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Air Stripping of Contaminated Water Sources—Air Emissions and Controls

control technology center

CTC

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AIR STRIPPING OF CONTAMINATED WATER SOURCES - AIR EMISSIONS AND CONTROLS

CONTROL TECHNOLOGY CENTER

SPONSORED BY:

Emission Standards and Engineering Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Air and Energy Engineering Research Laboratory
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NOTICE

This report was prepared by Radian Corporation, Research Triangle Park, NC. It has been reviewed for technical accuracy by the Emission Standards and Engineering Division of the Office of Air Quality Planning and Standards, and the Air and Energy Engineering Research Laboratory of the Office of Research and Development, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

ACKNOWLEDGEMENT

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1.0 INTRODUCTION

The Control Technology Center (CTC) was established by the Environmental Protection Agency (EPA) Office of Research and Development and the Office of Air Quality Planning and Standards to assist State and local air pollution control agencies in the implementation of their air toxics and other pollution control programs. Three levels of assistance can be accessed through the CTC. First, a CTC HOTLINE has been established to provide telephone assistance on matters relating to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

The technical guidance documents, such as this one, focus on topics of national interest that are identified through contact with State and local agencies. The purpose of this document is to identify air pollution control alternatives and present information on removal efficiencies, costs, and other relevant impacts of control. The decision of whether or not to regulate a source category and the selection of the technology on which to base regulation is the responsibility of the individual State or local authorities. This document is intended to provide technical assistance in making such decisions. By inclusion in this document, EPA does not necessarily endorse the use of any particular control technology for all applications.

This document is one of the first products to be developed by the CTC. Because of the number of questions that the CTC received about the control of air emissions from air stripping towers and the knowledge that this process is commonly used in many States, the CTC determined that information on this subject would be of interest to many State and local agencies

2.0 BACKGROUND

Packed tower air stripping is often selected to treat contaminated water sources. However, unless controlled, the contaminants are simply transferred from the water bodies to the air. The purpose of this study was to investigate the emission controls presently being used for air strippers, their performance, and the capital and operating costs of these controls. This information was collected through a literature search, telephone contacts, and site visits. This report presents the available performance and cost data for the air stripper emission controls identified in this study. When actual cost data were not available, estimates were made and are also presented in this report.

2.1 GROUND WATER CONTAMINATION SOURCES

In general, ground water contamination occurs due to four main sources. Underground storage tank leaks are often a source of ground water contamination. Improper disposal practices and accidental spills are another source of ground water contamination. Ground water contamination can also be caused by process leaks. Finally, landfill leachate, containing a wide range of chemicals, can be a major source of ground water contamination.

The above contamination sources can result in varying concentrations of many different compounds. The concentration of a given compound found does not appear to depend on the contamination source. Some of these contaminants may be potential carcinogens, while others may be toxic or cause odor or taste problems.

2.2 POTENTIAL CLEAN-UP TECHNIQUES

After ground water contamination has been discovered and a clean-up is deemed necessary, the type of clean-up technology must be selected. Air stripping, aqueous-phase carbon adsorption, diffused-air aeration, in-ground aeration, spray tower, redwood slat tower, and photochemical oxidation are some examples of ground water clean-up techniques presently being used. Of

these, air stripping and aqueous-phase carbon adsorption are the most prevalent.

Air stripping is often compared to aqueous-phase carbon adsorption when evaluating cleanup alternatives. When technically feasible, air strippers are often selected over carbon adsorbers due to their lower operating cost. In general cost comparisons, air stripping costs have been reported to range from 2 to 30 cents per 1,000 gallons compared to 20 to 90 cents per 1,000 gallons for aqueous-phase carbon adsorption.[1,2] Even with the additional expense of an air emission control device, the total cost of an air stripper system can be less than that of an aqueous-phase carbon adsorber.[3]

Costs of installing and operating the air stripping system with emissions control (carbon adsorber) were compared with costs for a temporary aqueous-phase, granular activated carbon (GAC) treatment system used at the Verona Well Field site.[3] In this comparison, the air stripping system with emission control resulted in the lower total project cost for operation longer than two years. For shorter operation periods, the aqueous-phase carbon system offers lower costs.

Each cleanup project requires careful consideration of technical, economic, and environmental factors. Although air stripping may offer economic advantages, aqueous-phase GAC may be selected for its capability to maintain effluent quality in spite of flow variation, changes in contaminant mix or levels, and ability to be thermally regenerated insuring destruction of contaminants.

2.3 DATA GATHERING APPROACH

A systematic contact procedure was followed to collect information on currently operating air strippers and their air emission control systems. Regional EPA Offices were contacted initially. They provided information on air strippers operating in their regions as well as other contacts in State agencies, private contractors, and at the site. The State personnel provided data and contacts with private contractors at specific sites as well. Private contractors mainly supplied data for specific air stripper systems. Equipment vendors were contacted throughout the investigation. In addition, literature sources were also reviewed during the study and pertinent information was

extracted from these published sources. The above information sources are briefly described below.

2.3.1 EPA Regional and Program Offices

EPA Regional offices were contacted at the starting point. Project managers for ground water clean-up projects were contacted first, if a name was available. The project managers often had data on an air stripping site and also provided names of sites other than their own that use air stripping. Contacts were made with several branches within a Region to obtain a thorough listing of air stripper sites. In the Waste Management Divisions within the Regional Offices, Superfund Branch Chiefs were usually contacted for information. In the Water Management Division, appropriate Branch Chiefs for either ground water or drinking water were contacted. Although not usually able to supply data on air strippers, the Branch Chiefs were able to provide names of other EPA personnel with data on air strippers.

In addition to Regional EPA Offices, the Municipal Environmental Research Laboratory (MERL) and Office of Drinking Water were contacted. MERL identified several reports on air stripping and other methods for contaminated water clean-up. The Office of Drinking Water supplied information on field studies.

2.3.2 State Air and/or Water Personnel

While contacting EPA personnel, the names of State personnel knowledgeable about air strippers operating in their state were sought. The State contacts given were usually involved with water quality offices or Superfund clean ups. Although not obtained for all States, these names were used as primary contacts within a State, when available.

Additional names were obtained from the National Air Toxics Information Cleaning House (NATICH) database. This database provided names of the persons involved with air discharge permits for all the States. Because of time constraints, not all States were contacted during this study. Contacts were made with agencies in about 30 States.

2.3.3 Equipment Vendors

Several equipment vendors were contacted for information on air strippers and control devices. Sometimes a previous EPA or State contact provided the name of a vendor. In other cases, if a vendor was known to have supplied equipment at a site, that vendor was contacted. Usually, however, a company was selected for contact because of its advertised listing in the Thomas Register or the "Pollution Engineering" Environmental Equipment Directory. Because of client confidentiality requirements by the vendors, little information was collected from this source.

2.3.4 Plant Personnel

When information on an air stripper was incomplete or unavailable to the EPA or State personnel, a contact at the site was sometimes given. Plant personnel were contacted only if referenced by someone.

2.3.5 Private Consultants

Private consultants were able to provide significant information on several sites. Plant personnel frequently referred questions on the air strippers to their consulting engineering firm. EPA and State personnel also sometimes referred questions to the consulting firm. In some instances, consulting firms provided contacts within their own firm for information on other air stripper installations.

2.3.6 Literature

A literature search was performed to gather general information on air stripping. Although not extensive, it did provide some data on air strippers and references for contacts in industry.

2.4 AIR STRIPPER SYSTEM INSTALLATIONS

This study identified 177 air stripper systems in the United States. It is uncertain what fraction of the total air stripper systems currently operating have been identified. Table 2-1 shows the location and general site data for the air strippers identified during this investigation.

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location			Startup			
Name	City	State	Date	Superfund	Type	References
Confidential			8/87	N	GW	4
Confidential			4/87	N	GW	4
General Dynamics	EPA Region I			N	GW	5
Private Industry					GW	6
Unidentified	City of Scottsdale	AZ			GW	7
Unidentified	Scottsdale	AZ	1984		DW	8
Hughes Aircraft	Tucson	AZ	4/87		GW	9
Motorola 52nd St.	Phoenix	AZ	6/87		GW	10
Unidentified	N. Hlywd-Brbnk Dist.	CA			DW	11
Aerojet	Sacramento	CA			GW	12
AMD, Inc. (1)	Sunnyvale	CA			GW	13
AMD, Inc. (2)	Sunnyvale	CA			GW	13
Applied Materials	Santa Clara	CA			GW	14
Baldwin Park	Valley County	CA	1988	N	DW	8
Bechtel National, Inc.	Merced	CA			GW	6
Beckman Instruments	Porterville	CA	8/85	N	GW	15,16
BKK Landfill	West Covina	CA			LF	6
Calabasas Landfill		CA			LF	6
Chico Well Sta. 16-01	Chico	CA			DW	11
Fairchild	South San Jose	CA			GW	17
Firestone	Salinas	CA	2/86		GW	15
Gas-N-Save, Armour Oil	Davis	CA			GW	16
McClellan AFB	Sacramento	CA		N	GW	18,19
Modern Landfill		CA			LF	6
Palos Verdes Landfill	Palos Verdes	CA			LF	20
Private Industry	San Jose	CA			GW	6
Raytheon	Mountain View	CA			GW	21

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location			Startup			
Name	City	State	Date	Superfund	Type	References
Sharpe Army Depot	Lathrop	CA			GW	22,23
Varian Associates	Santa Clara	CA			GW	24
Lowry Landfill	Denver	CO	1984	Y	LF	25
Unidentified	South Cheshire	CT	1985		DW	8
Unidentified	Meriden	CT			GW	6
Unidentified	Darien	CT	1984		DW	8
CT American Water Co.		CT			DW	6
Kellogg-Deering	Norwalk	CT	~5/87	Y	GW	26
Pratt & Whitney	Middletown	CT			GW	6
Private Industry		CT			GW	6
Unidentified	Ft. Pierce	FL	7/86	N	GW	27
Unidentified	Port Malabar	FL	4/84	N	GW	28,29
Five Ash Well	Ft. Lauderdale	FL	2/87	N	DW	30
Harris Corp.	Melbourne	FL	1984	Y	GW	31
IT Corporation		FL			GW	6
Piper Aircraft	Vero Beach	FL			GW	32
Pratt & Whitney	West Palm Beach	FL	~1983	Y	GW	31
Private Industry		FL			GW	6
Private Industry		FL			GW	6
Sydney Mine	Hillsborough County	FL	1/85	N	GW	33,34
Scofield Barracks	Wheeler AFB	HI	9/86	N	GW	35
Dyco Co., Inc.	Des Moines	IA	7/87	Y	GW	36
ACME Solvent	Rockford	IL			GW	37
Mystic Tape/Borden Chem.	Northfield	IL			GW	37
Sundstrand	Rockford	IL			GW	37
Main St. Well Field	Elkhart	IN	7/87	Y	DW	38,39
Boeing	Wichita	KS	10/86	N	GW	40,41

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location Name	City	State	Startup Date	Superfund	Type	References
General Electric	Arkansas City	KS			GW	40,42
Unidentified	Dedham	MA			GW	6
Unidentified	Acton Water District	MA	1984	N	DW	43
Unidentified	Burlington	MA			GW	6
Unidentified	Raynham	MA	1984		DW	8
M/A-COM	Burlington	MA			GW	6
Private Industry		MA			GW	6
Private Industry		MA			GW	6
Unidentified	Thurmont	MD			GW	6
U. S. Coast Guard	Traverse City	MI			GW	18
Verona Well Field	Battle Creek	MI	9/84	Y	GW	3,44,45
Wurtsmith AFB	Oscoda	MI	1982	N	GW	46
Organics/LaGrange Inc.	Fennville	MI			GW	47
Sundstrand Heat Transfer	Dowagiac	MI			GW	47
AAR Brooks & Perkins	Cadillac	MI			GW	47
Brunswick Div.	Muskegon	MI			GW	47
Clark Equip. Co.	Springfield	MI			GW	47
Dowell Div.	Kalkaska	MI			GW	47
Gast Manufacturing	Bridgman	MI			GW	47
Gast Manufacturing	Benton Harbor	MI			GW	47
Marathon Petr.	Cadillac	MI			GW	47
Cooper Ind.	Albion	MI			GW	47
U. S. Aviex	Niles	MI			GW	47
Westside Landfill	St. Jos. City	MI			LF	47
Chemcentral	Grand Rapids	MI			LF	48
Unidentified	Atwater	MN	4/85	N	GW	49
Unidentified	Spring Grove	MN	3/86	N	GW	49

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location			Startup			
Name	City	State	Date	Superfund	Type	References
Electronic Ind.	New Hope	MN	5/85	N	GW	49
General Mills	Minneapolis	MN			GW	49
Whitaker Site	Minneapolis	MN	5/85	N	GW	49
Private Industry	St. Louis	MO			GW	6
Eaton	Kearney	NE			GW	50
Monroe Auto	Cozad	NE	9/86	N	GW	50
Gilson Rd.	Nashua	NH	7/86	Y	GW	18
Unidentified	Town of East Hanover	NJ			GW	6
Unidentified	Rocky Hill	NJ	7/83		DW	8,51
Unidentified	Mountainside	NJ	1985		DW	8
Unidentified	Fairfield	NJ	1984		DW	52
Unidentified	Plainfield	NJ	1987		DW	8
Unidentified	Rockaway	NJ	2/82	N	DW	8,51,53
Unidentified	Vestal	NY			GW	6
Channel Master, Inc.	Ellenville	NJ			GW	6
Denville Water Dept.	Denville	NJ	1979		DW	51
E. Hanover Water Dept.	East Hanover	NJ	1984		DW	51
McGraw Edison	Olean	NJ			GW	6
Private Industry	Dover	NJ			GW	6
Private Industry		NJ			GW	6
South Brunswick TWP	Brunswick	NJ	1985		DW	8,51
VO-TECH H.S.	Warren County	NJ			GW	6
Unidentified	Hicksville, Long Island	NY	1985		DW	8,54
Unidentified	Garden City Park	NY	1985		DW	8
Unidentified	Lake Success	NY	1984	N	DW	52
Unidentified	Queens	NY	1984		DW	8
Unidentified	Floral Park	NY	1985		DW	8

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location Name	City	State	Startup Date	Superfund	Type	References
Unidentified	New Hyde Park	NY	1985		DW	8
Unidentified	Brewster	NY	1983	N	DW	8,54,55
Unidentified	South Huntington	NY			GW	6
Unidentified	Cortland	NY			GW	6
Unidentified	Northport	NY	1984		DW	6,8
Citizens Water Supply	Great Neck, Long Island	NY	1984		DW	8,54
EPA Region II	Hicksville	NY			GW	6
Jamaica Water Supply Co.	Nassau County	NY			DW	54
Jamaica Water Supply Co.	Nassau County	NY			DW	54
Private Industry		NY			GW	6
Private Industry		NY			GW	6
Private Industry		NY			GW	6
Suffolk Co. Water Auth.	Long Island	NY			DW	6
Unidentified	Zanesville	OH		N	DW	51
Unidentified	Dayton	OH	2/88	N	GW	56
Chem Dyne	Hamilton	OH			GW	57
Unidentified	Upper Merion (#3)	PA	1985		DW	8
Unidentified	Hatboro (#2)	PA	1985		DW	8
Unidentified	Warrington	PA	1982		DW	8
Unidentified	Upper Merion (#2)	PA	1985		DW	8
Superior Tube Co.	Norristown	PA	~1980	N	DW	52
Unidentified	Hatboro (#1)	PA	1984		DW	8
Unidentified	Flower Town Well	PA		N	DW	58
Allied Bendix	South Montrose	PA			GW	59
AMP, INC.	Williamstown (#1)	PA			GW	59
AMP, INC.	Codorus (#1)	PA			GW	59
AMP, INC.	Codorus (#2)	PA			GW	59

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location			Startup			
Name	City	State	Date	Superfund	Type	References
AMP, INC.	Williamstown (#2)	PA			GW	59
AMP, INC.	Springfield	PA			GW	59
Audubon Water Co.		PA			DW	6
Audubon Water Co.		PA			DW	6
AVCO Lycoming (1)	Williamsport	PA			GW	59
AVCO Lycoming (2)	Williamsport	PA			GW	59
AVCO Lycoming (3)	Williamsport	PA			GW	59
Boyertown Landfill		PA			LF	6
Fischer & Porter	Warminster	PA	2/86	Y	GW	60
4th St., AVCO Lycoming	Williamsport	PA			GW	59
Ind. Solvent & Chem.	Newberry	PA			GW	59
Laurel Pipeline Co.	Bethel	PA			GW	59
Lycoming Ck. Well Field	Williamsport	PA	1986		DW	8
McCoy Electronics, Inc.	Peters	PA			GW	59
Middletown Borough Auth.	Middletown Borough	PA			GW	59
PENNDOT (Bur. of Avia.)	Lower Swatara	PA			GW	59
Private Industry	Reading	PA			GW	6
Rockwell International	Du Bois	PA			GW	59
Spec. Screw Mach. Prod.		PA			GW	59
Sun Refining & Marketing	Norristown	PA			GW	59
Tyson's Dump Site	Upper Merion	PA			LF	61
Upper Merion Res. (#1)	Upper Merion	PA	1983	N	DW	58
Well L-8, N. Penn Water	Lansdale	PA			DW	59
Westinghouse Electric	Cumberland	PA			GW	59
Whistlewood Apts.		PA			GW	6
York County Refuse Auth.	Hopewell	PA			GW	59
J. T. Baker Co.		TN			GW	6

TABLE 2-1. LIST OF IDENTIFIED AIR STRIPPERS

Facility/Location			Startup			
Name	City	State	Date	Superfund	Type	References
Unidentified	Chesapeake	VA	1985		DW	8
Unifirst	Williamstown	VT			DW	62
Dudley's Store	East Montpelier	VT			GW	63
Spillanes Mobil	Shelburne	VT			GW	63
Dowty Electronics	Brandon	VT			GW	63
Keith Martin	N. Bennington	VT			GW	63
Unidentified	City of Tacoma	WA	1983	Y	GW	35,64
Ponders Corner	Tacoma	WA	1984	Y	GW	35
Unidentified	Schofield	WI		N	GW	65
Unidentified	Hartland	WI	2/84	N	DW	8,51,65
Unidentified	Rothschild	WI		N	GW	65
Unidentified	Wausau (#2)	WI	8/84	N	GW	65,66
Unidentified	Eau Claire	WI	1988	Y	GW	67
Unidentified	Wausau (#1)	WI		N	DW	65
Unidentified	Delavan	WI	9/84	N	DW	52

GW = Ground Water

LF = Landfill Leachate

DW = Drinking Water

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3.0 AIR STRIPPING TECHNOLOGY AND EMISSIONS

Air stripping is a method frequently used to remove volatile organic pollutants from ground water. The high removal efficiency and relatively low cost of air stripping make it an attractive technology for ground water cleanup. However, a major environmental concern is the cross media transfer of contaminants in the water to air, without reducing the volume of the contaminants. The transfer of ground water contaminants from ground water to air is the focus of this section. Air emissions from currently operating air strippers are characterized and the factors affecting emissions are discussed.

3.1 AIR STRIPPING TECHNOLOGY

Air stripping technology is based on the principle of vapor-liquid equilibrium. Contaminated water is contacted with large volumes of ambient air. The concentration of contaminants in the influent air is far below equilibrium, providing the driving force for transfer of contaminants from water to air. The schematic of a typical air stripper system is shown in Figure 3-1. Contaminated water is pumped from the water source to the tower, where it is countercurrently contacted with air. The water entering the tower trickles down over a packed media which generates a thin film of water for air contact. The thin film provides a large surface area for air to water contact.

Air flow through the stripper column is provided by a blower. The air blower can be placed either before or after the column. Placement of the blower before the column is referred to as forced draft. Placement of the blower after the stripper column is referred to as induced draft. In cases where the effluent air stream is routed to an air emission control device, blowers are often placed both before and after the column. This blower arrangement is normally referred to as a balanced draft.

The effluent air stream is generally exhausted from the stripping column to the atmosphere. However, the contaminated air stream is routed to an emission control device at several sites. Emission controls used to control air emissions from air strippers are discussed in Section 4.

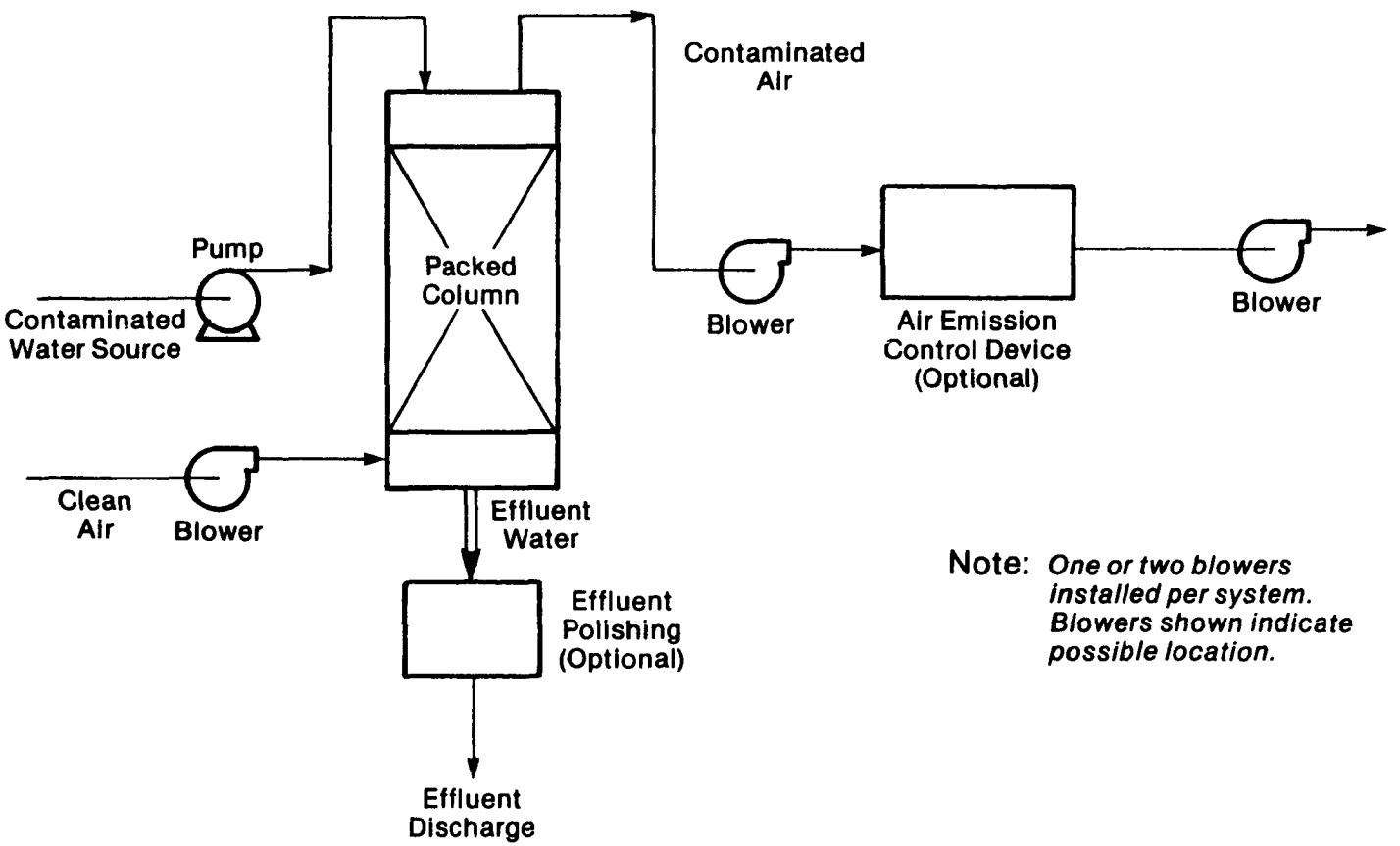

Figure 3-1. Typical air stripper system

The stripped water leaving the column can be treated several ways. Often it is discharged to a river, drainage ditch, or other surface water supply. In some cases, the stripper effluent is routed through another treatment unit such as an aqueous-phase carbon adsorber or routed to a water treatment system. Although not often done, the water can also be discharged back to the aquifier or other source of the contaminated water.

