

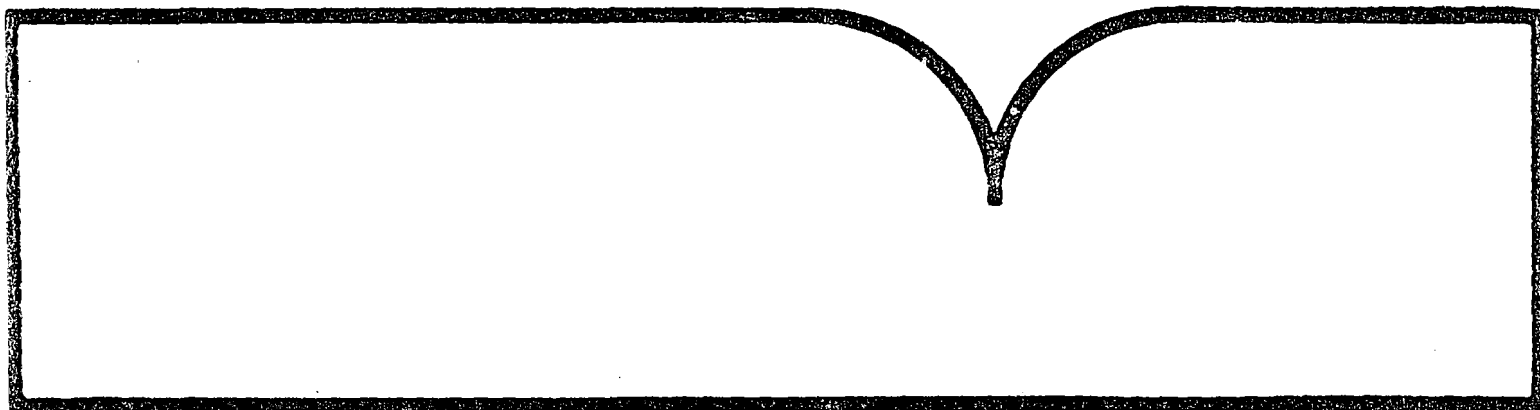
**Air Strippers and Their Emissions
Control at Superfund Sites**

**Research Triangle Inst.
Research Triangle Park, NC**

Prepared for

Environmental Protection Agency, Cincinnati, OH

Aug 88



EPA/600/D-88/153
August 1988

AIR STRIPPERS AND THEIR EMISSIONS CONTROL
AT SUPERFUND SITES

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EPA Contract 68-02-3992

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TECHNICAL REPORT DATA (Please read instructions on the reverse before completing)		
1. REPORT NO. EPA/600/D-88/153	2.	3. RECIPIENT'S ACCESSION NO. PB88-239082
4. TITLE AND SUBTITLE AIR STRIPPERS AND THEIR EMISSIONS CONTROL AT SUPERFUND SITES		5. REPORT DATE August 1988
6. AUTHOR(S) B. L. Blaney and M. Branscome		7. PERFORMING ORGANIZATION CODE
8. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Cincinnati, Ohio 45268 and Research Triangle Institute Research Triangle Park, North Carolina 27709		9. PERFORMING ORGANIZATION REPORT NO.
10. SPONSORING AGENCY NAME AND ADDRESS Hazardous Waste Engineering Research Laboratory U.S. Environmental Protection Agency Office of Research and Development Cincinnati, Ohio 45268		11. PROGRAM ELEMENT NO.
		12. CONTRACT/GRANT NO.
		13. TYPE OF REPORT AND PERIOD COVERED Technical: 2/87-A/87
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		
16. ABSTRACT Air stripping, a traditional means of making slightly contaminated ground-water potable, is being applied increasingly to more severe groundwater pollution at remedial action sites. Concentrations of volatile and semivolatile compounds at such sites may reach hundreds of parts per million. As a result, several changes have resulted in air stripping technology. New air stripping technologies are being employed to achieve very high (>99 percent) removal of volatile compounds and to increase the removal of semivolatiles. New stripper designs are being investigated for compactness and mobility. In addition, emissions controls are being added because air pollution impacts are larger. This paper discusses these trends and provides examples from groundwater cleanup at remedial action sites in the United States.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
18. DISTRIBUTION STATEMENT Rele. Public	19. SECURITY CLASS (This Report) None	20. SECURITY CLASS (This page) None
		21. NO. OF PAGES 25
		22. PRICE A03 12.45

NOTICE

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ABSTRACT

Air stripping, a traditional means of making slightly contaminated groundwater potable, is being applied increasingly to more severe groundwater pollution problems at remedial action sites. Concentrations of volatile and semi-volatile compounds at such sites may reach hundreds of parts per million. As a result, several changes have resulted in air stripping technology. New air stripping systems are being employed to achieve very high (>99 percent) removal of volatile compounds and to increase the removal of semivolatiles. New stripper designs are being investigated for compactness and mobility. In addition, emissions controls are being added because air pollution impacts are larger. This paper discusses these trends and provides examples from groundwater cleanup at superfund sites in the United States.

INTRODUCTION

Air stripping has been a frequently used option for removal of volatile organic compounds (VOC) from groundwater to make it potable. In the past, the levels of groundwater contamination to which air stripping was applied were in the low to mid parts per billion (ppb). In such cases, air stripping readily reduced VOC concentrations to below detection levels (typically 10 ppb). Air emission controls were not generally required because the mass of VOC released to the air was low.

More recently, environmental agencies have been faced with levels of groundwater contamination at remedial action sites which are ten to hundreds of times higher, sometimes reaching hundreds of parts per million (ppm). The need to efficiently remove higher concentrations in an environmentally safe manner has resulted in two major changes in the types of air stripper systems that are being used at some remedial action sites. First, the design of the strippers has been changed to achieve very high VOC removal efficiencies and to achieve semivolatile removals of 80 percent and above. This is often accomplished by raising the operating temperatures of the strippers to 60°C (140°F) or higher.

