal conductivity*
$U = H + 0{,}07\,\lambda_E$

$$d_a = \frac{2{,}2 * a * D}{a + D}$$



λ_E = *Soil thermal conductivity in 1 W/mK*
H = *Depth measured to centre of pipe*
D = *Tube outer diameter*
a = *Total distance between the two tube casing extremities*

Table 2 / Tableau 2



The following theories and data will be used in our calculations:

1. In depth examination of the preinsulated tube layout.
2. Flow temperature 90 °C
3. Return temperature 70 °C
4. Soil temperature 0 °C
5. Depth of pipe 1000 mm
6. Thermal conductivity of soil 1 W/mK
7. Thermal conductivity (λ) of PUR flexible foam 0.037 W/mK (CALPEX) (2)
8. Thermal conductivity (λ) of PUR rigid foam 0.033 W/mK (FLEXALEN) (3)
9. The thermal conductivity values (λ) of the outer casing and of the inside tube are those given by the manufacturers. (4)

(2) and (3) The optimal values often published in catalogues (CALPEX 0,032 W/mK) are those measured immediately after manufacture. After a few days, they decrease to those used above because of the diffusion of gases in the cells. After that, the values remain constant.
(SOURCE: The problem of diffusion in synthetic materials, by EUIROHEAT and POWER- Fernwärme International 7/11988 by Erik Geiss and Michael Kraaz Hannover)
(4) 0,22 W/mK for PB (FLEXALEN), 0,38 W/mK for PEX (CALPEX)

The data recalculated in this way for the two systems of preinsulated tubing can thus be correctly compared (see table 3) (flow, return, soil temperature, depth of tubing, thermal conductivity λ of the soil).
The basic data are fed into the chart which makes it possible to make calculations for different tubes (on flow and then on return), and then to make comparisons between each system.

The column marked " calculated" represents the actual calculated value, the column marked " catalogue " refers to the values quoted in the manufacturers technical literature.

In view of the considerable differences discovered, it seems extremely important to compare that which is comparable. With the exception of the considerable differences seen with twin tubing (which cannot be explained by the corrections alone) the system giving the best results must be considered to be the one with the best insulation.

To make the best selection, these calculation formulae are available to anyone interested. The parameters can be very wide which makes it possible to compare all types of materials and systems available on the market.
Those doubts arising from unreliable heat-loss comparisons are now history. Moreover, this accurate calculation of heat loss per linear meter now makes it possible to have a better overall view of the total losses involved in long distance networks which is a considerable advantage in evaluating the feasibility of the project.

Thanks to this method, the uncertainty surrounding a decision will gradually disappear. ☐

Thermal data / *caractéristiques thermiques*

Fluid temperature / *température du fluide*	90 °C
Ground temperature / *température du sol*	10 °C
Tube depth / *profondeur de pose*	1m
Thermal conductivity / *conductivité thermique*	0.8 W/mK
The thermal conductivity of the soil varies according to moisture content from: *La conductivité thermique du sol est variable selon la teneur en humidité de:*	0.3 to 3.0 W/mK

Reference (8)

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1cm

Inverse Heat Conduction In Soils

A New Approach Towards Recovering Soil

Moisture From Temperature Records

Diploma Thesis
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Subsections

2.4 The Effect of Soil Moisture on the Thermal Properties of Soils

The temporal variability of the parameters governing heat conduction in soil, c_h and k_h is determined mainly by the soil moisture. This is due to the fact that water and air are the only soil constituents which can vary considerably on a daily basis. In this section, analytical models for c_h and k_h are presented to describe this dependence.

2.4.1 Heat Capacity

The macroscopic volumetric heat capacity of a soil can be calculated by summing over all constituents and phases multiplied by their respective volumetric fractions θ_j :

$$c_h = \sum_{j=1}^{n} \theta_j c_{h,j} \tag{2.17}$$

Note that c_h increases linearly with increasing soil moisture content θ_w. *Table* 2.1 lists the volumetric heat capacities of some major soil constituents. Due to the small heat capacity of air, the contribution of air towards the total heat capacity may be neglected to a good approximation.

Table 2.1: Thermal properties and densities of soil materials, water and air at $10\ ^{\circ}C$ according to *De Vries and Afgan* (1975).