3.2 AIR EMISSIONS FROM AIR STRIPPERS

As discussed above, air stripping is a technology which transfers organic contaminants from water to air. Unless the contaminated air stream is routed to an air emissions control device, the organic compounds volatilized from the water become air emissions. To characterize these emissions from air strippers, data were collected on currently operating air strippers. A total of 177 operating air strippers were identified and available data on pollutant loadings, design, operation, and performance were collected. The completeness of data available for individual air strippers varied. However, the data collected for 52 of the 177 air strippers were sufficient to characterize air pollutant loadings. Of these 52, sufficient data (reported stripper efficiency) were available to estimate volatile organic emissions from 46 air strippers. The data collected on pollutant loadings, design, operation, and performance for the 52 air strippers are presented in Table 3-1.

The quality of the data presented in Table 3-1 varies widely. The basis for the majority of reported values is unknown. If the basis is known, the value is footnoted appropriately in Table 3-1. For some strippers, all data gathered were obtained through telephone contacts, while data for others are based on site visits or test reports. Concentration data presented in Table 3-1 are from weekly or monthly inlet water sampling, pilot studies, and estimates used for design of the air strippers. A single concentration was usually obtained for a contaminant although the inlet concentration varies with time. The water flow rates were either design capacities or actual measured rates. At some sites, the reported water flow rate is significantly lower than the design rate. The stripper removal efficiency data were from actual influent and effluent monitoring data in some cases and from estimated design efficiency in others.

TABLE 3-1. AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE

Facility/Location			Water Flow[a]			Pollutant Loading[c]	Air Stripper Design and Operation						
					Conc.		Column Packing			Air Flow[d]	Air To Water Ratio[d]	Reported Removal Eff.(%)[e]	
Name	City	State	(gpm)	Pollutant[b]	(ug/l)	(kg/yr)	Diam. (ft)	Ht. (ft)	No. of Cols.	(cfm)			REFERENCES
Confidential - Stover(1)			200[f]	BZ	1000[f]	381.6	4	20	1	2700[f]	100	100[f]	1
				TOL	1000[f]	381.6						100[f]	
				XYL	1000[f]	381.6						100[f]	
				VO	3000	1144.7						100	
Confidential - Stover(2)			600[f]	BZ	10000[f]	11446.8	4	25	2	4000[f]	50	99.9[f]	1
				XYL	5000[f]	5723.4						99.8[f]	
				EBZ	5000[f]	5723.4						99.8[f]	
				EDC	1000[f]	1144.7						99[f]	
				VO	21000	24038.4						99.8	
Unidentified	Scottsdale	AZ	3700	TCE	200[h]	1411.8	10	14	1	25000	50	99[h]	2
Unidentified	City of Scottsdale	AZ	7[f]	VOC	130000[f]	1736.1						98[f]	3
Hughes Aircraft	Tuscon	AZ	4200[f]	TCE	800[f]	6410.2	9/9	6/25	3/3	4800[f]	30[f]	99.4[f]	4
				TCA	100[f]	801.3						99.5[f]	
				EDC	200[f]	1602.6						99[g]	
				VO	1100	8814.1						99.3	
AMD, Inc.	Sunnyvale	CA	175[h]	VOC	2000[h]	667.7						99.5[h]	5
Baldwin Park	Valley County	CA	970	TCE	710[h]	1313.9	8	18	1	4000	30	99[h]	2
				PCE	330	610.7						99	
				VO	1040	1924.6						99	
Unidentified	South Chesire	CT	1700	TCE	100[h]	324.3	9x8	26	1	8000	35	99[h]	2
CT American Water Co.		CT	300	TCA	75[h]	42.9	4.5					70	3
Private Industry		CT	200	TCE	20000[h]	7631.2	4					99.9[h]	3
Unidentified	Ft. Pierce	FL	350[h]	TCE	11.3[h]	7.5	4	16	1	2000	50[f]	99[h]	6
				PCE	76[h]	50.7						99[h]	
				VO	87.3	58.3						99	
Unidentified	Port Malabar	FL	1000[f]	VOC	57[h]	108.7	9x9	12	1	9000[f]	70	99[h]	7,8

TABLE 3-1. AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE (Cont.)

Facility/Location			Water[a] Flow			Air Stripper Design and Operation							
						Pollutant	Column Packing			Air[d]	Air To	Reported	
Name	City	State	(gpm)	Pollutant[b]	Conc. (ug/l)	Loading[c] (kg/yr)	Diam. (ft)	Ht. (ft)	No. of Cols.	Flow (cfm)	Water Ratio[d]	Removal Eff.(%)[e]	REFERENCES
Sydney Mine	Hillsborough County	FL	150[f]	EDC	24[h]	6.9	4		1	4700[f]	220[f]	100[h]	9,10
				MCL	9[h]	2.6						100[h]	
				TCA	8[h]	2.3						100[h]	
				DCE	2[h]	0.6						100[h]	
				VO	43	12.3						100	
Boeing	Wichita	KS	56[h]	TCE	6000[h]	641.0			1			98[f]	11,12
Acton Water District	Acton	MA	417[h]	TCA	25[h]	19.9	5.5	20	1	3000	50	99	2,13
				DCE	25[h]	19.9						99	
				TCE	10[h]	8.0						99	
				VO	60	47.7						99	
Site A		MI	1400[h]	TCE	4000[h]	10683.7				8000[h]	40	99.8[h]	14
				TCA	300[h]	801.3						100[h]	
				VO	4360	11645.2						99	
Site B		MI	155[h]	CF	1500[i]	440.0	3	45	1	1300[h]	60	99.9[h]	15
				MCL	ND								
				EDC	ND								
Verona Well Field	Battle Creek	MI	1900[h]	EDC	5[h]	18.1	10	40	1	5500[f]	20	100[h]	16,17,18
				TCA	12[h]	43.5						100[h]	
				DCE	10[h]	36.2						100[h]	
				TCE	1[h]	3.6						100[h]	
				PCE	10[h]	36.2						100[h]	
				VO	38	137.7						100	
Electronic Ind.	New Hope	MN	75	TCE	200000	28617.1			1	10000	1000	ND	19
				MCL	20	2.9						ND	
				PCE	4700	672.5						ND	
				TCA	150	21.5						ND	
				EDC	8.9	1.3						ND	
				CF	15	2.1						ND	
				VO	204893.	29317.3						ND	

TABLE 3-1. AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE (Cont.)

Facility/Location							Air Stripper Design and Operation						
Name	City	State	Water Flow[a] (gpm)	Pollutant[b]	Conc. (ug/l)	Pollutant Loading[c] (kg/yr)	Column Packing Diam. (ft)	Column Packing Ht. (ft)	No. of Cols.	Air Flow[d] (cfm)	Air To Water Ratio[d]	Reported Removal Eff.(%)[e]	REFERENCES
Whitaker Site	Minneapolis	MN	50	TOL	23000	2194.0			1	270	40	ND	19
				EBZ	14000	1335.5						ND	
				XYL	53000	5055.7						ND	
				VO	90000	8585.1						ND	
Monroe Auto	Cozad	NE	1940	TCE	600[f]	2220.7	5		1	10000	40[f]	90	20
Unidentified	Rockaway	NJ	1400	TCE	250[h]	667.7	9	25	1	37500	200	100[h]	2,21,22
				MTBE	50[h]	133.5						95[h]	
				DIPE	50[h]	133.5						99[h]	
				VO	350[h]	934.8						99.1	
Unidentified	Rocky Hill	NJ	35	TCE	80[h]	5.3	6	10	2	2600	80[h]	99	2,22
Unidentified	Mountainside	NJ	625	TCE	1000[h]	1192.4	5x4	26	1	3300	40	99[h]	2
				PCE	100[h]	119.2						90[h]	
				VO	1100[h]	1311.6						98.2[h]	
Unidentified	Plainfield	NJ	3600[f]	PCE	200[f]	1373.6	12x10	24	1	19200	40[f]	99.6[f]	2
Denville Water Dept.	Denville	NJ	500	TCA	5[h]	4.8	9	25	1	4000	60[f]	100[h]	22
				PCE	7[h]	6.7						86[h]	
				VO	12[h]	11.4						91.8[h]	
E. Hanover Water Dept.	East Hanover	NJ	750	TCE	50[h]	71.5	7x13.8	4.5	1	6000	60[f]	76[h]	22
South Brunswick TWP	Brunswick	NJ	1100	TCE	75[h]	157.4	7	10	1	13000	90[f]	99[h]	2,22
				PCE	3[h]	6.3						99[h]	
				DCE	40[h]	83.9						99[h]	
				VO	118	247.6						99	
VO-Tech H.S.	Warren County	NJ	30	TCE	30[h]	1.7	1.5					95[h]	3
Unidentified	Queens	NY	3000	PCE	300[h]	1717.0	12x7	15	1	16000	40	97[h]	2
				TCE	100[h]	572.3						90[h]	
				VO	400[h]	2289.4						95.3[h]	
Unidentified	Garden City Park	NY	1200	PCE	90[h]	206.0	7.5	16	1	5600	35	94[h]	2

TABLE 3-1. AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE (Cont.)

Facility/Location							Air Stripper Design and Operation						
Name	City	State	Water[a] Flow (gpm)	Pollutant[b]	Conc. (ug/l)	Pollutant Loading[c] (kg/yr)	Column Packing Diam. (ft)	Ht. (ft)	No. of Cols.	Air Flow[d] (cfm)	Air To Water Ratio[d]	Reported Removal Eff.(%)[e]	REFERENCES
Unidentified	Brewster	NY	600	PCE	110[h]	125.9	4.8	17.8	1	3000	38[f]	99[h]	2,23,24
				EDC	49[h]	56.1						99[h]	
				TCE	17[h]	19.5						99[h]	
				VO	176	201.5						99	
Unidentified	New Hyde Park	NY	2400	TCE	300[h]	1373.6	12x7	21	1	12800	40	97[h]	2
				PCE	100[h]	457.9						90[h]	
				VO	400	1831.5						95.3	
Unidentified	Lake Success	NY	2400	TCE	30	137.4	7x12	21	1	14000	41	97	25
Unidentified	Floral Park	NY	3000	TCE	300[h]	1717.0	12x7	18	1	16000	40	97[h]	2
				TCA	50[h]	286.2						95[h]	
				VO	350	2003.2						96.7	
Unidentified	Northport	NY	1300	PCE	450[h]	1116.1	6	16	1	5200	30[f]	99[h]	2,3
Citizens Water Supply	Great Neck, Long Island	NY	2000	BZ	200[h]	763.1	10	24	1	21400	80[f]	99[h]	2,23
				PCE	55[h]	209.9						99[h]	
				TCE	40[h]	152.6						99[h]	
				VO	295	1125.6						99	
EPA Region II	Hicksville	NY	100	MEK	1000	190.8	3.5					99	3
Unidentified	Zanesville	OH	300	TCE	15000	8585.1	4	20	1	1850	45	97	25
				DCE	3000	1717.0						97	
				VO	18000	10302.2						97	
Unidentified	Hatboro (#1)	PA	215	TCE	300[h]	123.1	5.5	25	1	6300	220	99[h]	2
				MTBE	130[h]	53.3						99[h]	
				DIPE	20[h]	8.2						95[h]	
				EDC	15[h]	6.2						99[h]	
				PCE	10[h]	4.1						98[h]	
				VO	475	194.8						98.8	
Unidentified	Upper Merion (#3)	PA	690	TCE	15[h]	19.7	4.5	10	1	1400	15	95[h]	2

TABLE 3-1. AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE (Cont.)

Facility/Location			Air Stripper Design and Operation										
			Water[a] Flow			Pollutant[c] Loading	Column Packing Diam.	Column Packing Ht.	No. of	Air Flow[d]	Air To Water Ratio[d]	Reported Removal Eff.(%)[e]	
Name	City	State	(gpm)	Pollutant[b]	Conc. (ug/l)	(kg/yr)	(ft)	(ft)	Cols.	(cfm)			REFERENCES
Unidentified	Warrington	PA	120	TCE	130[h]	29.8	2.7	16	1	500	30	97[h]	2
Unidentified	Hatboro (#2)	PA	278	TCE	300[h]	159.1						99[h]	2
				EDC	80[h]	42.4						99[h]	
				PCE	10[h]	5.3						95[h]	
				VO	390	206.8						98.9	
Lycoming Ck. Well Field	Williamsport	PA	4168	TCE	350[h]	2783.1	10/10	23/23	2/2	56000	100	99[h]	2
				PCE	10	79.5						ND	
				DCE	10	79.5						ND	
				VO	370	2942.1						ND	
Superior Tube Co.	Norristown	PA	65[h]	TCE	9000[h]	1116.1	1.5-3		3	300[h]	30	98[h]	25
Tysons Dump	Upper Merion	PA	5[h]	1,2,3-TCP	30000[h]	298.4			1	170[h]		99[h]	26
				XYL	17000[h]	169.1						98[h]	
				TOL	210[h]	2.1						ND[h]	
				ANILINE	102[h]	1.0						58[h]	
				PHENOL	109[h]	1.1						74[h]	
				2-MPH	53[h]	0.5						70[h]	
				EBZ	40[h]	0.4						ND	
				VO	47514	472.6						ND	
Upper Merion Res. (#1)	Upper Merion	PA	13900	TCE	20[h]	530.4	12	14	2	27900	15	90[h]	27
Unidentified	Chesapeake	VA	9000	CF	77[h]	1322.1	13.7	30	2	54100	45	48[h]	2
				CHBrCl2	36[h]	618.1						81[h]	
				CHBr2Cl	34[h]	583.8						60[h]	
				CHBr3	8[h]	137.4						44[h]	
				VO	155[h]	2661.4						58.1	
Unifirst		VT	24[h]	PCE	125[h]	5.7						98.5[h]	28

TABLE 3-1. AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE (Cont.)

Facility/Location			Air Stripper Design and Operation									
			Water[a] Flow			Pollutant Loading[c]	Column Packing			Air Flow[d]	Air To Water Ratio[d]	Reported Removal Eff.(%)[e]	
Name	City	State	(gpm)	Pollutant[b]	Conc. (ug/l)	(kg/yr)	Diam. (ft)	Ht. (ft)	No. of Cols.	(cfm)			REFERENCES
City of Tacoma	Tacoma	WA	3500	1,1,2,2-TCA	300[h]	2003.2	12	23	5	145000	300	95[h]	29,30
				TCE	130[h]	868.1						99[h]	
				DCE	100[h]	667.7						99[h]	
				VO	530[h]	3539.0						96.7	
Unidentified	Wausau (#1)	WI	2000	TCE	72[h]	274.7	9.3	24.5	1	16000	30	98[h]	2,31
				DCE	82[h]	312.9						96[h]	
				PCE	60[h]	228.9						98[h]	
				TOL	30[h]	114.5						96[h]	
				XYL	17[h]	64.9						96[h]	
				VO	261[h]	995.9						97.0	
Unidentified	Hartland	WI	1000	TCE	240[h]	457.9	9	26.8	1	6700	50	99[h]	2,25,31

[a] This is the total flow to all air strippers at the site.

[b] Pollutant abbreviations used are: BZ = Benzene; TOL = Toluene; XYL = Xylene; VO = Total Volatile Organics (calculated as the sum of pollutants reported); EBZ = Ethylbenzene; EDC = Ethylene Dichloride or Dichloroethane; VOC = Volatile Organic Compounds (provided by facility rather than calculated); TCA = Trichloroethane; TCE = Trichloroethylene; MCL = Methylene Chloride; DCE = Dichloroethylene; PCE = Perchloroethylene or Tetrachloroethane; MTBE = Methyl-tertiary-butyl-ether; DIPE = Diisopropylether; MEK = Methyl Ethyl Ketone; 1,2,3-TCP = 1,2,3-Trichloropropane; 2-MPH = 2-Methylphenol; CHLBZ = Chlorobenezene; and CF = Chloroform.

[c] Pollutant loadings calculated using reported water flow and influent concentration. In some cases, only the design flow was available which may result in an overestimate of pollutant loading. All air strippers are assumed to operate 8,400 hours per year in calculating loadings which is equivalent to 350 days of operation each year.

[d] In most cases only the air to water ratio or the air flow rate was provided. In this case, one was calculated from the other using the reported water flow rate. However, in some cases, air to water ratios and air flow rates were provided that do not match precisely.

[e] These are efficiencies reported by the sites or other information sources and are generally not supported by test data. VO removal efficiencies are calculated based on the reported efficiencies for individual pollutants. The calculated VO removal efficiencies are weighted averages.

[f] Reported values are based on design.

[g] An efficiency for removal of EDC was not available. An efficiency of 99 percent was estimated based on the reported efficiencies for the other pollutants.

[h] Reported values are based on actual monitoring or sampling.

[i] Initial concentration based on sampling. Concentration has reportedly dropped since start-up.

As shown in Table 3-1, the water treated by air stripping contains various pollutants. By far, the majority of sites are contaminated with chlorinated ethanes or ethylenes. Of the 52 sites for which loadings are presented, 34 are contaminated with trichloroethylene, 17 have perchloroethylene, 9 have 1,1,1-trichloroethane, 7 have dichloroethylene, and 8 have dichloroethane contamination. The remaining sites are contaminated by toluene, xylenes, benzene, and several chlorinated methanes, ethers, and aromatics.

The data presented in Table 3-1 were used to estimate and characterize uncontrolled air emissions from each air stripper. Since contaminants are simply transferred from the influent water to air, the air emissions were estimated by multiplying the influent loading by the reported removal efficiency. Assuming 8400 hours per year of air stripper operation, annual emissions were calculated for each stripper by pollutant. The total volatile organic emissions were also calculated for each air stripper as the sum of the individual pollutants. These estimated air emissions are presented in Table 3-2. In addition, the air flow rates and calculated pollutant concentrations are provided in Table 3-2. The emission estimates presented in Table 3-2 do not account for air emission controls in place at some facilities.

The estimates of uncontrolled air emissions are further summarized in Table 3-3. The averages and ranges of estimated annual emissions and concentrations are presented by pollutant. As shown in Table 3-3, the average total volatile organic emissions from air strippers is 2.0 Mg/yr. The range of estimated total volatile organic emissions is 1.6 kg/yr to 24 Mg/yr. The average concentration of total volatile organics in the effluent air is 7.8 ppmv. Effluent air concentrations of total volatile organics range from 0.03 ppmv to 110 ppmv.

3.3 FACTORS AFFECTING AIR EMISSIONS

There are four major factors that effect air emissions from air strippers. These are: (1) the pollutant loading to the air stripper, (2) the removal efficiency obtained by the air stripper, (3) the changes in the pollutant loading with time, and (4) the annual period of operation. Each of these factors are discussed in detail below.

TABLE 3-2. ESTIMATES OF UNCONTROLLED AIR EMISSIONS

Facility/Location			Air Flow		Pollutant Conc. In Air[b]	Air Emissions[c]
Name	City	State	(cfm)	Pollutant[a]	(ppmv)	(kg/yr)
Confidential - Stover(1)			2700	BZ	3.00	381.6
				TOL	2.55	381.6
				XYL	2.21	381.6
				VO	7.76	1144.7
Confidential - Stover(2)			4000	BZ	60.77	11435.4
				XYL	22.34	5712.0
				EBZ	22.34	5712.0
				EDC	4.75	1133.2
				VO	110.19	23992.6
Unidentified	Scottsdale	AZ	25000	TCE	0.69	1397.7
Unidentified	City of Scottsdale	AZ		VOC	ND[d]	1701.4
Hughes Aircraft	Tuscon	AZ	4800	TCE	16.43	6371.8
				TCA	2.03	797.3
				EDC	5.54	1586.5
				VO	23.99	8755.6
AMD, Inc.	Sunnyvale	CA		VOC	ND	664.4
Baldwin Park	Valley County	CA	4000	TCE	4.02	1300.8
				PCE	1.51	604.6
				VO	5.53	1905.3
Unidentified	South Chesire	CT	8000	TCE	0.50	321.1
CT American Water Co.		CT		TCA	ND	30.0
Private Industry		CT		TCE	ND	7623.6
Unidentified	Ft. Pierce	FL	2000	TCE	0.05	7.5
				PCE	0.25	50.2
				VO	0.30	57.7
Unidentified	Port Malabar	FL	9000	VOC	0.20	107.7

TABLE 3-2. ESTIMATES OF UNCONTROLLED AIR EMISSIONS (Cont.)

Facility/Location			Air Flow	Pollutant[a]	Pollutant Conc. In Air[b]	Air Emissions[c]
Name	City	State	(cfm)		(ppmv)	(kg/yr)
Sydney Mine	Hillsborough County	FL	4700	EDC	0.02	6.9
				MCL	0.01	2.6
				TCA	0.01	2.3
				DCE	0.00	0.6
				VO	0.04	12.3
Boeing	Wichita	KS		TCE	ND	628.2
Acton Water District	Acton	MA	3000	TCA	0.08	19.7
				DCE	0.11	19.7
				TCE	0.03	7.9
				VO	0.22	47.3
Site A		MI		TCE	ND	10662.3
				TCA	ND	801.3
				VO	ND	11528.8
Site B		MI	1300	CF	4.7	439.6
				MCL	ND	ND
				EDC	ND	ND
Verona Well Field	Battle Creek	MI	5500	EDC	0.06	18.1
				TCA	0.10	43.5
				DCE	0.11	36.2
				TCE	0.01	3.6
				PCE	0.07	36.2
				VO	0.34	137.7
Monroe Auto	Cozad	NE	10000	TCE	2.47	1998.6
Unidentified	Rockaway	NJ	37500	TCE	0.22	667.7
				MTBE	0.06	126.9
				DIPE	0.06	132.2
				VO	0.34	926.8
Unidentified	Rocky Hill	NJ	2600	TCE	0.03	5.3

TABLE 3-2. ESTIMATES OF UNCONTROLLED AIR EMISSIONS (Cont.)

Facility/Location			Air Flow	Pollutant[a]	Pollutant Conc. In Air[b]	Air Emissions[c]
Name	City	State	(cfm)		(ppmv)	(kg/yr)
Unidentified	Mountainside	NJ	3300	TCE	4.43	1180.5
				PCE	0.32	107.3
				VO	4.75	1287.8
Unidentified	Plainfield	NJ	19200	PCE	0.71	1368.1
Denville Water Dept.	Denville	NJ	4000	TCA	0.01	4.8
				PCE	0.01	5.7
				VO	0.03	10.5
E. Hanover Water Dept.	East Hanover	NJ	6000	TCE	0.11	54.4
South Brunswick TWP	Brunswick	NJ	13000	TCE	0.15	155.8
				PCE	0.00	6.2
				DCE	0.11	83.1
				VO	0.26	245.2
VO-Tech H.S.	Warren County	NJ		TCE	ND	1.6
Unidentiifed	Queens	NY	16000	PCE	1.04	1665.5
				TCE	0.40	515.1
				VO	1.44	2180.6
Unidentified	Garden City Park	NY	5600	PCE	0.35	193.7
Unidentified	Brewster	NY	3000	PCE	0.42	124.7
				EDC	0.31	55.5
				TCE	0.08	19.3
				VO	0.80	199.4
Unidentified	New Hyde Park	NY	12800	TCE	1.29	1332.4
				PCE	0.32	412.1
				VO	1.61	1744.5
Unidentified	Lake Success	NY	14000	TCE	0.12	133.2

TABLE 3-2. ESTIMATES OF UNCONTROLLED AIR EMISSIONS (Cont.)