Second, air pollution control devices have been added to strippers because their organic emissions may result in a significant health hazard to site neighbors. For example, a system processing 100 gpm of water with 10 ppm of benzene would release 2 Mg/year of that compound to the atmosphere when operating at 99 percent efficiency. The health effects of such emissions may be significant, depending on local meteorology, compound toxicity and population distributions.

This paper describes these changes in air stripper technology that are resulting from their increased use at remedial action sites.

Air Stripping

Air stripping is a dynamic physical separation process which relies on the contact between clean air and contaminated media (typically water or soil) to induce transfer of the contaminant to the air. By continually replenishing the system with uncontaminated air the contaminants are stripped away from the polluted media.

Two major parameters influence the efficiency of air stripping. The first is the rate at which a contaminant will transfer from the liquid to air. The larger the ratio of the air to the liquid concentrations of a compound at equilibrium, the higher the rate of transfer from liquid to air during stripping. Volatile organic compounds (VOC) are only slightly water soluble and have high air-to-water equilibrium coefficients. Therefore, they are readily removed from water by air stripping [1].

Compounds which are more water soluble, such as acetone, are not as amenable to air stripping because their equilibrium coefficients are low. However, since the air-to-water equilibrium coefficient will increase with temperature, heating of the influent water is one means of increasing the efficiency of air stripping for these compounds.

The second parameter which has a major influence on air stripping efficiencies is the air to water contact area. The design of the air stripper will influence this parameter. Spray aeration, diffused aeration and multiple tray aeration all promote VOC transfer to air. However, they are not as efficient as packed tower aeration, the most common air stripper design.

Figure 1 shows a typical packed tower aerator which has a countercurrent flow of clean air and contaminated water. The unit generates contaminated air and a water effluent from which essentially all VOC has been removed. Obviously, air stripping may just transfer an environmental problem from one media to another if there is no means of capturing the stripped organics.

Applications of Air Stripping at Remedial Action Sites

Table I summarizes the operating characteristics of several ambient and high temperature air strippers at remedial action sites in the United States. For each site, data are provided on full-scale unit designs or on actual operating parameters of pilot-scale or full-scale units. Flow rates and concentrations of operating systems represent typical values during extended operation. Influent concentrations are approximate, due to daily variations. When the site data provided only a range of influent concentrations, upper limits are used. Removal efficiencies are either based on stated values in the literature or based on the influent and effluent concentrations in Table I. The table shows that air strippers have been designed to handle a wide range of influent concentrations and flow rates.

Frequently, influent concentrations will drop by one or two orders of magnitude during the course of operation at a remedial action site as contaminated groundwater is diluted. As this occurs, feed rates can be increased and/or the air to water ratio reduced to optimize stripper operation. At some sites, several air strippers may initially be in series to achieve high cleanup efficiencies and then operated in parallel as contamination levels decrease [12].

The data in this table show that air stripping can be used to treat a wide range of volumes and degrees of contamination of groundwater at remedial action sites. Large volumes (e.g. Tacoma, WA) may require a number of units in parallel. Large concentrations and stringent effluent limitations may be most economically handled by several units in series. High temperature air strippers (HTAS) are also being used to increase VOC removal efficiencies, as well as to remove water soluble organics from groundwater.

INNOVATIONS IN AIR STRIPPING

High Temperature Air Stripping

Since groundwater at certain remedial action sites contains relatively high (>1 ppm) organics, some of which are highly miscible in water (e.g. methyl ethyl ketone, acetone), improvements in air stripping have been undertaken to increase removal efficiencies. This is often accomplished by heating the influent stream, a technique called high temperature air stripping (HTAS).

The higher efficiencies obtained using HTAS are due to the increase with temperature of the air-to-water equilibrium constants of organic compounds. Only limited experimental data are available on the variation of equilibrium constants with temperature. However, temperature increases from 0°C (32°F) to 30°C (86°F) result in equilibrium constants increasing by a factor of 4 to 6 for a number of volatile compounds [15, 16]. Therefore, one would expect that increasing the influent stream temperature to 60°C (140°F) could improve removal efficiencies by at least a factor of ten.

Lamare, et al., have performed pilot-scale studies investigating the increased rate of removal of semivolatile compounds from water as a function of stripper feed temperature. This work was done as part of the development of a groundwater cleanup system at the Gilson Road site, Nashua, NH, which has a number of water soluble contaminants, as well as chlorinated and non-chlorinated volatile organics. Table II shows the removal efficiencies obtained at various temperatures with an air to water ratio of 500 over a temperature range of 12°C (54°F) to 75°C (170°F). Removal efficiencies are markedly increased by increasing feed temperature [13].

The full-scale treatment system at Gilson Road will utilize a 300 gpm HTAS. Iron and manganese will be removed upstream to prevent fouling of the stripper packing. The feed stream will be heated with an economizer and a trim heat exchanger before entering the stripper [17].

Johnson, et. al, found similar improvements in removal efficiencies for methyl ethyl ketone, another water soluble solvent which is frequently found at remedial action sites. Johnson's earlier tests had shown that a mobile air stripper capable of removing over 98 percent of more volatile compounds such as trichloroethene (TCE) could remove only 25 percent methyl ethyl ketone (MEK). Over 95 percent MEK removal was achieved in pilot-scale tests at 60°C and 150 air:water ratio and at 70°C with a 75 air: water ratio. Johnson proposed a series of four heated air strippers, each capable of achieving 99% removal, in order to obtain an effluent below 50 ppb from a feed stream containing 1,000 ppm MEK [12].