Substance	$\rho\ [\frac{kg}{m^3}]$	$c_h\ [\frac{J}{m^3K}]$	$k_h\ [\frac{W}{mK}]$

ref.(8), cont'd

Quartz	$2.66\ 10^3$	$2.0\ 10^6$	8.8
Clay	$2.65\ 10^3$	$2.0\ 10^6$	2.9
Organic matter	$1.3\ 10^3$	$2.5\ 10^6$	0.25
Water	$1.0\ 10^3$	$4.2\ 10^3$	0.57
Air (dry)	1.25	$1.25\ 10^3$	0.025

Figure 2.1 shows the heat capacity calculated for a sandy loam soil at Research Centre Foulum, Denmark (Schelde et al., 1998). As for all materials, the heat capacity of soils is dependent of temperature. The effect is very small over the temperature range of interest though, and can be neglected to a good approximation.

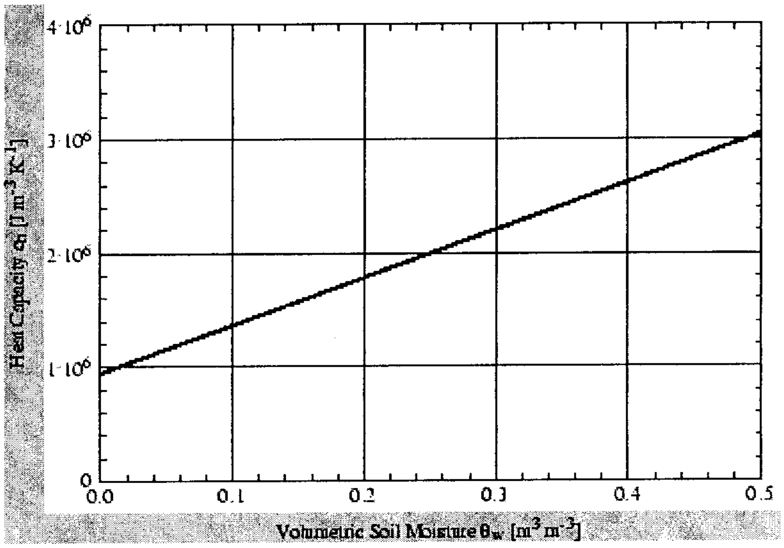

Figure 2.1: Heat capacity c_h as a function of volumetric soil moisture θ_w for an upper soil layer ($5\,cm$ to $15\,cm$) at Foulum, Denmark (§B.1). The solid line is calculated using *Eq. (2.17)* and the values $\eta = 0.54$ for porosity, $\theta_q = 0.39$ for volumetric quartz content, and $\theta_c = 0.042$ for volumetric clay content of the soil.

2.4.2 Thermal Conductivity

Many models and empirical formulae to calculate the macroscopic thermal conductivity of soils have been proposed (Sepaskhah and Boersma, 1979; Kersten, 1949; Kasubuchi, 1984; De Vries and Afgan, 1975; Nakshabandi and Kohnke, 1994). A good overview including a detailed evaluation ref. 8), cont'd

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of their applicability is given by *Farouki* (1986).

2.4.2.1 De Vries Model

In analogy to a model developed by Maxwell[2.2], *De Vries* (1952a) developed a model for the macroscopic thermal conductivity of ellipsoidal soil particles in a continuous medium of water (or air)

$$k_h = \frac{\sum_{j=1}^{n} \kappa_j \theta_j k_{h,j}}{\sum_{j=1}^{n} \kappa_j \theta_j} \tag{2.18}$$

where $k_{h,j}$ is the thermal conductivity and θ_j is the volume fraction of the jth constituent. κ_j is the ratio of the space average of the temperature gradient in the soil grains of kind j and the space average of the temperature gradient in the water (or air). Assuming a needle like shape for soil particles, *Nobre and Thomson* (1993) found that

$$\kappa_j = \frac{2}{3}\left[1 + \left(\frac{k_{h,j}}{k_{h,w}} - 1\right) g_j\right]^{-1} + \frac{1}{3}\left[1 + \left(\frac{k_{h,j}}{k_{h,w}} - 1\right)(1 - 2g_j)\right]^{-1} \tag{2.19}$$

where the g_j's are the shape factors given in *Tab.* 2.2.

