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Alternative Control Technology Document - Organic Waste Process Vents

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16. ABSTRACT

The purpose of this Alternative Control Technology (ACT) document is to provide technical information to address air emissions of volatile organic compounds (VOC) from organic process vents on waste management units treating organic-containing wastes that are exempted from the RCRA process vent air emission standards (40 CFR Parts 264 & 265, Subpart AA). This document contains technical information on air emission rates, control technologies, and environmental and cost impacts of alternative control technologies.

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Emission Standards Division

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1.0 INTRODUCTION

The Clean Air Act (CAA) Amendments of 1990 established new requirements for State implementation plans (SIP) for many areas that have not attained the national ambient air quality standards (NAAQS) for ozone. These requirements include an expansion of the applicability of reasonably available control technology (RACT) to smaller sources of volatile organic compounds (VOC) than had previously been required by the U.S. Environmental Protection Agency (EPA). They also include a requirement that certain nonattainment areas reduce VOC emissions beyond the existing RACT requirements so that continual progress is made toward attainment of the ozone NAAQS. In addition, certain areas require a demonstration through atmospheric dispersion modeling that VOC emission reductions will produce ozone concentrations consistent with the ozone NAAQS To help the States identify the kinds of VOC control needed to meet these and other requirements, the 1990 Amendments also required EPA to publish Alternative Control Technology (ACT) documents for VOC sources. This document was produced in response to that requirement.

The EPA has determined that organic emissions from process vents on management units treating hazardous and nonhazardous wastes may contribute to the formation of atmospheric ozone and may pose a risk to human health and the environment. Organic emissions from waste management unit process vents include photochemically reactive and nonphotochemically reactive organics, some of which are toxic or carcinogenic.

On June 21, 1990, EPA promulgated standards (55 FR 25454) that limit organic air emissions from process vents at new and existing hazardous waste treatment, storage, and disposal facilities (TSDF) permitted under Subtitle C of the Resource Conservation and Recovery Act (RCRA). However, RCRA-permitted TSDF are only a subset of the waste management universe with process vents. These standards regulated organic emissions from process vents associated with distillation, fractionation, thin-film evaporation, solvent extraction, and air or steam stripping operations that manage hazardous wastes with 10 parts per million by weight (ppmw) or greater total organics concentration. Owners or operators subject to the standards are required either (1) to reduce total organic emissions from all affected vents at the facility to below 1.4 kg/h (3 lb/h) and 2.8 Mg/yr (3.1 ton/yr), or (2) to install and operate a control device(s) that reduces total organic emissions from all affected vents at the facility by 95 weight percent.

The purpose of this ACT document is to provide information to address VOC emissions from process vents on waste management units treating organic-containing wastes that are exempted from the RCRA process vent standards (40 CFR Part 264 and 265, Subpart AA). It is important to note that the treatment technologies are the same; i.e., the technologies regulated by the RCRA process vent standards are also the most common ones with process vents that are exempt from the RCRA process vent standards. The information developed to support the RCRA process vent standards is also applicable to similar sources that are not subject to the RCRA air rules. The nonregulated units are a significant contributor to total air emissions from waste management unit process vents. For example, in 1986, steam stripping units that were exempt from RCRA permit requirements (and therefore exempt from the RCRA process vent standards in most cases) treated more than 30 times as much hazardous waste as did steam strippers that were regulated units under RCRA. The process vents addressed in this ACT include those on waste management units (i.e., distillation and stripping operations) at TSDF treating wastes with total organics concentration of less than 10 ppmw and those on treatment units that are part of a waste management system exempt from RCRA permitting, e.g., a nonhazardous waste treatment system or wastewater treatment system.

This ACT document presents technical information that State and local agencies can use to develop strategies for reducing VOC emissions from process vents on waste management units not regulated by the RCRA process vent rules. The information in this document will allow planners to identify process vent emission sources, identify available control alternatives, and evaluate the VOC reduction and cost of implementing controls.

Chapter 2.0 describes the waste industry, the operations commonly associated with process vents, and typical process vent emission sources and rates. Chapter 3.0 describes alternative control techniques for the reduction of VOC emissions from waste management unit process vents. Chapter 4.0 presents air, cross-media, and capital and annual cost analyses of the alternative control techniques.

2.0 INDUSTRY DESCRIPTION, PROCESSES, AND EMISSIONS

This chapter presents an overview of waste generation, the waste treatment processes and technologies with associated process vents, the sources and quantities of organic air pollutants emitted from these process vents, and current State and Federal regulations that are applicable to waste management unit process vents.

2.1 INDUSTRY DESCRIPTION

2.1.1 The Waste Management Industry

The waste management industry in the United States is diverse and complex, covering a broad spectrum of industry types and sizes. Wastes, both hazardous and nonhazardous, vary considerably in both composition and form, and the waste management processes and practices used in treating, storing, and disposing of these wastes also vary widely. Figure 2-1 presents a simplified waste system flowchart for the waste management industry indicating key elements of the industry. These major elements--generation, transportation, storage, treatment, and disposal--are discussed in the following sections.

2.1.1.1 General Waste Description. Title 40 of the Code of Federal Regulations (CFR), Part 261.2 (40 CFR 261.2), defines a solid waste as any discarded material (e.g., garbage, refuse, sludge, or other waste material) that is not excluded by definition. Part 261.3 divides hazardous waste into four categories:

- Characteristic wastes--wastes that exhibit any hazardous characteristic identified in 40 CFR Part 261, Subpart C, including ignitability, corrosivity, reactivity, or extraction procedure (EP) toxicity
- Listed waste--wastes listed in 40 CFR Part 261, Subpart D

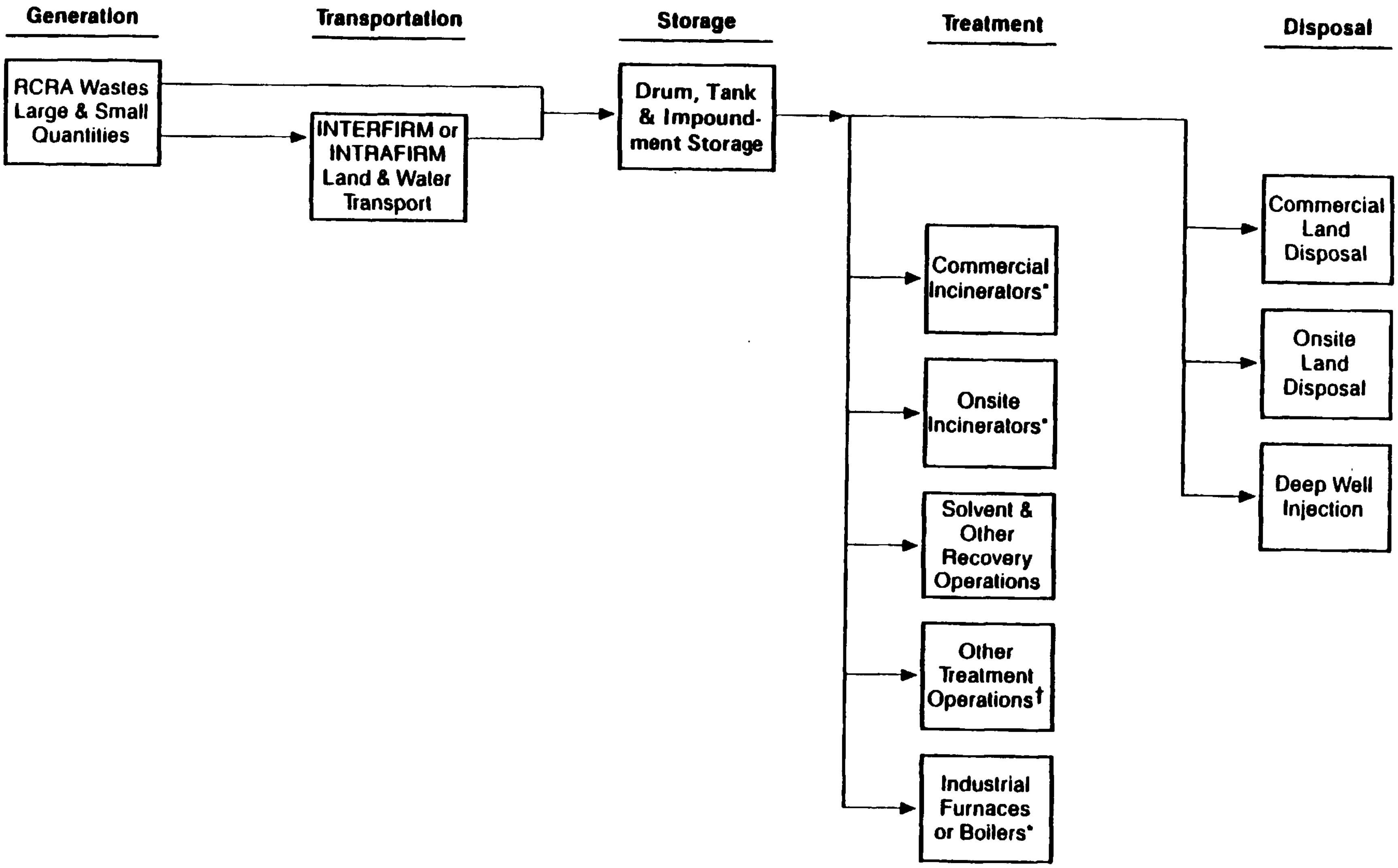

Figure 2-1. Simplified waste management system from generation to disposal.

- Mixture rule wastes--wastes that are (1) a mixture of solid waste and a characteristic waste unless the mixture no longer exhibits any hazardous characteristic, or (2) a mixture of a solid waste and one or more listed hazardous wastes

- Derived from rule wastes--any solid waste generated from the treatment, storage, or disposal of a hazardous waste, including any sludge, spill residue, ash, emission control dust, or leachate (but not including precipitation runoff).

Hazardous wastes are designated by Resource Conservation and Recovery Act (RCRA) alphanumeric codes. Codes D001 through D017 are referred to as "characteristic wastes." D001 represents wastes that are ignitable in character; D002, those that are corrosive; and D003, those that are reactive. Extracts of wastes that contain toxic concentrations of specific metals, pesticides, or herbicides are assigned one of the codes D004 through D017.

"Listed wastes" encompass four groups of alphanumeric codes published in 40 CFR Part 261, Subpart D. Hazardous wastes generated from nonspecific industry sources such as degreasing operations and electroplating are listed as codes beginning with the letter "F" (e.g., F001). Hazardous wastes from specific generating sources such as petroleum refining are assigned codes beginning with the letter "K" (e.g., K048). Waste codes beginning with "P" or "U" represent waste commercial chemical products and manufacturing chemical intermediates (whether usable or off-specification).

40 CFR Part 261, "Identification and Listing of Hazardous Wastes," not only lists hazardous wastes but also identifies specific wastes that are excluded from regulation as hazardous. These excluded wastes can be stored, treated, or disposed of without a RCRA permit.

General waste descriptions include hazardous wastes in the following forms: contaminated wastewaters, spent solvent residuals, still bottoms, spent catalysts, electroplating wastes, metal-contaminated sludges, degreasing solvents, leaded tank bottoms, American Petroleum Institute (API) separator sludges, off-specification chemicals, and a variety of other waste types. In reviewing waste data, more than 4,000 chemical constituents have been identified as components of the various waste types examined.[1]

2.1.1.2 Generators. The overwhelming majority of hazardous wastes are produced by large-quantity generators, those firms that generate more than 1,000 kg of hazardous waste per month.[2,3] Hazardous waste generators are most prevalent in the manufacturing industries (standard industrial classification [SIC] codes 20-39). Manufacturing as a whole accounts for more than 90 percent of the total quantity of hazardous waste generated. Two industry groups that stand out as generators are the chemical and petroleum industries (SIC 28 and 29); these industries alone account for more than 70 percent of total waste generation. The chemical industry (SIC 28), with only 17 percent of the generators, generated 68 percent of all the hazardous wastes produced in 1981.[4]

The 1981 National Survey of Hazardous Waste Generators and Treatment, Storage, and Disposal Facilities (Westat Survey)[5] provides estimates of the number of generators producing specific types of hazardous wastes. Just over half the generators indicated that they generate spent solvents, both halogenated and nonhalogenated (RCRA waste codes F001-F005). Only 10 percent of the generators generated listed hazardous wastes from specific industrial sources (e.g., slop oil emulsion solids from the petroleum refining industry--K049). Forty-three percent of generators produce ignitable wastes (RCRA waste code D001), a third generated corrosive wastes (D002), and more than a quarter generated wastes that failed EPA's test for toxicity (D004-D017). Just under 30 percent of the generators reported hazardous wastes that were spilled, discarded, or off-specification commercial chemical products or manufacturing chemical intermediates ("P" and "U" prefix waste codes).

Once a RCRA hazardous waste is generated, it must be managed (i.e., stored, treated, or disposed of) in accordance with legal requirements. Although nearly all hazardous waste is managed to some degree at the site where it is generated, the Westat Survey has shown that only about one in six generators manages hazardous waste exclusively onsite.[6] Of those generators that ship hazardous wastes to offsite management facilities for treatment, storage, and disposal, roughly a quarter still manage part of their hazardous wastes onsite. Although the survey estimated that 84 percent of the generators ship some or all of their hazardous wastes offsite, the vast majority of the quantities of hazardous waste are nonetheless managed onsite. About 96 percent of all generated hazardous wastes are managed onsite, with only 4 percent being shipped offsite for treatment, storage, or disposal.

Preliminary results of the National Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities (TSDR Survey) indicate that the total volume of hazardous waste managed in units onsite during 1986, regardless of the permit status of the units, was about 500 million Mg.[7] The physical characteristics of the 500 million Mg of RCRA hazardous waste managed in 1986 vary from dilute wastewater to metal-bearing sludges to soils contaminated with polychlorinated biphenyl (PCB). Over 90 percent (by weight) of RCRA hazardous waste is in the form of dilute aqueous waste (i.e., hazardous wastewater). The remaining wastes are organic and inorganic sludges and organic and inorganic solids.

2.1.1.3 Treatment, Storage, and Disposal Facilities. A significant segment of the hazardous waste industry is involved in hazardous waste management (i.e., treatment, storage, and disposal activities). Table 2-1 provides the RCRA definition of treatment, storage, and disposal.[8] Treatment, storage, and disposal facilities (TSDF) must apply for and receive a permit to operate under RCRA Subtitle C regulations. The RCRA Subtitle C permit program regulates 13 categories of waste management processes. There are four process categories each within storage and treatment practices and five categories within disposal practices.

The industry is complex and not easily characterized. The hazardous waste industry is also dynamic; that is, in response to changing demands and regulations, the facilities change the ways wastes are treated, stored, and disposed of. Of the treatment processes, tank treatment is most widely practiced, but no single treatment process is used in a majority of facilities.[9]

Evaluation of the various treatment technologies associated with TSDF has shown that waste management unit process vents are a significant source of organic air emissions, particularly process vents associated with distillation and other separation operations. Air emissions associated with process vents from distillation and stripping (air and steam) technologies used to treat hazardous waste, especially spent solvents (e.g., hazardous waste numbered F001-F005), are major contributors to the

TABLE 2-1. RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) HAZARDOUS WASTE MANAGEMENT DEFINITIONS[a]

Term	Definition
Storage	"Storage" means the holding of hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere.
Treatment	"Treatment" means any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste non-hazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.
Disposal facility	"Disposal facility" means a facility or part of a facility at which hazardous waste is intentionally placed into or on any land or water, and at which waste will remain after closure.

[a] Definitions are presented as stated in RCRA regulations (40 CFR 260.10) as of July 1, 1988.

Source: U.S. Environmental Protection Agency. Code of Federal Regulations. Title 40, Part 260.10. Washington, DC. Office of the Federal Register. July 1, 1988.

process vent emissions total. Organic emissions are discharged from process vents on distillation and separation units such as air strippers, steam strippers, thin-film evaporators, fractionation columns, batch distillation units, pot stills, and condensers and distillate receiving tanks that vent emissions from these units. Distillation and separation processes that treat wastes may be found in solvent reclamation operations, wastewater treatment systems, and in other waste pretreatment processes.

2.1.2 Current Regulations Applicable to Waste Management Unit Process Vents

2.1.2.1 State Regulations. The EPA examined State regulations, as well as existing Federal standards (including those under development), to determine the applicability of existing regulations to the control of waste management unit process vents.[10] The EPA found (as of 1987) that 6 States had established air toxics programs, 21 States had established generic standards for volatile organic compounds (VOC) independent of Federal regulations, and several States had extended control techniques guidelines (CTG) for VOC to TSDF. However, the standards vary widely in scope and application and, in many cases, controls have not been required when emissions are below 40 ton/yr, even in the 37 States with ozone nonattainment areas. Although a few States have controls in place, it appears that there were no general control requirements for TSDF process vents. Moreover, because TSDF with solvent recycling, one of the most typical waste management unit operations with associated process vents, generally are small operations, any new waste management units with process vents would likely have potential VOC emissions of less than 40 ton/yr; thus, prevention of significant deterioration (PSD) permit requirements may not apply. Existing Clean Air Act (CAA) standards that apply to the Synthetic Organic Chemical Manufacturing Industry (SOCMI) and petroleum refineries typically control emissions from production processes and generally do not apply to waste management sources.* In addition, EPA sent information requests to several large and small TSDF as part of the survey of existing regulations;

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*In December of 1983, EPA proposed New Source Performance Standards (NSPS) (40 CFR Part 60, Subpart NNN) to control emissions from SOCMI distillation operations. The recommended standards would require VOC emissions from new, modified, and reconstructed distillation operations to be reduced by 98 percent.

respondents to the EPA questionnaires did not indicate control requirements for process vents. Several of the facilities that were asked to provide information reported requirements for obtaining air contaminant source operating permits, but they reported no specific permit requirements for controlling process vent emissions.

2.1.2.2 RCRA Air Regulations. The process vent standards in 40 CFR Part 264 and 265, Subpart AA (promulgated 55FR 25454, June 21, 1990), limit emissions of organics from certain waste management unit process vents at new and existing hazardous waste TSDF requiring a RCRA permit (i.e., TSDF that need authorization to operate under RCRA Section 3005). The standards are applicable to all hazardous waste management units that are subject to the permitting requirements of Part 270 and hazardous waste recycling units that are located on hazardous waste management facilities otherwise subject to the permitting requirements of Part 270. Process vent air emissions from facilities or units that manage solid wastes not regulated as hazardous wastes pursuant to 40 CFR Part 261 and air emissions from hazardous waste from units or facilities exempt from the permitting provisions of 40 CFR 270.1(c)(2) are not regulated by the process vent standards in 40 CFR Part 264 and 265, Subpart AA (i.e., exempt units, other than recycling units, are not subject to the RCRA process vent standards even when they are part of a permitted facility).

The standards are applicable to process vents on affected hazardous waste management units that manage hazardous waste with an annual average total organics concentration of 10 parts per million by weight (ppmw) or greater and specifically include: (1) process vents on distillation, fractionation, thin-film evaporation, solvent extraction, and air or steam stripping operations and vents on condensers serving these operations; and (2) process vents on tanks (e.g., distillate receivers, bottoms receivers, surge control tanks, separator tanks, and hot wells) associated with distillation, fractionation, thin-film evaporation, solvent extraction, and air or steam stripping processes if emissions from these process operations are vented through the tanks.

2.1.2.3 RCRA Exemptions. In the RCRA regulations that define both a solid waste and a hazardous waste (i.e., 40 CFR 261.4), there are a number of general exclusions identifying materials that are not solid wastes and solid wastes that are not hazardous wastes. Because these excluded materials cannot be considered either a "solid waste" or "hazardous waste," as the case may be, these wastes (RCRA exempt wastes) are not subject to hazardous waste regulations under RCRA Subtitle C.* In addition, the RCRA regulations that codify the hazardous waste permit program (i.e., 40 CFR 270.1) identify specific facilities and/or units that are not required to obtain a RCRA permit (RCRA-exempt units). Because of these general RCRA exemptions, the following types of facilities or units are exempt from the RCRA process vent air emission standards in Subpart AA of 40 CFR Part 264 and 265 (it is the control of organic air emissions from these exempt waste management units that is the subject of this document):

- Generators that accumulate hazardous waste in tanks and containers for 90 days or less. (Note: The EPA intends to modify this exemption at a later date.)
- Units such as product (not hazardous waste) distillation columns generating organic hazardous waste still bottoms.
- Totally enclosed treatment facilities.
- Closed-loop recycling (reclamation) units.
- Elementary neutralization and wastewater treatment tanks.
- Units covered under the domestic sewage exclusion (i.e., publicly owned treatment works [POTW] receiving hazardous wastes).
- Units managing Subtitle D wastes.

These units are discussed in the following sections. Explanations are provided on why these units are not regulated by the RCRA air emission standards in 40 CFR Part 264 and 265, Subpart AA.

Generators' 90-Day Accumulation Tanks and Containers. In 40 CFR Part 270, hazardous waste generators who accumulate waste onsite in containers or tanks for less than the time periods provided in Section 262.34 are

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*Subtitle C--Hazardous Waste Management--of the RCRA statute as amended by Hazardous and Solid Waste Amendments (HSWA) establishes the program to regulate hazardous wastes from generation through proper disposal or destruction. Subtitle C contains the bulk of the requirements for RCRA permitting, closure, and post-closure, including criteria for identifying hazardous wastes.

specifically excluded from RCRA permitting requirements (i.e., a generator may accumulate hazardous waste onsite for 90 days or less without a RCRA permit or without having interim status (40 CFR 264.34)). To qualify for the exclusions in Section 262.34, generators who accumulate hazardous waste onsite for up to 90 days must comply with the substantive requirements for RCRA tanks and containers. Small-quantity generators (i.e., generators who generate more than 100 kg [222.2 lb] but fewer than 1,000 kg [2,222.2 lb] per calendar month) are allowed to accumulate waste onsite for up to 180 days or, if they must ship waste offsite for a distance of 320 km (200 miles) or more and if they meet certain other requirements set out in Section 262.34, for up to 270 days.

The promulgated regulation for process vents does not create a new exemption for 90-day accumulation, nor does it modify the existing regulation. However, because analysis indicates that 90-day tanks and containers have significant organic air emissions, EPA plans to propose (in 1990) a modification of the exemption to require that 90-day tanks meet the control requirements of the TSDF air standards that include the RCRA process vent standards. Until a final decision is made on regulating the emissions from these units, 90-day tanks that involve distillation/separation operations are not subject to additional controls under the process vents rules (Subpart AA). Therefore, generators of hazardous wastes (e.g., spent solvents identified as F001-F005 wastes) with onsite "90-day" tanks may have process vents associated with these nonpermitted units that are not controlled for organic air emissions. This document provides guidance on control technologies for these units until the proposed regulation is promulgated. [Note: Generators of hazardous wastes who ship these wastes offsite are required to designate, on the manifest, one facility that is authorized to handle the waste described on the manifest (40 CFR 262.20(b)). Hence, TSDF such as solvent recyclers that receive hazardous waste (e.g., spent solvents) should be RCRA-permitted facilities and thus potentially subject to the process vent rules.]

Process/Production Equipment. Under 40 CFR 261.4(c), hazardous wastes that are generated in process-related equipment such as product or raw material storage tanks or pipelines are exempt from RCRA regulation. This exemption applies until the waste is physically removed from the unit in which it was generated, unless the unit is a surface impoundment or unless the hazardous waste remains in the unit more than 90 days after the unit ceases to be operated for manufacturing, storage, or transportation of product or raw materials. Therefore, units such as product (not hazardous waste) distillation columns generating organic hazardous waste still bottoms are not subject to the RCRA process vent standards while the wastes are in the product distillation column unit. These product distillation columns may be subject to standards developed under the CAA, such as the proposed standards of performance for new stationary source VOC emissions from the SOCMI distillation unit operations (48 FR 57538, December 30, 1983) or similar standards proposed for the polymers and resins industry (52 FR 36678, September 30, 1987). However, distillation columns that manage such hazardous wastes (i.e., hazardous waste management units) are subject to the RCRA process vent standards (Subpart AA) if they are located at a RCRA-permitted facility.