Recently, a high temperature air stripper was installed at McClellan Air Force Base (AFB), Sacramento, CA as part of a groundwater treatment system. Initial testing of the stripper indicates that it removes all VOC to below detection limits, while appreciable amounts of MEK and acetone are also removed. This system is discussed in more detail at the end of this paper.

It should be noted that as the design feed temperature of an air stripper approaches 100 °C (212 °F), steam stripping may be a preferable treatment technique. This will be especially true if a condenser can be used as an emission control device. Steam stripping (which utilizes steam instead of air as the stripping medium) removes organics more efficiently than HTAS because it operates at higher temperatures. Steam stripping has been demonstrated for decontamination of groundwater containing ketones, alcohols and chlorinated solvents at concentrations up to 5,600 ppm [18]. However, steam stripping has higher capital and operating costs than HTAS due to the additional fuel use and, in some cases, the need for higher grade materials of construction [19, 20].

Centrifugal Force Air Stripping [6, 7]

Another innovation in air stripping technology is the use of centrifugal force distillation devices for the separation of volatiles from water. Such devices are more compact, making them readily mobile and easily sheltered in cold climates. They also are reported to have fewer fouling problems and require lower air-to-water ratios than conventional air strippers.

Figure 2 is the schematic diagram of a Hige[®] system which is being tested at the U.S. Coast Guard Base, Traverse City, MI. Filtered groundwater enters the center of a rotating bed of packing with high surface area-to-volume ratio. The bed's rotation produces centrifugal forces of 100 to 1,000 G's. Air enters the device countercurrently and mass transfer takes place in the packing, which has a pore size of 150 to 200 μ m. The decontaminated water is removed by gravity drain, while the VOC-laden air exits through the vapor outlet. The unit can process 100 to 300 gallons per minute of water and tests have shown that particles up to 100 μ m in diameter have passed through the packing. During normal testing, a 50 μ m filter is used upstream of the unit.

The Hige[®] is designed to handle a wide range of groundwater concentrations. Concentrations at the Coast Guard site were originally predicted to be on the order to 5 to 10 ppm. However, by the time the unit was brought into operation, earlier remediation action, which promoted in-situ biodegradation, had processed enough water so that subsurface dilution resulted in much lower concentrations of benzene, toluene and xylene (typically 100-500 ppb). The unit has obtained greater than 99% removal for these compounds, even in performance tests in which water was spiked to concentrations of 8 ppm benzene and 17 ppm toluene. The system operators, The Traverse Group, Inc., indicate that the unit should be cost competitive with air stripping columns and less expensive than carbon adsorption at influent concentrations of 10 ppm or higher. The company is currently developing designs for more compact, truck-mounted units.

CONTROL OF AIR STRIPPER EMISSIONS

Regulatory Requirements

The groundwater concentrations at remedial action sites may be over a hundred times higher than what has traditionally been encountered when air stripping was used for drinking water cleanup. The air emissions from such systems are proportionately greater and the resulting health impacts may be significant.

Federal policy requires any treatment technologies installed as part of a remedial action at a Superfund site to meet all "applicable, relevant and appropriate" environmental regulations, whether Federal or State. Some States, such as California and Ohio, have standards set based on the hazard to the surrounding community as determined by the levels of human exposure to the emitted organics. Others do not require an operating permit unless the emissions exceed some level set for VOC sources in general.

Michigan has VOC emission regulations which place stringent requirements on air strippers. The State requires all sources of VOC emissions to utilize best available control technology (BACT) to reduce emissions. For groundwater cleanup operations, the permittee must also analyze other treatment alternatives that cause less air pollution and demonstrate that they are not more cost effective than an air stripper with or without controls. Once air stripping is decided on and an air emission control is chosen, an impact analysis must be done to show that the controlled emissions result in an "acceptable environmental impact." Presently, health risks to the maximally exposed fence line individual are evaluated to determine that impact. The measure of acceptability is dependent upon the type of health effect of each of the emitted compounds. For most compounds, the 8-hour time weighted average must be less than 1 percent of its threshold limit value (TLV). For carcinogenic compounds, the lifetime cancer risk to the individual must be under 10^{-6} based on annual average pollutant concentrations. Best available toxicological data are used for other compounds to determine maximum annual exposure limits [21].

Another important part of Michigan's air permitting policy is that emitters must use worst case emission rates when determining exposure limits. Since groundwater cleanup often results in decreased emissions with time, the control technology must be designed to handle initial emissions rates. The State does allow permittees to reapply for revised permits at a later date, a provision which would allow for reduced operating costs, if granted [21].

Control Options

There are basically three control options* available to the cleanup of gases from air stripping:

1. Carbon adsorption
2. Thermal incineration, and
3. Catalytic incineration

Condensers will not be considered here because they are generally not effective for gas streams containing less than 10,000 ppm organics [22]. There are advantages and disadvantages to each, as will now be discussed. To provide a perspective on the size and concentrations of the off-gas streams to which these are, or might be, applied, Table III provides such information for the air strippers previously characterized in Table I.

Carbon Adsorption

Carbon adsorption is the most frequently used control technology for air stripping, having been shown to be cost-effective for removing hydrocarbons from dilute (<1 percent) air streams from a number of industrial processes. Package adsorber systems are available for turn-key installation from a number of manufacturers which simplifies their use, especially with mobile remedial action treatment units.

The capital cost of a system is principally dependent upon the amount and type of carbon chosen. Carbon requirement is given by [23]:

$$\text{Carbon requirement (lb carbon/1000 scf)} = (CM/k) \times 279$$

where we define:

- C = VOC concentration (mole fraction)
- M = VOC molecular weight (lb/lb mole)
- k = Carbon capacity (lb VOC/100 lb carbon).