Table 2.2: Subscripts and shape factors of soil constituent according to *Nobre and Thomson* (1993)

Constituent	Subscript j	Shape Factor g_j
Quartz	q	0.125
Clay	c	0.125
Organic matter	o	0.500
Water	w	-
Air (dry)	a	Variable

For air enclosures, the shape factor is dependent on the volumetric water content and is deduced by linear interpolation between the value for spherical shape at saturation and a value of 0.013 at dryness (*Kimball et al.*, 1976). Thus,

$$g_w = 0.013 + \left(\frac{0.022}{\theta_{w,wilt}} + \frac{0.298}{\eta}\right)\theta_w \tag{2.20}$$

ref.(8), cont'd

where $\theta_{w,wilt}$ is the wilting point moisture content, and η is the porosity of the soil. This approximation is only valid for $\theta_w > \theta_{w,wilt}$. For very dry soils2.3, the De Vries model may be applied using air as the continuous medium. *De Vries (1952a)* suggests that one should discontinue calculations with water as a continuous medium at $\theta_w < 0.03$ for coarse soils or at $\theta_w < 0.05 - 0.1$ for fine soils. *Farouki (1986)* indicates that the de Vries model gives values within $\pm 10\%$ over the applicable range of θ_w.

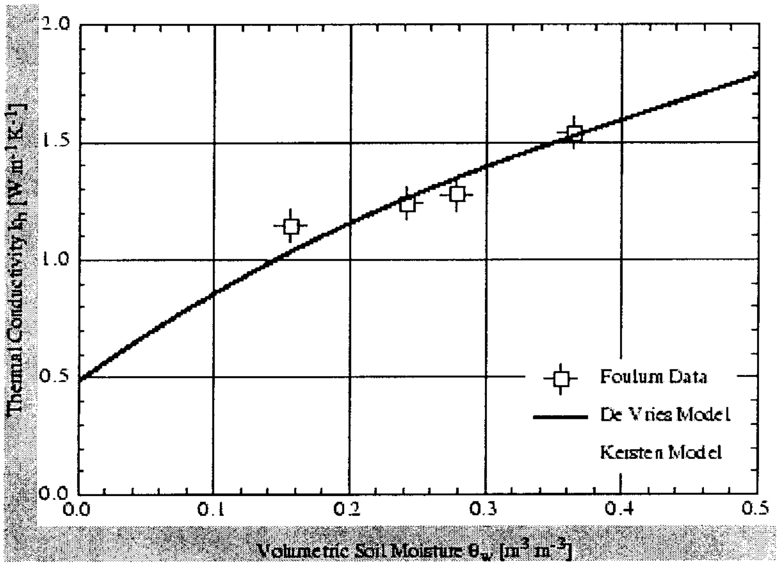

Figure 2.2: Thermal conductivity k_h as a function of volumetric soil moisture θ_w for an upper soil layer ($5\,cm$ to $15\,cm$) at Foulum, Denmark (*§B.1*). Points are field measurements using the needle probe method (*Schelde et al., 1998*), the solid line is calculated using the de Vries equation ($\eta = 0.54$, $\theta_q = 0.39$, $\theta_c = 0.042$), and the dashed line is calculated using the Kersten equation ($\rho_d = 1.20$, $a_1 = 1.24$, $a_2 = -0.11$, $a3 = 0.62$). The soil thermal conductivity measurements were determined in the laboratory at successively higher suction levels (1.0, 5.0, 10 and $50\ kPa$) using a minimum of three soil replicates for all layers.

Figure 2.2 shows the thermal conductivity calculated using the de Vries model for a sandy loam soil at Research Centre Foulum, Denmark (*Schelde et al., 1998*).

ref (8), cont'd

Below $\theta_w \approx 0.1$, the De Vries model overpredicts thermal conductivities, since water can no longer be considered a continuous medium in the soil. At complete dryness, the heat flow mainly passes through the grains and has to bridge the air-filled gaps between the grains around their contact points. As with the heat capacity, temperature dependence of k_h can be neglected to a first approximation.