Facility/Location			Air Flow	Pollutant[a]	Pollutant Conc. In Air[b]	Air Emissions[c]
Name	City	State	(cfm)		(ppmv)	(kg/yr)
Unidentified	Floral Park	NY	16000	TCE	1.29	1665.5
				TCA	0.21	271.9
				VO	1.50	1937.4
Unidentified	Northport	NY	5200	PCE	2.12	1104.9
Citizens Water Supply	Great Neck, Long Island	NY	21400	BZ	0.75	755.5
				PCE	0.10	207.8
				TCE	0.09	151.1
				VO	0.93	1114.3
EPA Region II	Hicksville	NY		MEK	ND	188.9
Unidentified	Zanesville	OH	1850	TCE	55.70	8327.6
				DCE	15.39	1665.5
				VO	71.09	9993.1
Unidentified	Hatboro (#1)	PA	6300	TCE	0.24	121.8
				MTBE	0.16	52.8
				DIPE	0.02	7.8
				EDC	0.02	6.1
				PCE	0.01	4.0
				VO	0.44	192.5
Unidentified	Upper Merion (#3)	PA	1400	TCE	0.17	18.8
Unidentified	Warrington	PA	500	TCE	0.71	28.9
Unidentified	Hatboro (#2)	PA		TCE	ND	157.5
				EDC	ND	42.0
				PCE	ND	5.0
				VO	ND	204.6

TABLE 3-2. ESTIMATES OF UNCONTROLLED AIR EMISSIONS (Cont.)

Facility/Location			Air Flow		Pollutant Conc. In Air[b]	Air Emissions[c]
Name	City	State	(cfm)	Pollutant[a]	(ppmv)	(kg/yr)
Lycoming Ck. Well Field	Williamsport	PA	56000	TCE	0.61	2755.3
				PCE	ND	ND
				DCE	ND	ND
				VO	ND	ND
Superior Tube Co.	Norristown	PA	300	TCE	45.11	1093.7
Tysons Dump	Upper Merion	PA		1,2,3-TCP	ND	295.4
				XYL	ND	165.7
				TOL	ND	ND
				ANILINE	ND	0.5
				PHENOL	ND	0.8
				2-MPH	ND	0.4
				EBZ	ND	ND
				VO	ND	ND
Upper Merion Res. (#1)	Upper Merion	PA	27900	TCE	0.21	477.3
Unidentified	Chesapeake	VA	54100	CF	0.16	634.6
				CHBrCl2	0.09	500.7
				CHBr2Cl	0.05	350.3
				CHBr3	0.01	60.4
				VO	0.32	1546.0
Unifirst		VT		PCE	ND	5.6
City of Tacoma	Tacoma	WA	145000	1,1,2,2-TCA	0.13	1903.0
				TCE	0.07	859.4
				DCE	0.08	661.1
				VO	0.28	3423.5

TABLE 3-2. ESTIMATES OF UNCONTROLLED AIR EMISSIONS (Cont.)

Facility/Location			Air Flow	Pollutant[a]	Pollutant Conc. In Air[b]	Air Emissions[c]
Name	City	State	(cfm)		(ppmv)	(kg/yr)
Unidentified	Wausau (#1)	WI	16000	TCE	0.21	269.2
				DCE	0.32	300.4
				PCE	0.14	224.4
				TOL	0.12	109.9
				XYL	0.06	62.3
				VO	0.85	966.1
Unidentified	Hartland	WI	6700	TCE	0.84	453.3

[a] Pollutant abbreviations used are: BZ = Benzene; TOL = Toluene; XYL = Xylene; VO = Total Volatile Organics (calculated as the sum of pollutants reported); EBZ = Ethylbenzene; EDC = Ethylene Dichloride or Dichloroethane; VOC = Volatile Organic Compounds (provided by facility rather than calculated); TCA = Trichloroethane; TCE = Trichloroethylene; MCL = Methylene Chloride; DCE = Dichloroethylene; PCE = Perchloroethylene or Tetrachloroethane; MTBE = Methyl-tertiary-butyl-ether; DIPE = Diisopropylether; MEK = Methyl Ethyl Ketone; 1,2,3-TCP = 1,2,3-Trichloropropane; 2-MPH = 2-Methylphenol; CHLBZ = Chlorobenezene; and CF = Chloroform.

[b] Pollutants concentration in air calculated from air flowrate and estimated emission rate based on ideal gas law. Molecular weight assumed to be 100 g/mol for VOC. Air temperature assumed to be 60 ^{o}F.

[c] Air emissions calculated from pollutant loading and reported removal efficiency based on 8400 hours per year operation.

[d] ND = No Data. Insufficient data available to calculate this value.

TABLE 3-3. SUMMARY OF ESTIMATED AIR EMISSIONS

Pollutant	No. of Data Points	Concentration (ppmv) Average	Concentration (ppmv) Range	Annual Emissions (kg/yr) Average	Annual Emissions (kg/yr) Range
Aniline	1	ND[a]	ND	5.0	NA[b]
Benzene	3	22	1-66	4,190	380-11,400
Bromoform	1	0.01	NA	60	NA
Chloroform	2	2.4	0.16-4.7	540	440-635
$CHBr_2Cl$	1	0.05	NA	350	NA
$CHBrCl_2$	1	0.09	NA	500	NA
Chlorobenzene	0	ND	ND	ND	ND
Dichloroethylene	7	2.3	>0.01-15	400	0.6-1,660
Diisopropylether	2	0.04	0.02-0.06	66	7.8-130
Ethylbenzene	1	22	NA	5,710	NA
Ethylene Dichloride	7[c]	1.8	9.02-5.5	410	6.1-1,590
Methylene Chloride	1	0.01	NA	2.6	NA
Methyl Ethyl Ketone	1	ND	ND	190	ND
2-Methylphenol	1	ND	ND	2.1	NA
Methyl Tertiary Butylether	2	0.11	0.06-0.16	90	53-130
Perchloroethylene	15[d]	0.49	>0.01-2.1	360	4.0-1,660
Phenol	1	ND	ND	9.8	ND
1,1,2,2-Tetrachloroethane	1	0.13	NA[a]	1,900	NA
Trichloroethane	8[e]	0.41	0.01-2.03	250	2.3-800
Trichloroethylene	34[f]	4.7	0.01-55.7	1,440	1.6-10,600
1,2,3-Trichloropropane	1	ND[b]	ND	1,920	NA
Toluene	2	1.3	0.12-2.6	250	110-380
Xylene	4[g]	8.2	0.06-22	1,790	62-5,710
Volatile Organic Compounds	3[h]	0.2	NA	820	110-1,700
Total Volatile Organics[i]	46[j]	7.8	0.03-110	2,020	1.6-24,000

[a]ND = No Data. Insufficient data available.
[b]NA = Not Applicable. Data available for only one stripper.
[c]Sufficient data were available to calculate concentration for only 6 of of the 7 data points.
[d]Sufficient data were available to calculate concentration for only 15 of the 17 data points.
[e]Sufficient data were avalaible to calculate concentration for only 6 of the 8 data points.
[f]Sufficient data were available to calculate concentration for only 29 of the 34 data points.
[g]Sufficient data were available to calculate concentration for only 3 of the 4 data points.
[h]Sufficient data were available to calculate concentration for only 2 of the 3 data points.
[i]Values presented for total volatile organics represent the averages and ranges of values presented in Table 3-2.
[j]Sufficient data were available to calculate concentration for only 37 of the 46 data points.

3.3.1 Pollutant Loading

The single most important factor affecting emissions from an air stripper is the volatile organic loading. Air strippers generally achieve high removal efficiencies. Therefore, the majority of pollutant quantities going into the air stripper (influent water) are transferred to the air. The pollutant loading is a function of two parameters, the pollutant concentration in the water and the flow rate to the air stripper. The pollutants present and the loadings vary widely at actual air stripper locations.

Pollutant loadings for the 52 air strippers were calculated from data collected on influent water flow rates and pollutant concentrations for these strippers. These calculated loadings were presented in Table 3-1 and are summarized in Table 3-4. As shown in Table 3-4, total volatile organic loadings range from 1.7 kg/yr to 29.3 Mg/yr. The individual loadings were calculated as the product of the water flow rate times the pollutant concentration. It was assumed that the volatile organic compounds reported are the only ones present in the water.

3.3.2 Removal Efficiency

The air stripper removal efficiency can also affect air emissions. The greater the removal efficiency, the higher the organic emissions. However, the removal efficiencies reported for operating air strippers are almost all above 90 percent, making the effect on air emissions minor. Over 50 percent of the reported efficiencies are greater than 99 percent. A summary of reported removal efficiencies is presented in Table 3-5 by pollutant.

The lowest removal reported, 44 percent, is for bromoform.[2] Low removals were also reported for this column for other brominated methanes and chloroform. Chloroform removal of up to 99 percent is reported for another air stripping column, so the previous column may not be designed to achieve high removal efficiency.[15] The removal efficiency can be enhanced by increasing the air to water ratio or increasing the packing height. Both of these parameters can be adjusted to achieve greater removal efficiencies. The

TABLE 3-4. SUMMARY OF CALCULATED LOADINGS FOR 52 AIR STRIPPERS

Pollutant	No. of[a] Data Points	Influent Concentration (ug/l) Average	Range	Calculated Loading (kg/yr) Average	Range
Aniline	1	226	NA[b]	15.1	NA
Benzene	3	3730	200-10,000	4200	382-11,400
Bromoform	1	8	NA	137	NA
Chloroform	3	530	1500	590	2.1-1,320
$CHBr_2Cl$	1	34	NA	584	NA
$CHBrCl_2$	1	36	NA	618	NA
Chlorobenzene	0	95	NA	6.3	NA
Dichloroethylene	7	409	2-3,000	365	0.6-1,720
Diisopropylether	2	35	20-50	71	8-134
Ethylbenzene	3	6,370	100-1,400	2,350	7-5,720
Ethylene Dichloride	8	173	5-1,000	360	1.3-1,600
Methylene Chloride	2	15	9-20	2.8	2.6-2.9
Methyl Ethyl Ketone	1	100	NA	190	NA
2-Methylphenol	1	160	NA	11	NA
Methyl Tertiary Butylether	2	90	50-130	93	53-134
Perchloroethylene	19	355	3-4,700	370	4.1-1,710
Phenol	1	198	NA	74	NA
1,1,2,2-Tetrachloroethane	1	300	NA	2,000	NA
Trichloroethane	9	81	5-300	225	1.7-800
Trichloroethylene	35	7,660	1-200,000	2,360	2-28,600
1,2,3-Trichloropropane	1	29,000	NA	1,940	NA
Toluene	4	6,710	30-23,000	719	114-2,190
Xylene	5	14,823	17-53,000	2,450	65-5,720
Volatile Organic Compounds	3	44,000	57-130,000	838	109-1,740
Total Volatile Organics	51[c]	11,120	12-205,000	2,740	1.7-29,300

[a]Note that the averages and ranges presented in this table represent more data points than in Table 3-3. The reason for this occurrence is that removal efficiencies were not available for all air strippers. Emissions could only be calculated if the removal efficiency was available.
[b]NA = Not Applicable. Data available for only one stripper.
[c]Only 51 because data are incomplete for Site B.

TABLE 3-5. SUMMARY OF REPORTED REMOVAL EFFICIENCIES

Pollutant	No. of Data Points	Reported Removal Efficiency (%) Average	Range	Henry's Law[a] Constant mg/l in air / mg/l in water
Aniline	1	58	NA[b]	0.00011
Benzene	3	99.6	99-100	0.130
Bromoform	1	44	NA	0.024
Chloroform	1	48	NA	0.141
$CHBr_2Cl$	1	60	NA	86,000
$CHBrCl_2$	1	81	NA	8.53
Chlorobenzene	0	ND	ND	0.164
Dichloroethylene	7	98.6	96-100	0.094
Diisopropylether	2	97.0	95-99	ND[b]
Ethylbenzene	1	99.8	NA	0.149
Ethylene Dichloride	7	99.3	79-100	0.050
Methylene Chloride	1	100	NA	0.133
Methyl Ethyl Ketone	1	99	NA	0.0018
2-Methylphenol	1	70	NA	ND
Methyl Tertiary Butylether	2	97.0	95-99	ND
Perchloroethylene	17	96.5	86-100	0.324
Phenol	1	74	NA	0.000019
1,1,2,2-Tetrachloroethane	1	95	NA	0.016
Trichloroethane	8	95.4	70-100	0.27
Trichloroethylene	34	98.3	76-100	0.184
1,2,3-Trichloropropane	1	99	NA	1.16
Toluene	2	98	96-100	0.129
Xylene	4	98.4	96-100	0.12
Volatile Organic Compounds	3	98.8	98-99.5	-
Total Volatile Organics	46	97.5	58.1-100	

[a]References 24, 32, 33, and 34. If different values were cited, an average of cited values is presented.
[b]NA = Not Applicable. Data available for only one stripper.
[c]ND = No Data. Insufficient data available.

effect of air to water ratio on the removal efficiency is shown graphically in Figure 3-2.[35]

Other compounds removed at less than 90 percent efficiency have higher water solubility and less volatility than the compounds removed at greater than 90 percent. The compounds observed having lower removal efficiency have lower Henry's Law constants. The Henry's Law constant is the constant of proportionality for equilibrium between low concentrations of a compound in water and air. As the Henry's Law constant increases, the ease of removal increases. The Henry's Law constants for each of the contaminants identified in this study are provided in Table 3-5 for comparison.

3.3.3 Pollutant Loading Changes

As discussed above, the major factor affecting emissions from air strippers is the volatile organic loading in the contaminated ground water. This loading does not usually remain constant, however. The water flow rates to air strippers generally remain constant, but pollutant concentrations typically vary with respect to time. This variance in influent concentration at fairly constant flow rate results in pollutant loading changes.

Historical influent pollutant concentrations for 10 operating air strippers were obtained. These data have been used to estimate emissions as a function of time for the 10 sites. Estimated emissions for these 10 sites are presented graphically in Figures 3-3 and 3-4. Emissions from the 10 sites are presented separately in two figures due to the differences in time periods for which data are available.

As shown in Figures 3-3 and 3-4, air emission rates generally decrease as a function of time. Typically, the initial air emission rate decreases rapidly and then levels off for a period of time. After this period of leveling off, the ground water pollutant concentrations and resulting emissions are expected to gradually drop. However, Figures 3-3 and 3-4 do not indicate a decrease in emission rates after the period of leveling off and for a couple of strippers the emission rate actually increases.[12,22,30]

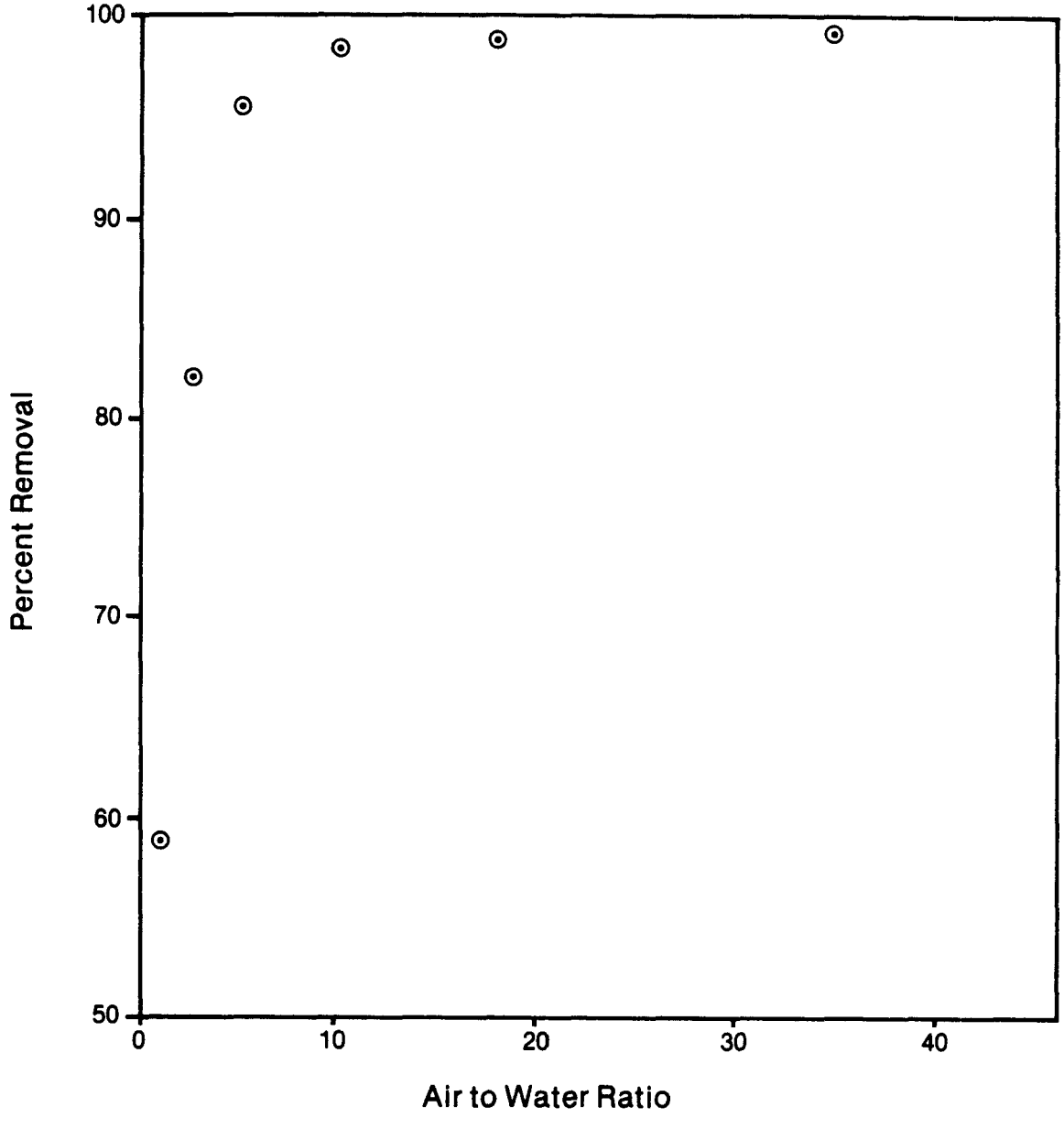

Figure 3-2. Removal efficiency of PCE for a pilot scale air stripper[35]

4870200R

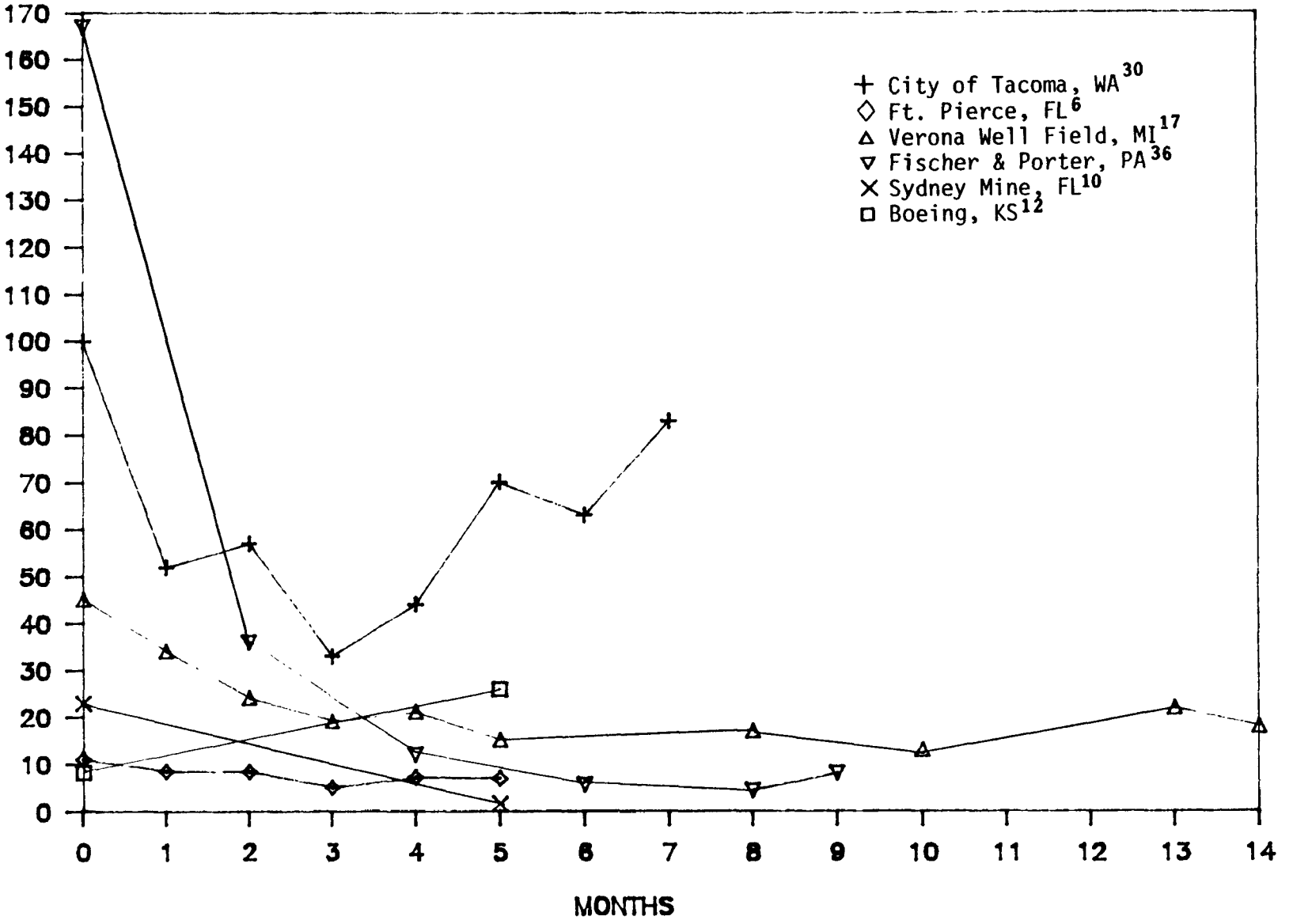

Figure 3-3. Emissions as a function of time for six air strippers

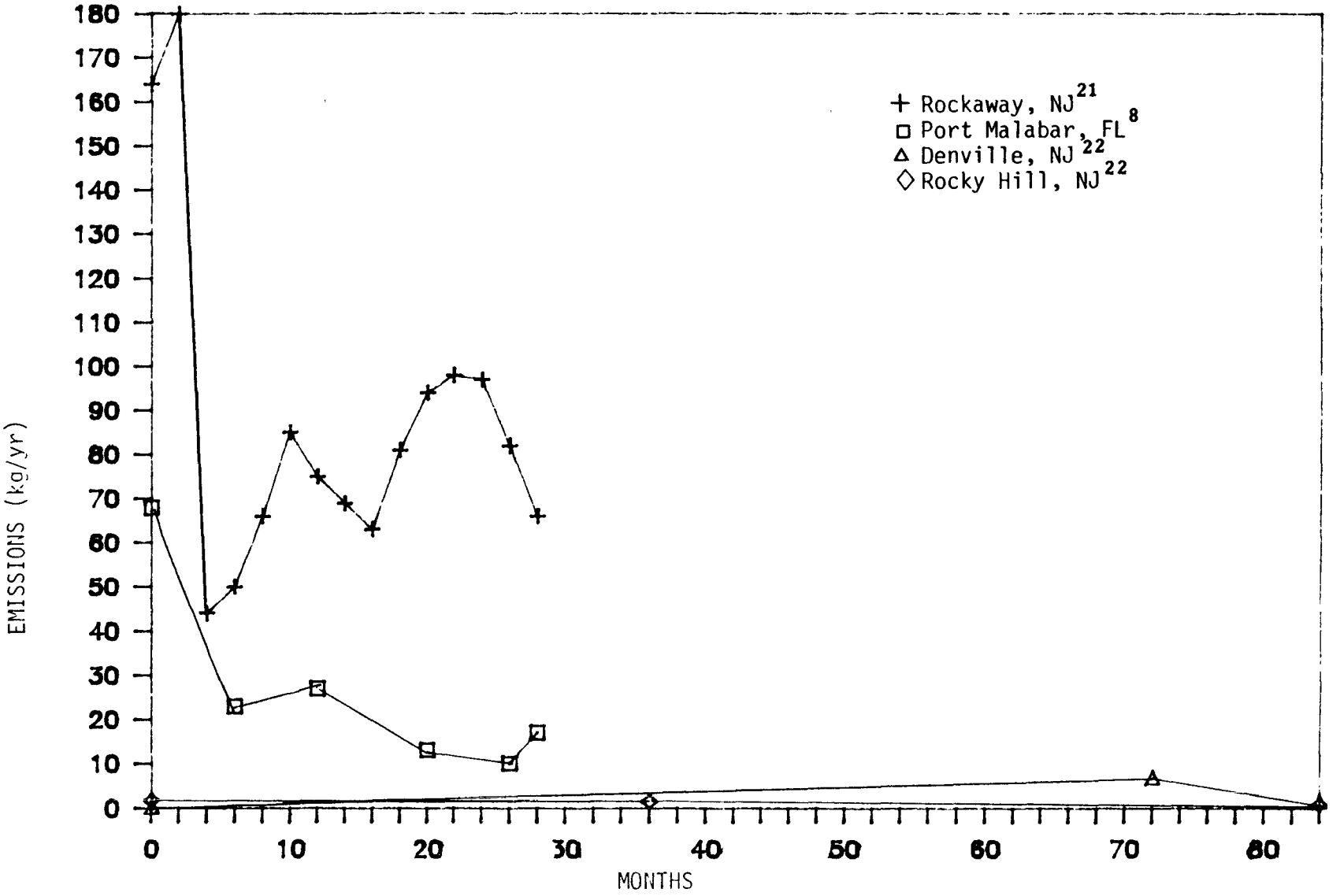

Figure 3-4. Emissions as a function of time at for four air strippers.