While the VOC concentration and molecular weight may be estimated for a given air stripper off-gas, the operating carbon capacity is influenced by a number of factors. These include the properties of the carbon, the humidity and composition of the feed stream and the desired percent of contaminant removed.

For industrial waste streams, which typically only have a few compounds in the air stream, the carbon requirement can be estimated by vendors based on adsorption isotherms. However, remedial action site strippers are usually producing off-gas streams containing a large number of organics whose concentrations vary with time. Therefore, it is important to monitor the adsorber exhaust stream periodically to determine when breakthrough is occurring so that the carbon can be replaced or regenerated.

Several other factors must be considered when designing a carbon adsorber. Gas entering the unit must be free of particles or liquid aerosols, which will block air flow through the adsorber. This can be a problem for units on air strippers which have high air:water ratios. Demisters must be added in such situations.

Also, carbon adsorber efficiency drops dramatically if gas stream relative humidity exceeds 50% because adsorbed water decreases the bed's adsorption capacity. When humidity levels exceed this threshold, the off-gas stream is heated. For ambient temperature air strippers (13 to 25°C), a temperature increase of 17°C (30°F) will decrease the relative humidity from 100 to 40 percent [24]. The reduction in humidity will increase the adsorptive capacity of the carbon for many compounds by a factor of three to four, which greatly exceeds the decrease in adsorptive capacity of the carbon resulting from the rise in temperature.

The off-gas from HTAS units may be particularly difficult to treat by carbon adsorption because of decreased adsorptive capacity from both high temperature and a high loading of water vapor.

The Verona Wall Field site in Battle Creek, MI uses carbon adsorption for ambient temperature air stripper emissions control. Details are provided at the end of this paper.

Thermal Incineration

Gas incinerators generally operate at 760 to 1200°C (1400 to 2200°F). The lower ranges are adequate for volatile organics of high heat of combustion, while higher temperatures (typically over 1800°F) are required to destroy hydro-

carbons of low heat content, such as halogenated compounds. Because the incinerator design and fuel usage are specific to the gas stream to be combusted, generalities about size cannot be made based solely on gas flow rate and VOC concentration.

Figure 3 shows a typical thermal incinerator. The unit is designed to promote good mixing of air, waste gas, and auxiliary fuel (if needed) prior to combustion. It is also important to have good turbulence in the combustion zone, along with at least a 0.5 to 1.0 second residence time. Energy can be recovered from the hot exhaust gases and used to preheat combustion air or the influent water stream to an air stripper.

Combustion air with a heating value of less than 1.9 MJ/scm (50 Btu/scf) usually requires auxiliary fuel to maintain desired combustion temperatures. This will typically be the case for air stripper exhaust gases which have much lower heat content. For example, stripper gas with 100 ppm benzene has a heat content of only 20 KJ/scm (0.53 Btu/scf). If the waste gas contains water droplets, additional fuel is required for water vaporization. Therefore, demisters should be used before incinerators.

Packaged, single unit thermal incinerators are available for gas rates ranging from about 0.14 scm/sec (300 scfm) to 24 scm/sec (50,000 scfm). These units can achieve greater than 98 percent destruction efficiency for most VOC [25].

If emissions are predominately halogenated organics, special considerations must be given to incinerator design. Such compounds require high (>1800°F) combustion temperatures to achieve high destruction efficiencies. Also, hydrogen chloride is the principal combustion product for such compounds. Acid gas scrubbers are required on large hazardous waste incinerators but will not generally be needed on air stripper control incinerators because HCl emissions are low.

The Gilson Road site uses an oil-fired boiler as a thermal incinerator to treat air emissions from a groundwater/leachate air stripping process. This air stream contains primarily tetrahydrofuran, methyl ethyl ketone, butyl alcohol, toluene, and smaller amounts of other organics. The desired destruction efficiency is 99.99 percent [20]. The unit is currently being tested.

The thermal incinerator at McClellan Air Force Base is discussed later in this paper.

Catalytic Incineration

A catalytic incinerator, or catalytic oxidizer, operates at lower temperatures than a thermal incinerator. Combustion temperatures are typically 320 to 650°C (600 to 1200°F). The catalyst serves to promote oxidation reactions that require high temperatures for thermal oxidation. This reduces the fuel requirements and associated costs.

While catalytic incinerators require less fuel, they have two drawbacks that may limit their applicability to controlling air stripper off-gases.

First, catalysts are specific to certain classes of compounds and may be poisoned by others. For example, catalysts will not usually work efficiently on both halogenated and nonhalogenated hydrocarbons. Second, catalytic incinerators are less forgiving than thermal incinerators to variations in feed stream composition.

An Engelhard TORVEX® Catalytic Reactor is in use at the Avenue A Area Site, U.S. Coast Guard Base, Traverse City, Michigan. The unit is being used to destroy emissions from the stripping of mainly nonchlorinated organics (e.g., benzene, xylene, and toluene) from groundwater. It has a 2,000 cfm capacity and operates at 260 to 320°C (500 to 600°F). It cost approximately \$72,000, consumes \$80/day of natural gas, and requires approximately 1 person-day every two weeks for operation and maintenance. Detailed air emissions measurements have not been performed on the unit, but its efficiency is purported to be over 90 percent by the vendor [6, 7].

CASE STUDIES

In order to provide more detailed examples of the application of air strippers and their emission controls at remedial action sites, two case studies are briefly presented. Besides demonstrating some of the general points made earlier in this paper, details about system design and operating problems are provided.

Verona Well Field [9-11]

The use of air stripping at the Verona Well Field site in Battle Creek, Michigan demonstrates (1) how a system can be designed to accommodate high initial concentrations in the groundwater and (2) the use of carbon adsorption for air pollution control.