Totally Enclosed Treatment Facilities. A "totally enclosed treatment facility" is a hazardous waste treatment facility that is "directly connected to an industrial production process and which is constructed and operated in a manner that prevents the release of any hazardous waste or any constituent thereof into the environment during treatment" (40 CFR 260.10). Totally enclosed treatment facilities are exempt from RCRA Subtitle C permit requirements under 40 CFR 264.1(g)(5), 40 CFR 265.1(c)(9), and 270.1(c)(2).

Two important characteristics define a totally enclosed treatment facility. The key characteristic of a totally enclosed treatment facility is that it does not release any hazardous waste or constituent of hazardous waste into the environment during treatment. Thus, if a facility leaks, spills, or discharges waste or waste constituents, or emits waste or waste constituents into the air during treatment, it is not a totally enclosed treatment facility within the meaning of these regulations. The second important characteristic is that it must be directly connected to an industrial production process. Treatment facilities located off the site of generation (e.g., commercial TSDF) are not directly connected to an industrial process and therefore are not exempt. In addition, storage and disposal units and ancillary equipment not used to treat hazardous wastes fall outside the definition of a totally enclosed treatment facility.

The EPA believes that most onsite treatment facilities are not totally enclosed. Distillation columns and other treatment technologies generally are designed to release emissions into the air. Therefore, by definition, these onsite technologies are generally not totally enclosed. (See 45 FR 33218, May 19, 1980 [no constituents released to air during treatment].) As a result of this definition, there should be no process vent emissions from units that are exempted as "totally enclosed treatment units."

Closed-loop Recycling Units. The RCRA process vent rules regulated the activity of reclamation at RCRA facilities for the first time. The EPA has amended 40 CFR 261.6, under its RCRA authority over reclamation, so that reclamation of hazardous wastes in waste management units of the type affected by the process vent rules (e.g., distillation columns or thin-film evaporators) is covered by the process vent rules. It should be recognized, however, that the rules apply only at facilities otherwise needing a RCRA permit. In addition, the closed-loop reclamation exemption in Part 261.4(a)(8) is not changed by these rules. Therefore, not all reclamation units will necessarily be affected by the process vent and equipment leak rules. "Closed-loop reclamation units" are exempt. As a result, process vents on distillation/separation operations exempted from the Subpart AA process vent rules as part of a closed-loop reclamation system may have significant uncontrolled organic air emissions.

Elementary Neutralization and Wastewater Treatment Tanks. The RCRA regulations also exclude elementary neutralization and wastewater treatment units as defined by 40 CFR 260.10 from obtaining a permit. The EPA amended these definitions (see 53 FR 34080, September 2, 1988) to clarify that the scope of the exemptions applies to the tank systems, not just the tank. For example, if a wastewater treatment or elementary neutralization unit is not subject to RCRA Subtitle C hazardous waste management standards, neither is ancillary equipment connected to the exempted unit. The amendments also clarify that a wastewater treatment tank must be part of an onsite wastewater treatment facility in order to be exempt. Thus, emissions from process vents on distillation, fractionation, thin-film evaporation, solvent extraction, or air or steam stripping operations that are considered a tank regulated under Section 402 or 307(b) of the Clean Water Act (CWA) are not subject to the RCRA process vent standards.

Domestic Sewage Units. Under the "domestic sewage exclusion" (DSE) [specified in Section 1004(27) of RCRA and codified in 40 CFR 261.4(a)(1)], solid or dissolved material in domestic sewage is not, by definition, a "solid waste" and, as a corollary, cannot be considered a "hazardous waste." Thus, the DSE covers:

- "Untreated sanitary wastes that pass through a sewer system"
- "Any mixture of domestic sewage and other wastes that passes through a sewer system to a POTW for treatment" [40 CFR 261.4(a)(1)].

The exclusion allows industries connected by pipeline to POTW to discharge hazardous wastes to sewers containing domestic sewage without having to comply with certain RCRA generator requirements such as manifesting and reporting requirements. Moreover, POTW receiving excluded wastes are not deemed to have received hazardous wastes and, therefore, are not subject to RCRA requirements for TSDF. [Note: The premise of the exclusion is that it is unnecessary to subject hazardous wastes mixed with domestic sewage to RCRA management requirements because these DSE wastes receive the benefit of treatment offered by POTW and are already regulated under CWA programs such as the National Pretreatment Program.]

Subtitle D Waste Management Units. RCRA Subtitle D wastes are all solid wastes regulated under RCRA not subject to hazardous waste regulations under Subtitle C. These wastes are defined in 40 CFR Part 257. In accordance with the above-mentioned definitions and exclusions, several categories of Subtitle D wastes have been identified. At least two of these categories include wastes with significant amounts of organics that could eventually be managed in units having associated process vents.[11] These two categories, industrial nonhazardous waste and small-quantity generator waste, are discussed briefly.

The principal source of data on industrial Subtitle D wastes is Summary of Data on Industrial Nonhazardous Waste Disposal Practices.[12] This report includes a review of compiled available data on industrial nonhazardous wastes characteristics and generation rates from 22 major manufacturing industries and indicates that the characteristics of industrial nonhazardous wastes vary from industry to industry and within each industry. Twelve of the twenty-two industries studied are expected to generate nonhazardous wastes that contain relatively high levels of organic constituents (and heavy metals). The information available on management practices of industrial nonhazardous wastes did not address waste treatment processes of the type that have associated process vents.

Hazardous wastes generated by conditionally exempt small-quantity generators are solid wastes that are exempt, under 40 CFR 261.5, from Subtitle C regulations and thus are Subtitle D wastes. Conditionally exempt wastes are defined as those wastes that meet the definition of a hazardous waste under 40 CFR Part 261 and that are generated at a rate of less than 100 kg/month. The National Small Quantity Hazardous Waste Generator Survey[13] indicates that about 18 percent of conditionally exempt wastes are spent solvents. The report also states that most small-quantity generator (SQG) (i.e., <1,000 kg/month) waste is managed offsite (85 percent), with about 65 percent being recycled offsite. Also, according to the survey, SQG wastes are managed onsite by: recycling (65 percent), discharge to public sewers (8 percent), solid waste facilities (5 percent), and Subtitle C facilities (4 percent).

Detailed data on the types of facilities and process units that manage Subtitle D wastes are not available (with the exception of data on surface impoundments, landfills, land application units, and wastepiles); therefore, no characterization can be made regarding the type of process vents and their operating parameters for those waste treatment units managing Subtitle D wastes (such as industrial nonhazardous waste and conditionally exempt hazardous wastes).

2.1.2.4 Exemptions to the Process Vent Standards. As promulgated, the RCRA process vent standards control organic emissions as a class from affected process vents at hazardous waste TSDF that are subject to permitting requirements under RCRA Section 3005. In addition, the rules are applicable only to specific types of waste management units that manage wastes classified as hazardous and that contain organics above a specific concentration.

Specified Waste Management Units. The RCRA standards for process vents apply only to those waste management units that are known to have associated process vents. These include (1) process vents on distillation, fractionation, thin-film evaporation, solvent extraction, and air or steam stripping operations and vents on control devices (e.g., condensers) serving these operations, and (2) process vents on tanks or vessels (e.g., distillate receivers, bottoms receivers, surge control tanks, separator tanks, and hot wells associated with distillation, fractionation, thin-film evaporation, solvent extraction, and air or steam stripping processes) if emissions from these operations are vented through the tank. The RCRA process vent standards exclude air emissions from vents on other closed (covered) and vented tanks not associated with the specified distillation/separation processes. For example, uncondensed overhead emitted from a distillate receiver (i.e., a tank) serving a hazardous waste distillation process unit is subject to the RCRA process vent regulations. On the other hand, if emissions from the distillation unit or a condenser serving the unit are not vented through the tank (i.e., they are vented directly to the atmosphere or through a vacuum pump), then vents that may be present on the tank are not subject to the RCRA standard for process vents. Unenclosed or uncovered processes, storage tanks, treatment tanks, and transfer facilities are not covered by the process vent rules, but EPA plans to regulate these sources with additional RCRA TSDF air standards for tanks and containers; proposal is planned for 1990.

Units Managing Waste with Less than 10 ppmw Total Organics Content. A hazardous waste management unit is not subject to the RCRA process vent rules if it treats wastes with less than a 10-ppmw total organics content on an annual average basis. Of the distillation/separation operations used to manage wastes, air stripping is the treatment device most commonly used with low organic concentration streams. Distillation-type operations would not likely be used to treat wastes with organic concentrations of less than 10 ppmw. Examples of facilities managing low-concentration wastes are sites where ground water (or wastewater) is undergoing remedial action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or corrective action persuant to RCRA.

It should also be noted that, with the annual average applicability criterion, a waste management unit would not be subject to the RCRA process vent standards if it occasionally treats hazardous wastes that exceed 10 ppmw and if at other times the organic contents of the wastes being treated in the unit are such that the weighted annual average total organic concentration of all wastes treated is less than 10 ppmw.

2.1.2.5 Waste Treated in RCRA-Exempt Units. As noted above, the RCRA process vent standards do not apply to all distillation, fractionation, thin-film evaporation, solvent extraction, and air and steam stripping operations managing hazardous waste even when they are part of a permitted facility. RCRA-exempt units, other than some recycling units, are not subject to the process vent rules. Neither are units of the type specified in the rule that do not meet all the applicability criteria contained in the rules; i.e., wastes may not be hazardous under RCRA or may not contain an organic concentration that triggers regulation.

Preliminary results of the National Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities (TSDR Survey) indicate about 3.6 million tons of hazardous waste were managed in units of the type specified in the RCRA process vent rules that required a RCRA permit during 1986.[14] About 10.6 million tons of hazardous waste were managed in units of the type specified in the process vent rules that were exempt from RCRA permitting requirements that same year. Table 2-2 summarizes the data on quantities of wastes managed in, and the RCRA permit status of, these selected treatment units. As these data indicate, there are a number of distillation/stripping units at TSDF exempt from the RCRA permit requirements that nonetheless treat both hazardous and nonhazardous wastes. These units may not be subject to the RCRA process vent rules in 40 CFR Part 264 and 265, Subpart AA, even though these nonregulated units have process vents that potentially emit organics to the atmosphere in quantities similar to process vents on units regulated under the RCRA process vent rules. These unregulated units are the focus of this ACT document.

2.2 PROCESS DESCRIPTIONS

The processes discussed in this section are those waste management operations that are used to treat, store, or dispose of organic-containing wastes and are known to have associated process vents. Distillation/

TABLE 2-2. QUANTITIES OF WASTE MANAGED IN, AND RCRA PERMIT STATUS OF, SELECTED TREATMENT UNITS IN 1986

	RCRA permit status (number of units)		Quantity of hazardous waste managed (tons)[c]		Quantity of nonhazardous waste managed (tons)[c]	
Type of unit	Regulated[a]	Exempt[b]	Regulated units	Exempt units	Regulated units	Exempt units
Air strippers	10	42	3,077,000	6,877,000	0	89,700
Steam strippers	17	23	96,000	3,251,000	0	0
Fractional distillation	53	72	90,400	187,000	112,200	79,000
Batch distillation	186	185	160,000	178,000	3,600	800
Solvent extraction	32	10	81,300	4,000	101,500	100
Thin-film evaporation	52	25	136,000	85,000	1,000	100

[a] Regulated units include units with a RCRA final permit and those operating under RCRA interim status.

[b] Exempt units include wastewater treatment/elementary neutralization units, recycling units, 90-day accumulation tanks, and other exempt units. Some recycling units would be regulated under the RCRA process vent rules.

[c] Waste quantity values are not additive horizontally because some wastes are managed in both units requiring a RCRA permit and those exempt from RCRA permitting requirements. However, a waste treated in one of the specified units is not likely to be treated in any other of the specified units.

Source: 1987 National Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities (TSDR Survey). Alpha Database. July 1989.

stripping operations of the type described below are used to reprocess, reduce total volume, or treat organics in the waste before the waste is properly disposed of. These distillation/stripping process units may or may not be controlled by the RCRA process vent standards described in Section 2.1.

For the purpose of this document, a process vent is defined as any open-ended pipe or stack that is vented to the atmosphere either directly, through a vacuum-producing system, or through an associated tank (e.g., distillate receiver, condenser, bottoms receiver, surge control tank, separator tank, or hot well). Vented means discharged through an opening, typically an open-ended pipe or stack, allowing the passage of a stream of liquids, gases, or fumes into the atmosphere. Under the process vent definition, the passage of liquids, gases, or fumes is caused by mechanical means such as compressors or vacuum-producing systems or by process-related means such as evaporation produced by heating and is not caused by tank loading or unloading or by natural means such as diurnal temperature changes.

The above vent description is the same as the definition used in the RCRA process vent standards discussed previously. Under this definition, the scope of this process vent control technology document is limited and does not include nonprocess-related vents such as those on storage tanks. This definition excludes tank working (loading and unloading) losses and tank breathing losses; tank working and breathing losses are not considered process vent emissions. Information on the control of sources with nonprocess-related vents is presented in other EPA documents. For example, the Hazardous Waste TSDF--Background Information for Proposed RCRA Air Emission Standards (February 1990, draft document) provides technical support for the upcoming RCRA air rules: Subpart CC--Air Emission Standards for Tanks, Surface Impoundments, and Containers of 40 CFR Parts 264 and 265, which is planned for proposal in 1990; and the VOC Emissions from Volatile Organic Liquid Storage Tanks--Background Information for Proposed Standards (EPA-450/3-81-003a), which provides technical support for the CAA rules: Standards of Performance for Volatile Organic Liquid Storage Vessels in 40 CFR Part 60, Subpart Kb.

Review of the various waste treatment technologies used at TSDF indicates that distillation and stripping operations (i.e., separation processes) are the waste management units most typically having associated process vents.[15] The following sections provide brief process descriptions and typical process vent configurations for the most common distillation and stripping operations.

2.2.1 Distillation

Distillation is the most commonly used separation and purification procedure in refineries, solvent recovery systems, large organic chemical manufacturing plants, and TSDF. The fundamental operating principles for a distillation column are the same regardless of the application. This section briefly discusses some of the principles involved in the various types of distillation operations to provide a better understanding of the operating characteristics of distillation units.

Distillation is an operation separating one or more feed stream(s) into two or more product streams, each product stream having component concentrations different from those in the feed stream(s). The separation is achieved by the redistribution of the components between the liquid and vapor phase as they approach equilibrium within the distillation unit. The more volatile component(s) concentrate in the vapor phase; the less volatile components(s) concentrate in the liquid phase. Both the vapor and liquid phases originate predominantly by vaporization and condensation of the feed stream.

Distillation systems can be divided into subcategories according to the operating mode, the method of applying heat to volatilize components, the operating pressure, the number of distillation stages, the introduction of inert gases, and the use of additional compounds to aid separation. A distillation unit may operate in a continuous or a batch mode. The operating pressures can be below atmospheric (vacuum), atmospheric, or above atmospheric (pressure). Distillation can be a single-stage or a multistage process. Inert gas, especially steam, is often introduced to vaporize the volatile constituent or to improve separation. In some cases, compounds are introduced to aid in distilling hard-to-separate mixture constituents (azeotropic and extractive distillation). Those types of distillation operations commonly used to manage wastes containing organic constituents are discussed below.

2.2.1.1 Batch Distillation. Batch distillation is commonly used to recover organics from hazardous wastes. Its principal use is for recovery of valuable organic chemicals (e.g., spent solvents) for recycling or reuse and the re-refining of waste oil. It also can be applied to reduce the organic air emission potential of hazardous and nonhazardous wastes by separating the volatile compounds from the wastes. Although it has been applied to aqueous wastes, its predominant application has been to organic wastes (i.e., wastes with high organic concentrations).

The simplest form of distillation is a batch operation that consists of a heated vessel (called the pot), a condenser, and one or more distillate receiving tanks. The waste material is charged to the pot and heated to boiling; vapors enriched in organics are then removed, condensed, and collected in receiving tanks. The distillation is continued to a cutoff point determined by the concentration of organics in the condensate or the concentration of organics remaining in the batch. A common modification is to add a rectifying column and some means of returning a portion of the distillate as reflux (see Figure 2-2). Rectification, or fractionation, is a multistage distillation operation that enables the operator to obtain products from the condensate that have a narrow composition range. Fractionating distillation is accomplished by using trays, packing, or other internals in a vertical column. The light end vapors evolving from the column are condensed and collected in a distillate receiver tank. Part of the distillate is returned to the top of the column so it can fall countercurrent to the rising vapors. Different distillate cuts are made by switching to alternate receivers, at which time the operating conditions may be changed. If the distillate is collected as one product, the distillation is stopped when the combined distillate reaches the desired average composition. Several references[16-19] are available that discuss batch distillation design and operation at a temperature determined by the boiling point of the waste, which may increase with the time of operation. The distillation can be carried out under pressure or under vacuum. The use of a vacuum reduces the operating temperature and may improve product

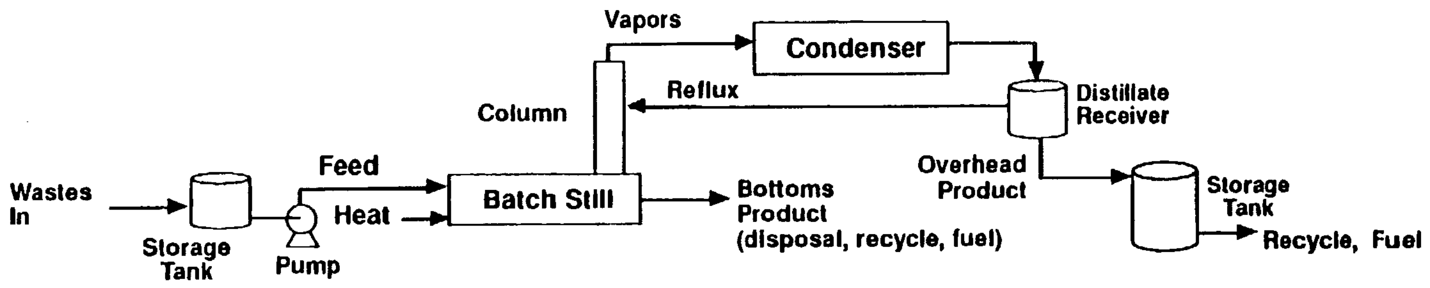


Figure 2-2. Schematic diagram of batch distillation with fractionating column.

recovery, especially when decomposition or chemical reaction occurs at higher temperatures.

Batch distillation provides a means for removing organics from a waste matrix and recovering the organics by condensation for recycle, sale as product, or for fuel. The products and residues include the condensate that is enriched in organics and recovered, noncondensibles that escape through the condenser vent, and the waste residue that remains in the pot. The noncondensibles are composed of gases dissolved in the waste and very volatile organic compounds with relatively low-vapor-phase concentrations. The waste material after distillation may have been concentrated with high-boiling-point organics or solids that are not removed with the overhead vapors. These still bottoms may be a free-flowing liquid, a viscous slurry, or an organic material that may solidify upon cooling. If the waste material contains water, a separate aqueous phase may be generated with the condensate. This phase may be returned to the batch or processed with additional treatment to remove organics or other contaminants.

Batch distillation is typically used for wastes that have a significant vapor-phase concentration of organics at the distillation temperature. If the waste can be pumped and charged to the still pot and the residue can be removed from the pot, then the waste is likely to be treatable for organic removal by this process. Such waste forms include dilute aqueous wastes (the operation would be similar to batch steam stripping, which is discussed later in this chapter), aqueous or organic sludges, or wastes with volatiles in a high-boiling-point organic solvent or oil. The batch distillation of sludges has not been demonstrated and evaluated in full-scale units; consequently, the processing of sludges in a batch distillation unit is subject to the same limitations described later for the batch steam stripping of sludges. Batch distillation has been used to remove organics from plating wastes and phenol from aqueous wastes, to recover and separate solvents, and to re-refine waste oils.[20,21] The applicability of batch distillation for a specific waste type can be evaluated by a simple laboratory distillation to assess potential organic recovery. As with other organic removal techniques, the process may require optimization in a pilot-scale or full-scale system for different types of wastes to determine operating conditions that provide the desired distillate composition or percent removal from the waste.

Batch stills usually are operated as a single equilibrium stage (i.e., with no reflux); consequently, the organic removal efficiency is primarily a function of the vapor/liquid equilibrium coefficient of the organics at distillation temperature and the fraction of the waste boiled over as distillate. The use of a rectifying section yields an overhead product with a composition that can be controlled by the operator. The removal efficiency for various waste types can be highly variable because of the dependence on both the properties of the waste (e.g., organic equilibrium) and the operating conditions that are used.

2.2.1.2 Continuous Distillation. Continuous distillation is used routinely in the chemical manufacturing industry. In a continuous distillation unit, one or more feed streams are separated into two or more product streams on a continuous, steady-state basis. Continuous fractionating distillation is the most commonly used type of distillation unit operation in large organic chemical plants. The efficiency of a continuous system at removing organics from a feed or waste stream is related to the equilibrium coefficient and the number of trays or height of packing. In principle, the removal efficiency in a multistage system can be designed to achieve almost any level. In practice, removal efficiencies are determined by practical limits in column design (such as maximum column height or pressure drop) and cost.

Continuous distillation operations require a feed stream that is a free-flowing liquid with a negligible solids content. Solids, including tars and resins, tend to foul the column trays or packing and heat exchangers. Consequently, wastes containing solids may require removal of the solids prior to processing through a continuous distillation unit. Unlike the batch operation, a continuous distillation unit requires a relatively consistent feed composition to maintain a consistent removal efficiency from the waste material. A continuous distillation unit may offer cost advantages over a batch operation for applications in which there is little variation in the type of feed and for relatively high volumes of waste materials.

2.2.1.3 Thin-Film Evaporation. Thin-film evaporators (TFE) are designed to promote heat transfer by spreading a thin layer of liquid on one side of a metallic surface while supplying heat to the other side.[22] The unique feature of this equipment is the mechanical agitator device, which permits the processing of high-viscosity liquids and liquids with suspended solids. However, if solid particles are large, a coarse filtration operation may be required to pretreat the waste stream going to the TFE. The mechanical agitator promotes the transfer of heat to the material by exposing a large surface area for the evaporation of volatile compounds and agitates the film to maintain the solids in suspension without fouling the heat transfer area. Heat can be supplied by either steam or hot oil; hot oils are used to heat the material to temperatures higher than can be achieved with saturated steam. TFE can be operated at atmospheric pressure or under vacuum as needed depending on the characteristics of the material treated. A TFE distillation operation is illustrated in Figure 2-3.

The two types of mechanically agitated TFE are horizontal and vertical. A typical unit consists of a motor-driven rotor with longitudinal blades that rotate concentrically within a heated cylinder. The rotating blade has a typical tip speed of 9 to 12 m/s (30 to 39 ft/s) and a clearance of 0.8 to 2.5 mm (0.032 to 0.098 in.) to the outer shell. In a vertical design, feed material enters the feed nozzle above the heated zone and is transported mechanically by the rotor and grating down a helical path on the inner heat transfer surface while the volatile compounds are volatilized and leave the evaporator on the top. The vapor-phase products from TFE are condensed in a condenser, and the bottom residues are collected for disposal.