3.3.4 Annual Period of Operation

The period of annual operation can affect the annual emissions from air stripping. Cold temperatures in some parts of the nation can cause freezing problems that prevent year-round operation. However, this situation is uncommon. Most of the operating strippers are operated year round, 24 hours per day and incur very few operational problems. Generally, only normal preventative maintenance is required with special attention given to bacterial buildup on the packing. Buildup of iron bacteria is the most common problem encountered. This potential problem is normally controlled by periodic recirculation of chlorine or an acidic solution (pH 3 to 4). This operation normally requires interruption of ground water stripping, but the downtime is generally less than 8 hours per occurrence.

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4.0 EMISSION CONTROLS

The presence of air emission controls on air strippers is generally dictated by applicable State regulations. These regulations vary considerably from State to State. Some States base their regulations on risk assessment. The short-term toxicity and long-term carcinogenic risks are determined for the emissions from a site and compared with preset limits. If the risks are greater than the maximum allowable risks, controls must be applied to the air stripper exhaust. Other States set a maximum allowable emission rate. This rate can either be independent of the type of compounds present or may be compound specific. When the emissions are estimated to exceed the set limit, controls must be applied. Often, the need for controls is determined on a case by case basis. State requirements are summarized in Table 4-1 for several States requiring control of air stripper emissions. When controls are required, an efficiency of 85 to 99 percent reduction is usually specified.[1,2,3]

Of the 177 air strippers identified in this study, 17 are equipped with air emission controls. Table 4-2 lists these 17 facilities and the air emission control installed at each site. Of these 17 facilities, one uses a catalytic incinerator, two have flares, two have thermal incinerators, and 12 have granular activated carbon adsorbers. Installation of the air control device was required by the State at 9 of these sites. One site, ADM, Incorporated, indicated that the air control device was not required. The reason for installation of this control device was not determined and two additional air strippers without controls were later installed at this site. The reason for installation of air emission control devices at the remaining 7 sites was not identified.

As shown in Table 4-2, twelve of the air strippers with air emission controls are used to treat ground water contamination. Four treat landfill leachate and one treats drinking water. All of the landfill leachate sites identified in this study use some type of air emission control.

Control device performance data were obtained for two of the facilities with emission control. Inlet and outlet concentration data based on sampling were obtained for these two sites. Both of these facilities use carbon

TABLE 4-1. AIR EMISSION REQUIREMENTS FOR AIR STRIPPERS

STATE	REQUIREMENT
Arizona	
Pima County APCD[a]	Emission controls are required for emissions of more than 40 lb/day of photochemically reactive hydrocarbons. At least 85 percent removal must be achieved by the control device.
New York[b]	Part 212. General Industrial Process Regulations. Emission controls are required if emissions exceed the maximum allowed by the following criteria: Compound Rating — Maximum Allowed Emissions A - most toxic — 1.0 lb/hr B — 10 lb/hr C — 10 lb/hr D - Least toxic — No maximum If control is required, the control technology must achieve 99 percent removal.
Michigan[c]	Emission controls are determined based on long term risk. Maximum allowable emissions are set for individual compounds and total amount of organic compounds. Control device efficiency is 90 percent.

TABLE 4-1. AIR EMISSION REQUIREMENTS FOR AIR STRIPPERS

STATE	REQUIREMENT
Vermont[d]	Section 5-261 of Air Pollution Control Regulations. Emission control requirements are determined case by case. Factors considered are: (1) degree of toxicity and emission rate of contaminant, (2) proximity of source to population, (3) emission dispersion, and (4) cumlative impact of emissions.
California - Bay Area AQMD[e]	Proposed rule - All emissions from air strippers must be controlled except for two exclusions. These exclusions are: (1) no control required if less than 15 lb/day emissions if not expected to cause risk, (2) no control required if emitted concentration is less than 300 ppmv.

[a]Reference 1.
[b]Reference 2.
[c]Reference 3.
[d]Reference 4.
[e]Reference 5.

TABLE 4-2. FACILITIES USING AIR EMISSION CONTROLS ON AIR STRIPPERS

Facility Name	City	State	Type[a]	Major Contaminants[b]	Type[c]	Control Reqd? (Y/N)	References
U.S. Coast Guard Base	Traverse City	MI	GW	BZ, Tol, Xyl	COX	Y	6
BKK Landfill	West Covina	CA	LF	Landfill Leachate	Flare	-	7
Unidentified	Plainfield	NJ	DW	PCE, TCE	GAC	-	8
AMD, Inc.	Sunnyvale	CA	GW	TCE, DCE, TCA, DCA	GAC	N	9
Hughes Aircraft	Tuscon	AZ	GW	TCE, DCE, TCA	GAC	Y	10
Lowry Landfill I	Denver	CO	LF	1,1-DCA, 1,2-DCA	GAC	Y	11
Motorola, 52nd Street	Phoenix	AZ	GW	TCA	GAC	-	12
Verona Well Field	Battle Creek	MI	GW	1,1,1-TCA, 1,1-DCA, PCE, TCE	GAC	Y	13,14,15
McClellan AFB	Sacramento	CA	GW	MEK, Acetone, various VOC	INCIN	Y	6,16
Site A		MI	GW	PR[d]	GAC	Y	17
Site B		MI	GW	PR[d]	GAC	Y	18
Gilson Road	Nashua	NH	GW	MeOH, EtOH, Acetone, MEK, Tol, others	INCIN	Y	6
Chem Central	Grand Rapids	MI	GW		GAC	-	19
Tyson's Dump	Upper Merion	PA	LF	1,2,3-TCP, Xyl, Tol, Aniline, Phenol	GAC	-	20
Unifirst	Williamstown	VT	GW	PCE	GAC	Y	21
Chem-Dyne	Hamilton	OH	GW	—	GAC	-	22
Palos Verdes Landfill	Palos Verdes	CA	LF	Landfill Leachate	Flare	-	23

[a]Source types: GW = Ground Water; LF = Landfill Leachate; DW = Drinking Water.
[b]Contaminants: BZ = Benzene; Tol = Toluene; Xyl = Xylene; PCE = Perchloroethylene, TCE = Trichloroethylene; DCE = Dichloroethylene; TCA = Trichloroethane; DCA = Dichloroethane; MEK = Methyl Ethyl Ketone; MeOH = Methanol; EtOH = Ethanol; 1,2,3-TCP = 1,2,3-Trichloropropane.
[c]Type: COX = Catalytic Oxidation; GAC = Granular Activated Carbon Adsorption; INCIN = Incineration.
[d]Information treated as confidential pending company review.

adsorption for control. In addition, reported control device efficiencies were obtained for seven other facilities. These efficiencies are generally based on either design efficiency, mass balances, or sampling of the control device inlet and outlet. The available data for each of these eight sites is summarized in Table 4-3.

A discussion of each control device currently being used to control emissions from air strippers is presented in the following subsections. The performance and operational history at each controlled facility is also discussed.

4.1 GRANULAR ACTIVATED CARBON ADSORPTION

Granular activated carbon adsorption (GAC) is the most prevalent air emission control technique used for air stripper emissions. A total of 12 facilities using carbon adsorption technology were identified in this study. Actual performance data were obtained for two of these operating carbon adsorbers. The overall removal efficiencies determined at these sites were 99.97 and 74 percent. In addition, reported removal efficiencies were obtained for three other operating carbon adsorbers. The reported efficiency for two of these carbon adsorbers is 90 percent, based on design. The reported efficiency for the third adsorber is 91 percent, based on testing. However, the test data for this adsorber are not currently available. Available performance data and the control system at each site are discussed below.

Tyson's Dump[20]

The air stripper at Tyson's Dump in Upper Merion, Pennsylvania, was designed to treat landfill leachate. It began operating in 1983. Activated carbon canisters were included in the system design to remove the organics emitted from the air stripper. A total flow of 170 cfm is routed to four parallel GAC canisters containing 55 gallons of carbon. The carbon is removed for disposal and replaced once per month. This air stripping system was recently shut down, and a new system is being built to provide better collection of contaminated ground water and removal performance.

TABLE 4-3. PARAMETERS AND REMOVAL EFFICIENCIES FOR AIR EMISSIONS CONTROL DEVICES

Facility Name	Control Device Type[a]	Design Air Flow (CFM)	Sampling Data Available Y/N	VO Remv. EFF. (%)
U.S. Coast Guard Base	COX	2000	N	90
Unspecified	GAC	20000	N	90
Hughes Aircraft	GAC	14400	N	90
Verona Well Field	GAC	5500	Y	74
McClellan AFB	INCIN	4000	N	99.9
Site A	GAC	8000	N	70-90
Gilson Road	INCIN	--	N	99.99
Tyson's Dump	GAC	250	Y	99.97
Unifirst	GAC	500	N	91

[a]Control Device Type: COX = Catalytic Oxidizer; GAC = Granular Activated Carbon Adsorber; ICIN = Incinerator.

The inlet and outlet of the carbon adsorber at Tyson's Dump have been sampled to determine the control device efficiency. The testing was conducted at this site for the U.S. EPA. The purpose of the testing was to obtain data supporting the development of Federal regulations for air emissions from hazardous waste treatment, handling, and disposal facilities (TSDF). A summary of the data obtained on inlet and outlet concentrations for the carbon adsorber at this facility are presented in Table 4-4. In addition to the inlet and outlet concentrations, the determined efficiencies are presented by pollutant. As shown in Table 4-4, an overall volatile organic removal efficiency of 99.97 percent was achieved during the testing.

Verona Well Field[13,14,15]

At Verona Well Field, air emission control was required by the State. The original design of this system included both the air stripper and carbon adsorption unit. The system was designed for removal of 1,1,1-trichloroethane, 1,1-dichloroethane, trichloroethylene, and tetrachloroethylene from contaminated ground water. The system began operation in September 1984.

Two parallel GAC beds of 9,500 pounds of carbon each are used for emission control. They are 10 feet in diameter and four feet deep. The total air flow of 5,500 cfm from the stripper is routed to two parallel carbon beds. The air entering the GAC beds is heated by a 250,000 BTU/hr natural gas indirect heater. The preheater is used to raise the temperature of the air by approximately $30^{o}F$, thereby lowering the relative humidity of the air to less than 40 percent. A relative humidity higher than 40 percent reportedly reduces the carbon adsorber removal efficiency of the GAC unit. After carbon reaches breakthrough, it is regenerated off-site. The carbon is removed from the beds and replaced with regenerated carbon.

This system was designed minimizing air flow in order to reduce the capital and operating costs for the carbon adsorber system. Larger diameter and taller height make it possible to achieve high efficiency at lower air flows. Lowering the air flow allowed for smaller carbon beds without a reduction in removal efficiency.

TABLE 4-4. GRANULAR ACTIVATED CARBON ADSORBER PERFORMANCE DATA FOR THE TYSON'S DUMP SITE[20]

Component	Inlet to Carbon Adsorber flow (kg/hr)	Inlet to Carbon Adsorber conc. (ppmv)	Effluent from Carbon Adsorber flow (kg/hr)	Effluent from Carbon Adsorber conc. (ppmv)	Organic Removal from Air[a] (wt %)
1,2,3 - Trichloropropane[b]	1.3E-2	6.7	1.4E-7	0.0008	99.999
(o,m) - Xylene[b]	5.2E-3	3.8	2.6E-6	0.0019	99.95
p - Xylene[b]	1.7E-3	1.3	1.7E-6	0.012	99.9
Toluene	2.8E-3	2.4	1.6E-6	0.0015	99.9
Ethylbenzene	7.5E-4	5.5	4.3E-7	0.0003	99.9
1,2 - Dichlorobenzene	9.7E-5	0.05[c]	1.4E-7	0.0001[c,d]	99.9
Other VO	4.8E-4	0.4	5.8E-7	0.0004	99.9
Total VO	2.4E-2	20.2	7.3E-6	0.017	99.97

[a]Calculated based on inlet and outlet concentrations.
[b]Concentrations given as both volatile and semi-volatile fractions. Volatile fraction data used only
[c]Component concentration below detection limit. One-half of limit used for analysis.
[d]Concentration reported for all isomers of dichlorobenzene.

Sampling data for the inlet and outlet of this carbon adsorber were obtained. The sampling was performed to determine if emissions met the permit requirements and determine removal efficiency of the GAC unit. Sampling was conducted over a period of 285 minutes. These data are presented in Table 4-5 for each pollutant. As shown in Table 4-5, the removal efficiency obtained during testing was 74 percent.

Unifirst[21]

The air stripping system at Unifirst in Williamstown, Vermont, has been operating since January 1986. The system is designed to remove perchloroethylene from ground water. Although the stripper is not large and the corresponding air flow is low (about 500 cfm) air emission control was required by the State. This system is near two schools, so every effort was made to control any potentially harmful emissions. The GAC unit is oversized for the air flow and concentration of organics, but no preheater is used on the air stream entering the carbon bed. The GAC unit is reported to achieve 90 to 92 percent removal efficiency based on sampling and analysis. The sampling was required by the State of Vermont to show permit compliance. The results of this sampling are presently being prepared in a test report. The carbon bed is regenerated on-site with steam.

Chem-Dyne[22]

In February 1987, the air stripping system at the Chem-Dyne site in Hamilton, Ohio began operating. The stripper was installed to cleanup ground water contaminated with a variety of organics compounds. The source of the contamination was leaking underground storage vats. The air flow rate through the GAC unit is 3,000 cfm. The carbon beds are steam regenerated on site. No information was available on the removal efficiency of the GAC unit.

Site A[17]

Site A began operating an air stripping system in February 1984. The system removes trichloroethylene and 1,1,1-trichloroethane from contaminated ground water. Air emission control was required by the State. The carbon adsorber system includes three parallel carbon beds of 3,000 pounds carbon

TABLE 4-5. GRANULAR ACTIVATED CARBON ADSORBER PERFORMANCE DATA FOR VERONA WELL FIELD[13]

Compound	Inlet Concentration (ppmv)	Outlet Concentration (ppmv)	Removal Efficiency (Wt. %)
1,1-Dichlorethane	56.6	52.0	8.0
1,2-Dichloroethane	1.1	ND[b]	100
1,2-Dichloroethylene	96.9	96.9	0
Perchloroethylene	107.9	ND	100
1,1,1-Trichloroethane	181.2	7.4	96
Trichloroethylene	18.4	ND	100
Total VO	462.1	156.3	74

[a] Percent Removal = (1- (outlet concentration/inlet concentration)) x 100%.
[b] ND = Not Detected

each. The inlet air is preheated, using a steam heat exchanger, before entering the carbon beds. A removal efficiency of 70 - 90 percent is reported for the GAC unit based on material balances. The carbon beds are regenerated with 3,900 pounds of steam approximately every other day. One bed is steam stripped for an hour while the other two remain in service. The organics recovered from the regeneration process, about 35-50 gallons per week, are shipped off-site for reclamation. The aqueous phase (condensed steam) from regeneration is fed back to the air stripper.

One problem encountered at this site is dishing and channeling of the carbon beds. This situation results in lower removal efficiency. Therefore, the carbon beds are raked periodically to minimize dishing and channeling.

Site B[18]

An air stripping system was installed at Site B in December of 1985. Originally, the air emissions were not controlled. However, after several months of air stripper operation, the emissions were exceeding the permitted level. Therefore, the State required that an air emission control be installed. A GAC system was installed in October of 1986. The carbon adsorber system consists of a single carbon bed containing 1,100 pounds of GAC. The carbon adsorber is used to control a 1,200-1,400 cfm air stream. The major pollutant removed from the air stream is chloroform. Air entering the carbon bed is preheated by a 20 kW electric heater.

Based on material balances, the removal efficiencies achieved by this system have been well below the design efficiency of 90 percent removal. The low removal efficiencies have been attributed to poor performance of the air preheater. The original air preheater was not sufficiently heating the air to achieve the desired reduction in relative humidity. A larger preheater was recently installed to alleviate this problem and the system is expected to achieve design removal efficiencies.

The carbon bed is regenerated on-site with steam. The system is shut down every 70 days for three hours to regenerate the carbon. After regeneration, dry clean air is blown through the bed to dry the carbon. Approximately 13 pounds of organic phase material are recovered during each regeneration and sent off-site for disposal. The aqueous phase from steam

regeneration is fed back to the stripper.

AMD, Inc.[9]

AMD, Inc., in Sunnyvale, California, installed an air stripping system in 1985 which included GAC for air emission control. This is a small unit which is used to treat ground water containing trichloroethylene and dichloroethylene. The GAC unit was not required by the State or regional air quality management district. The reason for installation of the air control device is not known. Since installation of the first air stripping system with GAC control, two additional air strippers have been installed at this site without air controls. No information was available on the removal efficiency of the GAC unit.

Hughes Aircraft[10]

In early April 1987, Hughes Aircraft in Tucson, Arizona, began operating an air stripping system with GAC for air emission control. Air emission control was required by the State. The air stripper system is used to treat ground water contaminated with trichloroethylene, 1,1,1-trichloroethane, and dichloroethylene. There are three parallel trains of air strippers, but the arrangement for the emissions control is not known. The GAC unit is designed to remove greater than 90 percent of the trichloroethylene at a total air flow of 14,400 cfm. The estimated inlet organic concentrations to the GAC unit used for design are 43 mg/m^3 (7.4 ppmv) trichloroethylene, 9.3 mg/m^3 (2.2 ppmv) dichloroethylene, and 3.6 mg/m^3 (0.61 ppmv) 1,1,1-trichloroethane.

Lowry Landfill[11]

At Lowry Landfill in Denver, Colorado, an air stripper was installed in 1984. An air emission control device was required by law to remove the 1,1,- dichloroethane and 1,2- dichloroethane from the air stream. The emission control currently used is a GAC canister. A second air stripper installed at this site will begin operation in about a month with no air emission control. Emissions control is no longer considered necessary and

feasible by the State. No information was available on the removal efficiency of the GAC unit.

Motorola[12]

In June 1987, an air stripper will begin operation at the Motorola 52nd Street site in Phoenix, Arizona. This system will treat ground water primarily contaminated with 1,1,1-trichloroethane. In addition, smaller quantities of dichloroethylene, trichloroethylene, and perchloroethylene are also present. Data are not available on performance of the full-scale system, but a pilot study was performed in late 1986 for air stripping with GAC for emission control. The overall removal efficiencies achieved by the pilot GAC unit ranged form 30 to 95 percent removal. Removal efficiencies were calculated from methane equivalents determined during testing. No information was available on the design removal efficiency of the full scale GAC unit. Problems encountered during the pilot study include insufficient relative humidity reduction by the preheater, less than 100 percent regeneration of the carbon causing a decrease in capacity, and desorption of organics from the carbon during operation due to a decrease in loading to the system.

Plainfield[8]

An air stripping system at Plainfield, New Jersey is currently being designed with air emission control. The system is designed to remove trichloroethylene and tetrachloroethylene from a drinking water supply. Air emission control is required by the State. The system is designed for an air flow rate of 20,000 cfm. The design removal efficiency for the GAC unit is 90 percent.

Chemcentral[19]

The air stripping system at Chemcentral in Grand Rapids, Michigan, is equipped with GAC for air emission control. No additional information is available on this system.

4.2 THERMAL INCINERATION

Thermal incineration is an air emission control technique currently used for control of emissions from air strippers. Two air stripping sites using thermal incineration were identified in this study. However, actual performance data are not available for either of these thermal incinerators. The design destruction efficiency at both sites is reportedly 99.9 percent or greater.[6,16]

EPA has previously determined that properly designed and operated thermal incinerators have been demonstrated to achieve greater than 98 percent efficiency.[24] Thermal incinerators operated at a combustion chamber temperature of 1,600^{o}F and a residence time of 0.75 seconds can achieve at least 98 percent destruction efficiency for most nonchlorinated organic compounds. Similarly, thermal incinerators operated at a combustion temperature of 2000^{o}F and a residence time of 1.0 seconds can achieve at least 98 percent destruction of most chlorinated organic compounds.

McClellan Air Force Base[6,16]

The air stripper at McClellan Air Force Base in Sacramento, California began operating in December, 1986. The incinerator was installed for destruction of methyl ethyl ketone, acetone, 1,1- and 1,2-dichloroethylene, vinyl chloride, and trichloroethylene stripped from ground water. Although this unit is referred to as a thermal incinerator, in a previous EPA report, other sources indicate that a catalyst is used to enhance the removal efficiency.[16] Natural gas is used as the auxiliary fuel to heat the air to 1,800^{o}F. The exhaust gases are used to heat the inlet water to the air stripper for greater removal efficiency. The incinerator is capable of treating an air flow of up to 4,000 cfm and is designed to yield 99.9 percent destruction of incoming organics. Operational problems with the air preheater have caused system shut-down for one month, but the exact cause was not specified.

Gilson Road[6]

The air stripper at the Gilson Road site in Nashua, New Hampshire, began operation in July 1986. The control device was installed primarily for the destruction of tetrahydrofuran, methyl ethyl ketone, butyl alcohol, and

toluene, but other organics are also present in the stripper exhaust. The control device used at Gilson Road is actually an oil-fired boiler used to thermally oxidize organic emissions from the air stripper. The design destruction efficiency for this boiler is 99.99 percent.

4.3 CATALYTIC INCINERATION

Catalytic incineration can be used to control the emissions from air strippers. Similar to thermal incineration, organic compounds in the air stripper exhaust are destroyed by oxidation. A catalyst is used to promote the oxidation reaction, allowing high removal efficiencies at lower temperatures. Catalyst fouling by chlorinated compounds and other materials can be a major concern for these units. However, at least one catalytic incinerator design and catalyst combination have been demonstrated effective at destroying chlorinated organic compounds.[25]

The only identified catalytic incinerator is located at the U. S. Coast Guard Base in Traverse City, Michigan. The air stripping system at the U. S. Coast Guard Base in Traverse City, Michigan, began operation in 1985. The catalytic incinerator was included in the initial design and installation of the air stripping system. The air stripper installed at this site is a rotary high gravity air stripper which achieves high removal efficiencies at lower air to water ratios than packed towers. The lower air flow for this type of air stripper results in higher pollutant concentrations in the air stripper exhaust.