The Verona Well Field is the major source of public potable water of the City of Battle Creek. In August 1981, it was determined that a number of private and city wells in the field were contaminated. An Initial Remedial Measure (IRM) was approved which included the use of a 2,500 gpm air stripper operating at 5,000 cfm to provide hydraulic blocking to encroachment of contaminated groundwater into the field. Table IV shows the design concentrations for major compounds in the influent and the actual concentrations during 29 months of operation. During this IRM phase, the load on the stripper was 2,000 gpm.

Recently, a Source Control Action (SCA) at one of the major pollution sources in the well field was initiated which will involve decontamination of the groundwater at a rate of 400 gpm. This stream will be combined with the 2,000 gpm IRM stream for a total feed of about 2,400 gpm to the stripper. Table 4 shows the anticipated total VOC concentrations of this groundwater stream over the first 150 days of extraction from the SCA site. Even allowing for dilution of this 400 gpm stream at the inlet to the stripper, these concentrations are initially orders of magnitude above the stripper design concentrations. To deal with this, the EPA required that liquid-phase carbon beds be used to treat the 400 gpm flow for the first month of operation. The implementation of this source control action started in early 1987.

The Verona Well Field air stripper has a carbon adsorption unit to treat the off-gas air. The system consists of two parallel beds, each approximately 4 ft deep and 10 ft in diameter. Each bed contains 9,500 pounds of carbon. The stripper offgas is heated prior to entering the carbon to reduce its humidity to 40 percent.

The capital cost of the air stripper and carbon adsorption beds, including design and installation, was \$550,000.

Table IV shows the air permit limits set by the State for emissions from the air stripper during the IRM phase. The off-gas from the units are being monitored 3 or 4 times per year to detect breakthrough. The carbon has been replenished about once per year during the IRM phase. The last two columns of Table IV present emissions from stripper and the carbon beds collected on August 2, 1985, about 11 months after system startup. Based on the breakthrough of dichlorinated hydrocarbons shown here, the decision was made to change the carbon. The cost of replenishing both beds with regenerated carbon is approximately \$18,000.

The air stripper has had few operational problems during the IRM phase. Iron oxide was initially plating out on the packed rings, but this problem was alleviated by recirculating sodium hypochlorite through the stripper about four times per year.

McClellan Air Force Base [14]

McClellan Air Force Base in Sacramento, California has groundwater contaminated with fuel and solvents from spills and storage tank leaks. There are volatile and semivolatile organics at ppm concentration in the groundwater. A treatment system composed of air stripping and liquid-phase carbon adsorption has been installed to remove these compounds to below detection limits. A biological treatment unit will be added between the two processes, shortly (Figure 4).

The groundwater is pumped through a series of heat exchangers to preheat the feed stream to the air stripper to 60 to 65°C (140 to 150°F). The stripping column is 8 feet in diameter and has 23 feet of packing, a maximum air flow of 4,000 cfm, and a feed rate of 1,000 gpm with provisions for recycling of 500 to 1,000 gpm. The extent of recycle is determined by the rate of groundwater flow, the temperature of the stripper feed and the proper air:water ratio. The bottoms from the air stripper pass through the primary heat exchanger to preheat the feed. A portion of the bottoms is recycled and the balance is further treated by carbon adsorption prior to discharge.

The liquid phase carbon adsorption process consists of three granular activated carbon trains in parallel, each with two contact vessels. Each vessel is 10 feet in diameter and 10 feet high and contains approximately 60,000 pounds of carbon.

The stripper offgas passes through a demister to reduce the water aerosol load on the incinerator and then through a heat exchanger, where the vapors are heated by the incinerator's offgas. Hydrocarbons in the stripper offgas are

destroyed by thermal combustion in a vapor phase incinerator that burns natural gas and is designed to achieve 99.99 percent destruction. The incinerator operates at 980°C (1800°F) and has an estimated thermal capacity of 5.5 million BTU/hr. Heat is recovered from the hot exhaust gases in a series of heat exchangers, which cool the offgas to about 230°C (450°F). These gases are then scrubbed with a solution of 20 percent caustic to remove HCl prior to discharge to the atmosphere.

The system includes three heat exchangers. Two utilize waste heat from the incinerator to heat the groundwater feed to the stripper and to preheat the stripper offgas prior to incineration. A third transfers heat from the stripper bottoms to the groundwater feed.

An interesting feature of the vapor system is the collection and treatment of vapors from other sources. Gas vents from the caps placed over the contaminated soil and from the groundwater storage tank are vented through the air stripper to the incinerator to destroy the VOC in these vapors.

The groundwater treatment system was evaluated in a 30 day shakedown test conducted early in 1987 and the results are listed in Table VI. During these tests, a 620 gpm recycle was used combine with a flow of 180 gpm of contaminated water. The stripper air flow during these tests was 2,500 cfm, the feed rate was 800 gpm, and the resulting air-to-water ratio was 20:1. The results shown in Table VI demonstrate that the system as a whole obtained its design objectives, with the exception of acetone which exceeded 1 ppm. Limited sampling of the stripper effluent indicated that VOC concentrations were reduced to below detection limits and acetone was reduced by about 30 percent. A biological treatment unit is being added after the stripper to further reduce ketone concentrations.

The total installed capital cost of the treatment train (including the air stripper, incinerator, and carbon adsorber) was approximately \$3.4 million. This includes the system's design, construction, and installation. The only major operating problem experienced to date has been fouling of the system, especially the heat exchangers, from biological activity. Initially the system was backflushed to reduce the fouling. The groundwater is now being chlorinated in order to minimize this source of fouling over the longer term.

CONCLUSIONS

As a result of advances in design, air stripping can be used to remove water soluble, as well as volatile, organic compounds from aqueous streams. At sufficiently high temperatures, removal efficiencies of over 90 percent can be obtained.