TFE have been used widely for many years in a number of applications such as processing of chemicals, pharmaceuticals, plastics, and foods.[23] Because of their unique features, their use in chemical and waste material processing has expanded rapidly. The flexibility in operating temperature and pressure add potential to TFE for recovering low-boiling-point organics from a complex waste matrix.

Waste forms suitable for TFE treatment include organic liquids, organic sludge/slurry, two-phase aqueous/organic liquids, and aqueous sludges. TFE would not be an economical means of treating dilute aqueous waste because of the high water content in the waste.

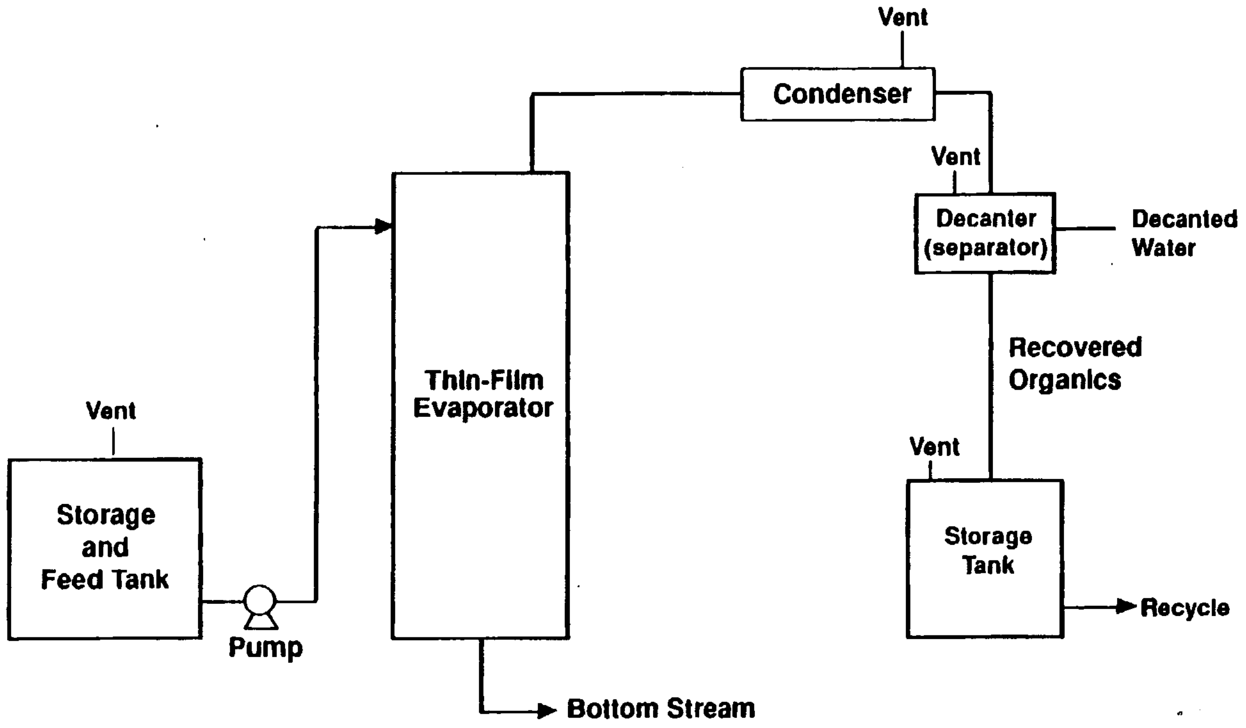


Figure 2-3. Schematic diagram of a thin-film evaporator system.

2.2.1.4 Steam Stripping. Steam stripping involves the fractional distillation of volatile constituents from a less volatile waste matrix. Both batch and continuous steam stripping are commercially proven processes and have been commonly used to remove organics from aqueous streams such as process wastewater. Several references discuss steam stripping in detail, including a steam-stripping manual published by EPA,[24] descriptions of the theory and design procedures,[25-28] and descriptions of applicability to hazardous wastes.[29-32] The basic operating principle of steam stripping is the direct contact of steam with the waste, which results in the transfer of heat to the waste and the vaporization of the more volatile constituents. The vapor is condensed and separated (usually decanted) from the condensed water vapor. A simplified diagram of a steam stripping operation is shown in Figure 2-4.

The batch steam stripping process is identical in principle to batch distillation except that the waste charge is heated by direct steam injection instead of being heated indirectly. Batch steam stripping may offer advantages at waste facilities because the unit can be operated in a manner most suitable for the particular batch of waste to be stripped. For example, the same unit may be used to remove volatiles from a batch of wastewater, from a waste containing solids, or from a high-boiling-point organic matrix. Batch stills may also be used if the material to be separated contains solids, tars, or resins that may foul or plug a continuous unit.

The heat input rate and fraction boiled over can be varied for each waste composition to obtain the recovery or removal desired for the specific batch of waste. If the system is cleaned between batches, an aqueous waste stream may be generated from the rinse water. This rinse water may be added to a similar batch to be stripped, accumulated in a separate batch for treatment, or sent to a wastewater treatment (WWT) unit. However, wastewater may be generated from cleaning any organic removal or treatment system and would not be unique to batch operations.

Continuous steam stripping requires a feed stream that is a free-flowing liquid with a negligible solids content. Solids, including tars and resins, tend to foul the column trays or packing and heat exchangers. Consequently, wastes containing solids may require removal of the solids

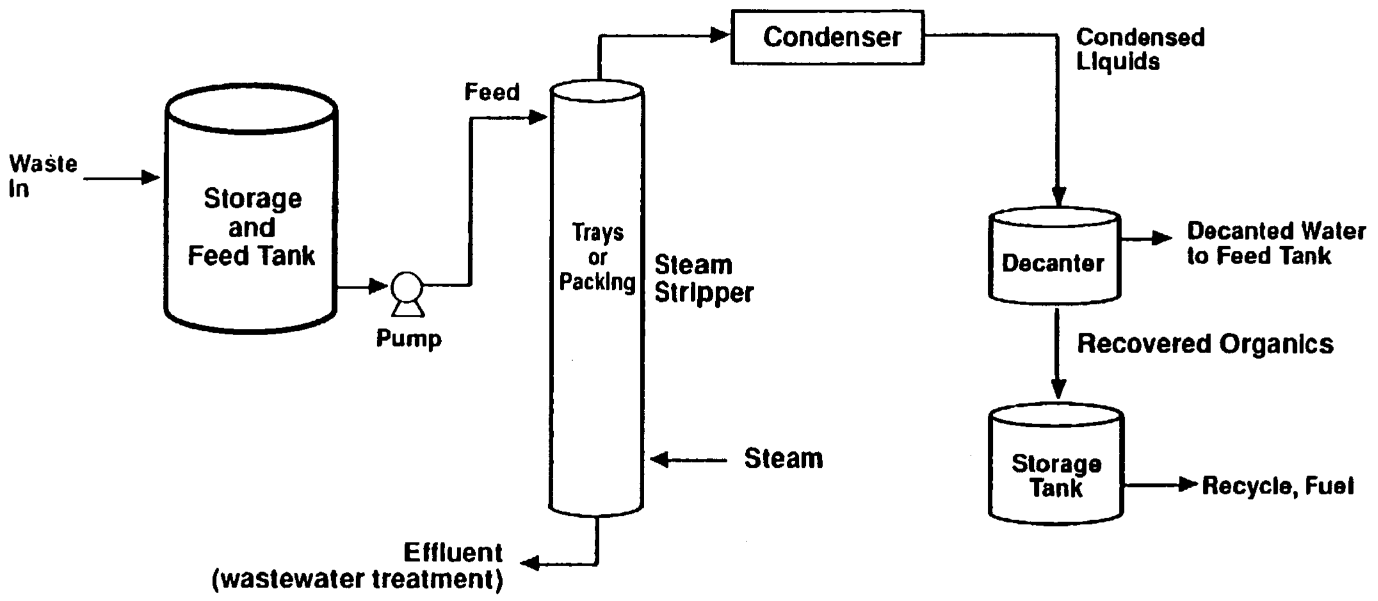


Figure 2-4. Schematic diagram of a steam stripping system.

prior to processing through a continuous steam stripper. Unlike the batch operation, a continuous steam stripper requires a relatively consistent feed composition to maintain a consistent removal efficiency from the waste material.[33] A continuous steam stripper may offer cost advantages over a batch operation for applications in which there is little variation in the type of feed and for relatively high volumes of waste materials.

The products and residues from steam stripping include the condensed vapors (condensate), noncondensible gases, and the treated waste or effluent. The condensate usually is decanted to remove any separate organic layer from the aqueous layer. The aqueous condensate is then recycled to the feed stream. The separate organic layer may be recovered and reused as product or fuel. If the condensate is a single phase of water containing dissolved organics, then additional treatment of the condensate may be necessary for ultimate control of organics. Most commercial processes rely on the formation of a separate organic phase and decanting for economical removal and recovery of organics. Noncondensibles in the overhead stream include gases dissolved in the waste material and very volatile compounds in low concentrations that are not condensed in the overhead system. The effluent from the steam stripper should be essentially free of the most volatile compounds; however, semivolatiles and compounds that are relatively nonvolatile may still be present in the stripper bottoms or effluent.

Preliminary treatment such as solids removal or pH adjustment is often used before wastewater is stripped in a continuous unit. Steam stripping of wastewaters that contain significant quantities of dissolved solids, emulsified oil, and suspended solids may in some cases foul the stripper and make it unusable. Therefore, removal of any separate oil or solid phase in the wastewater prior to stripping will improve performance and minimize maintenance problems. Continuous steam stripping has been used routinely in the chemical industry to recover organics for recycle and to pretreat wastewater for organic removal prior to the conventional WWT process. Some common applications include recovery of ethylene dichloride, ammonia, sulfur, or phenol for recycle and removal of phenol, mercaptans, vinyl chloride, and other chlorinated compounds from wastewater.[34] Batch steam stripping appears to be more common at hazardous waste facilities because it is adaptable to different types of wastes that may be received in batches.[35] For any given waste type, pilot-scale evaluations or trials in the full-scale process may be required to optimize the operating conditions for maximum removal at the lowest cost.

Removal efficiencies on the order of 95 to 100 percent are achievable for volatile compounds such as benzene, toluene, and one- or two-carbon chlorinated compounds.[36,37] Batch operations usually provide a single equilibrium stage of separation, and the removal efficiency is determined essentially by the equilibrium coefficient and the fraction of the waste distilled. The efficiency of a continuous system is related to the equilibrium coefficient and the number of equilibrium stages, which is determined primarily by the number of trays or height of packing. The organic removal efficiency also is affected by the steam input rate, column temperatures, and, in some cases, the pH. Temperature affects the solubility and partition coefficient of the volatile compound. The liquid pH also may affect the solubility and treatability of specific compounds, such as phenol. In principle, the removal efficiency in a multistage system can be designed to achieve almost any level. In practice, removal efficiencies are determined by practical limits in the column design (such as maximum column height or pressure drop) and cost. Consequently, steam stripping is difficult to characterize in terms of maximum achievable performance with respect to organic concentration in the treated waste.

2.2.2 Solvent Extraction[38,39]

Solvent extraction (in terms of waste treatment) is a process whereby a substance dissolved in or adsorbed by a waste is transferred from the waste to a solvent that preferentially dissolves that substance. When the waste to be treated is a liquid, the process may be called liquid-liquid extraction. The substance transferred is the solute; the treated effluent is referred to as the raffinate; and the solute-rich solvent phase is called the extract. For the process to be effective, the extracting solvent must be immiscible in the liquid and differ in density so that gravity separation is possible and there is minimal contamination of the raffinate with solvent. Solvents typically used include benzene, toluene, chloroform, methylene chloride, isopropyl ether, and butylacetate.

Solvent extraction can be performed as a batch process or by the contact of the solvent with the feed in staged or continuous contact equipment. There are two main classes of solvent extraction equipment--tanks in which mechanical agitation is provided for mixing of the two phases and tanks in which the mixing is done by the flow of the fluids themselves (e.g., a spray tower, packed tower, or sieve plate tower). Liquid-liquid extraction results in two streams, the raffinate and the extract, which usually require further treatment. If aqueous, the raffinate may be contaminated with small quantities of both the solute and the solvent. These may have to be removed by carbon adsorption. Solvent is typically recovered from the extract by use of one of the distillation processes described in this chapter, leaving a concentrated solute-solvent waste stream for recycle, reuse, incineration, or disposal. Distillation processes have potential organic emissions from condenser vents, accumulator tank vents, and storage tank vents. A schematic diagram of a solvent extraction system is illustrated in Figure 2-5.

The solvent extraction process is most suitable for the pretreatment of aqueous waste streams with high levels of organic constituents. It is a proven method for removing phenol, acetic acid, salicylic (and other hydroxy aromatic) acids, and petroleum oils from aqueous solutions. Solvent extraction is used to remove organic contaminants from aqueous wastes in several industries including petroleum refining, organic chemicals manufacturing, pulp and paper, and iron and steel. Solvent extraction is a limited technology in that it is almost always necessary to further treat the raffinate and/or the extract. Other limitations include the difficulty in finding a suitable solvent low in cost, high in extraction efficiency, and easily separable from the extracted substance. Though not as popular as distillation or stripping due to its higher cost, solvent extraction is widely used to recover valuable solvents. Typical removal efficiencies of solvent extraction range from 80 percent to close to 100 percent.

2.2.3 Air Stripping

Air stripping is a process that uses forced air to remove volatile compounds from a less volatile liquid. The contact between air and liquid

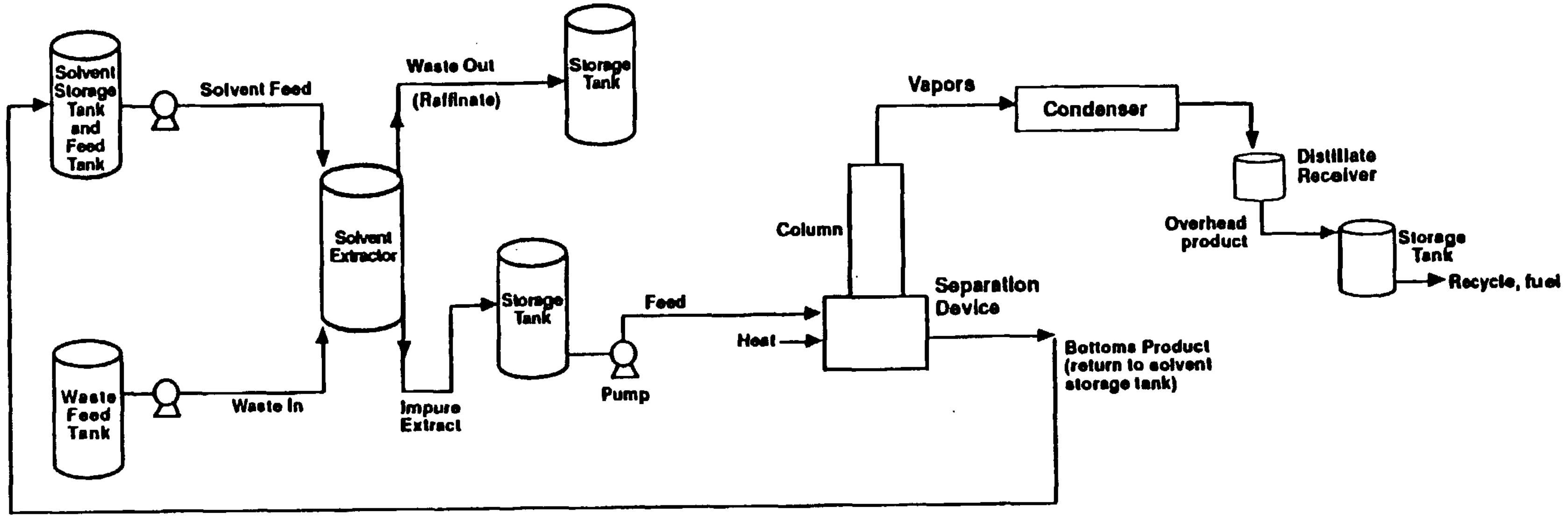


Figure 2-5. Schematic diagram of solvent extraction system.

can be accomplished in spray towers, mechanical or diffused-air aeration systems, multiple tray columns, and packed towers.[40,41] The focus of this section is on packed tower air strippers because packed tower aeration is the most common air stripper design (the other systems are not as efficient) and with this design the vapor-laden air can be sent to a control device for ultimate control of organic air emissions. In packed towers, the liquid to be treated is sprayed into the top of a packed column and flows down the column by gravity. Air is injected at the bottom of the column and rises countercurrent to the liquid flow. The air becomes progressively richer in organics as it rises through the column and can be sent to a control device to remove or destroy organics in the airstream. See Figure 2-6 for a schematic of a typical air stripping system with gas-phase organic emission control.

The principle of operation is the equilibrium differential between the concentration of the organics in the waste and the air with which it is in contact. Consequently, compounds that are very volatile are the most easily stripped. The packing in the column promotes contact between the air and liquid and enhances the mass transfer of organics to the air. The residues from air stripping include the organic-laden air and the water effluent from the air stripper. This effluent will contain very low levels of the most volatile organic compounds; however, semivolatile compounds that are not easily air-stripped may still be present. The process does not offer a significant potential for recovery and reuse of organics. Condensers generally are not used to recover the stripped organics because of the large energy requirements to cool the large quantity of noncondensibles (primarily air) and to condense the relatively low vapor-phase quantities of organic compounds.

Air stripping has been used primarily on dilute aqueous waste streams with organic concentrations that range from a few parts per billion to hundreds of parts per million. The feed stream should be relatively free of solids to avoid fouling in the column; consequently, some form of solids removal may be required for certain aqueous hazardous wastes. In addition, dissolved metals that may be oxidized to an insoluble form should be removed. Equipment may be designed and operated to air-strip organics from

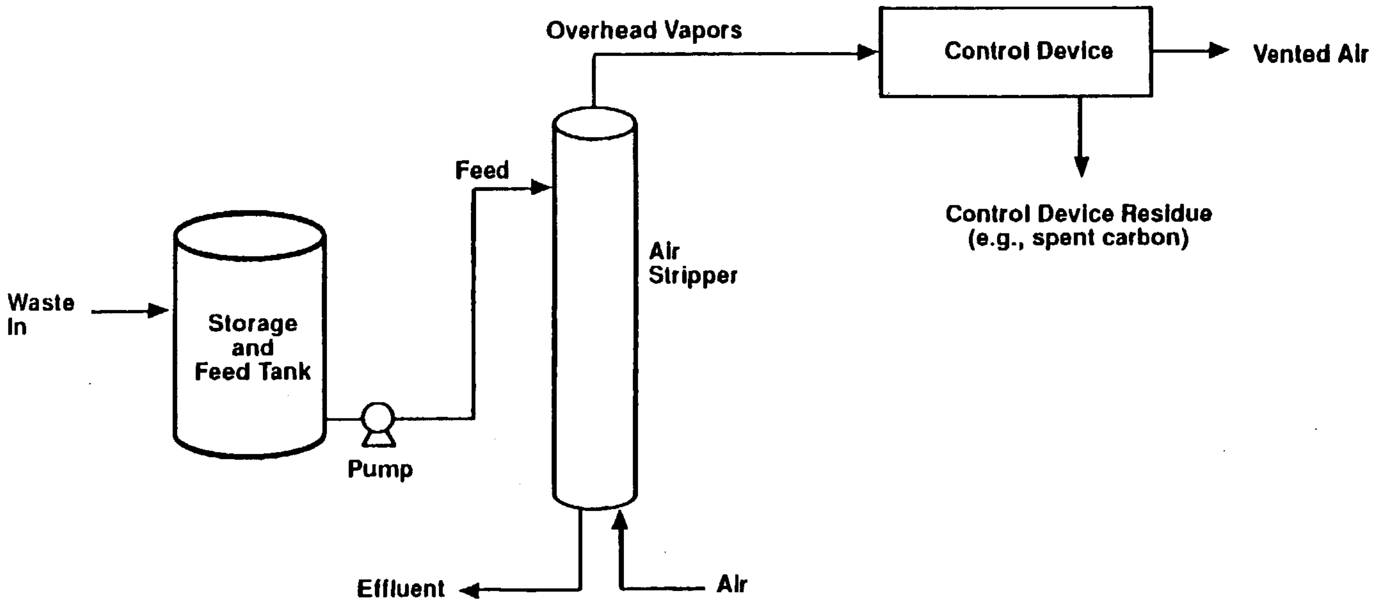


Figure 2-6. Schematic diagram of an air stripping system.

sludges and solids in a batch operation; however, this application has not been demonstrated extensively and is not a common practice. The major industrial application of air stripping has been in the removal of ammonia from wastewater.[42] In recent years, the use of air strippers has become a widely used technology in the removal of volatile compounds from contaminated ground water.[43,44]

Packed towers can achieve up to 99.9 percent removal of volatiles from water.[45] The major factors affecting removal efficiency include the equilibrium between the organics and the vapor phase (usually measured by Henry's law constant for dilute aqueous wastes) and the system's design, which determines mass transfer rates. Removal efficiency increases as the equilibrium coefficient increases; consequently, the extent of removal is strongly affected by the type of waste and the volatility of the individual organic constituents. Mass transfer rates (and removal efficiency) are also a function of the air-to-water ratio, height of packing, and type of packing.[46] The operating temperature is also an important variable that affects efficiency because of its direct effect on the vapor/liquid equilibrium. Higher temperatures result in higher vapor-phase concentrations of organic and higher removal rates. Air strippers have operational difficulties in freezing weather that may require heating the input waste stream, heating and insulating the column, or housing the operation inside an enclosure. Air strippers are typically designed to remove key or major constituents. Compounds more volatile than the design constituent are removed at or above the design efficiency, and less volatile compounds are removed at a lower efficiency.

2.3 AIR EMISSION SOURCES

2.3.1 Process Vent Emissions from Distillation/Steam Stripping Units

The discussions on distillation column and steam stripping operating theory and design show the basic factors of column operation. Vapors separated from the liquid phase in a column (by direct application of heat [i.e., steam stripping] or by indirect heating [e.g., batch distillation or thin-film evaporation]) rise out of the column to a condenser. The gases and vapors entering the condenser can contain organics, water vapor, and noncondensibles such as oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2). The vapors and gases originate from vaporization of liquid feeds, dissolved gases in liquid feeds, inert carrier gases added to assist in distillation (only for inert carrier distillation), and air leaking into the column, especially in vacuum distillation. Most of the gases and vapors entering the condenser are cooled enough to be collected as a liquid phase. The noncondensibles (O_2, N_2, CO_2, and other organics with low boiling points), if present, are not usually cooled to the condensation temperature and are present as a gas stream at the end of the condenser. Portions of this gas stream are often recovered in devices such as scrubbers, adsorbers, and secondary condensers. Vacuum-generating devices (pumps and ejectors), when used, might also affect the amount of noncondensibles. Some organics can be absorbed by condensed steam in condensers located after vacuum jets. In the case of oil-sealed vacuum pumps, the oil losses increase the organic content of the noncondensibles exiting the vacuum pump. The noncondensibles from the last process equipment (condensers, pumps, ejectors, scrubbers, adsorbers, etc.) constitute the emissions from the distillation unit unless they are controlled by combustion devices such as incinerators, flares, and boilers.

The most frequently encountered emission points from distillation and steam stripping operations are condensers, accumulators, hot wells, steam jet ejectors, vacuum pumps, and pressure relief valves. These emission points are illustrated for several types of units in Figures 2-7 through 2-10. Emissions of organics are created by the venting of noncondensible gases that concurrently carry out some hydrocarbons.