2.4.2.2 Kersten Equation

Kersten (1949) proposes a purely empirical formula for the calculation of the thermal conductivity based on measurements for five different soils

$$k_h = 0.1442\,(a_1 \log\theta_w - a_2)\,10^{a_3\rho_d} \tag{2.21}$$

where the thermal conductivity k_h is given in $\left[\frac{W}{mK}\right]$, the dry density ρ_d in $\left[\frac{g}{cm^3}\right]$, and a_1, a_2 and a_3 are dimensionless empirical constants. Values of a_1, a_2 and a_3 valid for unfrozen sand soils are 0.750, 0.400 and 0.625, respectively. According to *Farouki (1986)* the equation generally applies to soils with low silt-clay content (less than about 20 %). It should ideally be applied to coarse soils with an intermediate quartz content of about 60 % of the soil solids. Kersten's equation does not apply to dry soils or to crushed rocks. *Figure 2.2* shows the thermal conductivity calculated using the Kersten equation as compared to the de Vries model and field measurements. At moistures below approx. $0.05\ \frac{m^3}{m^3}$ both models are no longer applicable.

2.4.3 Thermal Diffusivity

The thermal diffusivity is defined by *Eq. (2.22)*. It governs the temperature response of a soil to thermal perturbations.

$$D_h = \frac{k_h}{c_h} \tag{2.22}$$

Figure 2.3 shows the thermal diffusivity calculated using the De Vries and Kersten equation for a sandy loam soil at Research Centre Foulum, Denmark (*Schelde et al.*, 1998). For mineral and loam soils, the thermal diffusivity shows a maximum value at a relatively low value of θ_w.

ref(8), cont'd

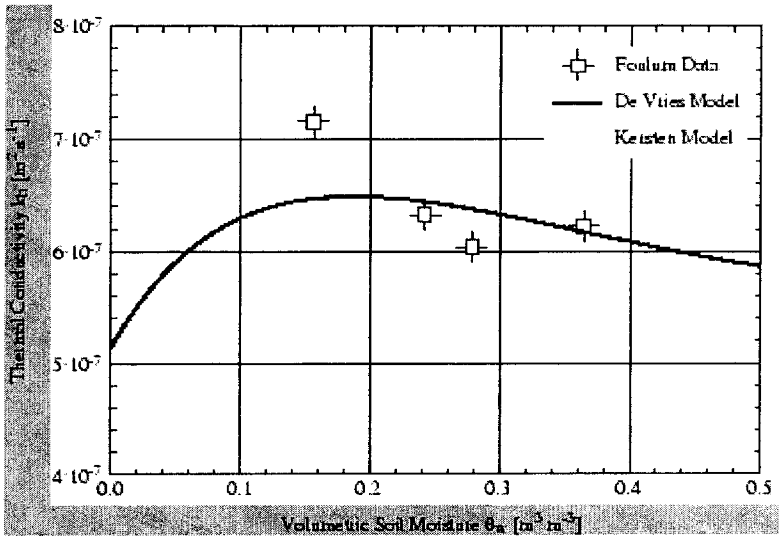

Figure 2.3: Thermal diffusivity c_h as a function of volumetric soil moisture θ_w for an upper soil layer ($5\,cm$ to $15\,cm$) at Foulum, Denmark (*§B.1*). The solid and dashed lines are calculated using the De Vries and Kersten model, respectively *(Fig. 2.2)*. Points are calculated using field measurements of k_h (see the caption to *Fig. 2.2*).

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Reference (9)

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Engineering material properties

This table gives various engineering material properties listed alphabetically. The units are SI.