Uncontrolled stripping of groundwater at remedial action sites may result in significant air emissions impacts. Carbon adsorption and incineration are the most frequently used emission control options. Thermal incineration appears to be the control technique of choice at sites where high temperature air stripping is used because the waste heat from the incinerator can be used to heat the stripper feed.

ACKNOWLEDGMENTS

We would like to thank the individuals who provided data for use in this article, particularly those whose private communications are listed in the references. The authors assume full responsibility for any misinterpretation of that data.

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TABLE I. Operational Data for Some Air Strippers at Remedial Action Sites

Site	Flow (gpm)	Water Influent Concentration ^a (ppb)	Effluent Concentration Objective ^a (ppb)	Percent Removal	Air:Water Ratio ^b	Air Flow (cfm)
<u>Ambient Temperature Influent</u>						
Wurtsmith AFB - TFE Plume [2] (2 parallel units)	900	500	<1.5	>99	30	3,900
- Benzene Plume PT [3]	85	<8,820	NA	>90	65	730
Sydney Mines Design [4]	150	2,225	NA	NA	200	4,000
Tacoma, WA Design [5] (5 parallel units)	<3,500	<1,000	NA	>89	310	145,000
Traverse City USCG Base [6,7]	90	1,000	<10	99	52	600
Tysons Dump PT [8]	5	<47,000	<500	>98	250	170
Verona Well Field [9-11]	2,000	<41	<7	>90	20	5,000
<u>HTAS Operation</u>						
Hydro Group Design [12] (60°C, 3 units in series)	<100	1x10 ⁶ MEK	<500 MEK	>99	200	2,700
Roy Weston PT [13] (60°-70°C)	NA	NA	NA	<76% propanol 99% THF	50-500	NA
McClellan AFB [14] (620 gpm recycle, 180 gpm makeup 65°C)	800	<4,400 ^c	<0.5	>99	20	2,500

Abbreviations: Not available (NA) and pilot test (PT).

^a Total volatile organics, unless otherwise indicated.

^b Volumetric.

^c Sum of highest concentrations of VOC detected in groundwater stream, diluted by 180/800 to account for recycle.

TABLE II. Influence of Feed Temperature on Removal of Water Soluble Compounds from Groundwater

Compound	Percent Removed at Selected Temperatures		
	12°C	35°C	73°C
2-Propanol	10	23	70
Acetone	35	80	95
Tetrahydrofuran	50	92	>99

Source: Reference 12.

TABLE IV. Verona Well Field Air Stripper VOC Influent and Air Emissions During IRM Phase

Compound	Influent Concentration (pph)		Air Emissions (ug/m ³)		
	Design	Actual ^a	Permit	Stripper (8/2/85)	Carbon (8/2/85)
1,1,-DCA	38	5.5	250	243	234
1,2-DCA	8	<1.0	350	4.6	ND
1,1,1-TCA	150	12	1,000	1,014	50
1,2-DCE	230	9.7	-	487	424
1,1-DCE	11	<1.0	-	ND	ND
TCE	52	<1.1	420	92	ND
PCE	120	11	810	785	ND

Abbreviations: Initial Response Measure (IRM), Not Available (NA), dichloroethane (DCA), dichloroethylene (DCE), trichloroethane (TCA), trichloroethylene (TCE), perchloroethylene (PCE), methylene chloride (MeCl) and vinyl chloride (VC).

^a Average of monthly measurements from September 1984 to January 1987.
Source: References 10 and 11.

TABLE III. Air Stripper Emissions Stream Characteristics and Control Techniques at Remedial Action Sites

Site	Uncontrolled Stripper Off-Gas			Control Device
	Air Flow (cfm)	Emission Rate (g/sec)	Approximate VOC Concentration (ppm benzene) ^a	
<u>Ambient Temperature Feed</u>				
Wurtsmith AFB				
- TCE Plume (2 parallel units)	3,900	0.027	28	None
- Benzene Plume PT	730	<0.041	<2.4x10 ²	None/PT
Sydney Mines Design	4,000	<0.022	<22	None
Tacoma, WA Design (5 units in parallel)	145,000	<0.19	<5.2	None
Traverse City USCG Base	600	0.004	26	Catalytic Incinerator
Tysons Dump PT	170	0.014	3.3x10 ²	None/PT ^b
Verona Well Field	5,000	0.068	54	Carbon Adsorber
<u>Heated Feed</u>				
Hydro Group PT (60°, 3 units in series)	2,700	<6.1	<9.0x10 ³	None/PT
Roy Weston PT (60°-70°C)	NA	NA	NA	None/PT ^c
McClellan AFB (620 gpm recycle, 180 gpm makeup, 65°C)	2,500	<1.1 ^d	<1.8x10 ^{3d}	Thermal Incinerator

Abbreviations: Not available (NA), total volatile organics compounds (VOC), and pilot tests (PT).

^a Calculated in terms of benzene equivalents.

^b Carbon adsorber is planned for full-scale stripper.

^c Thermal incinerator is being used at site for which these pilot tests were done.

^d Upper limit to mass flow and concentration based on sum of maximum concentrations of individual VOC detected in groundwater.

TABLE V. Modelled VOC Concentrations in
Extracted Groundwater at Source
Control Action, Verona Well Field

Time (days)	Average Total VOC Concentration (ug/l)
1	125,000
8	11,000
15	6,500
22	4,600
29	4,400
149	2,800

Source: Reference 9.