The total volume of gases emitted from a distillation or steam stripping operation varies from unit to unit and depends upon air leaks into the vacuum column (reduced pressure increases leaks and increased size increases leaks), the volume of inert carrier gas used, gases dissolved in the feed, efficiency and operating conditions of the condenser and other process recovery equipment, and physical properties of the organic constituents. Knowledge of the quantity of dissolved gases in the column in conjunction with information on organic vapor physical properties and condenser operating parameters allows estimation of the organic emissions that may result from a given distillation unit operation.

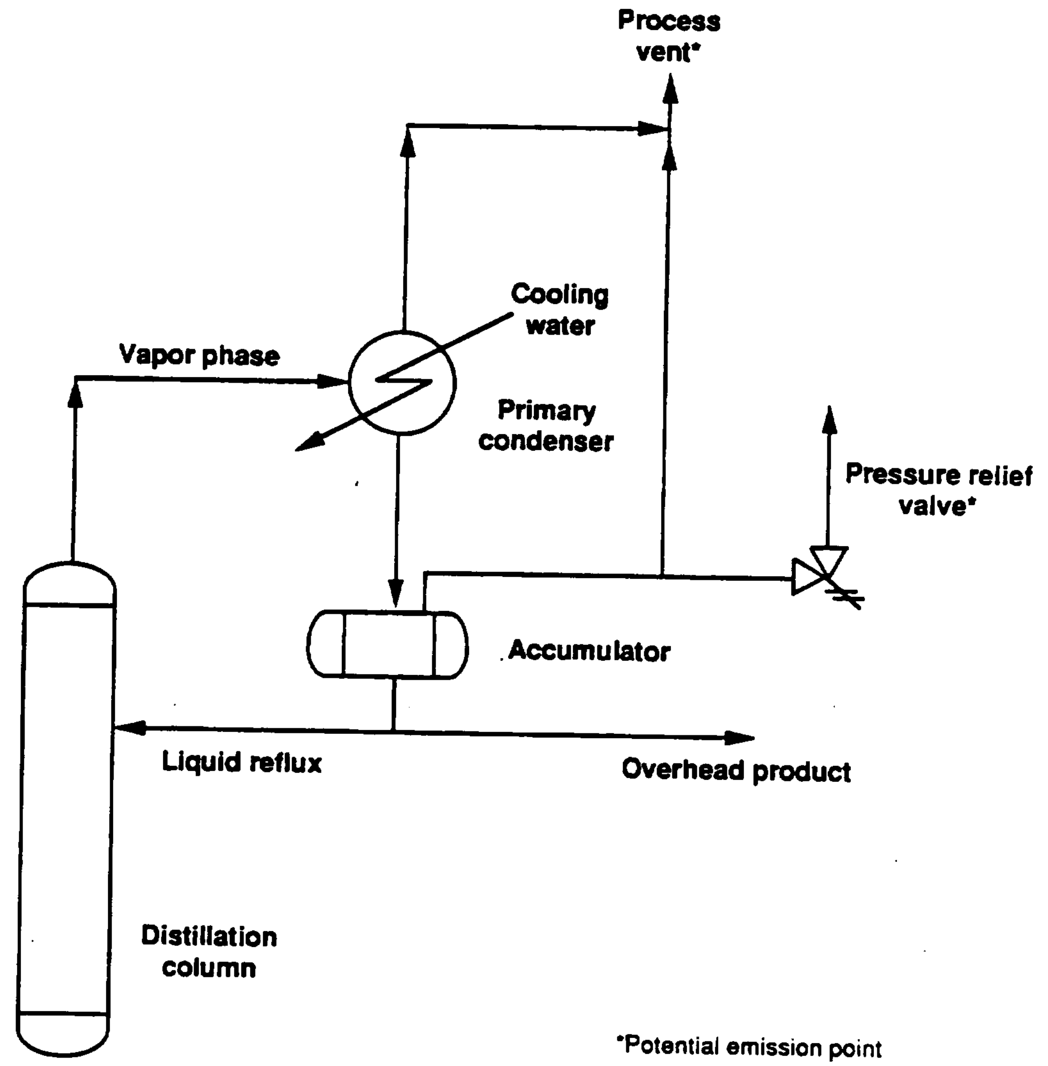
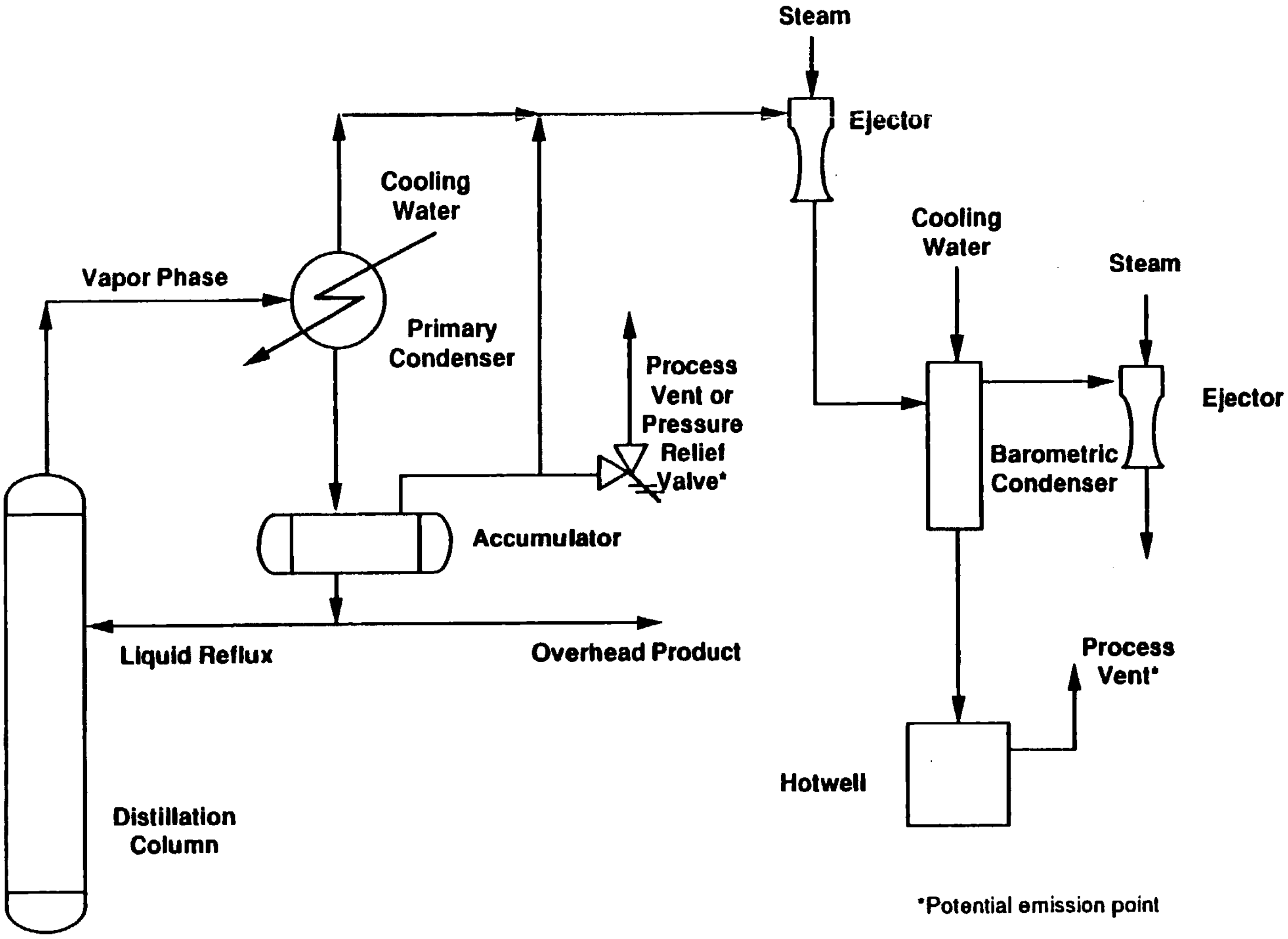
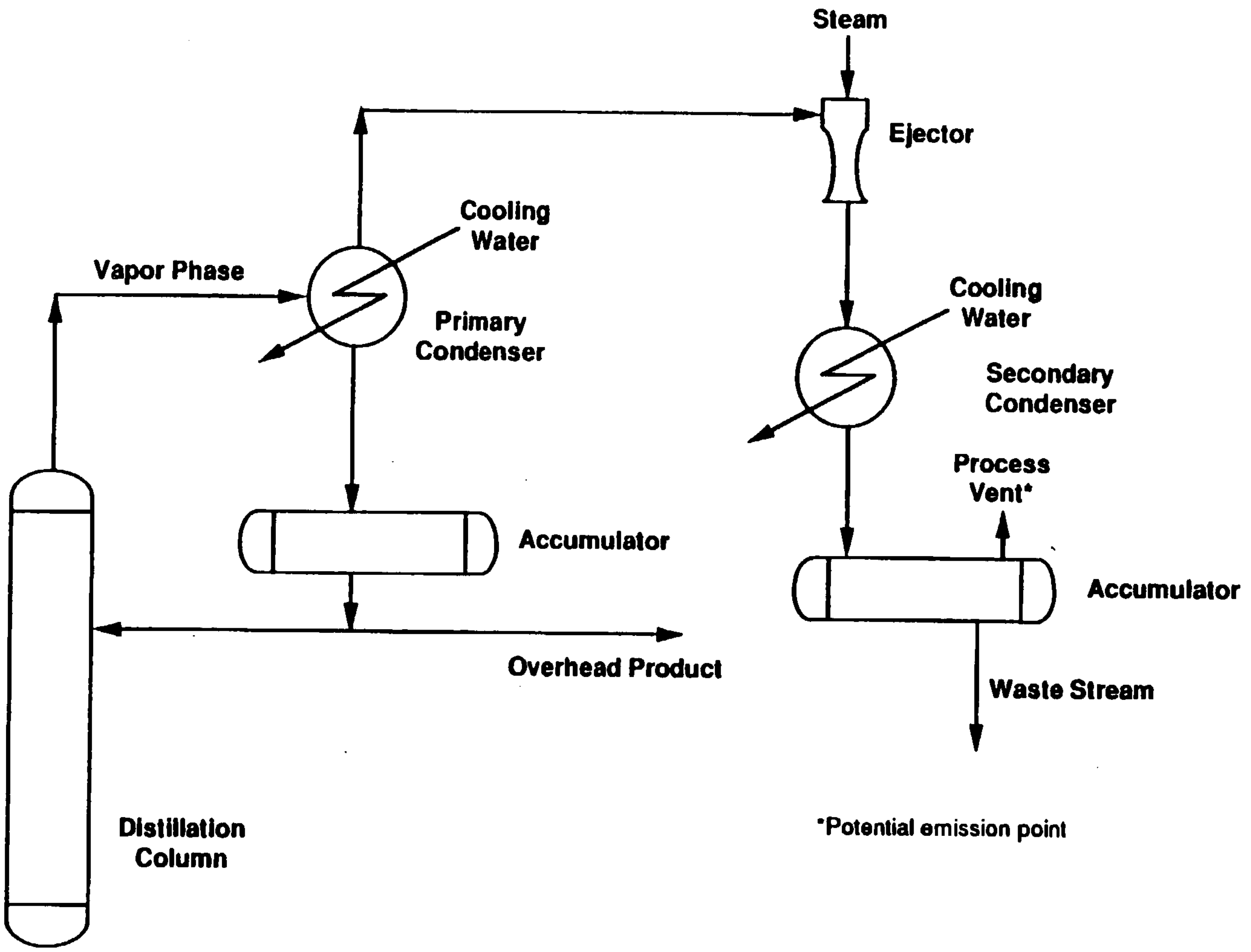


Figure 2-7. Potential emission points for a nonvacuum distillation column.



*Potential emission point

Figure 2-8. Potential emission points for a vacuum distillation column using steam jet ejectors with barometric condenser.



*Potential emission point

Figure 2-9. Potential emission points for a vacuum distillation column using a steam jet ejector and surface condensers.

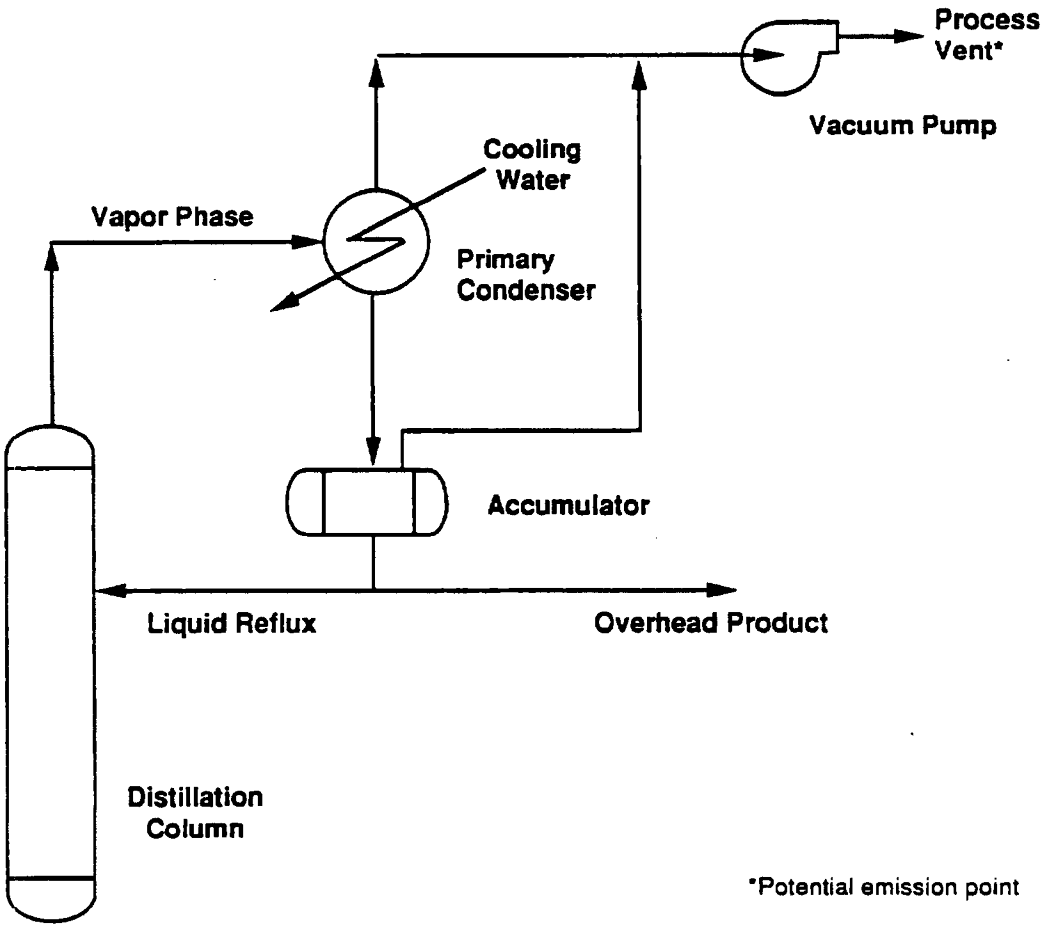


Figure 2-10. Potential emission points for a vacuum distillation column using a vacuum pump.

The operating parameters for distillation-type units tend to be unit-specific and vary to such a great extent from unit to unit that it is difficult to develop precise emission factors for distillation and steam stripping operations that can be applied industry-wide. However, extensive data bases have been gathered for both the organic chemical industry distillation units and the hazardous waste treatment, storage, disposal, and recycling industry management units, which includes distillation and stripping units. The chemical manufacturing industry data base[47] contains information on operating characteristics, emission controls, process vent flows, and emission characteristics. The data base was developed from extensive data for organic chemical plants available from surveys performed for EPA.[48,49] This data base provides some insight into the types of distillation operations in use in the organic chemical manufacturing industry. Table 2-3 gives the total number and types of distillation units in the survey.

The data base contains information on the type of distillation involved, the product recovery and emission control equipment, the vent stream characteristics, and the other distillation units in the plant. The vent stream characteristics listed for each column in the data base (determined downstream of product recovery devices, but upstream of combustion devices) include:

- Volumetric flow rate
- Heat content
- VOC emission rate
- VOC concentration.

Complete information on vent stream characteristics was not available for some of the reported distillation units. Also, there were units with zero flow rate (because no noncondensible gases were vented to the atmosphere) and units for which offgases were recycled to the manufacturing process. However, only those distillation columns for which complete vent stream characterization was available for all columns in a plant were retained in the screened data base. Table 2-4 gives an overview of the screened data base.

TABLE 2-3. OVERVIEW OF DISTILLATION UNITS IN THE CHEMICAL MANUFACTURING INDUSTRY

	Number of units	Percentage of total
1. Operating pressure		
a. Vacuum	318	31
b. Nonvacuum	582	56
c. Information not available[a]	137	13
	1,037	100
2. Mode of operation		
a. Batch	4	<1
b. Continuous	1,033	>99
	1,037	100
3. Type of unit		
a. Flash	37	3
b. Fractionating	1,000	97
	1,037	100
4. Units with no flow rate from the process vent	231	22
5. Units with process vent emissions recycled	219	21

[a] For 13 percent of the 1,037 total units, operating pressure information is not given because it is claimed to be confidential.

Source: U.S. Environmental Protection Agency. Distillation Operations in Synthetic Organic Chemical Manufacturing--Background Information for Proposed Standards. Appendix C. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-83-005a. December 1983.

TABLE 2-4. OVERVIEW OF DISTILLATION UNIT OPERATIONS

1. Screened Units

Total number of units in survey	1,037
Units at plants with incomplete data available	392
Units with recycled emissions, or zero flow rate	450
Number of units in the screened data base	195

2. Operating Characteristics of Units in the Screened Data Base

	Average	Range
Offgas flow rate, m^3/min (scfm)	1.0 (36)	0.001-18 (0.005-637)
VOC emission rate precontrolled,[a] kg/h (lb/h)	36 (78)	0-1670 (0-3668)
VOC emission rate controlled,[b] kg/h (lb/h)	5.9 (13)	________

VOC = Volatile organic compounds.

[a] Calculated downstream of product recovery devices (i.e., adsorbers, absorbers, and condensers), but upstream of combustion devices.

[b] Controlled VOC emission rates were estimated using a 98-percent destruction efficiency for flares, boilers, and incinerators (where it was indicated that control devices were being used).

Source: U.S. Environmental Protection Agency. Distillation Operations in Synthetic Organic Chemical Manufacturing--Background Information for Proposed Standards. Appendix C. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-83-005a. December 1983.

With regard to distillation and stripping units processing wastes, limited information is available on process vent operating characteristics. However, EPA is completing a multiyear project to collect information on the Nation's generation of hazardous wastes and the capacity available to treat, store, dispose, and recycle (TSDR) that waste (i.e., the 1987 National TSDR Survey). The TSDR data base[50] contains up-to-date nationwide information on the hazardous waste management technologies each facility has onsite, including the number of hazardous waste management units by process type (e.g., number of batch distillation, fractionation, thin-film evaporation, steam stripping, and air stripping units), annual waste throughput by process units, and type of air pollution control device serving the unit. The TSDR data base does not contain information on the process vent stream characteristics such as volumetric flow, temperature, and organic concentration. Because of the lack of adequate process vent stream data, estimation of organic air emissions by process unit type, e.g., fractionation as opposed to thin-film evaporation, is not possible.

The preliminary results of the TSDR Survey data base have been screened to identify the number of waste management units at TSDF that are likely to have associated process vents. Table 2-5 presents these preliminary results.

2.3.2 Process Vent Emissions from Air Stripper Units

As previously discussed in Section 2.2, air stripping is a technology that transfers organic contaminants from water (i.e., wastewater or, in some cases, ground water) to air. Unless the contaminated airstream is routed to an air emissions control device, the organic compounds volatilized from the water become air emissions. There are four major factors that affect air emissions from air strippers: (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 is discussed below.

The single most important factor affecting organic emissions from an air stripper is the pollutant loading. Air strippers generally achieve high removal efficiencies, e.g., greater than 90 percent. Therefore, the majority of pollutant quantities contained in the influent water to the air stripper are transferred to the air. The pollutant loading is a function

TABLE 2-5. DISTILLATION, SEPARATION, AND STRIPPING UNITS AT TSDF

Type of unit	Number of units	Percentage of total
Fractionation	125	18
Batch distillation	370	52
Solvent extraction	42	6
Thin-film evaporation	77	11
Air stripping	52	7
Steam stripping	40	6
Total	706	100

Note: The total number of units shown includes both RCRA-regulated units and RCRA-exempt units operating in 1986.

Source: 1987 National Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities (TSDR Survey). Alpha Database. July 1989.

of two parameters, the pollutant concentration in the water and the flow rate (of water) to the air stripper. The pollutants present and the loadings vary widely at actual air stripper locations. Pollutant loadings for more than 50 air strippers were calculated from data collected on influent water flow rates and pollutant concentrations for these strippers.[51] These calculated loadings are summarized in Table 2-6. As shown in this table, total organic loadings for air strippers range from 1.7 kg/yr to 29.3 Mg/yr.

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; and over 50 percent of the reported efficiencies are greater than 99 percent.[52] This makes the effect of removal efficiency on air emissions less significant. 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. Compounds removed at less than 90 percent efficiency were observed to 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.

As discussed above, the major factor affecting emissions from air strippers is the organic loading in the contaminated water being treated. For wastewaters, both the organic loading and the flow rate would typically remain fairly constant, especially for wastewater generated as part of a continuous industrial process. However, organic loading does not usually remain constant for ground water. The water flow rates to air strippers generally remain constant, but ground water pollutant concentration typically varies with time. Variance in influent concentration at fairly constant flow rate results in pollutant loading changes. Historical influent pollutant concentrations for air strippers treating ground water show that air emission rates generally decrease as a function of time. Generally, the initial air emission rate decreases rapidly and then levels off for a

TABLE 2-6. SUMMARY OF CALCULATED LOADINGS FOR AIR STRIPPERS

Pollutant	No. of occurences	Influent concentration, µg/L		Calculated loading, kg/yr	
		Average	Range	Average	Range
Aniline	1	226	NA	15.1	NA
Benzene	3	3,730	200-10,000	4,200	382-11,400
Bromoform	1	8	NA	137	NA
Chloroform	3	530	1,500	590	2.1-1,320
$CHBr_2Cl$	1	34	NA	584	NA
$CHBrCl_2$	1	36	NA	618	NA
Chlorobenzene	1	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
Other volatile organic compounds	3	44,000	57-130,000	838	109-1,740
Total volatile organics	51	11,120	12-205,000	2,740	1.7-29,300

NA = Not applicable. Data available for only one stripper.

Source: U.S. Environmental Protection Agency. Air Stripping of Contaminated Water Sources--Air Emissions and Controls. U.S. Environmental Protection Agency. Research Triangle Park, NC. Publication No. EPA-450/3-87-017. August 1987.

period of time. After this period of leveling off, the ground-water pollutant concentrations and resulting emissions are expected to drop gradually.

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 preventive maintenance is required with special attention given to bacterial buildup on the packing.

2.4 EMISSION ESTIMATES

2.4.1 Air Emissions from Distillation and Steam Stripping Units

As noted above, a condenser system is typically used to recover the organic (and water) vapors present in the overheads stream from distillation units (e.g., pot stills, fractionation units, thin-film evaporators, and batch distillation units) and steam stripping units. The condensed overheads stream is fed to a decanter where the organic and water phases are usually gravity-separated. Any noncondensible gases (e.g., highly volatile organic compounds) not recovered by the condenser system make up the process vent emissions from distillation and steam stripping units.

Review of recent emission test data gathered by EPA provided a number of organic emission rates for condenser (process) vent emissions at waste solvent treatment facilities (WSTF, a subset of TSDF).[53] These process vent emission rates are based on site-specific data for TSDF/WSTF utilizing some form of distillation technology; operations tested included batch distillation, steam stripping, and thin-film evaporation units. The vent data consist of results of emission tests of vents on primary or secondary condensers, condensers vented to distillate receiving tanks (i.e., accumulator tanks or overheads receivers), or vacuum distillation vents; results of the tests are presented in Appendix A.