The catalytic incinerator at Traverse City was installed for destruction of benzene, toluene and xylene stripped from ground water. The catalytic oxidation unit is designed for a flow of 2,000 cfm and operates at 500^{o}F to 600^{o}F. The design efficiency for this catalytic incinerator was 90 percent. However, no performance data are available.

The performance of catalytic incinerators has been demonstrated for control of organic air emissions from various sources. In general, destruction efficiencies of greater than 95 percent can be achieved at about 840^{o}F with a catalyst bed volume of 0.5 to 2 cubic feet per 1,000 scfm.[24] In addition, two pilot scale studies have been conducted to demonstrate the

performance of catalytic incinerators for control of air stripper emissions. The destruction performance achieved during pilot scale testing of an air stripper exhaust stream containing benzene and toluene is presented graphically in Figure 4-1.[26] This air stream contained less than 10 ppm total organics.

In another pilot scale study, a proprietary catalyst and fluidized bed catalytic incineration system were tested.[25] The destruction efficiencies achieved by this unit on four mixtures of chlorinated and nonchlorinated organics is presented in Figure 4-2.[25] The pollutant concentrations for each of these mixtures is provided in Table 4-6. These mixtures were selected to simulate actual air stripper emission streams.

4.4. FLARES

Flares were identified as the control used to control emissions from air stripping operations at two landfill sites. These flare were not installed specifically for air stripper emissions control. Instead, the air stripper emissions were routed to an existing flare at the landfill.

The two landfill sites using flares for air stripper emission control are the BKK Landfill in West Corina, California, and the Palos Verdes Landfill in Palos Verdes, California.[7,23] The air strippers at both locations are used to treat landfill leachate. No performance or operation data are available for either of these sites.

Figure 4-1. Destruction Efficiency of a Pilot Scale Catalytic Incinerator for Benzene and Toluene in Air Stripper Exhaust.[26]

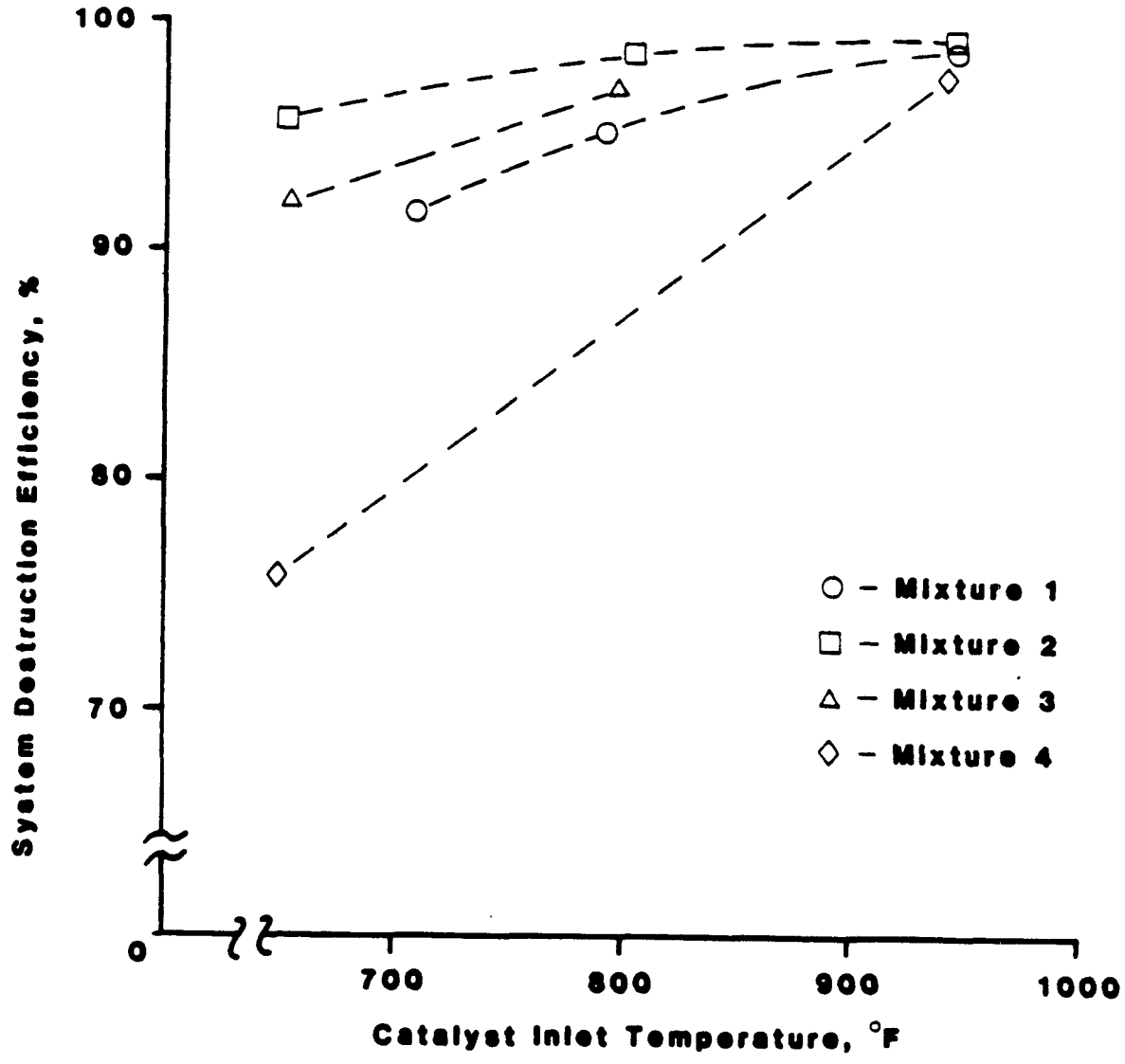

Figure 4-2. Destruction Efficiency of a Pilot Scale Catalytic Incinerator for Organic Mixtures Simulating Air Stripper Exhaust.[25]

TABLE 4-6. MIXTURE COMPOSITIONS AND TARGET CONCENTRATIONS FOR CATALYTIC OXIDATION TESTS[a]

Mixture Designation	Mixture Compounds	Target Inlet Concentration (ppmv)
Mixture 1	Trichloroethylene	6.3
	1,2-dichloroethylene	8.5
Mixture 2	Trichloroethylene	2.7
	Benzene	1.5
	Ethylbenzene	5.6
	Pentane	11.5
	Cyclohexane	14.1
Mixture 3	Vinyl chloride	7.5
	Trichloroethylene	1.8
Mixture 4	1,2 dichloroethane	10
	Trichloroethylene	10
	1,1,2-trichloroethane	10
	Tetrachloroethylene	10
Mixture 4	1,2 dichloroethane	50
	Trichloroethylene	50
	1,1,2-trichloroethane	50
	Tetrachloroethylene	50

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5.0 COST OF CONTROLS

This section presents a discussion of the capital and operating costs for the controlled air stripping systems identified in this study. Limited cost data were available for granular activated carbon (GAC) control for four sites and catalytic incineration control for one site. These data are presented in this section. In addition to these cost data, estimates of costs of thermal incineration and catalytic incineration controls were also made in this study for the four air stripper sites where GAC cost data were available. These cost estimates are made for comparison purposes and are based on the actual air stripper operating data and standard EPA costing procedures.

Flares were identified in this study as controls for emissions from air strippers treating ground water at two landfill sites.[1,2] However, due to the limited applicability of flares for controlling air stripper emissions, control costs were not estimated for flares in this study. In addition, no attempt was made to estimate thermal incineration and GAC control costs for the one site using catalytic incineration.

5.1 GRANULAR ACTIVATED CARBON

Installed cost data were obtained from four sites using GAC control.[3,4,5,6] The nature of these cost data varies from site to site. Actual installed cost data were obtained for Site B. For another site (Verona Well Field), cost estimates made during an Options Feasibility study were provided. Contractor design cost estimates were available for the site in Plainfield, New Jersey. For Site A, plant personnel estimated costs based on the cost of similar equipment operating at that site. Annual operating cost data were available for two sites, Verona Well Field and Plainfield. Operating costs for Sites A and B were estimated in this study so that total annualized costs for GAC control could be compared to total annualized costs estimated for thermal and catalytic incinerators. A discussion of the available installed cost data and the estimated operating costs for the four GAC systems are presented below.

5.1.1 Installed Costs

The installed cost of the GAC control system is dependent on the amount of carbon required to ensure adequate VO removal. The air flow rate passing through the bed, the adsorption cycle time, and the adsorption capacity for the specific pollutants in the air stream affect the required amount of carbon. Table 5-1 presents the air stream and carbon bed data for the air stripper systems for which control cost data were available. Carbon bed data for the Plainfield site were not available. The total weight of carbon required for the other three sites ranges from 1,100 to 19,000 lbs. Air flow rates for the four sites range from 1,300 to 20,000 cfm. The adsorption capacity of the carbon (lb VO/lb carbon) is dependent on the type of VO in the air stream as well as the temperature and humidity of the air stream. All four GAC units listed in Table 5-1 are used to remove chlorinated hydrocarbons from the air passing through the beds. The air streams are preheated to reduce the relative humidity before passing through the carbon beds at three facilities. This information is not available for the Plainfield site. The temperature and relative humidity of the air streams following preheating for sites A and B and the Verona Well Field site are also presented in Table 5-1.

Installed capital cost data for the GAC units at the four air stripper sites are presented in Table 5-2. The costs estimates for all sites are presented in third quarter 1986 dollars for comparison purposes. The cost data for site A were estimated by the plant personnel based on the cost of similar equipment operating at that site. The costs for site B are based on actual installed cost data. The cost data for Verona Well Field are based on the estimate made by the site for an Options Feasibility study. The cost data for the Plainfield site are based on contractor design cost estimates.

The GAC systems at sites A and B include preheaters and steam regeneration systems. The GAC system at Verona Well Field includes a preheater but no steam regeneration system. No detailed information was available on the GAC system at Plainfield. None of the sites provided enough details in their cost estimates to determine what components were included in their estimates.

TABLE 5-1. AIR STREAM AND CARBON BED DATA FOR FOUR FACILITIES

Facility	Air Flow (cfm)	Temperature (^{o}F)	Relative Humidity (%)	Bed Type	No. of Beds	Carbon Weight (lb/Bed)	Reference
Site A	8,000	N/A	<40	Fixed	3	3,000	3
Site B	1,300	>80	<40	Fixed	1	1,100	4
Verona Well Field	5,500	100[a]	<40	Fixed	2	9,500	5
Plainfield	20,000	N/A	N/A	N/A	N/A	N/A	6

[a]Site representative reported temperature to be 30^{o}F above ambient.
N/A - Not available.

TABLE 5-2. INSTALLED COSTS FOR GAC CONTROL

Facility	Installed Cost ($, 3rd Quarter 1986)	Reference
Site A	150,000	3
Site B	152,000[a]	4
Verona Well Field	223,000[b]	5
Plainfield	500,000	6

[a]Fourth quarter 1985 cost data escalated to third quarter 1986 using M&S Equipment Cost Index.[7]

[b]Second quarter 1984 cost data escalated to third quarter 1986 using M&S Equipment Cost Index.[7]

5.1.2 Operating Costs

Verona Well Field did provide estimates of operating and maintenance costs made for an Options Feasibility study.[5] In addition, actual carbon regeneration and replacement costs were provided for the Verona Well Field system. Operating and maintenance costs were also provided for the Plainfield Site.[6] These costs, however, may not include carbon replacement. These operating cost estimates and estimates made using standard EPA costing procedures for sites A and B are presented here. Some actual utility usage data were available for sites A and B. These usage data were used to estimate utility costs for these sites. Standard engineering factors were used to estimate other direct and indirect operating costs. The information used to estimate the operating costs for sites A and B are presented in Table 5-3. The unit cost factors presented in Table 5-3 were updated using appropriate indices.

The operating costs estimated for each site are presented in Table 5-4. The estimated operating costs range from $77,800 for site B to $221,400 for the Plainfield Site.

5.2 THERMAL INCINERATION

Installed and operating costs for thermal incineration control were estimated based on air stripper operating parameters for the four sites reporting GAC cost data. The methodology used to estimate these costs is provided in Reference 8. The estimated costs are presented below for comparison to the costs presented above for the four sites using GAC control.

5.2.1 Installed Costs

Costs were estimated for thermal incineration control based on the air flow rate for each site. The major equipment costs for the incinerator systems include the incinerators and recuperative heat exchangers. The cost of the incinerators including fan and motor, and instrumentation and controls

TABLE 5-3. UNIT COST FACTORS AND CONSUMPTION BASES FOR GAC CONTROL

Operating Costs	Basis for Annual Consumption	Site	Unit Cost
Direct Operating Costs			
1. Utilities:			
a. Water	12 gal/100 lb steam[a]	A, B	$0.00033/gal[b]
b Steam	3900 lb/51 hr[c]	A	$0.00518/lb[b]
	440 lb/480 hr[d]	B	$0.00518/lb[b]
c. Electricity	Fan: 8000 cfm[c], 10 in. P	A	$0.0508/kWh[e], 8600 hrs[a]
	Fan: 1300 cfm[d], 10 in. P	B	$0.0508/kWh[e], 8600 hrs[a]
	Preheater: 20 kW[d]	B	$0.0028/ft^3[e], 8600 hrs[a]
d. Natural Gas	Preheater: 3.9 MMscf[c]	A	$0.0028/ft^3[e], 8600 hrs[a]
	Preheater: 2.4 MMscf[f]	Verona	$0.0028/ft^3[e], 8600 hrs[a]
2. Operating Labor:			
a. Operating Labor	0.5 hrs/shift, 8600 hrs[a]	A, B	$11.99/hr[b]
b. Supervision	15% of operating labor[a]	A, B	-
3. Maintenance			
a. Labor	0.5 hrs/shift, 8600 hrs[a]	A, B	$11.99/hr[b]
b. Materials	100% of maintenance labor[a]	A, B	-
4. Replacement			
a. Parts (carbon)	9000 lb/5 yr[c]	A	$1.89[g]
	1100 lb/5 yr[d]	B	$1.89[g]
b. Labor	100% of replacement parts		
Indirect Operating Costs			
1. Overhead	80% of (2a+2b+3a+3b)[a]	A, B, Verona	-
2. Property Tax	1% of total capital cost[a]	All	-
3. Insurance	1% of total capital cost[a]	All	-
4. Administration	2% of total capital cost[a]	All	-
5. Capital Recovery	0.163 x total capital cost[a]	All	-

TOTAL ANNUALIZED COST = DIRECT + INDIRECT OPERATING COSTS

[a]Reference 8
[b]Reference 9. Adjusted to 3rd quarter 1986 using Reference 10.
[c]Reference 3.
[d]Reference 4.
[e]Reference 11.
[f]Reference 12.
[g]Reference 8. Adjusted to 3rd quarter 1986 using Reference 10.

TABLE 5-4. ESTIMATED OPERATING COSTS FOR GAC CONTROL

	Annual Operating Cost ($, 3rd quarter 1986)			
	Site A	Site B	Verona Well Field	Plainfield
Direct Operating Costs				
1. Utilities:				
a. Water	28	0	-	
b. Steam	3,420	41	-	
c. Electricity	6,990	9,880	10,410[a]	
d. Natural Gas	10,930	N/A[b]	6,720	
2. Operating Labor:				
a. Operating Labor	6,450	6,450	20,900[c]	120,000[d]
b. Supervision	970	970	-	
3. Maintenance				
a. Labor	6,450	6,450	-	
b. Materials	6,450	6,450	-	
4. Replacement				
a. Parts	4,340	530	24,689[e]	
b. Labor	4,340	530	-	
Indirect Operating Costs				
1. Overhead	15,620	15,620	16,000	-
2. Property Tax	1,500	1,520	2,230	5,000
3. Insurance	1,500	1,520	2,230	5,000
4. Administration	3,000	3,040	4,460	10,000
5. Capital Recovery	24,450	24,780	36,350	81,375
TOTAL ANNUALIZED COST	96,400	77,800	124,100	221,400

[a]Reference 12. Adjusted to 3rd quarter 1986 using Reference 11.
[b]N/A for not available
[c]Reference 12. Adjusted to 3rd quarter 1986 using Reference 10.
[d]Total annual operating and maintenance cost from Reference 13. Assumed to include overhead.
[e]Reference 12. Includes labor.

was estimated based on the required combustion chamber sizes. The combustion chamber for each site was sized to provide a residence time of one second to ensure a combustion efficiency of 99 percent. The air flow rates at the four sites were as presented in Table 5-1. The incineration combustion temperature was set at 2000°F.[8] The incinerators design includes a heat exchanger to recover 35 percent of the heat from the combustion flue gas. Heat from the flue gas is transferred to the air exhaust from the stripper. The cost of the heat exchanger was estimated based on the surface area required for heat exchange.

The costs of the incinerator and heat exchanger were used to estimate the base equipment cost (BEC) for the system. The direct and indirect installation expenses were factored from the BEC using standard engineering cost factors.[8] The estimated installed costs for the four incinerator systems are presented in Table 5-5. The installed costs for these units range from $187,500 for site B to $432,000 for the Plainfield site.

5.2.2 Operating Costs

Operating costs were estimated for the thermal incinerators designed for each of the four sites. These estimated costs are partially dependent on the air flow rate to the incinerator. Natural gas and electricity requirements for the incinerators increase proportionally with increasing air flow rate. Higher air flow rates require additional fuel to heat the air stream to combustion temperature. Additional fan capacity is required to handle the flue gas rates leaving the incinerator. Other direct operating costs, such as operating labor, are only partially proportional to the air flow capacity of the unit. Indirect operating costs, such as a property tax and insurance, are independent of the system operating capacity. These costs were estimated based on the total capital investment (TCI) for the incinerator system at each site. The standard engineering cost factors used to estimate the direct and indirect operating costs for each of the four incinerator systems are presented in Table 5-6.

TABLE 5-5. ESTIMATED INSTALLED COSTS FOR THERMAL INCINERATORS AT FOUR SITES[a]

Cost Elements	Cost Factor	Installed Cost ($, 1986) Site A	Site B	Verona Well Field	Plainfield
Direct Costs					
Purchased Equipment Cost[b]	1.0	195,000	115,000	175,000	265,000
Other Direct Costs					
Foundation and supports	0.08				
Erection and handling	0.14				
Electrical	0.04				
Piping	0.02				
Insulation	0.01				
Painting	0.01				
TOTAL DIRECT COST	1.30	253,500	149,500	227,500	344,500
Indirect Costs					
Engineering and Supervision	0.10				
Construction and Field Expenses	0.05				
Construction Fee	0.10				
Start Up	0.02				
Performance Test	0.01				
Model Study	--				
TOTAL INDIRECT COST	0.28	54,600	32,200	49,000	74,200
CONTINGENCY	0.05	9,750	5,750	8,750	13,250
TOTAL	1.63	317,850	187,450	285,250	431,950

[a]Reference 8
[b]Includes costs for all major and auxiliary equipment, controls and instrumentation, taxes, and freight.

TABLE 5-6. UNIT COST FACTORS AND CONSUMPTION BASES FOR THERMAL INCINERATION CONTROL

Operating Costs	Basis for Annual Consumption	Site	Unit Cost
Direct Operating Costs			
1. Utilities:			
a. Natural Gas	2000°F combustion temperature, 35% heat recovery[a]	All	$0.00280/scfm[b]
	8000 scfm[c]	A	
	1300 scfm[d]	B	
	5500 scfm[e]	Verona Well Field	
	20000 scfm[f]	Plainfield	
b. Electricity	8 in. P, flue gas flow rate (2000°F)[a]	All	$0.0508/kWh[b]
2. Operating Labor:			
a. Operating Labor	0.5 hrs/shift, 8600 hrs[a]	A, B	$11.99/hr[g]
b. Supervision	15% of operating labor[a]	A, B	-
3. Maintenance			
a. Labor	0.5 hrs/shift, 8600 hrs[a]	A, B	$11.99/hr[g]
b. Materials	100% of maintenance labor[a]	A, B	-
4. Replacement			
a. Parts	N/A		
b. Labor	N/A		
Indirect Operating Costs			
1. Overhead	60% of (2a+2b+3a+3b)[a]	A, B	-
2. Property Tax	1% of total capital cost[a]	A, B	-
3. Insurance	1% of total capital cost[a]	A, B	-
4. Administration	2% of total capital cost[a]	A, B	-
5. Capital Recovery	0.163 x total capital cost[a]	A, B	-
TOTAL ANNUALIZED COST			

[a]Reference 8.
[b]Reference 11.
[c]Reference 3.
[d]Reference 4.
[e]Reference 5.
[f]Reference 6.
[g]Reference 9. Adjusted to 3rd quarter 1986 using Reference 10.

The estimated operating costs for each of the four sites are presented in Table 5-7. The operating costs range from $128,700 for site B to $1,123,000 for the Plainfield site.

5.3 CATALYTIC INCINERATION

During this study, one air stripper system was identified using catalytic incineration to control air emissions. Only purchase cost data for this catalytic incinerator at the Traverse City, MI air stripper was provided.[14] Installed and operating costs for the incinerator were estimated based on methodology provided in Reference 8 and are presented in Table 5-8 and 5-9, respectively. No attempt was made to estimate GAC or thermal incineration system costs for this facility. However, installed and operating costs for catalytic incineration control were estimated based on air stripper operating parameters for the four sites reporting GAC cost data (sites A, B, Verona Well Field, and Plainfield). These estimated costs for catalytic incineration systems are presented below for comparison to the costs for GAC control.

5.3.1 Installed Costs

Costs were estimated for catalytic incineration control based on the air flow rate data available for each of the four sites. The major equipment costs for the incinerator systems include the incinerators, catalyst, and recuperative heat exchangers. The costs of the incinerator less catalyst was estimated for each system based on the air flow rate entering the incineration unit. The catalyst requirement for each system was estimated based on the air flow rates for each site and an assumed space velocity through the catalyst bed of 30,000 hr^{-1}. This space velocity was selected to ensure 95 percent destruction efficiency.[8] The catalytic incinerator design includes a heat exchanger to recover 35 percent of the heat from the combustion flue gas.[8] Heat from the flue gas is transferred from the flue gas to the air exhaust from the stripper. The heat exchangers were sized to raise the temperature of

TABLE 5-7. ESTIMATED OPERATING COSTS FOR THERMAL INCINERATION CONTROL AT FOUR SITES

	Annual Operating Cost ($, 1986)			
	Site A	Site B	Verona Well Field	Plainfield
Direct Operating Costs				
1. Utilities:				
a. Fuel	384,420	62,140	264,470	959,600
b. Electricity	26,820	4,360	17,840	67,050
2. Operating Labor:				
a. Operating Labor	6,450	6,450	6,450	6,450
b. Supervision	970	970	970	970
3. Maintenance				
a. Labor	6,450	6,450	6,450	6,450
b. Materials	6,450	6,450	6,450	6,450
4. Replacement				
a. Parts	-	-	-	-
b. Labor	-	-	-	-
Indirect Operating Costs				
1. Overhead	15,620	15,620	15,620	15,620
2. Property Tax	3,190	1,875	2,840	4,340
3. Insurance	3,190	1,875	2,840	4,340
4. Administration	6,380	3,750	5,670	8,680
5. Capital Recovery	31,920	18,800	28,350	43,410
TOTAL ANNUALIZED COST	491,900	128,700	357,900	1,123,400

TABLE 5-8. ESTIMATED INSTALLED COSTS FOR CATALYTIC INCINERATOR AT TRAVERSE CITY, MI

Cost Elements	Cost Factor[a]	Installed Cost ($, 3rd quarter 1986)
Direct Costs		
Purchased Equipment Cost[b]	1.0	121,780
Other Direct Costs		
Foundation and Supports	0.08	
Erection and Handling	0.14	
Electrical	0.04	
Piping	0.02	
Insulation	0.01	
Painting	0.01	
TOTAL DIRECT COST	1.30	158,300
Indirect Costs		
Engineering and Supervision	0.10	
Construction and Field Expenses	0.05	
Construction Fee	0.10	
Start Up	0.02	
Performance Test	0.01	
Model Study	--	
TOTAL INDIRECT COST	0.28	34,100
CONTINGENCY	0.05	6,100
TOTAL	1.63	198,500

[a]Reference 8
[b]Purchased equipment costs include all major and auxiliary equipment, controls and instrumentation, taxes and freight.