TABLE VI. Influent and Effluent Concentrations of Major Compounds^a
Processed in Groundwater Treatment System at McClellan AFB
During 30 Day Startup Tests

Compound	Concentrations (ppb)	
	Influent	Effluent
1,1-DCE	750 - 6,500	<0.5
1,2-DCE	<0.5 - 6,100	<0.5
VC	41 - 2,400	<0.5
TCE	300 - 1,300	<0.5
1,1,1-TCA	210 - 1,150	<0.5
MEK	4,900 - 25,000	45 - 800
MIBK	1,200 - 3,700	45 - 130
Acetone	5,100 - 35,000	100 - 6,300

Abbreviations: Dichloroethylene (DCE), vinyl chloride (VC), trichloroethylene (TCE), trichloroethane (TCA), methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK).

^a Compounds in groundwater with maximum concentrations exceeding 1 ppm.

Source: Reference 14.

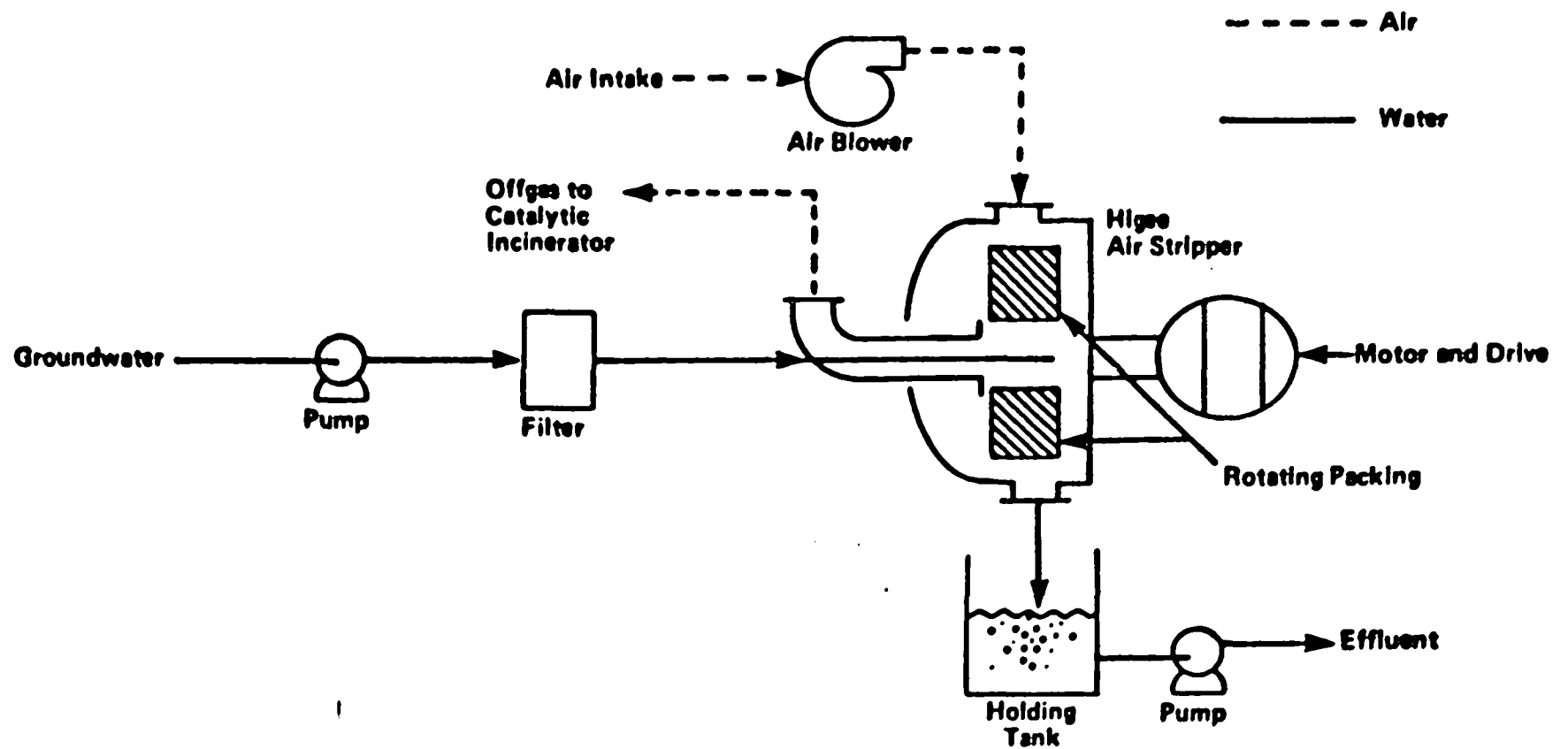


Figure 2. Hlgeo[®] air stripper system at U.S. Coast Guard Station, Traverse City, MI.