Emission tests conducted by EPA show waste management unit process vent flow rates ranging from 0.0014 to 3.1 L/s (0.003 to 6.6 cfm) and mass organic emission rates ranging from 0.0015 to 34.8 Mg/yr (0.0017 to 38.4

ton/yr) at hazardous waste management units involving distillation/separation operations. (See Appendix A.) The organic emission rates for primary condensers, expressed in pounds/hour, varied from a few hundredths of a pound to nearly 10 lb/h; secondary condensers had emission rates of between 2 and 5 lb/h. Because process vent emissions vary to such a great extent from unit to unit, accurate emission factors for distillation and steam stripping operations that can be applied to specific units in the waste management industry are not presented. Emissions estimates for individual units must be made on a case-by-case basis.

In addition, insufficient data and information were available to allow characterization of other process vents such as those on accumulator tanks, separator tanks, surge control tanks, or hot wells in service at TSDF/WSTF process units. Emissions from these points in the process are not considered significant, unless the uncondensed overhead from the distillation operation is vented at this point in the process. For example, the primary condenser may be vented through an accumulator tank or a separator tank. A bottoms receiver should contain the waste only after the more volatile constituents have been removed; therefore, emissions from vents on these tanks should be low relative to the process vents on the unit.

Table 2-4 presents the organic emission rates for process vents on distillation operations at organic chemical manufacturing plants. These distillation units are production related and tend to be much larger than units treating wastes only. As a result, process vent flow rates and emissions from production units are generally higher than those from waste treatment units.

2.4.2 Air Emissions from Air Strippers

To characterize emissions from air strippers, data on pollutant loadings, design, operation, and performance were collected from operating air strippers nationwide.[54] Although the completeness of data available for individual air strippers varied, the data collected were sufficient to characterize air pollutant loadings. The data collected on organic pollutant loadings, design, operation, and performance for the air strippers are presented in Appendix B.

The quality of the data collected varied widely. Concentration data were 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 typically may vary with time. The water flow rates were either design capacities or actual measured rates. The removal efficiency data were from actual influent and effluent monitoring data in some cases and from estimated design efficiency in others.

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

The data collected from the facilities were used to estimate and characterize uncontrolled organic air emissions from each air stripper. Because 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 8,400 h/yr of air stripper operation, annual emissions were calculated for each stripper by pollutant. The total organic emissions were also calculated for each air stripper as the sum of the individual pollutants.

The estimates of uncontrolled air emissions are summarized in Table 2-7. The averages and ranges of estimated annual emissions and concentrations are presented by pollutant. As shown in Table 2-7, 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 parts per million by volume (ppmv). Effluent air concentrations of total volatile organics range from 0.03 ppmv to 110 ppmv. Air flow rates from the air strippers surveyed varied from a low of 170 cfm to a high of about 145,000 cfm; the average volumetric flow rate for these air strippers was about 17,000 cfm. The estimated air emissions are also presented in Appendix C together with the air flow rates and calculated pollutant concentrations. The emission estimates presented in Appendix C do not

TABLE 2-7. SUMMARY OF ESTIMATED AIR EMISSIONS FROM AIR STRIPPERS[55]

Pollutant	No. of data points	Concentration, ppmv		Annual emissions, kg/yr	
		Average	Range	Average	Range
Aniline	1	ND	ND	5.0	NA
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[a]	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[b]	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	1,900	NA
Trichloroethane	8[c]	0.41	0.01-2.03	250	2.3-800
Trichloroethylene	34[d]	4.7	0.01-55.7	1,440	1.6-10,600
1,2,3-Trichloropropane	1	NA	ND	1,920	NA
Toluene	2	1.3	0.12-2.6	250	110-380
Xylene	4[e]	8.2	0.06-22	1,790	62-5,710
Other volatile organic compounds	3[f]	0.2	NA	820	110-1,700
Total volatile organics[g]	46[h]	7.8	0.03-110	2,020	1.6-24,000

ND = No data. Insufficient data available.
NA = Not applicable. Data available for only one stripper.

[a] Sufficient data were available to calculate concentration for only 6 of the 7 data points.

[b] Sufficient data were available to calculate concentration for only 15 of the 17 data points.

[c] Sufficient data were available to calculate concentration for only 6 of the 8 data points.

[d] Sufficient data were available to calculate concentration for only 29 of the 34 data points.

[e] Sufficient data were available to calculate concentration for only 3 of the 4 data points.

[f] Sufficient data were available to calculate concentration for only 2 of the 3 data points.

[g] Values presented for total volatile organics represent the averages and ranges of values presented in Appendix B.

[h] Sufficient data were available to calculate concentration for only 37 of the 46 data points.

Source: U.S. Environmental Protection Agency, Air Stripping of Contaminated Water Sources--Air Emissions and Controls. Control Technology Center. Research Triangle Park, NC. Publication No. EPA-450/3-87-017. August 1987. 125 p.

account for air emission controls in place at some facilities. As is the case for distillation and steam stripping operations, emission factors are not presented for air strippers because of the variability in emissions from unit to unit. Emission estimates for individual units should be made on a case-by-case basis.

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48. Houdry Division, Air Products and Chemicals, Inc. Survey Reports on Atmospheric Emissions from the Petrochemical Industry. Prepared for U.S. Environmental Protection Agency. Research Triangle Park, NC. Data on file in Docket No. A-80-25. 1972.

49. Trip Reports. Hydroscience, Inc. EPA Contract No. 68-02-2577. Docket No. A-80-25, Subcategory II-B. 1977-1980.

50. Reference 7.

51. Reference 38, p. 3-19.

52. Reference 44, p. 3-20.

53. Memorandum, Zerbonia, R., RTI, to Colyer, R., EPA/SDB, and Lucas, R., EPA/CPB. October 19, 1987. Evaluation and development of emission factors for (TSDF process) vents. (RCRA Docket Item: F-90-AESF-S0021.)

54. Reference 44, p. 3-17.

55. Reference 54.

3.0 EMISSION CONTROL TECHNIQUES

This chapter discusses organic emission control techniques applicable to waste management unit process vent streams. These control techniques are grouped into two broad categories: vapor recovery (noncombustion) control devices and vapor combustion control devices.

Design and operating efficiencies of this emission control equipment are also discussed in this chapter. Basic design considerations for condensers, absorbers, adsorbers, flares, industrial boilers, process heaters, thermal oxidizers, and catalytic oxidizers are explained briefly. The conditions affecting the organic removal efficiency of each type of device are examined, and its applicability to process vents is evaluated. Performance monitoring practices for these control devices are also addressed.

3.1 VAPOR RECOVERY CONTROL DEVICES

This section describes three noncombustion control processes that involve recovery of the captured organics--adsorption, absorption, and condensation. The organic removal efficiency and applicability of each device to process vent streams is also discussed.

Vapor recovery control devices are generally applied to recover organics from a vent stream for use as a product or to recycle a compound to the feed stream. The chemical structure of the organic removed is usually unaltered. Although vapor recovery control devices are widely applied in industry, they are not universally applicable to all process vent streams. The conditions under which these systems are and are not applicable are identified in the following sections.

3.1.1 Adsorption

3.1.1.1 Control Description. Adsorption is a mass transfer operation involving interaction between gaseous and solid-phase components. The gas-phase (adsorbate) surface is captured on the solid-phase (adsorbent) surface by physical or chemical adsorption mechanisms. The most commonly encountered industrial adsorption systems use activated carbon as the adsorbent. Activated carbon is effective in capturing certain organic vapors by the physical adsorption mechanism. However, activated carbon has a finite adsorption capacity. When the carbon becomes saturated (i.e., all of the carbon surface is covered with organic material), there is no further organic removal; all vapors pass through the carbon bed. At this point (referred to as "breakthrough"), the organic compounds must be removed from the carbon before adsorption can resume. This process is called desorption or regeneration.

The two basic configurations for carbon adsorption systems are regenerative and nonregenerative systems. Regenerative systems can be categorized as fixed, moving, or fluidized. The most common adsorption system for controlling air pollutants is the fixed carbon bed. Fixed-bed carbon adsorbers are used for controlling continuous, organic gas streams with flow rates ranging from 30 to 3,000 m^3/min (1,000 to over 100,000 ft^3/min). The organic concentration can be as low as several parts per billion by volume (ppbv) or as high as 25 percent of the lower explosive limit of the vapor stream constituents. Fixed-bed carbon adsorbers may be operated in either intermittent or continuous modes. For intermittent operation, the adsorber removes organics only during a specific time period. Intermittent mode of operation allows a single carbon bed to be used because it can be regenerated during the off-line periods. For continuous operation, the unit is equipped with two or more carbon beds so that at least one bed is always available for adsorption while other beds are being regenerated. A schematic diagram of a typical fixed-bed, regenerative carbon adsorption system is given in Figure 3-1.[1] The process vent gases are filtered and cooled before entering the carbon bed. The inlet gases to an adsorption unit are filtered to prevent bed contamination. The gases are cooled to maintain the bed at optimum operating

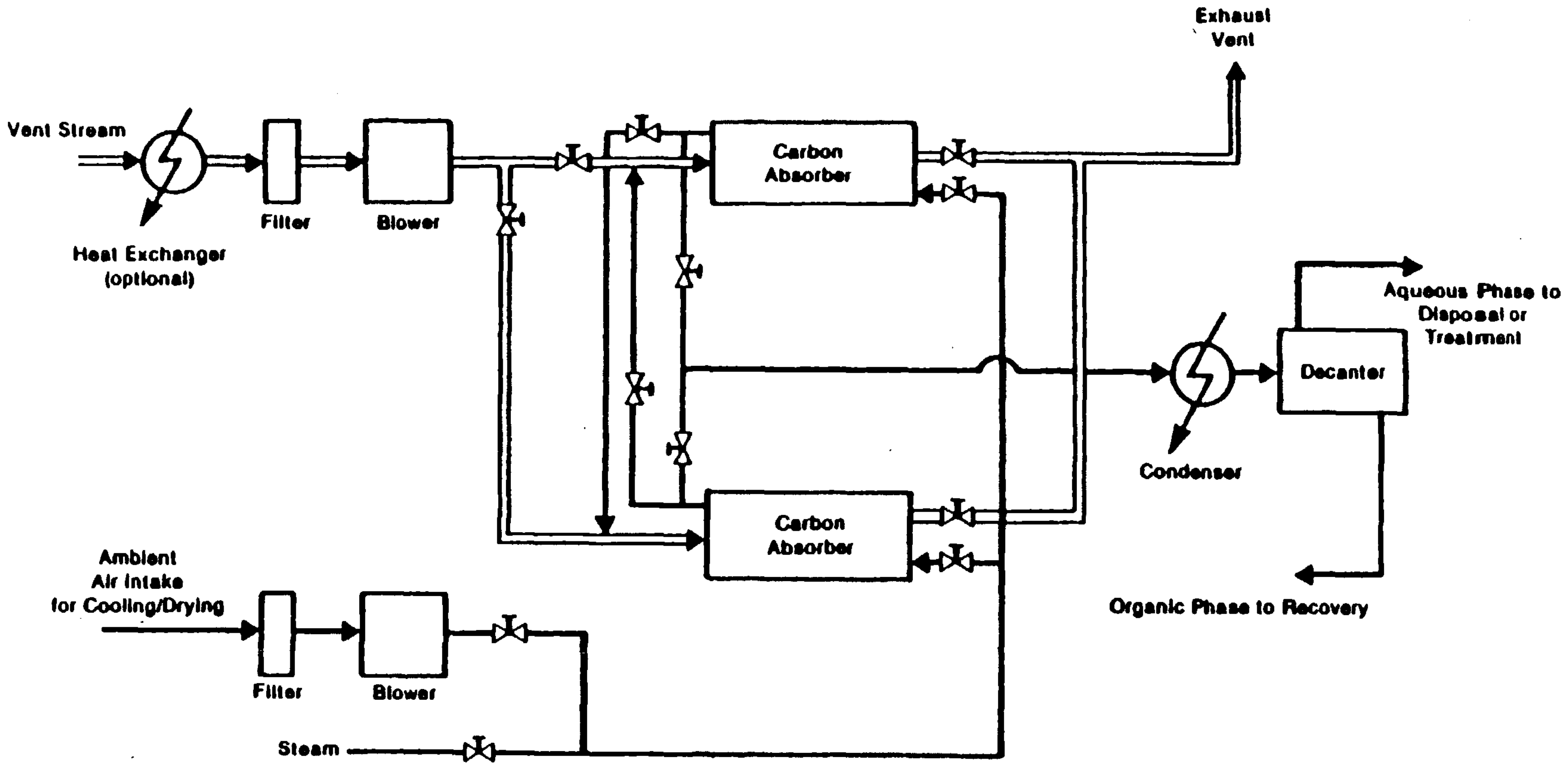

Figure 3.1. Two-stage regenerative adsorption system process flow diagram.

temperature and to prevent fires or polymerization of the hydrocarbons. Vapors entering the adsorber stage of the system are passed through the porous activated carbon bed.

Adsorption of inlet vapors occurs in the bed until the activated carbon is saturated with organics. The dynamics of the process may be illustrated by viewing the carbon bed as a series of three layers or mass transfer zones (MTZ). Gases entering the bed are highly adsorbed first in the upper zone. Because most of the organic is adsorbed in the upper zone, very little adsorption takes place in the middle and lower zones. Adsorption in the middle zone increases as the upper zone becomes saturated with organics and proceeds through the lower zone. When the bed is completely saturated (breakthrough), the incoming organic-laden vent gases are routed to an alternate bed while the saturated carbon bed is regenerated. Typically, the duration of the adsorption cycle varies considerably depending on the solvent being reclaimed and its regeneration characteristics.

Regeneration of the carbon bed is accomplished by heating the bed or applying vacuum to draw off the adsorbed gases. Low-pressure steam is frequently used as a heat source to strip the adsorbent of organic vapor. The steam-laden vapors from regeneration are then sent to a condenser, and the condensate typically is sent on to some type of solvent recovery system. The regenerated bed is put back into active service while the saturated bed is purged of organics. (Note: Organic emissions resulting from regeneration should also be controlled and accounted for in the efficiency determination of the overall system.) The regeneration process may be repeated many times, but eventually the carbon must be replaced.

The life span of activated carbon depends on the nature of the pollutants being controlled. For clean organics, a carbon life of 10 to 20 years can be expected; for a stream containing trace amounts of high-boiling-point materials, 5 to 10 years is reasonable; but the presence of polymerized organics may require carbon reactivation every 1 to 3 years.[2]

Nonregenerative systems (e.g., carbon canisters) are applicable for controlling organic emissions that are expected to vary in types of organics and concentrations and to occur at relatively low total mass rates. Nonregenerated systems are carbon canisters typically consisting of a 0.21-m^3 (55-gal) drum with inlet and outlet pipe fittings. Use of carbon canisters is limited to controlling low-volume gas streams with flow rates less than 3 m^3/min (100 ft^3/min). Carbon cannot be regenerated directly in the canister. Once the activated carbon in the canister becomes saturated by the organic vapors, the carbon canister must be removed and replaced with a fresh carbon canister. The spent carbon canister is then recycled or discarded depending on site-specific factors.

The design of a carbon adsorption system depends on the chemical characteristics of the organic compound being recovered (the adsorbate), the physical properties of the vent gas stream (temperature, pressure, humidity, and volumetric flow rate), and the physical properties of the adsorbent. The adsorbent concentration and type are key factors in the design of a carbon adsorption system. The adsorption characteristics of each compound are assessed based on their physical properties data, for example, polarity, refractive index, boiling point, molecular weight, and solubility in water. Nonpolar compounds and compounds with high refractive indices tend to be adsorbed more readily[3] than polar compounds such as water. High vapor pressure/low boiling point adsorbates and low molecular weight compounds adsorb less readily.[4] Compounds with molecular weights greater than 142 adsorb readily but are difficult to desorb.[5]

If the adsorbate is water-soluble, water left as condensate in the bed after steaming and cooling can contain adsorbate.[6] When the adsorber is brought on-line, the water and adsorbate will evaporate from the bed during the first part of the adsorption cycle, slightly increasing the initial outlet concentration for a brief time.

The temperature of the vent gas also influences the design of a carbon adsorption system. The capacity of an adsorbent decreases as system temperature increases. Carbon bed operating temperature can also affect carbon adsorber performance. Excessive bed temperatures can result from the release of heat from exothermic chemical reactions that may occur in the carbon bed. Typical heat generation is 465 to 700 kilojoules (kJ) per kg (200 to 300 British thermal units [Btu] per lb) of organic adsorbed. Ketones and aldehydes are especially reactive compounds that exothermically polymerize in the carbon bed. If temperatures rise too high, spontaneous combustion will result in carbon bed fires. To avoid this problem, carbon adsorbers applied to gas streams containing these types of compounds must be carefully designed and operated to allow sufficient airflow through the bed to remove excess heat.

High humidity will decrease capacity. Above an organic concentration of 1,000 ppm, high moisture does not significantly affect performance. Thus, obtaining good adsorber performance for gas streams with a high relative humidity (i.e., >50 percent) and low organic concentration (i.e., <1,000 ppm) requires preconditioning the gas stream upstream of the carbon bed. In addition to humidity, contaminants such as particulate, entrained liquid droplets, and organic compounds with high boiling points can also reduce adsorber efficiency.

Adsorption capacity increases with an increase in the partial pressure of the vapor, which is proportional to the total pressure of the system. Residence time in the bed is a function of gas velocity. Capture efficiency, the percentage of organics removed from the inlet gas stream by the adsorbent, is directly related to residence time. Gas velocity can be determined for a given volume of contaminant gas as a function of the diameter of the adsorber.

The physical properties of the adsorbent affect the adsorption capacity, rate, and pressure drop across the adsorber bed. The more important physical properties of the adsorbent that promote effective adsorption include a large surface-to-volume area and a preferential attraction for the compound being adsorbed.

Providing a sufficient bed depth is very important in achieving efficient organic removal. If the adsorber bed depth is shorter than the required MTZ, breakthrough will occur immediately, thus rendering the system ineffective. Actual bed depths are usually many times the MTZ to allow for adequate cycle times.

3.1.1.2 Performance Monitoring. The purpose of performance monitoring is to ensure that the carbon adsorption system is being operated properly and maintained within design specifications. To ensure that the carbon adsorption system is operated within design specifications, the owner or operator should:

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.

2. For carbon adsorption systems, such as fixed-bed carbon adsorbers, that regenerate the carbon bed directly in the control device, install a monitoring device to measure the concentration level of the organic compounds in the exhaust vent stream from the carbon bed or install a monitoring device to measure a parameter that demonstrates the carbon bed is regenerated at a predetermined time cycle.

3. For a carbon adsorption system, such as a fixed-bed carbon adsorber, that regenerates the carbon bed directly onsite in the control device, replace the existing carbon in the control device with fresh carbon at a regular, predetermined time interval that is no longer than the carbon service life.

4. For a carbon adsorption system, such as a carbon canister, that does not regenerate the carbon bed directly onsite in the control device, replace the existing carbon in the control device with fresh carbon regularly by using one of the following procedures:

    - Monitor the concentration level of the organic compounds in the exhaust vent stream from the carbon adsorption system on a regular schedule and replace the existing carbon with fresh carbon immediately when carbon breakthrough is indicated. The monitoring frequency should be at an interval no greater than 10 percent of the time required to consume the total carbon working capacity.

    - Replace the existing carbon with fresh carbon at a regular, predetermined time interval that is less than the design service life of the carbon.

The amount of organic recovered from the regenerated bed as a function of cycle time provides a secondary indicator of system efficiency and can be monitored.

Also, the carbon bed temperature (after regeneration and completion of any cooling cycles) and the amount of steam used to regenerate the bed have been identified as indicators of product recovery efficiency for regenerative systems. Temperature monitors and steam flowmeters, which indicate the quantity of steam used over a period of time, are available.[7]

3.1.1.3 Control Effectiveness. The organic removal efficiency of an adsorption unit depends upon the physical properties of the compounds present in the offgas, the gas stream characteristics, and the physical properties of the adsorbent.[8]

Gas temperature, pressure, and velocity are important in determining adsorption unit efficiency. The adsorption rate in the bed decreases sharply when gas temperatures are above 38 °C (100 °F).[9,10] High temperature increases the kinetic energy of the gas molecules, preventing the organics from being retained on the surface of the carbon. Increasing stream pressure generally will improve organic capture efficiency; however, care must be taken to prevent solvent condensation and possible fire. The gas velocity entering the carbon bed must be quite low to allow time for adsorption to take place. The required depth of the bed for a given compound is directly proportional to the carbon granule size and porosity and to the gas stream velocity (bed depth must increase as the gas velocity increases for a given carbon type).

Emission source test data for full-sized, fixed-bed carbon adsorbers operating in industrial applications have been compiled by EPA for a study of carbon adsorber performance. The analysis of these data supports the conclusion that for well-designed and -operated carbon adsorbers, continuous organic removal efficiencies of at least 95 percent are achievable over long periods. Several units have been shown to achieve organic removal efficiencies of 97 to 99 percent continuously.[11] An equivalent level of performance is indicated by results of emission source tests conducted on carbon canisters.

3.1.1.4 Applicability of Adsorption to Vent Streams. Although carbon adsorption is an excellent method for recovering some valuable process chemicals, it cannot be used as a universal control method for process vents. The conditions under which carbon adsorption is not recommended may exist in some process vents. These include streams with very high or low molecular weight compounds, and mixtures of high- and low-boiling-point organic compounds. The range of organic concentration to which carbon adsorption can be applied is from only a few parts per million to concentrations of several percent.[12] Adsorbing process vent streams with high organic concentration may result in excessive temperature rise in the carbon bed due to the accumulated heat of adsorption of the organic loading. However, high organic concentrations can be diluted to make a workable adsorption system. The molecular weight of the compounds to be adsorbed should be in the range of 45 to 130 g/g-mol for effective adsorption. Carbon adsorption may not be the most effective emission control technique for compounds with low molecular weights (below 45 g/g-mol) owing to their smaller attractive forces or for high molecular weight components (>130 g/g-mol) that attach so strongly to the carbon bed that they are not easily removed.[13] Properly operated adsorption systems can be very effective for homogeneous offgas streams but can have problems with a multicomponent system containing a mixture of light and heavy hydrocarbons.[14] The process vent gas streams addressed in this document are likely to be a mixture of organics, with one or two major constituents and one or more minor constituents. Two or more organics in the vent gas streams, as a general rule, will have the following effects:

- The adsorption of organic compounds having higher molecular weights will tend to displace those having lower molecular weights. Lighter compounds will tend to be separated or partitioned from the heavier compounds and will pass through the bed at a faster rate. This will increase the MTZ and may require additional carbon bed depth or shorter operating cycles.
- Carbon retentivity may be reduced.
- Efficiencies of any given system will tend to be lower on a multiple organic application.
- The lower explosive limit (LEL) of the mixture will vary directly with the LEL of the individual components. Safety considerations may dictate more or less dilution air to reduce flammability potential.[15]

3.1.2 Absorption

3.1.2.1 Control Description. Absorption is the selective transfer of one or more components of a gas mixture into a solvent liquid. The transfer consists of solute diffusion and dissolution into a solvent. For any given solvent, solute, and set of operating conditions, there exists an equilibrium ratio of solute concentration in the gas mixture to solute concentration in the solvent. The driving force for mass transfer at a given point in an operating absorption tower is related to the difference between the actual concentration ratio and the equilibrium ratio.[16] Absorption may entail only the dissolution of the gas component into the solvent or may also involve chemical reaction of the solute with constituents of the solution.[17] The absorbing liquids (solvents) used are chosen for high solute (organic) solubility and include liquids such as water, mineral oils, nonvolatile hydrocarbon oils, and aqueous solutions of oxidizing agents like sodium carbonate and sodium hydroxide.[18]

Devices based on absorption principles include spray towers, venturi scrubbers, packed columns, and plate columns. Spray towers require high atomization pressure to obtain droplets ranging in size from 500 to 1,000 μm to present a sufficiently large surface contact area.[19] Although they can remove particulate matter effectively, spray towers have the least effective mass transfer capability and, thus, are restricted to particulate removal and control of high-solubility gases such as sulfur dioxide and ammonia.[20] Venturi scrubbers have a high degree of gas-liquid mixing and high particulate removal efficiency but also require high pressure and have relatively short contact times. Therefore, their use is also restricted to high-solubility gases.[21] As a result, organic control by gas absorption is generally accomplished in packed or plate columns. Packed columns are used primarily for handling corrosive materials and liquids with foaming or plugging tendencies or where excessive pressure drops would result from use of plate columns. They are less expensive than plate columns for small-scale or pilot plant operations where the column diameter is less than 0.6 m (2 ft). Plate columns are preferred for large-scale operations, where internal cooling is desired or where low liquid flow rates would inadequately wet the packing.[22]

A schematic of a packed tower is shown in Figure 3-2. The gas to be absorbed is introduced at the bottom of the tower and allowed to rise through the packing material. Solvent flows from the top of the column, countercurrent to the vapors, absorbing the solute from the gas phase and carrying the dissolved solute out of the tower. Cleaned gas exits at the top for release to the atmosphere or for further treatment as necessary. The saturated liquid is directed to a regeneration unit. Here, the absorbent is treated in such a way that the absorbent may be recycled and the pollutant disposed of appropriately. Regeneration may be achieved by various processes such as vaporization, rectification, steam stripping, desorption, or extraction.