Density	Acrylic	1400	kg/m^3
Density	Air (2800 m)	0.9800	kg/m^3
Density	Air (STP)	1.2930	kg/m^3
Density	Aluminum 2024-T3	2770	kg/m^3
Density	Aluminum 3003	2700	kg/m^3
Density	Aluminum 6061-T6	2700	kg/m^3
Density	Aluminum 7079-T6	2740	kg/m^3
Density	Ammonia - liquid	682.10	kg/m^3
Density	Argon - liquid	1390	kg/m^3
Density	Beryllium QMV	1850	kg/m^3
Density	Borosilicate Ohara E6	2180	kg/m^3
Density	Borosilicate Tempax	2230	kg/m^3
Density	Concrete	2242	kg/m^3
Density	Copper - pure	8900	kg/m^3
Density	Dow Corning 200 (350cSt)	968.00	kg/m^3
Density	Fused silica	2200	kg/m^3
Density	Glass wool	64.00	kg/m^3
Density	Gold - pure	1.932E+04	kg/m^3
Density	Helium - liquid	125.00	kg/m^3
Density	Hydrogen - liquid	70.00	kg/m^3
Density	Iron	7830	kg/m^3
Density	Lead - pure	1.134E+04	kg/m^3
Density	Magnesium AZ31B-H24	1770	kg/m^3
Density	Magnesium HK31A-H24	1790	kg/m^3
Density	Methane - liquid	424.00	kg/m^3
Density	Molybdenum - wrought	1.030E+04	kg/m^3
Density	Neon - liquid	1200	kg/m^3
Density	Nickel - pure	8900	kg/m^3
Density	Nitrogen - liquid	804.00	kg/m^3
Density	Nylon	1700	kg/m^3
Density	Platinum	2.145E+04	kg/m^3
Density	Polycarbonate	1300	kg/m^3
Density	Polyethylene	2300	kg/m^3
Density	PTFE	1200	kg/m^3
Density	SiC Alpha	2975	kg/m^3
Density	SiC sintered KT	2975	kg/m^3
Density	Silver - pure	1.050E+04	kg/m^3

Reference (9), cont'd

Thermal Conductivity	Dow Corning Q3-6605	0.8400	W/m*°C
Thermal Conductivity	Epoxy (Epotek 353ND)	0.0490	W/m*°C
Thermal Conductivity	Epoxy (Masterbond 11A0)	1.4400	W/m*°C
Thermal Conductivity	Glass wool	0.0400	W/m*°C
Thermal Conductivity	Gold - pure	297.70	W/m*°C
Thermal Conductivity	Helium	2.7700	W/m*°C
Thermal Conductivity	Ice	2.2000	W/m*°C
Thermal Conductivity	Iron	83.50	W/m*°C
Thermal Conductivity	Lead - pure	37.04	W/m*°C
Thermal Conductivity	Limestone	0.5000	W/m*°C
Thermal Conductivity	Magnesium HK31A-H24	114.20	W/m*°C
Thermal Conductivity	Magnesium AZ31B-H24	95.19	W/m*°C
Thermal Conductivity	Methane	0.3030	W/m*°C
Thermal Conductivity	Molybdenum - wrought	143.60	W/m*°C
Thermal Conductivity	Nickel - pure	91.73	W/m*°C
Thermal Conductivity	Nitrogen	0.1460	W/m*°C
Thermal Conductivity	Nylon	0.2400	W/m*°C
Thermal Conductivity	Platinum	69.23	W/m*°C
Thermal Conductivity	Polycarbonate	0.2000	W/m*°C
Thermal Conductivity	Polypropylene	0.4000	W/m*°C
Thermal Conductivity	Polystyrene foam	0.3600	W/m*°C
Thermal Conductivity	Polyurethane foam	0.0260	W/m*°C
Thermal Conductivity	PTFE	0.2400	W/m*°C
Thermal Conductivity	Quartz	1.3200	W/m*°C
Thermal Conductivity	SiC Alpha	77.50	W/m*°C
Thermal Conductivity	SiC sintered KT	80.00	W/m*°C
Thermal Conductivity	Silastic E	0.1800	W/m*°C
Thermal Conductivity	Silastic L	0.2800	W/m*°C
Thermal Conductivity	Silicone foam (Poron)	0.0600	W/m*°C
Thermal Conductivity	Silver - pure	417.10	W/m*°C
Thermal Conductivity	Snow (light)	0.6000	W/m*°C
Thermal Conductivity	Snow (packed)	2.2000	W/m*°C
Thermal Conductivity	Soil (coarse)	0.5200	W/m*°C
Thermal Conductivity	Soil (dry w/stones)	0.5200	W/m*°C
Thermal Conductivity	Soil (dry)	0.2300	W/m*°C
Thermal Conductivity	Soil (w/42% water)	1.1000	W/m*°C
Thermal Conductivity	Steel AISI 304	16.27	W/m*°C
Thermal Conductivity	Steel AISI C1020	46.73	W/m*°C
Thermal Conductivity	Tantalum	53.65	W/m*°C
Thermal Conductivity	Titanium B 120VCA	7.4420	W/m*°C