TABLE 5-9. OPERATING COSTS FOR CATALYTIC INCINERATION CONTROL AT TRAVERSE CITY, MI

	Annual Operating Cost ($, 1986)
Direct Operating Costs	
1. Utilities:	
a. Fuel	28,670
b. Electricity	4,840
2. Operating Labor:	
a. Operating Labor	2,450
b. Supervision	360
3. Maintenance	
a. Labor	2,450
b. Materials	2,450
4. Replacement	
a. Parts	4,220
b. Labor	4,220
Indirect Operating Costs	
1. Overhead	5,940
2. Property Tax	1,990
3. Insurance	1,990
4. Administration	3,980
5. Capital Recovery	32,355
TOTAL ANNUALIZED COST	95,920

the air entering the incinerator to 895^{0}F. This inlet temperature ensures that an adequate overall reaction rate can be achieved to obtain the desired destruction efficiency without damaging the catalyst.[8] The cost of the heat exchanger was estimated based on the surface area required for heat exchange.

The major equipment costs discussed above were summed and used to estimate the base equipment cost (BEC) for the system. The direct and indirect installation expenses were factored from the BEC using the same standard engineering cost factors presented for the thermal incinerator system in Table 5-5. The installed costs for the four catalytic incinerator systems are shown in Table 5-10. The installed costs for these units range from $134,600 for site B to $585,700 for the Plainfield Site.

5.3.3 Operating Costs

Operating costs were estimated for the catalytic incinerators sized for each of the four sites. These estimated costs are partially dependent on the air flow rate to the incinerator. Natural gas and electricity requirements for the incinerators increase proportionally with increasing air flow rate. Higher air flow rates require additional fuel to heat the air stream to combustion temperature; additional fan capacity is required to handle the higher flue gas rates leaving the incinerator. The catalyst required for the systems also increase proportionally with the air flow rate to maintain the desired space velocity. Therefore, catalyst replacement costs will also be dependent on the air flow rate. Other direct operating costs, such as operating labor, are only partially proportional to the air flow capacity of the unit and suggested values were used to estimate these costs. Indirect operating costs, such as a property tax and insurance, are independent of the system operating capacity. These costs were estimated based on the total capital investment (TCI) of the incinerator system at each site. The standard engineering cost factors used to estimate the direct and indirect operating costs for each of the four incinerator systems are presented in Table 5-11.

TABLE 5-10. ESTIMATED INSTALLED COSTS FOR CATALYTIC INCINERATORS AT FOUR SITES

Cost Elements	Cost Factor[a]	Installed Cost ($, 1986) Site A	Site B	Verona Well Field	Plainfield
Direct Costs					
Purchased Equipment Cost[b]	1.0	188,210	82,600	153,840	359,300
Other Direct Costs					
Foundation and Supports	0.08				
Erection and Handling	0.14				
Electrical	0.04				
Piping	0.02				
Insulation	0.01				
Painting	0.01				
TOTAL DIRECT COST	1.30	244,670	107,380	199,990	467,090
Indirect Costs					
Engineering and Supervision	0.10				
Construction and Field Expenses	0.05				
Construction Fee	0.10				
Start Up	0.02				
Performance Test	0.01				
Model Study	--				
TOTAL INDIRECT COST	0.28	52,700	23,130	43,075	100,604
CONTINGENCY	0.05	9,410	4,130	7,690	17,970
TOTAL	1.63	306,780	134,640	250,760	585,660

[a]Reference 8
[b]Purchased equipment costs include all major and auxiliary equipment, controls and instrumentation, taxes, and freight.

TABLE 5-11. UNIT COST FACTORS AND CONSUMPTION BASES FOR CATALYTIC INCINERATION CONTROL

Operating Costs	Basis for Annual Consumption	Site	Unit Cost
Direct Operating Costs			
1. Utilities:			
a. Natural Gas	1000°F combustion temperature, 35% heat recovery[a]	All	$0.00280/scfm[b]
	8000 scfm[c]	A	
	1300 scfm[d]	B	
	5500 scfm[e]	Verona Well Field	
	20000 scfm[f]	Plainfield	
b. Electricity	0 in. P, flue gas flow rate[a] (1000°F)	All	$0.0508/kWh[b]
2. Operating Labor:			
a. Operating Labor	0.5 hrs/shift, 8600 hrs[a]	A, B	$11.99/hr[b]
b. Supervision	15% of operating labor[a]	A, B	-
3. Maintenance			
a. Labor	0.5 hrs/shift, 8600 hrs[a]	A, B	$11.99/hr[g]
b. Materials	100% of maintenance labor[a]	A, B	-
4. Replacement			
a. Parts	Catalyst volume, 3 year lifetime[a]	All	$2700/ft^3[h]
b. Labor	100% of replacement parts[a]		
Indirect Operating Costs			
1. Overhead	80% of (2a+2b+3a+3b)[a]	A, B	-
2. Property Tax	1% of total capital cost[a]	A, B	-
3. Insurance	1% of total capital cost[a]	A, B	-
4. Administration	2% of total capital cost[a]	A, B	-
5. Capital Recovery	0.163 x total capital cost[a]	A, B	-
TOTAL ANNUALIZED COST			

[a]Reference 8.
[b]Reference 11.
[c]Reference 3.
[d]Reference 4.
[e]Reference 5.
[f]Reference 6.
[g]Reference 9. Adjusted to 3rd quarter 1986 using Reference 10.
[h]Reference 8. Adjusted to 3rd quarter 1986 using Reference 10.

The estimated operating costs for each of the four sites are presented in Table 5-12. The operating costs range from $86,100 for site B to $605,700 for the Plainfield Site.

5.4 CONTROL TECHNOLOGY COST COMPARISON

Table 5-13 presents a summary of the installed and annualized costs for GAC, thermal incineration, and catalytic incineration controls for all four sites. As seen in the table, GAC systems have the lowest annualized cost while thermal incinerators have the highest annualized cost at all sites.

TABLE 5-12. ESTIMATED OPERATING COSTS FOR CATALYTIC INCINERATION CONTROL AT FOUR SITES

	Annual Operating Cost ($, 1986)			
	Site A	Site B	Verona Well Field	Plainfield
Direct Operating Costs				
1. Utilities:				
a. Fuel	137,290	21,680	93,940	354,070
b. Electricity	19,450	3,360	13,400	48,650
2. Operating Labor:				
a. Operating Labor	6,450	6,450	6,450	6,450
b. Supervision	970	970	970	970
3. Maintenance				
a. Labor	6,450	6,450	6,450	6,450
b. Materials	6,450	6,450	6,450	6,450
4. Replacement				
a. Parts	16,500	3,110	11,410	42,520
b. Labor	16,500	3,110	11,410	42,520
Indirect Operating Costs				
1. Overhead	15,624	15,624	15,624	15,624
2. Property Tax	3,070	1,350	2,510	5,860
3. Insurance	3,070	1,350	2,510	5,860
4. Administration	6,140	2,700	5,020	11,720
5. Capital Recovery	30,680	13,460	25,070	58,570
TOTAL ANNUALIZED COST	268,600	86,100	201,200	605,700

TABLE 5-13. SUMMARY OF COSTS FOR GAC INCINERATION AND CATALYTIC INCINERATION CONTROLS

SITE A

Air Stripper	
Water Flow Rate	1,400 gpm
Organic Concentration	
Trichloroethylene	4,000 ppb
Trichloroethane	300 ppb
Total Organics	4,300 ppb
Organic Removal Efficiency	99 %
Organic Emissions	11.5 Mg/yr
Air Flow Rate	8,000 cfm

Air Emission Control Efficiency and Costs

	Carbon Adsorber	Thermal Incinerator	Catalytic Incinerator
Control Efficiency (%)	~80	98	95
Installed Cost ($)	150,000	318,000	307,000
Direct Operating Cost ($)	50,400	432,000	210,000
Total Annualized Cost ($)	96,400	492,000	269,000

TABLE 5-13. (Continued)

SITE B

Air Stripper

Water Flow Rate	155 gpm
Organic Concentration	
Chloroform	1,500 ppb
Methylene Chloride	NR
Ethylene Dichloride	NR
Chloroform Removal Efficiency	99.9 %
Chloroform Emissions	0.44 Mg/yr
Air Flow Rate	1,300 cfm

Air Emission Control Efficiency and Costs

	Carbon Adsorber	Thermal Incinerator	Catalytic Incinerator
Control Efficiency (%)	NR	98	95
Installed Cost ($)	152,000	187,000	134,000
Direct Operating Cost ($)	31,300	86,800	51,600
Total Annualized Cost ($)	77,800	129,000	86,100

NR = Not Reported

TABLE 5-13. (Continued)

VERONA WELL FIELD

Air Stripper	
Water Flow Rate	1,900 gpm
Organic Concentration	
Ethylene Dichloride	5 ppb
Trichloroethane	12 ppb
Dichloroethylene	10 ppb
Trichloroethylene	1 ppb
Perchloroethylene	10 ppb
Total Organics	38 ppb
Organic Removal Efficiency	~100 %
Organic Emissions	0.14 Mg/yr
Air Flow Rate	5,500 cfm

Air Emission Control Efficiency and Costs

	Carbon Adsorber	Thermal Incinerator	Catalytic Incinerator
Control Efficiency (%)	74	98	95
Installed Cost ($)	223,000	285,000	251,000
Direct Operating Cost ($)	62,700	303,000	150,000
Total Annualized Cost ($)	124,000	358,000	201,000

TABLE 5-13. (Continued)

PLAINFIELD

Air Stripper

Water Flow Rate	3,600 gpm
Organic Concentration	
Perchloroethylene	200 ppb
Organic Removal Efficiency	99.6 %
Organic Emissions	1.4 Mg/yr
Air Flow Rate	19,200 cfm

Air Emission Control Efficiency and Costs

	Carbon Adsorber	Thermal Incinerator	Catalytic Incinerator
Control Efficiency (%)	90	98	95
Installed Cost ($)	500,000	432,000	586,000
Direct Operating Cost ($)	120,000	1,047,000	508,000
Total Annualized Cost ($)	221,000	1,123,000	606,000

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13. Letter from Dyksen, J.E., Malcom Pirnie, Inc., to Vancil, M.A., Radian Corporation. March 13, 1987. 1 p. plus enclosures.

14. Trip Report. C. C. Allen, M. Brancome and K. Leese, Research Triangle Institute, to Dr. Benjamin Blaney, EPA-HWERL. March 2, 1987. 11 p. Appendix C. Report of May 29, 1986, visit to U. S. Coast Guard Facility, Traverse City, Michigan.

6.0 SITE VISIT REPORTS

Three site visits were conducted during this study. The purpose of these visits was to obtain information on air stripper systems with GAC control. Detailed information on the design and operation of the air strippers and GAC control devices were obtained during the visits.

6.1 SITE A[1]

Site A manufactures heat exchanger equipment. Trichloroethylene and 1,1,1-trichloroethane were used in this process for degreasing operations. The two compounds were discovered in ground water near the plant, and air stripping technology was installed to clean up the groundwater in February 1984.

6.1.1 General Information

Through routine monitoring of wells, the Michigan Department of Natural Resources discovered ground water contamination by trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA). Investigation revealed that an oil and solvent storage facility at site A was the possible contamination source. Liquid losses during handling were identified as the cause of contamination. The storage tanks at the facility were tested for leaks, but none were detected.

Twelve purge wells and approximately 60 to 70 monitoring wells were installed to define the contamination plume and supply contaminated water to the air stripper for treatment. The purge wells were placed in banks of three around the plume. The air stripper began operating in February 1984.

6.1.2 Process Description

A diagram of the air stripping process is shown in Figure 6-1. Water is pumped from the purge wells and combined in a single pipeline at the air stripper. The water is pumped to the top of the packed column and is countercurrently contacted with air. The column stands 66 feet high and is

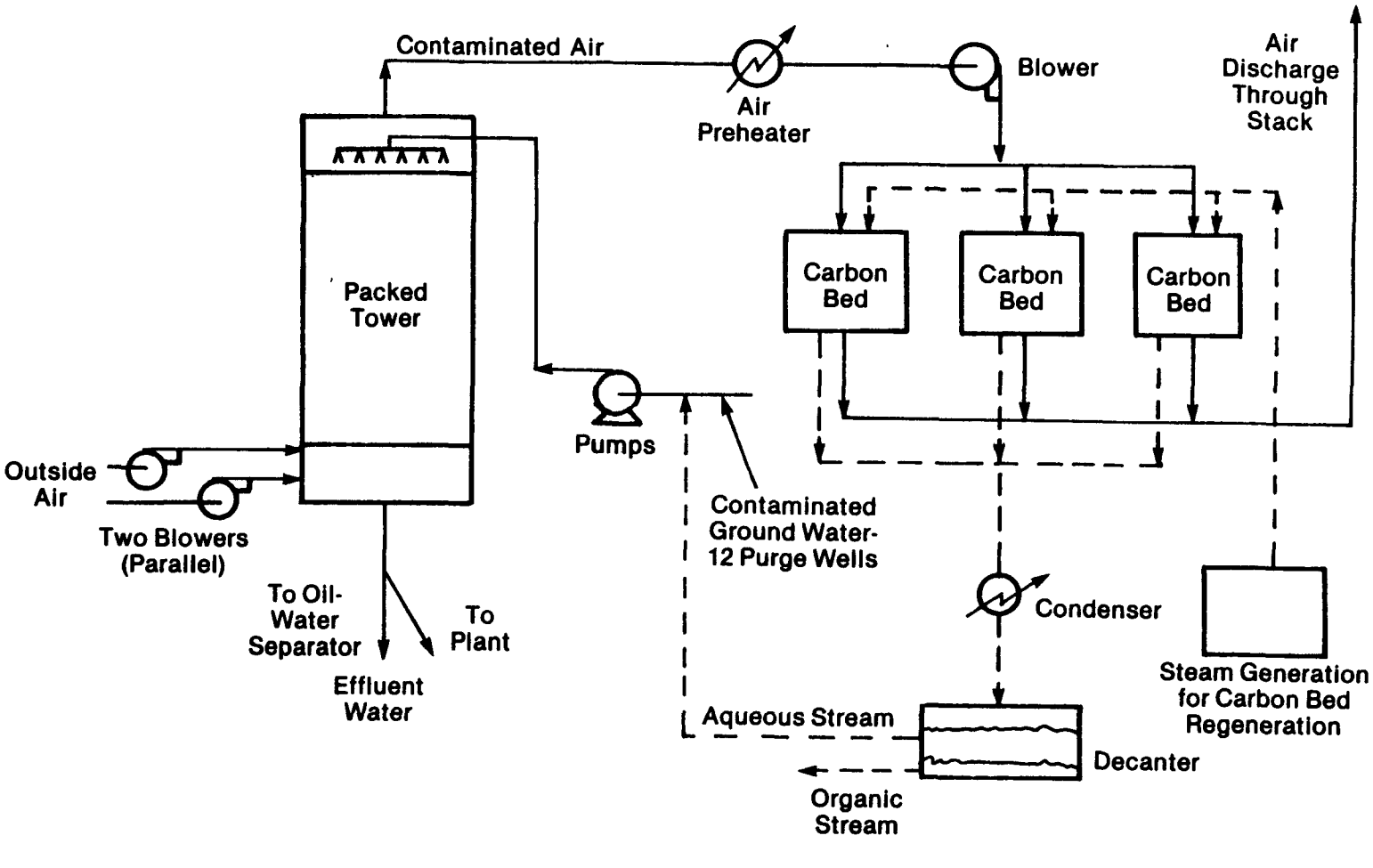

Figure 6 - 1. Air Stripping System with On-Site Carbon Regeneration at Site A

made of fiberglass; the internal structure (packing support, liquid distributors, etc) is made of stainless steel. Water is discharged from the air stripper to two different locations. Approximately 1,100 gpm of the 1,400 gpm total water effluent is sent to an oil-water separator and is discharged with other wastewater from the facility. The remaining effluent is used as non-contact cooling water in the plant. This water, necessary for plant operation, is stored in a 100,000 gallon tank. The tank supplies only enough water for about six hours of plant operation, so it is necessary for the air stripper to operate continuously.

The well pumping system is equipped with a warning system to notify plant personnel if pumps have failed. Additionally, the water supply rate from the wells can be controlled at several points. The flow rate from each well or the flow from a bank of three wells can be varied.

Outside air is drawn into the system at 7,000-9,000 cfm by two blowers operating in parallel. The air flows through the air stripping column, a steam preheater, a blower, the granular activated carbon (GAC) adsorber beds, and out an 80 foot stack. The blowers work in combination to both force and induce air through the system. The preheater is used to lower the relative humidity of the air to below 40 percent. This increases the amount of volatile organic (VO) adsorption on the GAC by preventing condensation of water in the GAC pores. The three VIC carbon adsorber beds are arranged in parallel and contain 3,000 pounds of carbon each.

Steam is used to regenerate the carbon adsorber units. During regeneration, one bed is removed from service and steam is passed through the bed for one hour. The bed is then put back on-line, and another bed is removed from contaminated air service to be regenerated. This is done for all three beds until they are completely regenerated. Initially, the carbon beds were regenerated every 10 - 12 hours, but influent concentrations have decreased since startup. Regeneration is now required every 48 hours.

The steam and VO leaving the carbon bed from the regeneration process are condensed and allowed to separate in a decanter. The aqueous phase is recycled into the influent stream to the stripping tower; the organic phase, approximately 35-50 gallons per week of TCE, is collected and disposed of as a hazardous waste. TCE is not reused because it no longer contains proprietary additives included by the solvent supplier.

Very few problems have been encountered with the air stripping system. The forced air arrangement for the carbon beds has caused some minor difficulties. The air caused dishing of the carbon bed and allowed channeling of air through the bed, lowering the VO removal efficiency. The beds are raked occasionally to control this problem.

During the past year, the air stripping system was shut down for four days to effect repairs and cleaning. Chlorine was recirculated through the air stripping tower to clean iron bacteria deposits from the packing.

6.1.3 Performance Data for the Air Stripper and GAC

Air and water regulations affect the size of the air stripper system, the need for air emission controls, and how long the system must operate. The State of Michigan requires that the water discharged from the stripper contain less than 5 ppb VO. The level of contamination allowed in the ground water at the end of the cleanup has not been determined yet. The air permit allows a maximum discharge of approximately 2.5 lb/hr VO. This is based on a 10^{-6} increase in cancer risk off-site from the facility based on the Michigan long-term (MILT) air dispersion model and estimated ground water contamination. The air stripper was built anticipating a 10 year lifetime. The actual time needed to clean the ground water is unknown, however. Carbon replacement is not expected at any time.

The air stripper is currently removing about 99.9 percent of the influent VO in the water. Initially, the influent concentration was about 20 ppm VO. This has decreased to 3 - 5 ppm TCE and 200 - 400 ppb TCA and is remaining steady at this concentration. The tower effluent water typically contains 2 - 8 ppb TCE and non-detectable concentrations of TCA, based on biweekly sampling results.

The activated carbon beds are currently removing 70 - 90 percent of the VO in the air exhaust from the column. This estimated removal range is based on material balances taking into account the organic volumes recovered during regeneration of the carbon.

6.1.4 Cost Data

Little cost data are available on the system. In 1984, one of the three carbon units was installed new for approximately $60,000, including the equipment cost of about $35,000. It is estimated that it would now cost about $150,000 to replace all three carbon beds.

6.2 SITE B[2]

From 1965 to 1982, site B extracted conjugated estrogens from equine mares' urine with either methylene chloride or 1-2, dichloroethane. Chloroform was also used on-site as a bacteriostatic agent. In 1981, ground water contamination by these three chemicals was discovered and cleanup using air stripping was initiated.

6.2.1 General Information

In 1981, a tank truck overflowed with liquid being emptied from the waste holding tank at site B. Soil was excavated to clean up the spill. As a precaution, a ground water sample was taken at the time to test for additional contamination. The sample revealed contamination by chloroform, methylene chloride, and 1,2-dichloroethane, although this was not from the tank spill.

The holding tank was tested for leaks, but none were detected. Through dye tracing of the drain system at the plant, a drain from the barrel washing area was identified as the contamination source. All drains in the facility were designed to feed the single waste holding tank. The barrel washing area, however, drained to a dry well instead of being connected to the collection system. The solvents seeped from the dry well and contaminated the ground water.

Monitoring wells were placed to define the plume of contamination. After defining the plume of contamination, five purge wells were installed and air stripping technology was selected. Construction of the air stripper was completed in four months. The air stripper began operating in December 1985. As determined using water contamination estimates and air dispersion modeling,

no air emission controls were required by the State of Michigan. However, emission testing after system start-up revealed that air emissions were exceeding the permitted amount of 0.6 lbs/hr. Granular activated carbon (GAC) was installed on the air exhaust to reduce emissions. The air stripper and emission control systems have been operating continually since.

6.2.2 Process Description

A diagram of the air stripping system is shown in Figure 6-2. Water from the five purge wells is pumped through a single line to the air stripping column. In the three foot diameter, 45 foot tall column, air and water countercurrently contact over the packed media. The column has an average water flow of 155 gpm and an air flow of 1,200 - 1,400 cfm. Water flows by gravity from the tower to a drainage ditch feeding into the Black River and eventually into Lake Michigan. Outside air is drawn into the system by a forced draft blower. The air flows through the column, an electric preheater, the GAC bed, a second blower, and out the stack. The two blowers work in combination to both force and induce air through the system. The air preheater is used to increase the air temperature to above $80^{o}F$, thus lowering the relative humidity to below 40 percent. This increases the amount of volatile organic (VO) adsorption on the GAC by preventing condensation of water in the GAC pores.

The carbon bed is steam regenerated on-site every 7 days. The system is shut down for three hours and the organics are steam stripped from the carbon bed. The steam and organics are condensed and then separated in a decanter. The aqueous phase is sent back through the air stripper, and the collected solvent is disposed of as a hazardous waste. Usually about 13 pounds of VO are recovered per regeneration cycle. The bed is dried with clean air after regeneration.