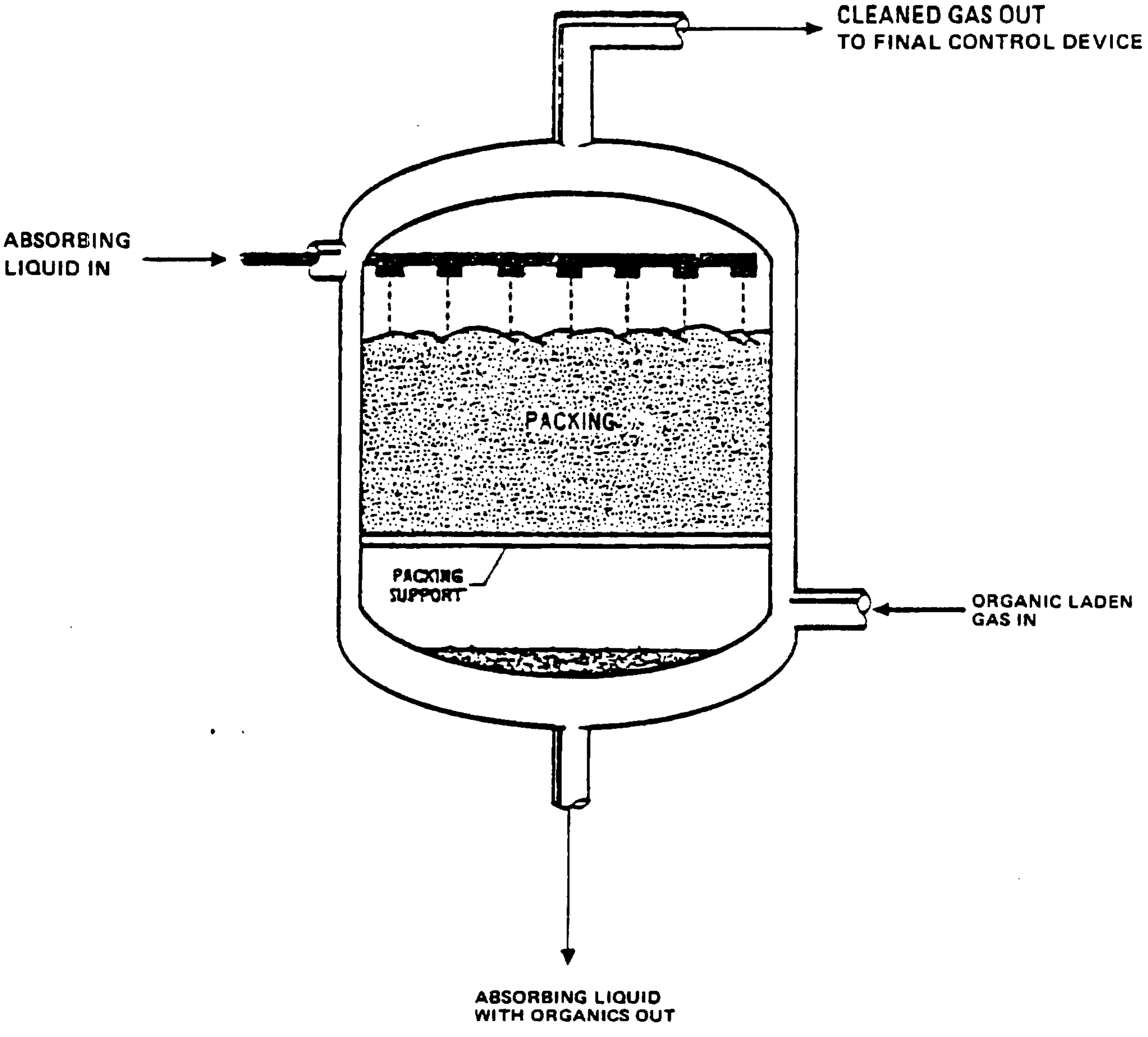

Figure 3-2. Packed tower for gas absorption.

The major tower design parameters to be determined for absorbing any substance are column diameter and height, system pressure drop, and liquid flow rate required. These parameters are derived from considering the total surface area provided by the tower packing material, the solubility and concentrations of the components, and the quantity of gases to be treated.

3.1.2.2 Performance Monitoring. The purpose of performance monitoring is to ensure that the absorption system is being operated properly and maintained within design specifications. A viable monitoring program is mandatory in "tracking" the performance of the air pollution control equipment. To ensure that the absorber is operated within design specifications, the owner or operator should:

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.
2. Install a monitoring device to measure the concentration level of the organic compounds in the exhaust vent stream from the absorber.

A secondary parameter that can be monitored to give an indication of the operating or removal efficiency is the quantity of organic removed over time.

3.1.2.3 Control Effectiveness. The organic removal efficiency of an absorption device depends on the solvent selected and on proper design and operation. For a given solvent and solute, an increase in absorber size or a decrease in the operating temperature can affect the organic removal efficiency of the system. It may be possible in some cases to increase organic removal efficiency by a change in the absorbent. Typical gas absorption efficiencies range from 60 to 96 percent.[23] In an EPA survey of methylene chloride emission sources, two process vent gas absorbers were controlled by wastewater scrubbers at an estimated 87-percent methylene chloride control efficiency.[24]

Systems that use organic liquids as solvents usually include the stripping and recycling of the solvent to the absorber. In this case, the organic removal efficiency of the absorber depends on the solvent stripping efficiency.

3.1.2.4 Applicability of Absorption to Vent Streams. Gas absorption as an emission control method is currently most widely used for the removal of water-soluble inorganic contaminants (e.g., sulfur dioxide, hydrogen sulfide, hydrogen chloride, and ammonia) from airstreams, with water being the most common solvent or scrubbing fluid used. Water may also be used for the absorption of organic compounds that have relatively high water solubilities (e.g., most alcohols, organic acids, aldehydes, ketones, amines, and glycols). For organic compounds that have low water solubilities, other solvents (usually organic liquids with low vapor pressures) are used. Although absorption will be attractive for some process vents, it cannot be used to control all process vents. Because its use depends on the economics of recovery, absorption can be better classified as a product recovery device rather than an organic control device. Absorption is attractive if a suitable solvent is available, a significant amount of organics can be recovered, and the recovered organics can be reused. It is usually not considered when the organic concentration is below 200 to 300 ppmv.[25] Generally, vent gas streams will consist of low-concentration organics. The control of low-concentration organics by absorption, however, usually requires long contact times and large quantities of absorbent for adequate emissions control. Adsorption may be best suited for use in conjunction with other control methods such as incineration or adsorption to achieve a desired degree of emissions control.

3.1.3 Condensation

3.1.3.1 Control Description. Condensation is a process of converting all or part of the condensible components of a vapor phase into a liquid phase. This is achieved by the transfer of heat from the vapor phase to a cooling medium. If only a part of the vapor phase is condensed, the newly formed liquid phase and the remaining vapor phase will be in equilibrium. In this case, equilibrium relationships at the operating temperatures must be considered. The heat removed from the vapor phase should be sufficient to lower the vapor-phase temperature to (or below) its dewpoint temperature (temperature at which first drop of liquid is formed).

Condensation devices are of two types: surface condensers and contact condensers.[26] Surface condensers generally are shell-and-tube types of heat exchangers. The coolant and the vapor phases are separated by the tube wall, and they never come in direct contact with each other (see Figure 3-3). Vapors are cooled in contact condensers by spraying a relatively cold liquid directly into the gas stream. The coolant is often water, although in some situations another coolant may be used. Most contact condensers are simple spray chambers, like the one pictured in Figure 3-4.

Contact condensers are, in general, less expensive, more flexible, and more efficient in removing organic vapors than surface condensers. On the other hand, surface condensers may recover marketable condensate and minimize waste disposal problems. Often, condensate from contact condensers cannot be reused and may require significant wastewater treatment prior to disposal. Surface condensers must be equipped with more auxiliary equipment and have greater maintenance requirements. Surface condensers are considered in the discussion of control efficiency and applicability because they are used more frequently in the hazardous waste management industry.

The major equipment components used in a typical surface condenser system for organic removal are shown in Figure 3-5. This system includes shell-and-tube dehumidification equipment, shell-and-tube heat exchanger, refrigeration unit, and recovered organic storage tanks and operating pumps. Most surface condensers use a shell-and-tube type of heat exchanger to remove heat from the vapor.[27] As the coolant passes through the tubes, the organic vapors condense outside the tubes and are recovered. The coolant used depends on the saturation temperature of the organic vapor stream. Chilled water can be used down to 7 °C (45 °F), brines to -34 °C (-30 °F), and chlorofluorocarbons below -34 °C (-30 °F).[28] Temperatures as low as -62 °C (-80 °F) may be necessary to condense some organic vapors.[29]

Designing surface condensers involves calculating the rate of heat transfer through the wall of the exchanger per unit time, its "duty," or calculating the heat-transfer area. If the heat-transfer area, the overall heat-transfer coefficient, and the mean temperature difference are known, the condenser duty can easily be calculated. Calculation of heat-transfer coefficients, a tedious step in definitive design, is avoided in predesign evaluations where approximate values are adequate. An extensive tabulation

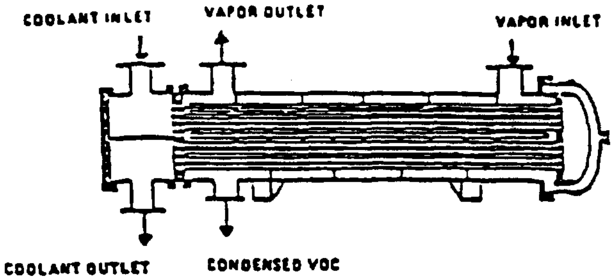

Figure 3-3. Schematic diagram of a shell-and-tube surface condenser.

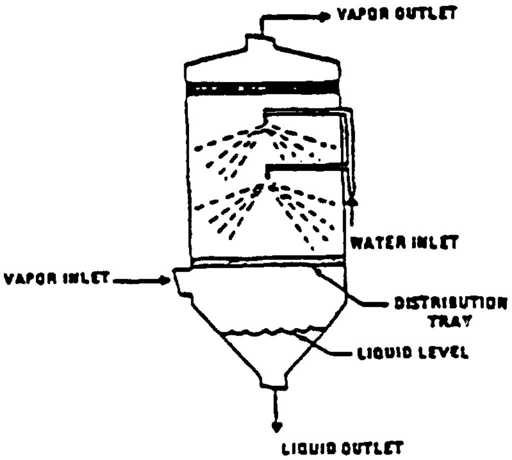

Figure 3-4. Schematic diagram of a contact condenser.

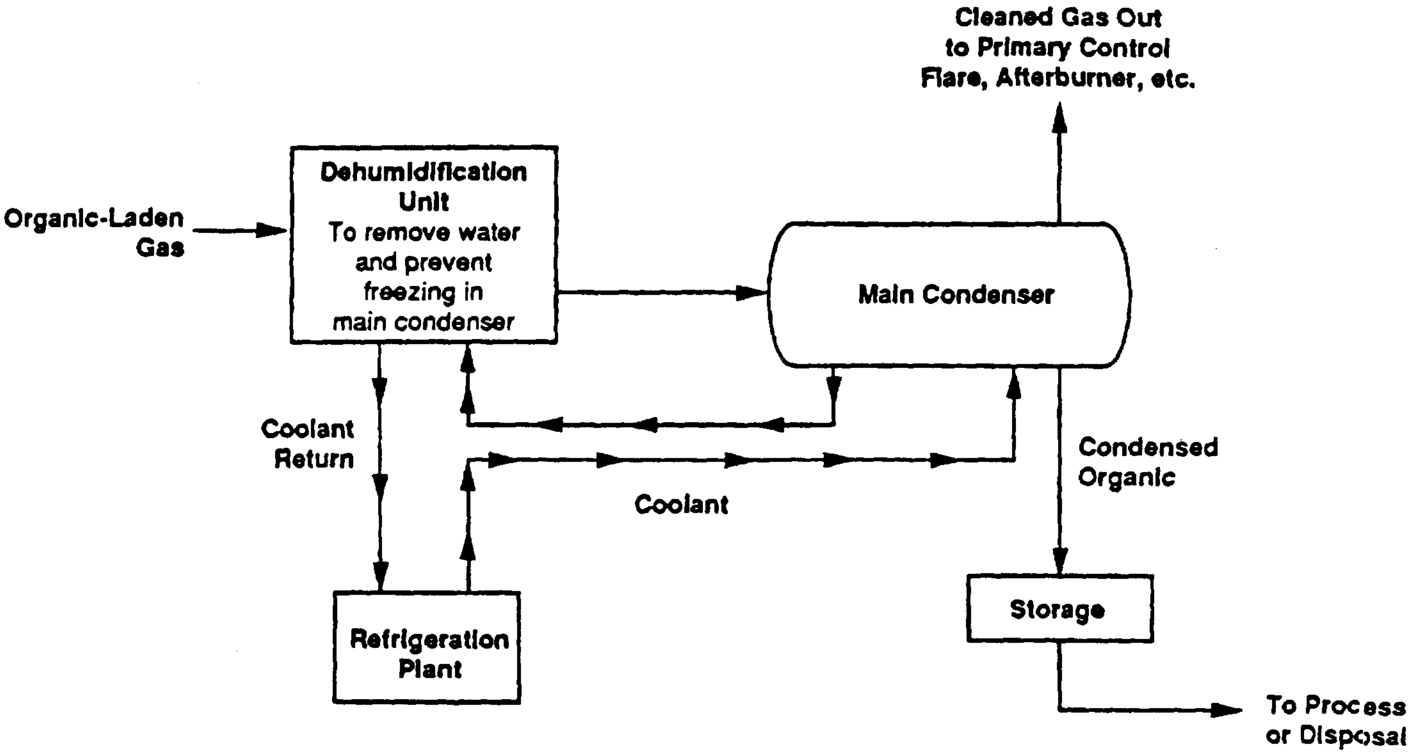

Figure 3-5. Condensation system.

of typical overall coefficients, based on industrial practice, is found in Reference 30 (pp. 10-39 to 10-42) along with the information needed to determine the appropriate mean temperature difference, T_m. In practice, the vapor stream will contain multicomponents, air, and at least one other gas, thus complicating the design procedures.[31]

3.1.3.2 Performance Monitoring. To ensure that the condenser is operated within design specifications, the owner or operator should:

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.

2. Install a monitoring device to measure the concentration level of the organic compounds in the exhaust vent stream from the condenser.

3. Install a temperature monitoring device. The device should be capable of monitoring temperature at two locations and have an accuracy of ±1 percent of the temperature being monitored in degrees Celsius or ±0.5 °C, whichever is greater. One temperature sensor should be installed at a location in the exhaust vent stream from the condenser, and a second temperature sensor should be installed at a location in the coolant fluid exiting the condenser.

A secondary parameter that can be monitored to give an indication of the operating or removal efficiency is the quantity of organic removed over time.

3.1.3.3 Control Effectiveness. The organic removal efficiency for a condenser depends upon the gas stream organic composition and concentrations as well as the condenser operating temperature. Condensation can be an effective control technique for gas streams having high concentrations of organic compounds with high boiling points. However, condensation is not effective for gas streams containing low organic concentrations or composed primarily of organics with low boiling points. At these conditions, organics cannot readily be condensed at normal condenser operating temperatures. This point is demonstrated in the results of an EPA field evaluation of a condenser used to recover organics from a steam stripping process treating wastewater at a plant manufacturing ethylene dichloride and vinyl chloride monomer. Condenser removal efficiencies for specific organic constituents in the controlled vent stream ranged from a high value of 99.5 percent for 1,2-dichloroethane to a low value of 6 percent for vinyl chloride. Efficiencies of condensers usually vary from 50 to 95 percent.[32]

3.1.3.4 Applicability of Condensers to Vent Streams. A primary condenser system is usually an integral part of distillation operations. These condensers are needed to provide reflux in fractionating columns and to recover distilled products. At times, additional (secondary) condensers are used to recover more organics from the vent stream exiting the primary condenser. Condensers are sometimes present as accessories to vacuum-generating devices (e.g., barometric condensers).

The use of a condenser to control organic emissions may not be applicable to some process vent streams. Secondary condensers used as supplemental product recovery devices are not well suited for vent streams containing organics with low boiling points or for vent streams containing large quantities of inerts such as carbon dioxide, air, and nitrogen. Low boilers and inerts cannot be condensed at normal operating temperatures, and they usually carry over some organics. For example, condensation is not generally considered effective for process vents on air stripping units and other streams that contain less than 10,000 ppm organics.[33]

3.2 COMBUSTION CONTROL DEVICES

Combustion control devices, unlike vapor recovery control devices, alter the chemical structure of the organic compounds. Combustion is complete if all organics are converted to carbon dioxide and water. Incomplete combustion results in some of the organic compounds being totally unaltered or being converted to other organic compounds such as aldehydes or acids.

The combustion control devices discussed in the following sections are flares, thermal incinerators, catalytic incinerators, and boilers and process heaters. Each device is discussed separately with respect to its operation, destruction efficiency, and applicability to process vent streams. Many combustion devices are widely applied where organic control of process vent streams is mandated by current regulations.

3.2.1 Flares

3.2.1.1 Control Description.

Flaring is an open combustion process in which the oxygen required for combustion is provided by the ambient air around the flame. Good combustion in a flare is governed by flame temperature, residence time of components in the combustion zone, turbulent mixing of the components to complete the oxidation reaction, and oxygen for free radical formation.

There are two types of flares: ground-level flares and elevated flares. Reference 34 presents a detailed discussion of different types of flares, flare design and operating considerations, and a method for estimating capital and operating costs for flares. The basic elements of an elevated flare system are shown in Figure 3-6. Process offgases are sent to the flare through the collection header. The offgases entering the header can vary widely in volumetric flow rate, moisture content, organic concentration, and heat value. The knock-out drum removes water or hydrocarbon droplets that could create problems in the flare combustion zone. Offgases are usually passed through a water seal before going to the flare. This prevents possible flame flashbacks, caused when the offgas flow to the flare is too low and the flame front pulls down into the stack.

Purge gas (nitrogen, carbon dioxide, or natural gas) also helps to prevent flashback in the flare stack caused by low offgas flow. The total volumetric flow to the flame must be controlled carefully to prevent low-flow flashback problems and to avoid a detached flame (a space between the stack and flame with incomplete combustion) caused by an excessively high flow rate. A gas barrier or a stack seal is sometimes used just below the flare head to impede the flow of air into the flare gas network.

The organic vapor stream enters at the base of the flame where it is heated by already burning fuel and pilot burners at the flare tip (see Figure 3-7A). Fuel flows into the combustion zone where the exterior of the microscopic gas pockets is oxidized. The rate of reaction is limited by the mixing of the fuel and oxygen from the air. If the gas pocket has sufficient oxygen and residence time in the flame zone, it can be burned completely. A diffusion flame receives its combustion oxygen by diffusion of air into the flame from the surrounding atmosphere. The high volume of fuel flow in a flare requires more combustion air at a faster rate than

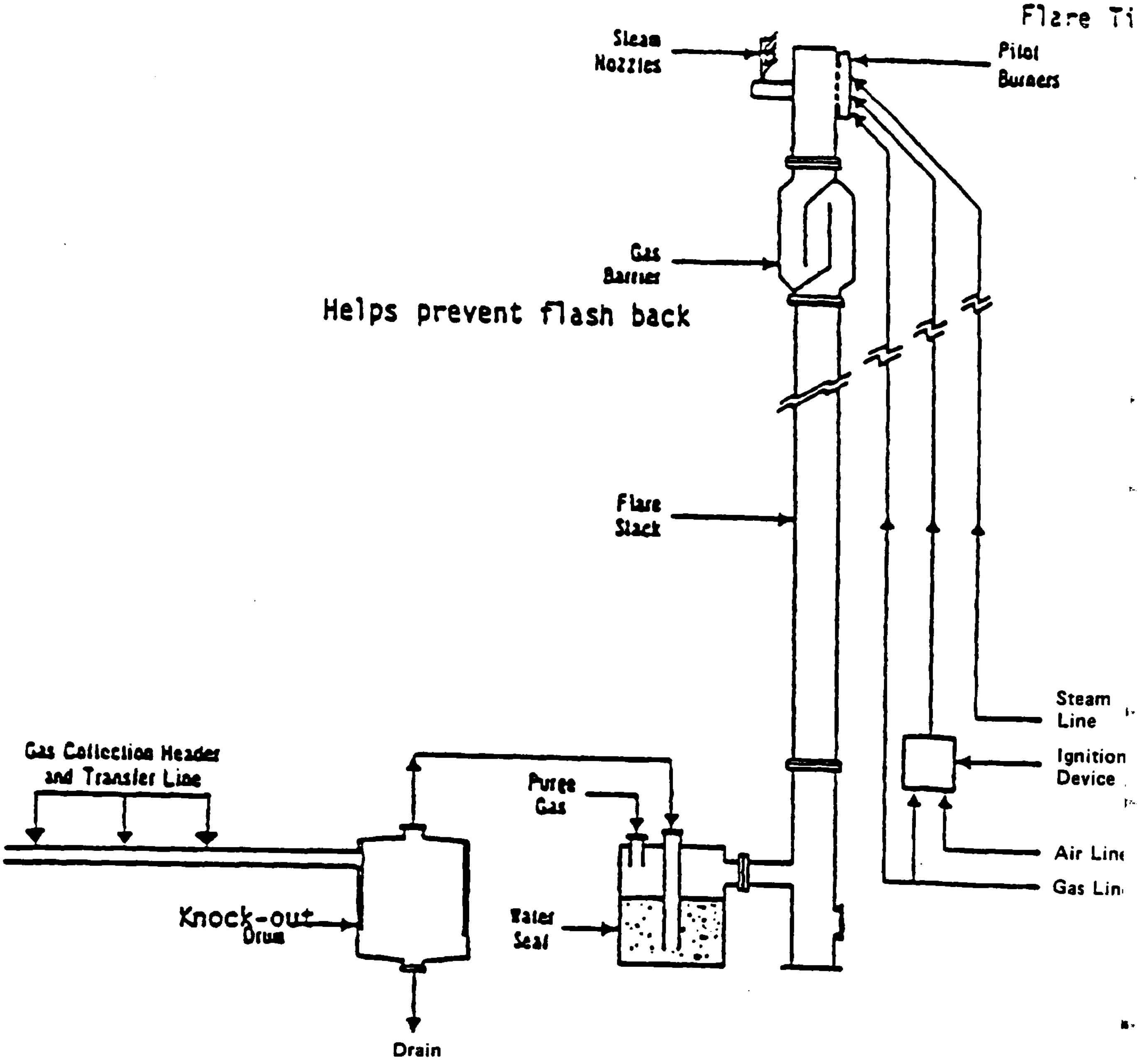

Figure 3-6. Steam-assisted elevated flare system.