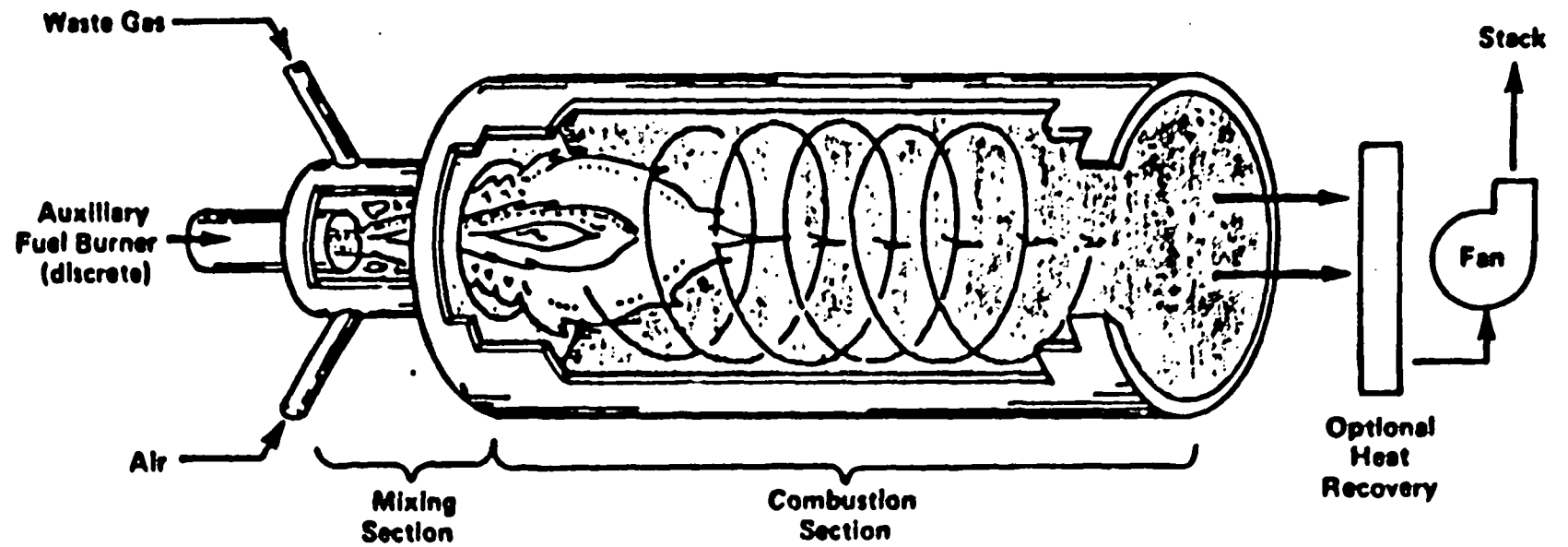


Figure 3. Thermal Incinerator.

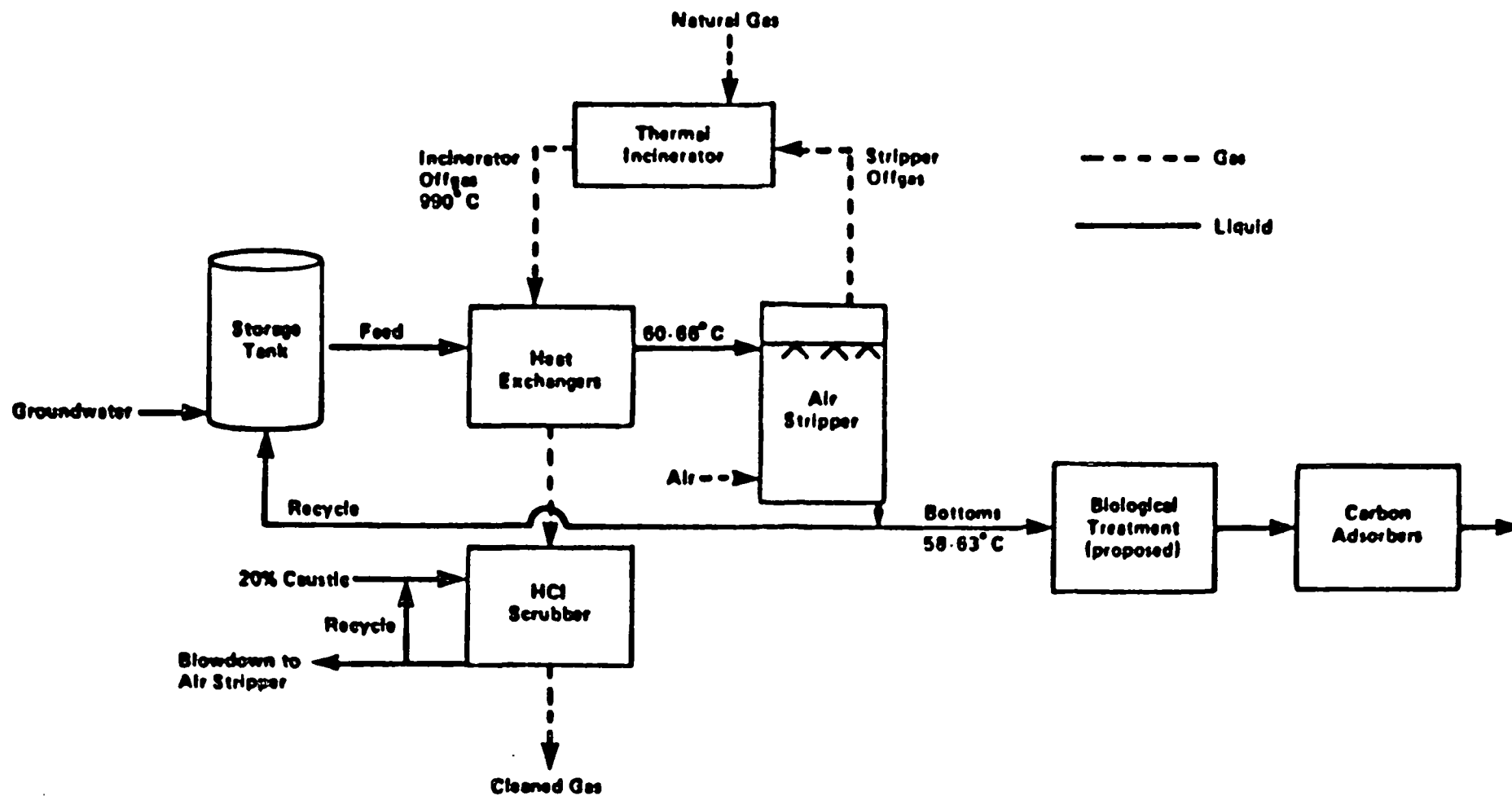


Figure 4. Groundwater treatment system, McClellan Air Force Base, Sacramento, CA.