Some problems have been encountered during system operation. Fouling by iron bacteria causes a noticeable increase in pressure drop across the column. This has occurred once at this site and was controlled by recycling acidified water through the tower. Another problem experienced involves the air

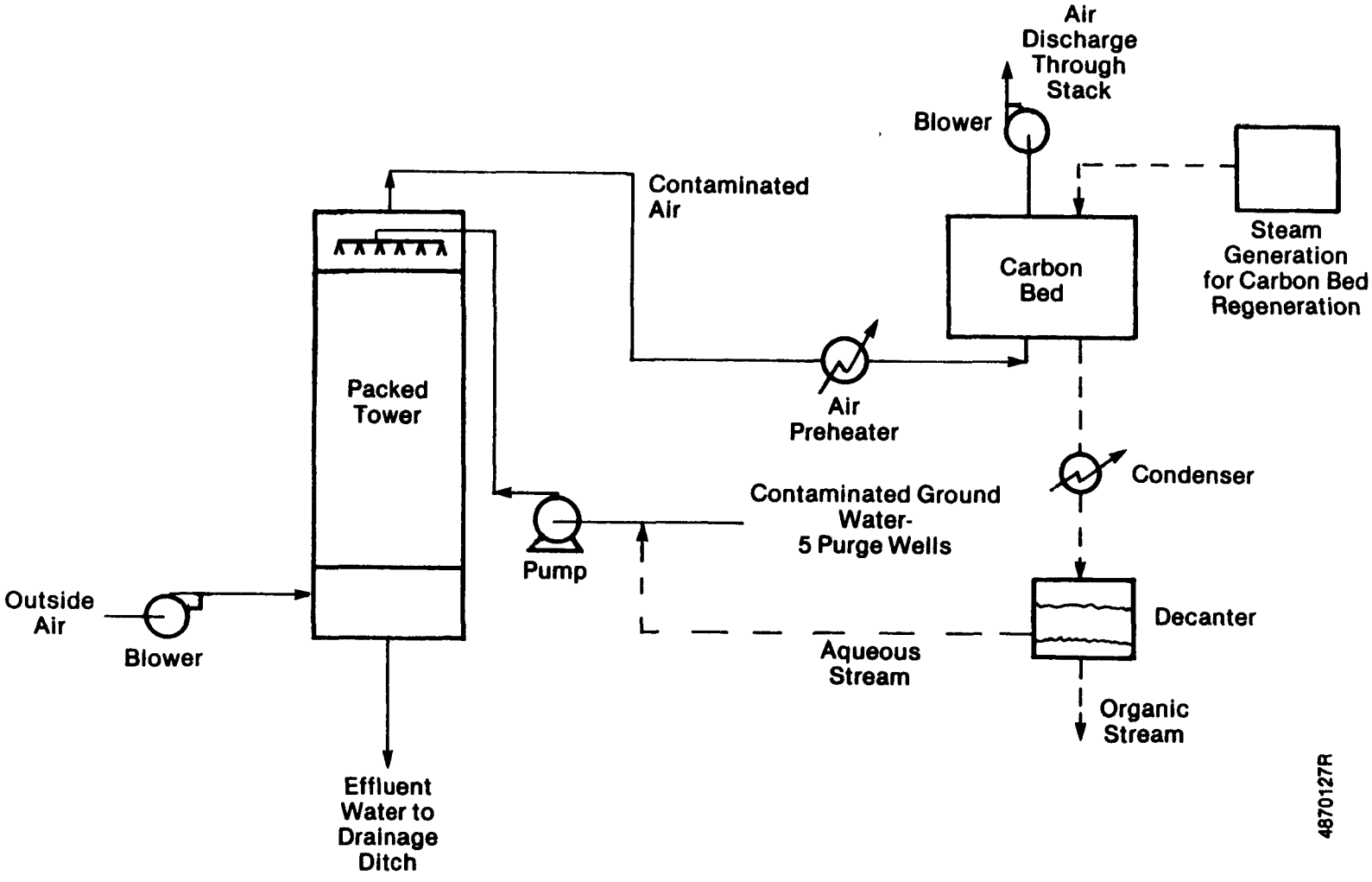

Figure 6 - 2. Air Stripping System with On-Site Carbon Regeneration at Site B

preheater. The preheater was not sufficiently heating the air and led to poor VO removal by the GAC. The original preheater was not lowering the relative humidity of the air to 40 percent. An elbow in the duct near the heater may have been causing stratification of the air and uneven heating. The original preheater was recently replaced with a larger unit and VO removal is expected to improve to about 90 percent.

6.2.3 Performance Data for the Air Stripper and GAC System

The State of Michigan has regulations limiting both air and water contaminant discharges. These regulations affect the size of the system, the need for air emission controls, and the length of time the system must operate. For the air stripper at site B the water discharged from the tower must contain less than 5 ppb total VO and air emissions must be less than 0.6 lbs/hr. This air emission rate yields less than 10^{-6} maximum lifetime cancer risk at the facility boundaries using the Michigan long-term (MILT) air dispersion models. The tower must also operate until the groundwater contains less than 5 ppb VO for an extended time. The wells are then monitored for three years after shut-down to ensure that contamination does not increase.

The system has been operating continuously since December 1985, and one or two more years of operation is anticipated until the groundwater is cleaned up. Initially, the influent water contained approximately 1.5 ppm chloroform and smaller concentrations of 1,2-dichloroethane and methylene chloride. This rapidly decreased to lower levels, where it has remained steady since. The effluent water has consistently been at <1 ppb total volatile organics. No data are available on the air discharge, but the GAC is designed to remove 90 percent of the entering VO. This removal has not been observed because of the humidity problems mentioned previously. Testing will be performed shortly to determine VO removal effectiveness with the new preheater.

6.2.4 Cost Data

Little cost data were available for the system. It was estimated that the carbon steel stripping tower and auxiliaries cost $130,000 to construct. Approximately $150,000 capital was expended on air emission control. Generally, air emission control at least doubles the capital costs for the system and greater than doubles the operation and maintenance costs.

6.3 VERONA WELL FIELD[3]

Verona Well Field supplies drinking water to Battle Creek, Michigan. In early 1984, ground water clean up was deemed necessary to contain the spread of a contamination plume in the well field. In September, 1984, an air stripping system began operating for this purpose.

6.3.1 General Information

Routine well monitoring at Verona Well Field identified contamination by several volatile organic compounds in the ground water. An investigation revealed that the sources of the contamination were: (1) a leaking underground storage tank at a solvent recycling company, Thomas Solvents, about 1 mile south of the well field, (2) spills at a railroad loading spur for the same company, and (3) spills at a section of railroad southeast of the well field. Since Thomas Solvents declared bankruptcy, "Superfund" money was allocated for the clean up. From June to September 1984, aqueous-phase granular activtated carbon (GAC) was used to treat the ground water while the air stripper was being installed. In September 1984, the air stripper began operation. Gaseous-phase, granular activated carbon was installed for air emission control. The system draws water from a row of existing wells in the field. Pumping from these wells prevents the plume from spreading to other wells currently supplying potable water. In late 1986, several wells were installed near the site of the underground storage tank. In April 1987, the air stripper will start treating ground water pumped from these wells.

6.3.1 Process Description

A diagram of the air stripper is shown in Figure 6-3. Contaminated water from the well field and storage tank site is pumped to a wet well at the air stripper. The water is pumped at 2,000-2,400 gpm to the top of the column. The water flows over the packed media and is countercurrently contacted with air. Water leaves the column and is discharged to a river. The 10 foot diameter, 60 foot high column is constructed of PVC wrapped with fiberglass. The column is packed with 40 feet of polypropylene packing. The system operates only at design air and water flow rates. No controls are used to vary the operating rates.

Air is induced through the column at 5,500 cfm by a blower following the column. The blower then forces air through a preheater and two parallel GAC beds. The air is discharged to the atmosphere through two stacks after exiting the GAC beds. The preheater raises the air temperature about $30^{o}F$ and lowers the relative humidity to 40 percent or less. Air temperature is measured before and after the preheater.

The GAC beds are four feet deep and 10 foot in diameter and contain a total of 19,000 pounds of carbon. The carbon beds are replaced when breakthrough occurs. After an estimated 50 percent of the carbon capacity has been used, periodic testing of the outlet air is to determine if breakthrough has occurred. The time required to reach 50 percent of capacity is estimated from theoretical relationships supplied by the carbon vendor. When breakthrough occurs, the air stripping system is shut down and the spent carbon is vacuumed out of the beds. The carbon is shipped off-site for regeneration and new carbon is charged to the beds. The entire carbon replacement process takes about three days.

No major operational difficulties have been observed with the air stripping system. Some plugging and fouling has occurred because of deposits from iron bacteria, but this has been controlled through occasional recycling of chlorine through the tower. Fouling is indicated by an increase in pressure drop across the column. Neither of these problems, however, caused the system to shut down. The cold weather can cause operating problems in the tower. Water splashing from inside the column freezes on the air

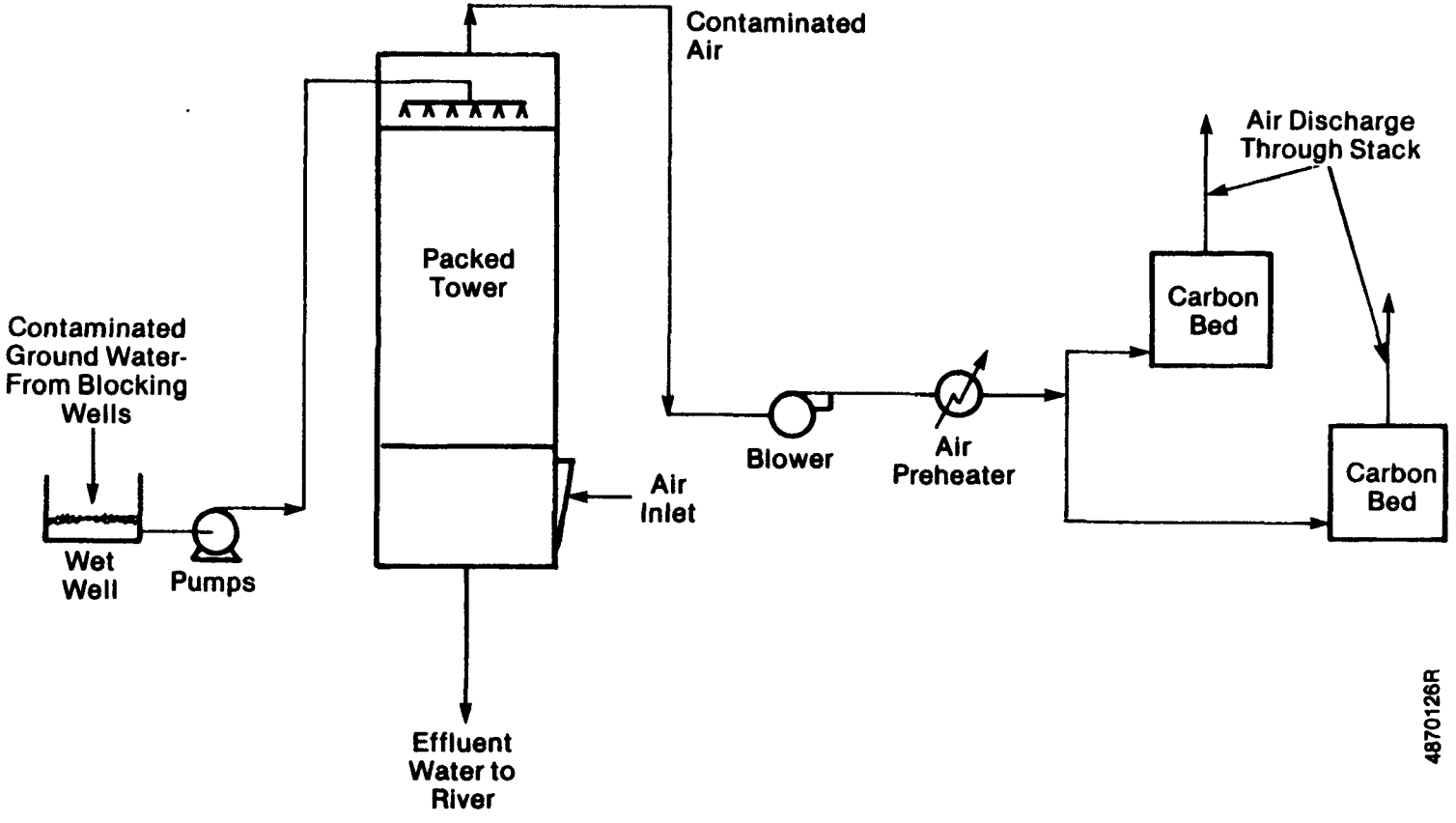

Figure 6 - 3. Air Stripping System with Non-Regenerable Carbon at Verona Well Field

intake port and can partially clog it. This reduces the air flow and increases the pressure drop across the column. The chlorination recycle pipe became disconnected at the top of the column and it is suspected that this was caused by the cold weather.

6.3.3 Performance Data for the Air Stripper and GAC System

The air stripper has been removing nearly 100 percent of the volatile organics in the influent water. Typically, the influent contains approximately 50 ppb VO, while the effluent concentration is reduced to non-detectable amounts of VO.

Limited testing has been done on the effectiveness of the GAC units for controlling air emissions. Grab air sampling was conducted twice. Results of one of these efforts indicated a VO removal of approximately 74 percent.

Additional sampling will be performed after the current GAC beds have adsorbed an estimated half of capacity. The sampling will both reveal when breakthrough occurs and allow the Michigan Department of Natural Resources (DNR) to compare actual carbon adsorption with the theoretical relationships supplied by the vendor.

6.3.4 Cost Data

The air stripping system was purchased by the U. S. EPA with "Superfund" money. Operation and maintenance for the first year was also paid by the U.S. EPA. After that operational responsibility was transferred to the Michigan DNR.

The air stripping system at Verona Well Field was built anticipating a five year lifetime. Because of additional contamination discovered near the well field, more than five years will be required to complete the clean up. As other contamination sites are discovered in the Battle Creek area, water from the sites will be pumped to the air stripper at Verona Well Field for treatment.

6.4 REFERENCES

1. Trip Report. R. H. Howle and M. A. Vancil, Radian Corporation, to file. 6 p. Report of March 12, 1987 visit to site A.

2. Trip Report. R. H. Howle and M. A. Vancil, Radian Corporation, to file. 5 p. Report of March 12, 1987 visit to site B.

3. Trip Report. R. H. Howle and M. A. Vancil, Radian Corporation, to file. 6 p. Report of March 11, 1987 visit to Verona Well Field.

7.0 POSITIVE AND NEGATIVE AIR IMPACTS FOR CONTROLS

The air emission controls discussed in Sections 4 and 5 are demonstrated technologies for the reduction of organic emissions from air strippers. However, these control techniques can result in the generation of other pollutants. This section provides a discussion of both the positive and negative air emission impacts resulting from each of three control techniques: granular activated carbon (GAC) adsorption, thermal incineration, and catalytic incineration. The air impacts of each control are evaluated for three actual air strippers currently controlled by carbon adsorption. These three air strippers are Site A, Site B, and Verona Well Field discussed in Section 5. Sufficient data are not available for the Plainfield Site to include it in the evaluation of air impacts.

Although carbon adsorption control greatly reduces the organic emissions from air stripping, the overall control scheme results in increased emissions of combustion pollutants. Fuel combustion is required for the generation of steam for carbon regeneration and to preheat inlet air to the carbon adsorber. As discussed in Section 4, preheating is required to lower the relative humidity of the air stream. This may be accomplished by an electric heater, a steam heat exchanger, or an indirect fired heater. Regardless of the method for heating the inlet air some form of fuel combustion is required. The pollutant emissions resulting from fuel combustion include SO_x, NO_x, and particulate matter. The quantity of these combustion pollutants resulting from steam generation or indirect heating was estimated using AP-42 emission factors for combustion of natural gas.[1] Similarly, combustion emissions resulting from electricity generation were estimated based on emission factors for combustion of coal to produce electricity.[2] The emission factors used are presented in Table 7-1.

Both thermal incineration and catalytic incineration result in emissions of NO_x and particulate matter. Emission factors for generation of these pollutants were not available for incinerators. Therefore, available emission factors for similar combustion devices were used. The combustion emissions

TABLE 7-1. EMISSION FACTORS FOR FUEL COMBUSTION

Source	SO_2 (lb/MBtu)	NO_x (lb/MBtu)	PM (lb/MBtu)
Steam Generation (Natural gas for Site A)[a]	0	0.134	0.003
(Fuel mixture for Verona Well Field)[b]	0.810	0.210	0.058
Gas Fired Preheater[a]	0	0.134	0.003
Electricity Generation[c] (coal fired)	1.64	1.27	0.205
Thermal Incineration[a]	0	0.134	0.003
Catalytic Incineration	0[a]	0.1[d]	0.003[a]

[a]Reference 1.
[b]Fuel mixture for off-site steam generation not specified. Estimated average fuel mixture for steam boilers as 55% natural gas, 30% residual oil, 15% distillate oil (Source: Draft Background Information Document for Industrial Boilers, U. S. EPA).
[c]Reference 2.
[d]Reference 3.

resulting from thermal incineration were estimated using emission factor provided in AP-42 for natural gas-fired boilers.[1] Particulate emissions from catalytic incinerators were also estimated based on the emission factor for natural gas-fired boilers. The NO_x emissions from catalytic incinerators were estimated based on an emission factor for natural gas-fired process heaters to reflect the lower operating temperature of catalytic incinerators.[3] These emission factors are also presented in Table 7-1.

The positive and negative air impacts estimated for Site A, Site B, and Verona Well Field are presented in Figures 7-1 through 7-3. The volatile organic removals for carbon adsorption are based on reported efficiencies at the specific sites with the exception of Site B. A removal efficiency of 70 percent was estimated for this facility based on information obtained for this site. The assumed efficiencies for thermal and catalytic incineration were 98 percent and 95 percent, respectively. Fuel combustion requirements for generation of steam and electricity were estimated based on site specific data. The estimated steam electricity and combustion fuel requirements estimated for each facility are provided in Table 7-2.

As shown in Figures 7-1 through 7-3, combustion pollutants generated as a result of the different control technologies can be significant. The most noticable generation of combustion pollutants are the estimated NO_x emissions resulting from thermal incineration.

TABLE 7-2. ESTIMATED UTILITY REQUIREMENTS FOR EACH SITE

Control/Utility	Site A	Site B	Verona Well Field
GAC			
Steam (lb/yr)[a]	608,000	8,630	19,000
Electricity (kW)[a]	--	20.3	--
Natural Gas (scfm)[a]	59.4	--	37.0
Thermal Incineration			
Natural Gas (scfm)	245	62.0	169
Catalytic Incineration			
Natural Gas (scfm)	134	22.0	92.0

[a]Utility demand is not continuous. More is needed when the carbon is regenerated. Uses reported as continuous.

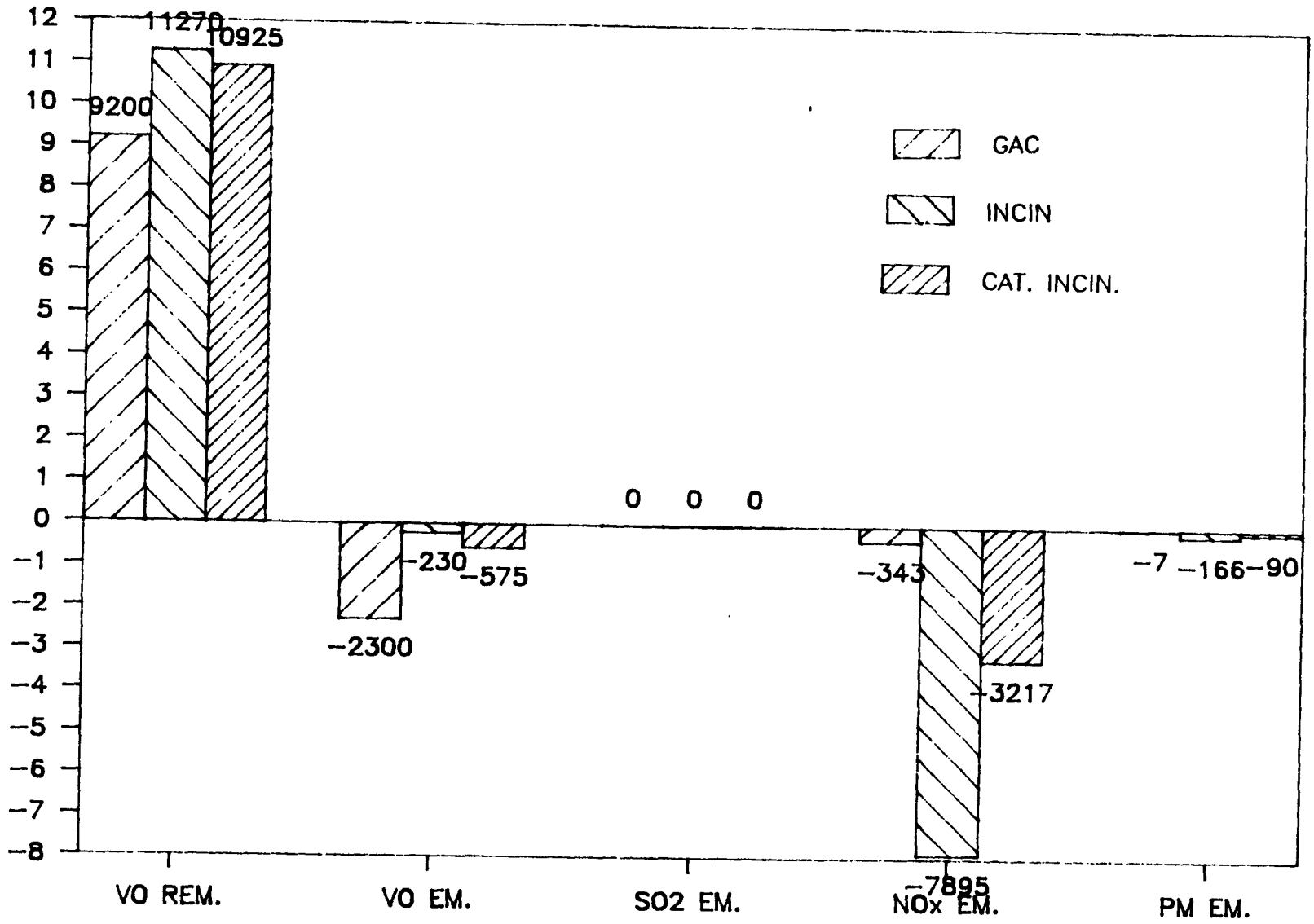

Figure 7-1. Organic Removal and Estimated Emissions for Control Devices at Site A.

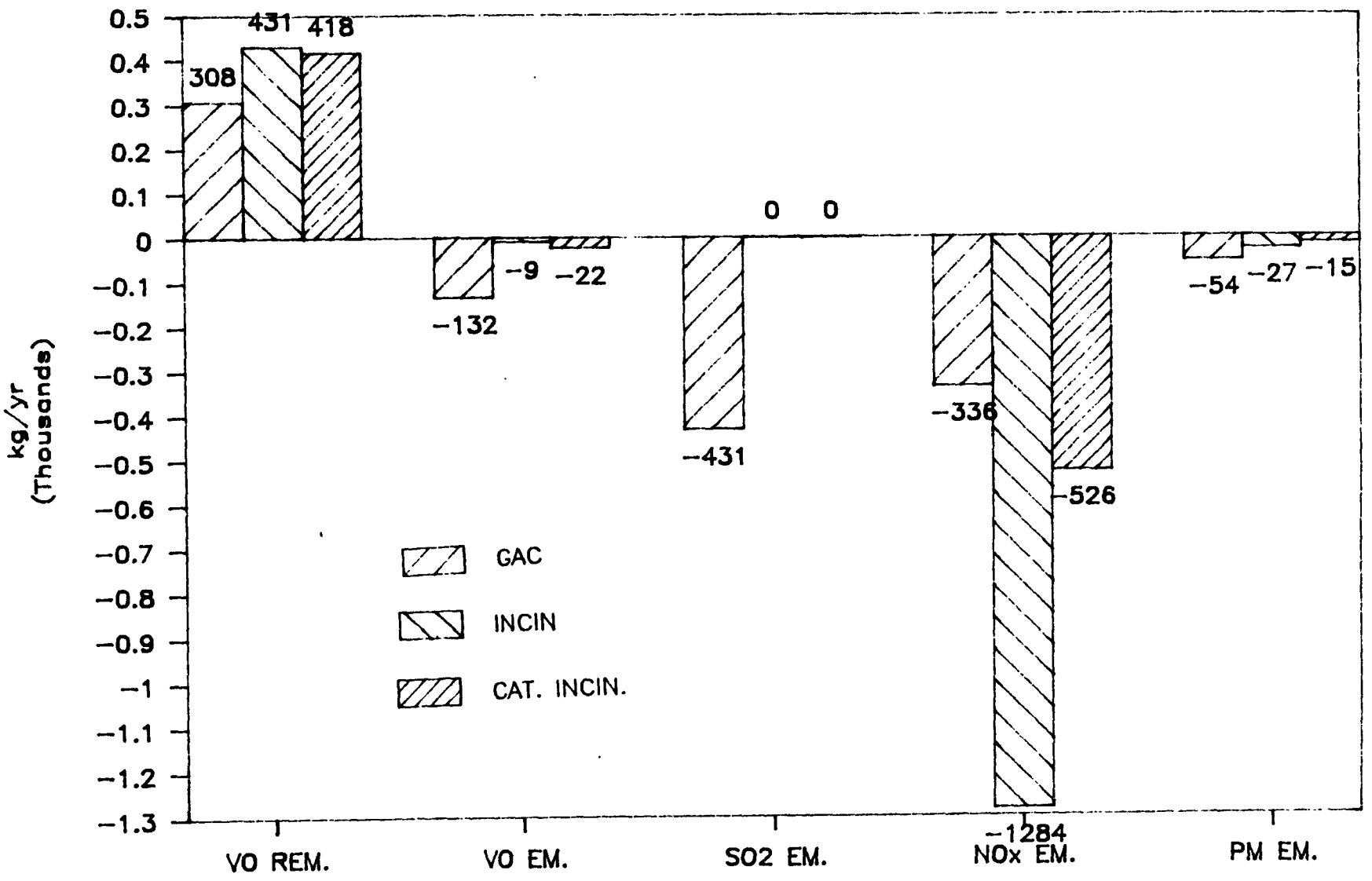

Figure 7-2. Organic Removal and Estimated Emissions for Control Devices at Site B.