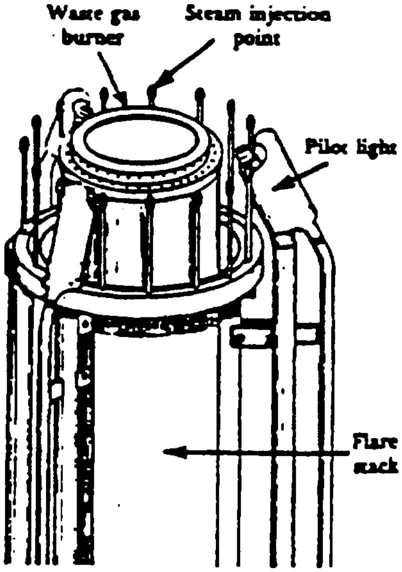

Figure 3-7A. Flare tip.

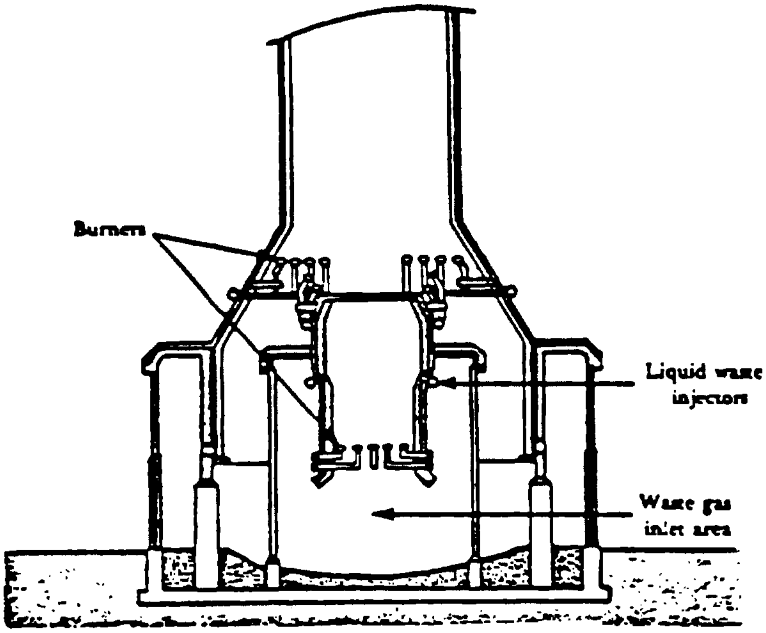

Figure 3-7B. Ground flare.

simple gas diffusion can supply, so flare designers add steam injection nozzles to increase gas turbulence in the flame boundary zones, thus drawing in more combustion air and improving combustion efficiency. This steam injection promotes smokeless flare operation by minimizing the cracking reactions that form carbon. Significant disadvantages of steam usage are the increased noise and cost. The steam requirement depends on the composition of the gas flared, the steam velocity from the injection nozzle, and the tip diameter. Although some gases can be flared smokelessly without any steam, typically 0.15 to 0.5 kg of steam per kilogram of flare gas is required.

Steam injection is usually controlled manually with the operator observing the flare (either directly or on a television monitor) and adding steam as required to maintain smokeless operation. Several flare manufacturers offer devices that sense a flare's flame characteristics and adjust the steam flow rate automatically to maintain smokeless operation.

Some elevated flares use forced air instead of steam to provide the combustion air and the mixing required for smokeless operation. These flares consist of two coaxial flow channels. The combustible gases flow in the center channel, and the combustion air (provided by a fan in the bottom of the flare stack) flows in the annulus. The principal advantage of air-assisted flares is that expensive steam is not required. Air assistance is rarely used on large flares because airflow is difficult to control when the gas flow is intermittent. About 597 W (0.8 hp) of blower capacity is required for each 45 kg/h (100 lb/h) of gas flared.[35]

Ground flares are usually enclosed and have multiple burner heads that are staged to operate based on the quantity of gas released to the flare (see Figure 3-7B). The energy of the gas itself (because of the high nozzle pressure drop) is usually adequate to provide the mixing necessary for smokeless operation, and air or steam assist is not required. A fence or other enclosure reduces noise and light from the flare and provides some wind protection.

Ground flares are less numerous and have less capacity than elevated flares. Typically, they are used to burn gas "continuously," while steam-assisted elevated flares are used to dispose of large amounts of gas released in emergencies.

3.2.1.2 Performance Monitoring. To ensure that flares meet a reasonable emission control efficiency, EPA prescribed design and operating guidelines in 40 CFR 60.18 and 40 CFR 264.1033 that should be followed. They are:

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.

2. Design a flare to operate with no visible emissions.

3. Use EPA Reference Method 22 in 40 CFR Part 60 to determine if a flare is being operated with no visible emissions. The observation period is 2 hours and can be used according to Method 22.

4. Operate a flare with a flame present at all times.

5. Calculate the net heating value of the gas being combusted in a flare using the following equation:

$$H_T = K \left(\sum_{i=1}^{n} C_i H_i \right) , \qquad (3\text{-}1)$$

where

H_T = Net heating value of the sample, MJ/scm; where the net enthalpy per mole of offgas is based on combustion at 25 °C and 760 mm Hg, but the standard temperature for determining the volume corresponding to 1 mol is 20 °C

K = Constant, 1.74×10^{-7} (1/ppm) (g-mol/scm) (MJ/kcal) where standard temperature for (g-mol/scm) is 20 °C

C_i = Concentration of sample component i in ppm on a wet basis, as measured for organics by Reference Method 18 in 40 CFR Part 60 and measured for hydrogen and carbon monoxide by ASTM D1946-82

H_i = Net heat of combustion of sample component i, kcal/g-mol at 25 °C and 760 mm Hg. The heats of combustion may be determined using ASTM D 2382-83 if published values are not available or cannot be calculated.

6. Use a flare only if the net heating value of the gas being combusted is 11.2 MJ/scm (300 Btu/scf) or greater, if the flare is steam-assisted or air-assisted, or if the net heating value of the gas being combusted is 7.45 MJ/scm (200 Btu/scf) or greater if the flare is nonassisted.

7. Operate steam-assisted and nonassisted flares with an exit velocity less than 18.3 m/s (60 ft/s).

8. Operate a steam-assisted or nonassisted flare with an exit velocity equal to or greater than 18.3 m/s (60 ft/s) but less than 122 m/s (400 ft/s) if the net heating value of the gas being combusted is greater than 37.3 MJ/scm (1,000 Btu/scf).

9. Operate a steam-assisted or nonassisted flare with an exit velocity less than the velocity, V_{max}, and less than 122 m/s (400 ft/s). For a steam-assisted or nonassisted flare, V_{max} is determined using the following equation:

$$\text{Log}_{10}\ (V_{max}) = (H_T + 28.8)/31.7 \quad , \qquad (3\text{-}2)$$

where

V_{max} = Maximum allowed velocity, m/s

H_T = Net heating value

28.8 = Constant

31.7 = Constant.

10. Operate an air-assisted flare with an exit velocity less than the velocity, V_{max}, which is determined using the following equation:

$$V_{max} = 8.706 + 0.7084\ (H_T) \quad , \qquad (3\text{-}3)$$

where

V_{max} = Maximum allowed velocity, m/s

8.706 = Constant

0.7084 = Constant

H_T = Net heating value.

11. Determine the actual exit velocity of a flare by dividing the volumetric flow rate (in units of standard temperature and pressure), as determined by Reference Methods 2, 2A, 2C, or 2D in 40 CFR Part 60 as appropriate, by the unobstructed (free) cross-sectional area of the flare tip.

12. Use a steam-assisted, air-assisted, or nonassisted flare.

3.2.1.3 Control Effectiveness. The flammability limits of the gases flared influence ignition stability and flame extinction (gases must be within their flammability limits to burn). When flammability limits are narrow, the interior of the flame may have insufficient air for the mixture to burn. Outside the flame, so much air may be induced that the flame is extinguished. Fuels with wide limits of flammability are therefore usually easier to burn (e.g., hydrogen and acetylene). However, despite wide flammability limits, some chemicals such as carbon monoxide are difficult to burn because of low heating value and slow combustion kinetics.

The autoignition temperature of a fuel affects combustion because gas mixtures must be at high enough temperature and at the proper mixture strength to burn. A gas with low autoignition temperature will ignite and burn more easily than a gas with a high autoignition temperature. Hydrogen and acetylene have low autoignition temperatures and carbon monoxide has a high one.

The heating value of the fuel also affects the flame stability, emissions, and flame structure. A lower heating value fuel produces a cooler flame that does not favor combustion kinetics and is more easily extinguished. The lower flame temperature will also reduce buoyant forces, which reduces mixing (especially for large flares on the verge of smoking). For these reasons, organic emissions from flares burning gases with low-Btu content may be higher than those from flares burning high-Btu gases.

The density of the gas flared also affects the structure and stability of the flame through the effect on buoyancy and mixing. The velocity in many flares is very low; therefore, most of the flame structure is developed through buoyant forces as a result of the burning gas. Lighter gases therefore tend to burn better. The density of the fuel also affects the minimum purge gas required to prevent flashback and the design of the burner tip.

Poor mixing at the flare tip or poor flare maintenance can cause smoking (particulate). Fuels with high carbon-to-hydrogen ratios (greater than 0.35) have a greater tendency to smoke and require better mixing if they are to be burned smokelessly.

A series of flare destruction efficiency studies has been performed by EPA. Based on the results of these studies, EPA concluded that 98-percent combustion efficiency can be achieved by steam-assisted and air-assisted flares burning gases with heat contents greater than 11 MJ/m^3 (300 Btu/ft^3).[36] To achieve this efficiency level, EPA developed the set of flare design guidelines presented in Section 3.2.1.1 of this chapter.

3.2.1.4 Applicability of Flares to Vent Streams. The flare is a useful emission control device and can be used for most nonhalogenated organic streams. It can handle fluctuations in organic concentration, flow rate, and inerts content very easily. However, the low volumetric flows typically associated with waste distillation-unit process vents and the low organic concentrations in process vent streams from air strippers are conditions that do not favor the use of flares. Flares are best suited and generally designed to control normal operating vents or emergency upsets that release large volumes of gases; and, in the case of dilute gas streams, supplemental fuel costs can eliminate flares as a viable control alternative. On the other hand, it is possible (as is done in refineries) to combine a number of process vents in a common gas line, which can be sent to a flare.

3.2.2 Thermal Incineration

3.2.2.1 Control Process Description. Any organic chemical heated to a high enough temperature in the presence of enough oxygen will be oxidized to carbon dioxide and water. This is the basic principle of operation of a thermal incinerator. The theoretical temperature required for thermal oxidation to occur depends on the structure of the chemical involved. Some chemicals are oxidized at temperatures much lower than others. The organic destruction efficiency of a thermal oxidizer can be affected by variations in chamber temperature, residence time, inlet organic concentration, compound type, and flow regime (mixing). An efficient thermal incinerator system must provide:

- A chamber temperature high enough to enable the oxidation reaction to proceed rapidly to completion
- Enough turbulence to obtain good mixing between the hot combustion products from the burner, combustion air, and organics

- Sufficient residence time at the chosen temperature for the oxidation reaction to reach completion.

A thermal incinerator is usually a refractory-lined chamber (fire-box) containing a burner at one end. As shown in Figure 3-8, discrete dual fuel burners and inlets for the vent gas and combustion air are arranged in a premixing chamber to mix the hot products from the burners thoroughly with the vent gas airstreams. The mixture of hot reacting gases then passes into the main combustion chamber. This section is sized to allow the mixture enough time at the elevated temperature for the oxidation reaction to reach completion (residence times of 0.3 to 1 s are common). Energy can then be recovered from the hot flue gases in a heat recovery section. Preheating of combustion air or vent gas is a common mode of energy recovery; however, it is sometimes more economical to generate steam. Insurance regulations require that if the waste stream is preheated, the organic concentration must be maintained below 25 percent of the LEL to prevent explosion hazards.

Thermal incinerators designed specifically for organic incineration with natural gas as the auxiliary fuel may also use a grid-type (distributed) gas burner as shown in Figure 3-9.[37] The tiny gas flame jets on the grid surface ignite the vapors as they pass through the grid. The grid acts as a baffle for mixing the gases entering the chamber. This arrangement ensures burning of all vapors at lower chamber temperature and uses less fuel. This system makes possible a shorter reaction chamber yet maintains high efficiency.

Other parameters affecting incinerator performance (i.e., organic vapor destruction efficiency) are the vent gas organic vapor composition, concentration, and heating value; the water content in the stream; the amount of excess combustion air (the amount of air above the stoichiometric air needed for reaction); the combustion zone temperature; the period of time the organics remain in the combustion zone (i.e., residence time); and the degree of turbulent mixing in the combustion zone.

The vent gas heating value is a measure of the heat available from the combustion of the organic in the vent gas. Combustion of vent gas with a heating value less than 1.86 MJ/Nm^3 (50 Btu/scf) usually requires burning auxiliary fuel to maintain the desired combustion temperature. Auxiliary

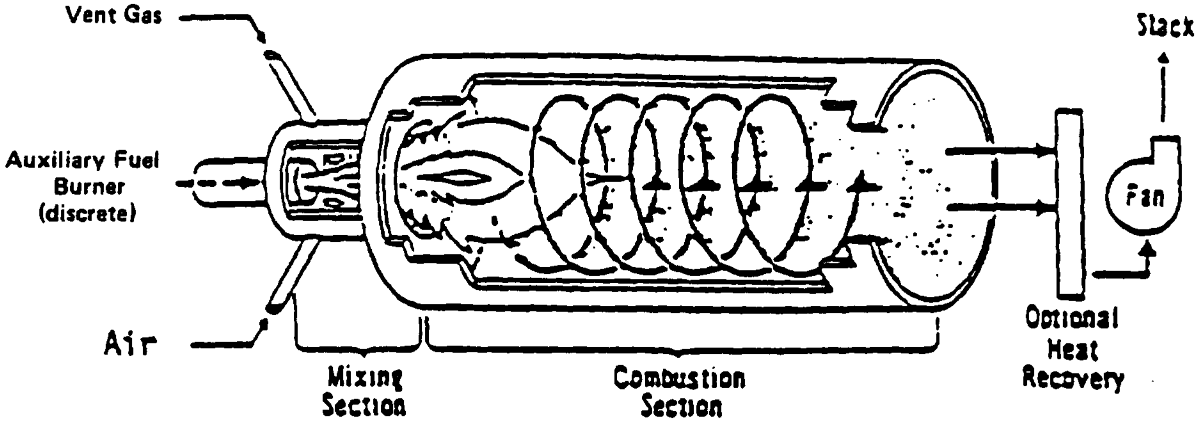

Figure 3-8. Discrete burner, thermal oxidizer.

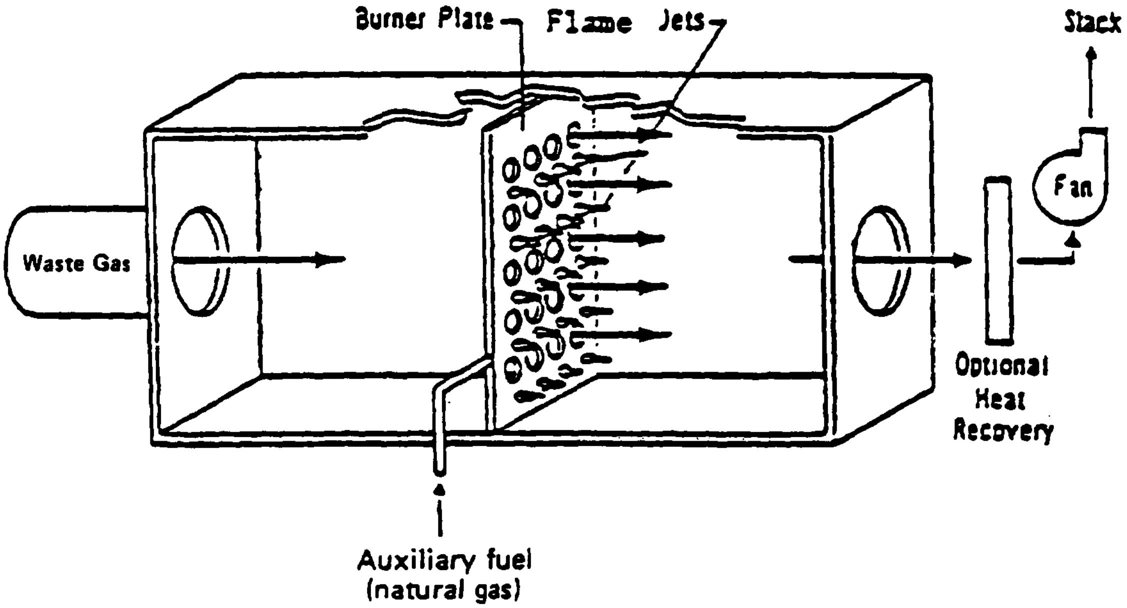

Figure 3-9. Distributed burner, thermal oxidizer.

fuel requirements can be lessened or eliminated by the use of recuperative heat exchangers to preheat combustion air. Vent gas with a heating value above 1.86 MJ/Nm^3 (50 Btu/scf) may support combustion but may need auxiliary fuel for flame stability.

A thermal incinerator handling vent gas streams with varying heating values and moisture content requires careful adjustment to maintain the proper chamber temperatures and operating efficiency. Water requires a great deal of heat to vaporize, so entrained water droplets in a vent gas stream can substantially increase auxiliary fuel requirements because of the additional energy needed to vaporize the water and raise it to the combustion chamber temperature. Combustion devices are always operated with some quantity of excess air to ensure a sufficient supply of oxygen. The amount of excess air used varies with the fuel and burner type, but it should be kept as low as possible. Using too much excess air wastes fuel because the additional air must be heated to the combustion chamber temperature. A large amount of excess air also increases flue gas volume and may increase the size and cost of the system. Packaged, single-unit thermal incinerators can be built to control streams with flow rates in the range of 0.1 Nm^3/s (200 scfm) to about 24 Nm^3/s (50,000 scfm).

3.2.2.2 Performance Monitoring. To ensure that the thermal incinerator is operated within design specifications, EPA recommends the following procedures (48 FR 57538, December 30, 1983):

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.

2. Install a temperature monitoring device. The device should have an accuracy of ±1 percent of the temperature being monitored in degrees Celsius or ±0.5 °C, whichever is greater. The temperature sensor should be installed at a location in the combustion chamber downstream of the combustion zone.

Also, visible emissions from an incinerator indicate incomplete combustion, that is, inefficient operation.

3.2.2.3 Control Effectiveness. The organic destruction efficiency of a thermal oxidizer can be affected by variations in chamber temperature, residence time, inlet organic concentration, compound type, and flow regime (mixing). Test results show that thermal oxidizers can achieve 98-percent destruction efficiency for most organic compounds at combustion chamber temperatures ranging from 700 to 1,300 °C (1,300 to 2,370 °F) and residence times of 0.5 to 1.5 s.[38] This information, used in conjunction with kinetics calculations, indicates that the combustion chamber parameters for at least a 98-percent organic destruction efficiency are a combustion temperature of 870 °C (1,600 °F) and a residence time of 0.75 s (based upon residence in the chamber volume at combustion temperature). A thermal oxidizer designed to produce these conditions in the combustion chamber should be capable of high destruction efficiency for almost any organic even at low inlet concentrations.

At temperatures over 760 °C (1,400 °F), the oxidation reaction rates are much faster than the rate of gas diffusion mixing. The destruction efficiency of the organic then becomes dependent upon the fluid mechanics within the oxidation chamber. The flow regime must ensure rapid, thorough mixing of the organic stream, combustion air, and hot combustion products from the burner. This enables the organic to attain the combustion temperature in the presence of enough oxygen for a sufficient time for the oxidation reaction to reach completion.

Previous EPA studies (48 FR 57538, Dec. 30, 1983; 48 FR 48932, Oct. 21, 1983) that considered thermal oxidizer efficiency, auxiliary fuel use, and costs concluded that 98-percent organic destruction or a 20-ppmv compound exit concentration (whichever is less stringent) is the highest reasonable control level achievable by all new incinerators in operations such as distillation processes, considering current technology.[39] Because of much slower combustion reaction rates at lower inlet organic concentrations, maximum achievable organic destruction efficiency decreases as inlet concentration decreases. For vent streams with organic concentrations above approximately 2,000 ppmv (corresponding to 1,000 ppm organics in the incinerator inlet stream because air dilution is typically 1:1), a 98-percent (by weight) organic destruction is achievable. For vent streams with organic concentrations below approximately 2,000 ppmv, it has been determined that an incinerator outlet concentration of 20 ppm (volume, by compound) is the lowest achievable by all new thermal oxidizers.[40] As a result, combustion of inlet streams below approximately 2,000 ppmv may not achieve the 98-percent-by-weight destruction efficiency.

The 98-percent efficiency estimate is predicated upon thermal incinerators operated at 870 °C (1,600 °F) with a 0.75-s residence time for nonhalogenated organic compounds. If the vapor stream contains halogenated compounds, a temperature of 1,100 °C (2,000 °F) and a residence time of 1 s is needed to achieve a 98-percent destruction efficiency.

3.2.2.4 Applicability of Thermal Incinerators to Vent Streams. In terms of technical feasibility, thermal incinerators are applicable as a control device for many process vents. They can be used for organic streams with any concentration and with any type of organic compounds. They can be designed to handle minor fluctuations in flows. However, excessive fluctuations in flow (upsets) might not allow the use of incinerators and would require the use of a flare. The presence of compounds such as halogens or sulfur might require some additional equipment such as acid-gas scrubbers.

The practical application of thermal incinerators for control of organic emissions from process vents is limited by the inlet (vent) stream flow conditions. Both the vent stream volumetric flow rate and the vent stream organic concentration limit applicability to some extent. Because a combustion chamber volume of 1.01 m^3 (35.7 ft^3) is the smallest size commercially available, the use of thermal incinerators for low-flow process vents (e.g., <10 scfm) may not be appropriate. At a residence time of 1 s, a 1.01-m^3 combustion chamber can accommodate a total volumetric flow (i.e., a flue gas flow rate) of about 2,000 scfm. For a vent stream requiring a combustion chamber volume smaller than 1 m^3, natural gas and air can be added to maintain the desired (or design) temperature and residence time to compensate for the application of an oversized incinerator combustion chamber. However, dilution of the vent stream can lead to reduced destruction efficiencies (<98 percent) if the organic concentration following dilution falls below 2,000 ppmv. The limit to which an oversized thermal incinerator can be used for a low-flow rate vent stream and the limit to which a vent stream with a flow rate within design specifications (i.e., >500 scfm) but with a low organic concentration (i.e., <2,000 ppmv) can be effectively controlled using thermal incineration is an engineering judgment based on the desired control device efficiency and the limit on acceptable cost-effectiveness values (the cost per unit of emission reduction).