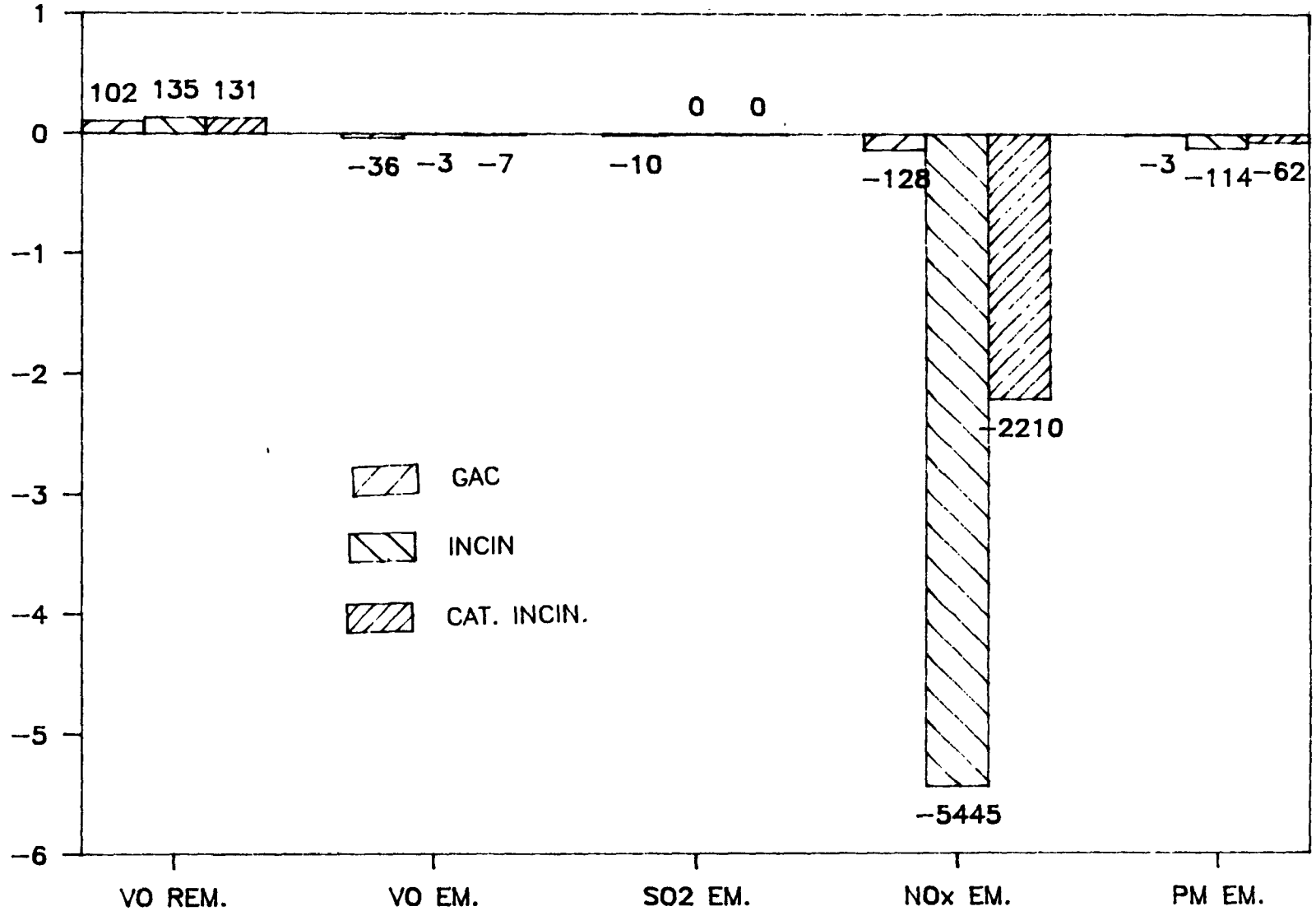

Figure 7-3. Organic Removal and Estimated Emissions for Control Devices at Verona Well Field.

7.1 REFERENCES

1. U. S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. Research Triangle Park, N. C. Publication No. AP-42. September 1985.

2. 40 CFR 60, Subpart D.

3. Shareef, S.A., C.L. Jamgochian, and L.E. Keller. (Radian Corporation). Fired Heaters: Nitrogen Oxides Emissions and Controls. (Prepared for U. S. Environmental Protection Agency). Research Triangle Park, N. C. EPA Contract No. 68-02-3994. September 30, 1985. 143 p.

APPENDIX A

TABLE A-1. EPA Telephone Contacts

Contact	Affiliation	Telephone No.	Topics of Conversation
REGION 1			
Dave Cochrane	NPDES Permits	(617) 565-3505	identification of air stripper
Steve Farrick	Superfund Project Mgr.	(617) 565-3683	one air stripper in MA
Ivan Rios	Superfund Project Mgr.	(617) 565-3681	one air stripper in MA
Ted Landry	Acting Section Chief, NPDES	(617) 565-3508	identification of air stripper
Chet Janowski	Superfund Project Mgr.	(617) 565-3652	one air stripper in NH
Tony DePalma	Dept. Head, Permits	(617) 565-3493	identification of air stripper
Ron Jennings	Technical Assistance Section	(617) 565-3617	identification of air stripper
Chuck Larson	Ground Water Branch Chief	(617) 565-3586	identification of air stripper
REGION 2			
Ed Als	Superfund Project Mgr.	(212) 264-0522	one air stripper in NY
Bob Wing	Superfund Project Mgr.	(212) 264-8670	identification of air stripper
Walter Andrews	Water Supply Branch Chief	(212) 264-1800	one air stripper in NY
Pam Tames	Superfund Project Mgr.	(212) 264-2646	one air stripper in NY
John Frisco	Superfund Branch Chf.	(212) 264-1872	identification of air stripper
REGION 3			
Jeff Pike	Tyson's Dump Project Mgr.	(215) 597-8886	one air stripper in PA
Gerallyne Val	Superfund Project Mgr.	(215) 597-8186	one air stripper in PA
Walter Graham	Superfund Section Chf.	(215) 597-8177	identification of air stripper
Harry Harbold		(215) 597-0910	identification of air stripper
Dan Donnelly	Central Regional Lab	(301) 224-2740	identification of air stripper
Joseph Protowski	Water Supply Branch Chf.	(215) 597-8227	identification of air stripper
Thomas Voltaggio	Superfund Branch Chief	(215) 597-8132	identification of air stripper
REGION 4			
Jim Orban	Superfund Project Mgr.	(404) 347-2643	identification of air stripper
Ken Orloff	Groundwater Branch Off.	(404) 347-3781	identification of air stripper
Mike Leonard	Groundwater Branch	(404) 347-2913	identification of air stripper
Michelle Glenn	Superfund Project Mgr.	(404) 347-2643	identification of air stripper
Al Smith	Superfund Branch Chief	(404) 347-4097	identification of air stripper

TABLE A-1. EPA Telephone Contacts (continued)

Contact	Affiliation	Telephone No.	Topics of Conversation
REGION 5			
Joan Calabres	Superfund Project Mgr.	(312) 886-0622	one air stripper in WI
Cindy Nolan	Superfund Project Mgr.	(312) 886-0400	one air stripper in IN
Greg Van de Laan	Site Management Section	(312) 886-6217	three air stippers in region
Ken Westlake	RCRA/SF Section Chief	(312) 886-7580	identification of air stripper
Joseph Harrison	Drinking Water/Groundwater Protection Branch Chief	(312) 353-2650	identification of air stripper
REGION 6			
Don Williams	Superfund Project Mgr.	(214) 767-9713	identification of air stripper
Steve Gilrein	Superfund Project Mgr.	(214) 767-2737	identification of air stripper
Tom Love	Water Supply Branch	(214) 767-9932	identification of air stripper
REGION 7			
Pat Costello	Groundwater Branch	(913) 236-2815	identification of air stripper
Stan Calow	Drinking Water Branch	(913) 236-2815	one air stripper in MO
Alice Fuerst	Superfund Project Mgr.	(913) 236-2856	one air stripper in IA
Chet McLaughlin	RCRA Branch	(913) 236-2852	identification of air stripper
Robert Morby	Superfund Branch Chief	(913) 236-2855	identification of air stripper
REGION 8			
Richard Long	Groundwater Branch Chf.	(303) 293-1542	identification of air stripper
Don Schosky	Hazardous Waste Mgmt.	(303) 293-1642	identification of air stripper
Vera Moritz	Superfund Project Mgr.	(303) 293-1640	one air stripper in Co
Liz Evans	Superfund Project Mgr.	(303) 293-1533	identification of air stripper
REGION 9			
James Thompson	Groundwater Branch Chf.	(415) 974-8267	identification of air stripper
Neil Ziemba	Superfund Branch	(415) 974-7174	contacts for 11 air strippers
Patty Cleary	Project Manager	(415) 974-8015	one air stripper in CA
Dan Opalski	Project Manager	(415) 974-7552	one air stripper in AZ
Nick Morgan	Superfund Branch	(415) 974-8603	one air stripper in CA
Clair Tiedeman	Project Manager	(415) 974-7032	one air stripper in AZ
Steve Johnson	Project Manager	(415) 974-7232	one air stripper in CA
Betsy Curnow	Project Manager	(415) 974-8364	two air strippers in CA
Glenn Kistner	Project Manager	(415) 974-7199	one air stripper in CA
Ken Greenburg	Section Chief, Permits	(415) 974-9748	identification of air stripper
Leo Levinson	Project Manager	(415) 974-7101	one air stripper in CA

TABLE A-1. EPA Telephone Contacts (continued)

Contact	Affiliation	Telephone No.	Topics of Conversation
REGION 10			
Lee Woodruff	Drinking Water Branch	(206) 442-4092	identification of air stripper
Carol Thompson	Superfund Project Mgr.	(206) 442-2709	one air stripper in WA
Phil Wong	Superfund Project Mgr.	(206) 442-7216	one air stripper in WA
OTHER EPA			
Mike Cummins	ODW Technical Support Division	(513) 569-7979	identification of air stripper
Ben Lykins	ODW, Municipal Environmental Research Lab	(513) 569-7403	identification of air stripper
Walter Feige	ODW, Municipal Environmental Research Lab	(513) 569-7496	one air stripper in NY
Dick Miltner	ODW, Municipal Environmental Research Lab	(513) 569-7403	one air stripper in CA

TABLE A-2. STATE TELEPHONE CONTACTS

Contact	Affiliation	Telephone No.	Topics of Conversation
ALABAMA			
Joe Power	Drinking Water Office	(205) 271-7773	identification of air stripper
ARIZONA			
Larry Crisafully		(602) 258-6381	data on three air strippers
Carroll Dekle	Air Quality	(602) 257-2282	identification of air stripper
Dave Shelgren	Air Quality	(602) 257-2301	air emission regulations
Dick Lemon	Pima County APCD	(602) 792-8686	air emission regulations
CALIFORNIA			
Cliff Sharp	Dept. Health Services	(916) 323-6111	identification of air stripper
Jan Meyer	Toxic Substance Control	(916) 324-3781	identification of air stripper
Tom Berkins	Regional Water Quality San Fransisco Bay	(415) 464-1255	data on one air stripper
Johnson Lam	Regional Water Quality San Fransisco Bay	(415) 464-1287	data on one air stripper
Bob Marek	Regional Water Quality San Fransisco Bay	(415) 464-0884	data on five air strippers
John Marshak	Toxic Substances Control Central Valley	(916) 361-5724	identification of air stripper
Scott Hubenberger	Water Quality Control San Diego	(619) 265-5114	identification of air stripper
John Swanson	Permits Chief, Bay Area AQMD	(415) 771-6000	air emission regulations
Sandra Lopez	Engineer, Bay Area AQMD	(415) 771-6000	air emission regulations
Bill Ryan	Senior Engineer, Sacramento Toxic Substances Control	(916) 739-3996	data on three air strippers
Nestor Acedera	South Coast Toxic Substances Control	(213) 620-2824	identification of air stripper
George Rutt	South Coast AQMD	(818) 572-6209	identification of air stripper
Eric Shelton	Sacramento AQMD	(916) 366-2107	data on one air stripper
Carol Nejih	CA Dept. of Health	(213) 620-2824	data on one air stripper
CONNECTICUT			
Elsie Patton	Groundwater Office	(203) 566-7295	identification of air stripper

TABLE A-2. STATE TELEPHONE CONTACTS

Contact	Affiliation	Telephone No.	Topics of Conversation
FLORIDA			
Jeffrey Watts	Dept. of Environmental Reg.	(904) 488-3601	data on two air strippers
Bill Darling	Dept. of Environmental Reg.	(305) 894-7555	data on one air stripper
Mike Webb	Dept. of Environmental Resources	(904) 487-1762	identification of air stripper
Lew Devilon	Dept. of Environmental Resources	(305) 964-9668	identification of air
Stephanie Brooks	Dept. of Environmental Resources	(305) 964-9668	data on one air stripper
Don Harris	Dept. of Environmental Resources	(904) 487-2776	data on one air stripper
Russ Walker	Dept. of Environmental Resources	(904) 487-2776	data on one air stripper
GEORGIA			
Wright Addison	Drinking Water	(404) 656-5660	identification of air stripper
IDAHO			
Dick Rogers	Drinking Water	(208) 334-5867	identification of air stripper
ILLINOIS			
Mangu Bator	Environmental Protection Agency	(217) 782-7326	data on three air strippers
IOWA			
Dennis Alt	Environmental Protect. Division	(515) 281-8998	identification of air stripper
KANSAS			
Carl Mueldener	Drinking Water/ Groundwater	(913) 862-9360	identification of air stripper
Jim Power	Drinking Water/ Groundwater	(913) 862-9360	data on two air strippers

TABLE A-2. STATE TELEPHONE CONTACTS

Contact	Affiliation	Telephone No.	Topics of Conversation
MAINE			
George Seel	Bureau of Oil and Hazardous Waste	(207) 289-2651	identification of air stripper
MASSACHUSETTS			
Gene Knight	Dept. of Environmental Quality	(617) 327-2658	air emission regulations
MICHIGAN			
Pat McKay	Dept. of Natural Resources	(517) 335-3388	data on one air stripper
Jack Larson	Dept. of Natural Resources, Jackson District	(517) 788-9598	data on three air strippers
Dick Vandebunt	Dept. of Natural Resources, Planewell District	(616) 685-6851	data on one air stripper
Gene Hall	Dept. of Natural Resources, Jackson District	(517) 788-9598	data on one air stripper
MINNESOTA			
Lou Chamberlain	Pollution Control Agency	(612) 296-7371	data on five air strippers
MISSISSIPPI			
Lee Jones	Drinking Water	(601) 354-6616	identification of air stripper
NEBRASKA			
Richard Schlenker	Dept.of Environmental Control	(402) 471-4217	data on two air strippers
Mike Steffensmeier	Dept.of Environmental Control	(402) 471-2186	identification of air stripper
NEW JERSEY			
Paul Schorr	Bureau of Safe Drinking Water	(609) 292-5550	data on five air strippers

TABLE A-2. STATE TELEPHONE CONTACTS

Contact	Affiliation	Telephone No.	Topics of Conversation
NEW YORK			
Jim Covey	Drinking Water	(518) 474-5456	identification of air stripper
Warren Longacker	Drinking Water	(518) 474-5285	data on four air strippers
Don Spencer	Air Toxics	(518) 457-7454	air emission regulations
NORTH CAROLINA			
Wally Venrick	Drinking Water	(919) 733-2321	identification of air stripper
Tom Earington	NRCD Permits	(919) 733-2314	identification of air stripper
OREGON			
Dave Leland	Drinking Water	(503) 229-5784	identification of air stripper
PENNSYLVANIA			
Doug Lester	Pennsylvania Air Quality	(717) 787-9702	air emission regulations
SOUTH CAROLINA			
Max Vatavia	Drinking Water	(803) 734-5342	identification of air stripper
TENNESSEE			
Jim Hanes	Drinking Water	(615) 741-6636	identification of air stripper
WASHINGTON			
Harry Watters	Air Permitting	(206) 344-7334	data on two air strippers
WISCONSIN			
Lee Boushon	Groundwater	(608) 266-0857	data on five air strippers

TABLE A-3. FACILITY TELEPHONE CONTACTS

Contact	Facility	Telephone No.	Topics Discussed
Joe Gehin	City of Wausau, WI	(715) 845-5279	air stripper at WI site
Thomas Yohe	Philadelphia Sub. Wat. Co.	(215) 525-1400	air strippers at PA sites
Dennis Ellison	City of Tacoma, WA	(206) 593-8214	data on air stripper in WA
Ron McKinnon	City of Rockaway, NH	(201) 627-7200	air stripper at NJ site
Gary Mearz	City of Denver, CO	(303) 295-1451	air stripper at CO site
Elayne Hays	Hillsborough County, FL	(813) 272-6674	air stripper at FL site
Larry Dayian	Acton Water Dist, MA	(617) 263-9107	air stripper at MA site
Mike Gingrass	AMD, Inc.	(408) 749-4225	air stripper at CA site
Glenn Dirks	Varian Associates	(408) 986-9888	air stripper at CA site
Mike O'Brien	Cooper Industries	(713) 739-5618	air stripper at MI site
Mr. Kaiser	U. S. Aviex	(616) 683-6767	air stripper at MI site
Earl Kennett	Sundstrand	(616) 782-2141	air stripper at MI site
Mrs. Hicks	Organics LaGrange Labs	(312) 764-6700	air stripper at MI site
Mario Ierardi	Civilian Engr., McClellan AFB	(916) 643-1250	air stripper at CA site
Mike Everhardt	Boeing	(316) 526-2121	air stripper at KS site
Harry Kunkel	Chem-Dyne	(513) 867-8789	air stripper at OH site
Chet Miller	General Electric	(316) 442-3600	air stripper at KS site

TABLE A-4. EQUIPMENT VENDOR TELEPHONE CONTACTS

Contact	Company	Telephone No.	Topics Discussed
Randy Bailey	R. E. Wright & Assoc.	800-238-3320	identification of air stripper
	Enviro-Chem	(919) 469-8490	identification of air stripper
Matt Sutton	Groundwater Tech.	(415) 671-2387	catalytic incinerators
Mark Ross Trane	Thermal	(215) 828-5400	thermal incinerator
Elliot Werk	Groundwater Technology	(617) 769-7606	data on one air stripper
Jerry Hitchingham	Duall	(517) 725-8184	identification of air stripper
Tony Joering	PSE Env. Serv.	(215) 337-3060	data on one air stripper
Dick Selznick	Baron Blakeslee	(201) 233-5629	identification of air stripper
Jeff Swett	H.C.T. Co.	(415) 934-8221	identification of air stripper
Andy Zienkiewicz	Hydro Group	(201) 563-1400	identification of air stripper
Dan Felton	New England Pollution Control	(203) 853-1990	data on one air stripper
Bill Alcorn	Chem Met Corp.	(216) 569-3245	catalytic incinerators
	AMCEC Corp.	(312) 954-1545	thermal incinerators
Bob Kenson	Met-Pro Corp.	(215) 723-6751	catalytic incinerators
Kate Jones	Johnson-Matthey	(215) 341-8500	catalytic incinerators
Paul Miller	Groundwater Tech.	(215) 388-1466	catalytic incinerators
Bob Yarrington	Englehard	(201) 964-2729	catalytic incinerator
	Croll-Reynolds	(201) 232-2400	identification of air stripper
	MOCO	(313) 728-6800	thermal incinerators
Mark Stenzel	Calgon Corp.	(412) 787-6700	activated carbon use
Ed Dowd	ARI	(312) 359-7810	catalytic incinerator
Rusty Kroll	McGill, Inc.	(918) 445-2431	thermal incinerators
Ed McCall	HIRT Air Pollution Control	(213) 728-9164	thermal incinerators
Buddy Rose	General Industries	(919) 735-8115	identification of air stripper
Mr. Bush	Groundwater Tech	(602) 966-0808	data on one air stripper
Craig Anderson	Bay West	(612) 488-1008	identification of air stripper
Vic Mendoza	National Air Oil Burner Co.	(215) 743-5300	thermal incinerators

TABLE A-5. ENGINEERING CONSULTANTS TELEPHONE CONTACTS

Contact	Company	Telephone No.	Topics Discussed
Julie Rutheford	EDI	(616) 942-9600	one air stripper in MI
Jeff Sutherland	EDI	(616) 942-9600	one air stripper in MI
Eric Strang	EDI	(616) 942-9600	two air strippers in MI
Bob Rosain	CH2M Hill	(206) 453-5000	one air stripper in WA
Bob Schilling	CH2M Hill	(206) 453-5000	three air strippers in WA,HI
Greg McIntyre	CH2M Hill	(904) 377-2442	one air stripper in FL
Bob Stevens	CH2M Hill	(404) 523-0300	one air stripper in FL
Don Gallo	CH2M Hill	(414) 272-2426	one air stripper in OH
Dick Powell	CH2M Hill	(813) 888-6777	one air stripper in FL
Bill Byers	CH2M Hill	(503) 752-4271	one air stripper in MI
John Dyksen	Malcolm Pirnie	(201) 845-0400	data on 26 air strippers
Jun Yashitani	Camp, Dresser & McKee	(312) 786-1313	one air stripper in IN
Enos Stover	Private Consultant	(405) 624-9458	two air strippers
Janet Mahanah	U.S. Army Toxics and Hazardous Materials Agency	(301) 671-2054	air emissions control report
Jim Hussey	Dames & Moore	(602) 371-1110	one air stripper in AZ
Steve Sontag	Metcalf & Eddy	(415) 964-7100	one air stripper in CA
Wayne Weber	Metcalf & Eddy	(617) 246-5200	information on sites with incineration
Carl Johnson	Johnson Associates	(802) 229-5976	one air stripper in VT

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

Air stripping towers are being used to remove low concentrations of organic contaminants from water. This report describes the technology and methods used to control air pollution resulting from this procedure. The cost of the controls is presented along with other positive and negative impacts of the technology.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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