3.2.3 Boiler and Process Heater Combustion Control Devices

3.2.3.1 Control Description. Fired-process equipment or furnaces include boilers, heaters, and incinerators. Such equipment is employed in most chemical plants to provide heat conveniently, efficiently, and at the temperature level required. Indirect-fired furnaces (boilers and process heaters) are those in which heating media are separated from process streams.

Industrial boilers are of two types: fire-tube and water-tube. Fire-tube units are similar to shell-and-tube heat exchangers with combustion gases flowing through the tubes. The center tube of the bundle, much larger than the rest, constitutes the combustion chamber. Flow reverses at the end of the bundle and passes back through numerous smaller outer tubes. Efficient and compact, fire-tube boilers are always shop-fabricated. Steam pressures are limited by the strength of the large cylindrical shell and are, of course, less than could be contained in smaller tubes. Thus, fire-tube furnaces are employed primarily for generating modest amounts of low-pressure saturated steam. Because of geometry, the combustion chamber and flue gas tubes are not compatible with continuous cleaning. This, in addition to a limited combustion residence time, restricts fire-tube boilers to fuels no dirtier or less convenient than residual oil.

Water-tube boilers contain steam within the tubes while combustion occurs in a boxlike open chamber. In large boilers, hundreds to thousands of tubes, usually 7 to 12 cm (2.7 to 4.7 in.) in diameter, are installed side by side, forming the walls of the combustion chamber and of baffles that control flow of, and remove heat from, combustion gases. In the combustion area, known as the radiant section, gas temperatures drop from about 1,930 °C (3,506 °F) to 1,030 °C (1,886 °F). After combustion products have been thus cooled by radiation to wall tubes, they pass at high velocity through slots between more tubes suspended as large banks in the gas stream. This is known as the convection section. In the radiant section, such direct exposure to higher-temperature gases would damage the tube metal. Gas entering the convection section at about 1,030 °C (1,886 °F) leaves near 330 °C (626 °F). Tubes in the radiant section are normally filled with circulating, boiling liquid to avoid hot spots. Any superheating desired occurs in the hot end of the convection system.

Because of the large, open combustion chambers, coal and wood fueling are common in water-tube furnaces. Flyash and soot are cleaned from convection tubes by automatic "soot blowers" that direct high-velocity steam or air jets against outer surfaces of tubes while the boiler is operating. Water-tube boilers can be shop-fabricated with heating duties up to 100,000 kJ/s (94,860 Btu/s). Modern units burning coal and wood or residual oil are fitted with dust collectors for flyash removal.

Frequently, the need arises for process heat at temperatures above those available from the systems already described. In these situations and even where an intermediate medium can be used, the process fluid itself is passed through tube coils in a fired furnace. The process system may be reactive, as with pyrolysis furnaces, which have been used extensively to thermally crack hydrocarbons for ethylene and propylene manufacture. The process stream may be nonreactive as well. Such is the case when a fired furnace is used as a reboiler in the distillation of heavy petroleum liquids.

Boilers and process heaters can be designed as control devices to limit organic emissions by incorporating the vent stream (e.g., the uncondensed overhead from distillation) with the inlet fuel, or by feeding the stream into the boiler or process heater through a separate burner. These devices are most applicable where high vent stream heat recovery potential exists.

The parameters that affect the efficiency of a thermal incinerator (e.g., boilers and process heaters) are the same parameters that affect the efficiency of these devices when they function as air pollution control devices. These parameters are temperature, residence time, inlet organic concentration, compound type, and flow regime (mixing).

3.2.3.2 Performance Monitoring. To ensure that the boilers or process heaters are operated within design specifications, the owner or operator should:

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.

2. For boilers or process heaters having a design heat input capacity less than 44 MW, install a temperature monitoring device equipped with a continuous recorder. The device should have an accuracy of ±1 percent of the temperature being monitored in degrees Celsius or ±0.5 °C, whichever is greater. The temperature sensor should be installed at a location in the furnace downstream of the combustion zone.

3. For boilers or process heaters having a design heat input capacity greater than or equal to 44 MW, install a monitoring device to measure a parameter that demonstrates that good combustion operating practices are being used (e.g., concentration of CO, O_2, hydrocarbons).

3.2.3.3 Control Effectiveness. A boiler or process heater furnace can be compared to an incinerator where the average furnace temperature and residence time determine the combustion efficiency. However, when a vent gas is injected as a fuel into the flame zone of a boiler or process heater, the required residence time is reduced due to the relatively high flame zone temperature. The following test data, which document the destruction efficiencies for industrial boilers and process heaters, are based on injecting the wastes identified into the flame zone of each combustion control device.

A series of EPA-sponsored studies of organic vapor destruction efficiencies for industrial boilers and process heaters have been conducted. One study investigated the destruction efficiency of five process heaters firing a benzene vapor and natural gas mixture. The results of these tests showed 98 to 99 percent overall destruction efficiencies for C_1 to C_6 hydrocarbons.[41]

3.2.3.4 Applicability of Industrial Boilers and Process Heaters as Control Devices for Process Vent Streams. Industrial boilers and process heaters are currently used by industry to combust offgases from refinery operations. These devices are most applicable where high vent stream heat recovery potential exists.

The primary purpose of a boiler is to generate steam. Process heaters are applied within a plant for a variety of reasons including natural gas reforming, thermal cracking, process feedstock preheating, and reboiling for some distillation operations. Both devices are essential to the operation of a plant and, as a result, only streams guaranteed not to reduce the device's performance or reliability warrant use of a boiler or process heater as a combustion control device. Variations in vent stream flow rate and/or heating value could affect the heat output or flame stability of a boiler or process heater and should be considered when using these combustion devices. Performance or reliability may be affected by the presence of corrosive products in the vent stream. Because these compounds could corrode boiler or process heater materials, vent streams with a relatively high concentration of halogenated or sulfur-containing compounds are usually not combusted in boilers or process heaters. When corrosive organic compounds are combusted, the flue gas temperature must be maintained above the acid dewpoint to prevent acid deposition and subsequent corrosion from occurring.

The introduction of some process vent streams into the furnace of a boiler or heater could alter the heat transfer characteristics of the furnace. Heat transfer characteristics depend on the flow rate, heating value, and elemental composition of the process vent stream and the size and type of heat-generating unit being used. Often, there is no significant alteration of the heat transfer, and the organic content of the process stream can, in some cases, lead to a reduction in the amount of fuel required to achieve the desired heat production. In other cases, the change in heat transfer characteristics after introduction of the process stream may adversely affect the performance of the heat-generating unit and increase fuel requirements. If, for a given process vent stream, increased fuel is required to achieve design heat production to the degree that equipment damage (e.g., tube failure due to local hot spots) might result, then a heat-generating unit would not be applicable as an organic control device for that vent stream. In addition to these reliability problems, there also are potential safety problems associated with ducting process vents to a boiler or process heater. Variation in the flow rate and organic content of the vent stream could, in some cases, lead to explosive mixtures that could cause extensive damage. Another related problem is flame fluttering, which could result from these variations.

When a boiler or process heater is applicable and available, it is an excellent control device because it can provide at least 98-percent destruction of organics. In addition, near-complete recovery of the vent stream heat content is possible. However, both devices must operate continuously and concurrently with the pollution source unless an alternate control strategy is available in the event the heat-generating capacity of either unit is not required.

3.2.4 Catalytic Oxidation

3.2.4.1 Control Description. A catalyst is a substance that changes the rate of a chemical reaction without being permanently altered. Catalysts in catalytic incinerators cause the oxidizing reaction to occur at a lower temperature than is required for thermal oxidation. Catalyst materials include platinum, platinum alloys, copper oxide, chromium, and cobalt. These materials are plated in thin layers on inert substrates designed to provide maximum surface area between the catalyst and the organic vapor stream.

Figure 3-10 presents a catalytic incinerator. The vent gas is introduced into a mixing chamber where it is heated to approximately 320 °C (~600 °F) by the hot combustion products of the auxiliary burners. The heated mixture then passes through the catalyst bed. Oxygen and organics diffuse onto the catalyst surface and are adsorbed in the pores of the catalyst. The oxidation reaction takes place at these active sites. Reaction products are desorbed from the active sites and diffuse back into the gas. The combusted gas can then be routed through a waste heat recovery device before exhausting into the atmosphere.

Combustion catalysts usually operate over a temperature range of 320 to 650 °C (600 to 1,200 °F). Lower temperatures can slow down or stop the oxidation reaction. Higher temperatures can shorten the life of the catalyst or evaporate the catalyst from the inert substrate. Vent gas streams with high organic concentrations can result in temperatures high enough to cause catalyst failure. In such cases, dilution air may be required. Accumulations of particulate matter, condensed organics, or polymerized hydrocarbons on the catalyst can block the active sites and reduce efficiency. Catalysts can also be deactivated by compounds containing sulfur,

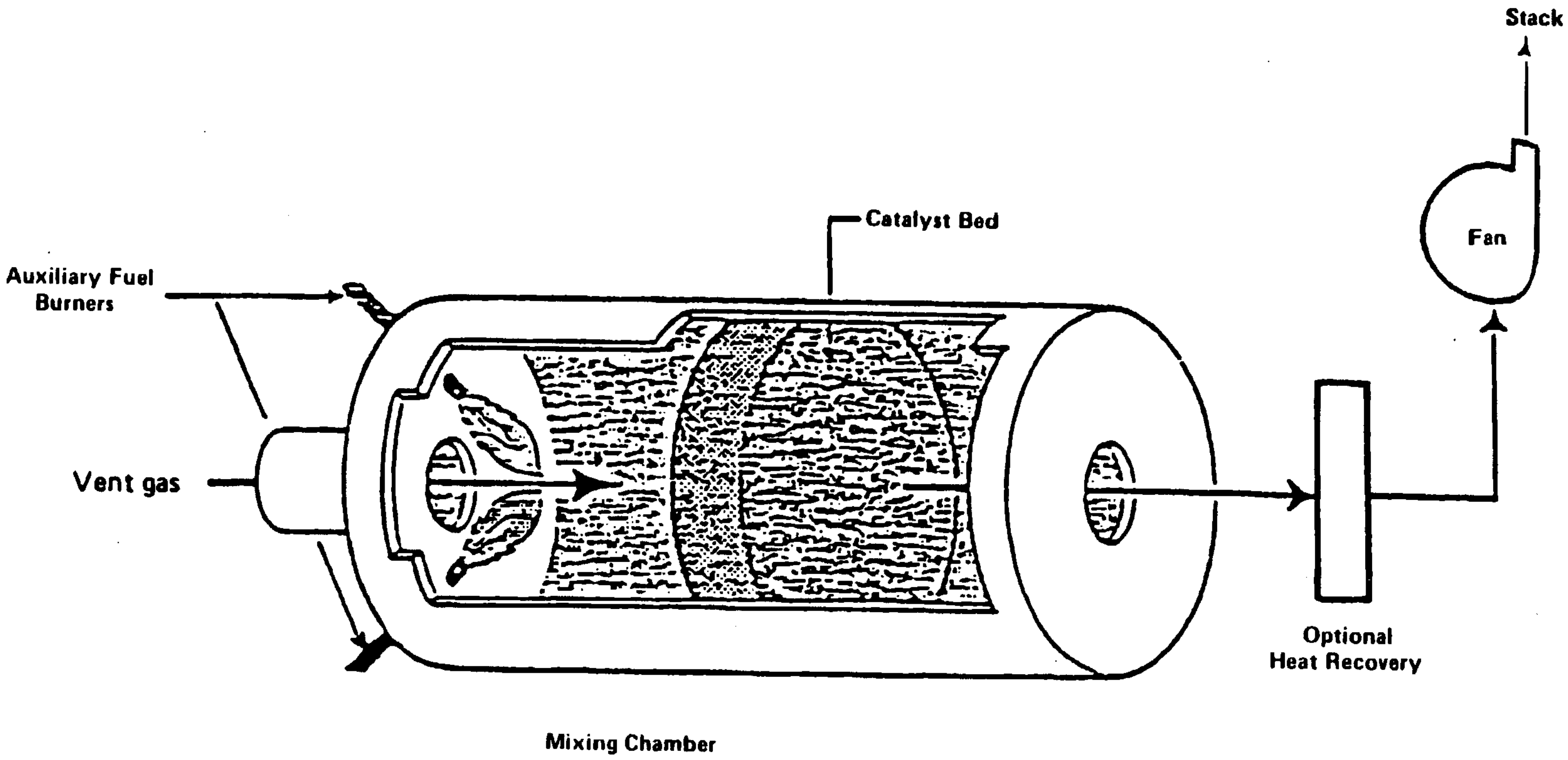

Figure 3-10. Catalytic incinerator.

bismuth, phosphorus, arsenic, antimony, mercury, lead, zinc, tin, or halogens. If these compounds deactivate the catalytic unit, organics will pass through unreacted or be partially oxidized to form compounds (aldehydes, ketones, and organic acids) that are highly reactive atmospheric pollutants that can corrode plant equipment. As a result, gases containing compounds with chlorine, sulfur, and other atoms that may deactivate the supported noble metal catalysts often used for VOC control were not suitably controlled by catalytic oxidation systems. Therefore, the use of catalytic oxidation for control of gaseous pollutants has generally been restricted to organic compounds containing only carbon, hydrogen, and oxygen.

Catalysts now exist, however, that are tolerant of some deactivating compounds. Most of the development of poison-tolerant catalysts has focused on the oxidation of chlorine-containing organics. These organic compounds are widely used as solvents and degreasers and are often the subject of concern in VOC control. Catalysts such as chromia/alumina, cobalt oxide, and copper oxide/manganese oxide have been used for oxidation of gases containing chlorinated compounds in limited applications. Platinum-based catalysts are active for oxidation of sulfur-containing VOCs, although they are rapidly deactivated by the presence of chlorine. Compounds containing atoms such as lead, arsenic, and phosphorous should, in general, be considered poisons for most oxidation catalysts.

3.2.4.2 <u>Performance Monitoring</u>. To ensure that the catalytic incinerator is operated within design specifications, the owner or operator should:

1. Install a flow indicator that provides a record of vent stream flow to the control device. The flow indicator sensor should be installed in the vent stream as near as possible to the control device inlet but before being combined with other vent streams.

2. Install a temperature-monitoring device. The device should be capable of monitoring temperature at two locations and have an accuracy of ±1 percent of the temperature being monitored in degrees Celsius or ±0.5 °C, whichever is greater. One temperature sensor should be installed in the vent stream as near as possible to the catalyst bed inlet, and a second temperature sensor should be installed in the vent stream as near as possible to the catalyst bed outlet.

Also, as with thermal incineration, visible emissions from a catalytic incinerator indicate incomplete combustion, that is, inefficient operation.

3.2.4.3 Control Effectiveness. Catalytic incineration destruction efficiency depends on organic composition and concentration, operating temperature, oxygen concentration, catalyst characteristics, and space velocity. Space velocity is commonly defined as the volumetric flow of gas entering the catalyst bed chamber divided by the volume of the catalyst bed. The relationship between space velocity and organic destruction efficiency is strongly influenced by catalyst operating temperature. As space velocity increases, organic destruction efficiency decreases, and as temperature increases, organic destruction efficiency increases. A catalytic unit operating at about 450 °C (840 °F) with a catalyst bed volume of 0.014 to 0.057 m^3 (0.5 to 2 ft^3) per 0.47 scm/s (1,000 scfm) of vent gas passing through the device can achieve 95-percent organic destruction efficiency.[42,43] Destruction efficiencies of 98 percent or greater can be obtained on some streams by using the appropriate catalyst bed volume to vent gas flow rate. Some catalytic units have been reported to achieve 97.9- to 98.5-percent destruction efficiencies.[44] These higher efficiencies are usually obtained by increasing the catalyst bed volume to offgas flow ratio. The cost of this increased catalyst bed can be prohibitive.

3.2.4.4 Applicability of Catalytic Oxidizers to Vent Streams. The sensitivity of catalytic oxidizers to organic inlet stream flow conditions, their inability to handle high organic concentration offgas streams, the sensitivity of the catalyst to deactivating compounds, and their higher cost for destruction efficiencies comparable to thermal oxidizers may limit the application of catalytic units for control of organics from process vent streams.

3.3 SUMMARY OF DATA ON CONTROL DEVICES APPLIED TO PROCESS VENTS

The chemical manufacturing industry data base (discussed in Section 2.3) contains information on the types of control devices used to control process vent stream emissions from distillation units used in the chemical manufacturing industry. These data provide some indication of the types of distillation operations in use in organic chemical manufacturing and the control systems currently being used for control of process vent emissions. The total number and types of distillation units in the survey as well as a summary of the types of combustion control devices and product recovery devices used are presented in Table 3-1.

With regard to distillation and stripping units that process only wastes, the TSDR data base (discussed in Section 2.3) contains up-to-date information on the types of air pollution control devices serving waste management units at TSDF. The preliminary results of the TSDR Survey were used to identify units of the type that are likely to have associated process vents (e.g., thin-film evaporators [TFE], batch stills, and steam strippers) and the types of air pollution control devices serving these units. Those preliminary results are presented in Table 3-2.

As shown in Table 3-2, vapor recovery devices (i.e., condensers, adsorbers, and absorbers) are the technology of choice to control distillation and stripping units at TSDF; more than 80 percent of the reported control devices utilize a form of vapor recovery. In general, these devices are most attractive for the control of process vents on waste management units in cases where a significant quantity of usable organics can be recovered. Condensers are by far the most commonly reported technology used. However, the survey did not distinguish between condensers primarily used for product recovery and those used to reduce air pollutant emissions. As a result, the application of condensers may appear somewhat skewed because unit operations of this type (i.e., distillation operations) are expected to utilize primary condensers for recovery of usable organics as a part of the process. Vapor recovery as a control device (i.e., adsorbers, absorbers, and condensers) may not be applicable to some process vent streams. For example, adsorbers may not always be applicable to vent streams containing very low molecular weight compounds. Absorbers are generally not applied to streams with organic concentrations below 200 to 300 ppmv. Condensers are not well suited for application to vent streams containing low-boiling-point organics or to vent streams with large inert concentrations. Even though these restrictions exist, condensers and adsorbers are the primary technology applied to process vent streams in the Synthetic Organic Chemical Manufacturing Industry (SOCMI) and at TSDF and

TABLE 3-1. OVERVIEW OF DISTILLATION UNITS IN CHEMICAL MANUFACTURING INDUSTRY

	Number of units	Percentage of total
1. Operating pressure		
a. Vacuum	318	31
b. Nonvacuum	582	56
c. Information not available[a]	137	13
	1,037	100
2. Mode of operation		
a. Batch	4	<1
b. Continuous	1,033	>99
	1,037	100
3. Type of unit		
a. Flash	37	3
b. Fractionating	1,000	97
	1,037	100
4. Installed product recovery devices[b]		
a. Scrubbers	79	8
b. Absorbers	12	1
c. Carbon adsorption	5	<1
	96	10
5. Installed combustion controls		
a. Flares	78	8
b. Incinerators	72	7
c. Boilers	9	1
	159	16
6. Units with no flow rate	231	22
7. Units with emissions recycled	219	21

[a] For 13 percent of the 1,037 total units, operating pressure information is not given or is reported as confidential.

[b] In addition to condensers that are used primarily for product recovery rather than air pollution control.

Source: U.S. Environmental Protection Agency. Distillation Operations in Synthetic Organic Chemical Manufacturing--Background Information for Proposed Standards. Appendix C. Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-83-005a. December 1983.

TABLE 3-2. DISTILLATION, SEPARATION, AND STRIPPING UNITS AT TSDF

Type of unit	Number of units	Percentage of total
1. Type of unit		
a. Fractionation	125	18
b. Batch distillation	370	52
c. Solvent extraction	42	6
d. Thin-film evaporation	77	11
e. Air stripping	52	7
f. Steam stripping	40	6
2. Units with air pollution controls		
a. Fractionation	104	22
b. Batch distillation	255	53
c. Solvent extraction	8	2
d. Thin-film evaporation	69	14
e. Air stripping	15	3
f. Steam stripping	27	6
3. Units reporting no air pollution controls		
a. Fractionation	8	4
b. Batch distillation	143	75
c. Solvent extraction	5	3
d. Thin-film evaporation	15	8
e. Air stripping	17	9
f. Steam stripping	3	2
4. Type of air pollution controls installed		
a. Condenser	339	69
b. Wet ionizing scrubber	5	1
c. Packed bed scrubber	14	3
d. Carbon adsorption device	39	8
e. Vapor/fume incinerator	24	5
f. Flare	9	2
g. Boiler	9	2
h. Other	50	10

Note: The total number of units shown includes both RCRA-regulated units and RCRA-exempt units operating in 1986. Totals are not shown because some units were reported to have more than one control device (e.g., a condenser followed by a vapor incinerator) and some facilities did not complete the section on control devices.

Source: 1987 National Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities (TSDR Survey). Alpha Database. July 1989.

these technologies are expected to remain the technology of choice to control process vent organic emissions from waste management units.

The combustion control devices typically used are incinerators, flares, and industrial boilers. However, these technologies account for less than 10 percent of the reported control devices in use at TSDF. In general, these devices are applicable to a wide variety of vent stream characteristics and can achieve at least 98-percent destruction efficiency.[45] Combustion devices are capable of adapting to moderate changes in effluent flow rate and concentration while control efficiency is not affected by the type of organic present. This is generally not the case with noncombustion (vapor recovery) control devices. In general, combustion control devices are both capital- and energy-intensive except where boilers or process heaters are applied and the energy content of the vent stream is recovered. However, because boilers or process heaters are essential to the operation of a plant, only streams that are certain not to reduce performance and reliability warrant use of these systems for air pollution control. Application of a scrubber prior to atmospheric discharge may be required when vent streams containing high concentrations of halogenated or sulfonated compounds are combusted in an enclosed combustion device. The TSDR data base did not indicate if the scrubbers, which constituted 4 percent of the air pollution controls installed at TSDF, were operated in association with combustion devices. In addition, vent streams with high concentrations of corrosive halogenated or sulfonated compounds may preclude the use of flares because of possible flare tip corrosion and may preclude the use of boilers and process heaters because of potential internal (boiler) corrosion.

There are some disadvantages associated with organic control by combustion: (1) high capital and operating costs result from thermal oxidation techniques, which could require a plot of land as large as 90 m by 90 m (300 ft by 300 ft) for installation; (2) because offgas must be collected and ducted to the combustion device, long duct runs may lead to condensation of combustibles and possibly to duct fires; and (3) because thermal oxidizers use combustion with a flame for achieving organic destruction, the unit must be located at a safe distance from process equipment in which flammable chemicals are used. However, it is likely that high operating cost is the principal reason vapor/fume incinerators are used in only 5 percent of the reported cases.

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4.0 ENVIRONMENTAL AND COST IMPACTS

This chapter presents the emission reductions, costs, and cost-effectiveness values of various options for control of organic emissions from waste management unit process vents. Waste management unit process vents encompass a wide range of equipment types, sizes, and operating techniques. Therefore, a wide range of vent stream parameters were used to characterize waste management unit process vents industry-wide in order to evaluate the potential impacts of controlling organic emissions from these sources.

The individual technologies for controlling organic emissions from waste management unit process vents are discussed in Chapter 3.0. Due to the wide variation in process vent operating parameters (i.e., flow rates and organic concentrations), the most effective control technology for a given type of waste management unit process vent stream will vary. In this chapter, example options for controlling process vents are presented with cost analyses for each control option.

4.1 CONTROL TECHNOLOGY ANALYSIS METHODOLOGY--MODEL UNITS

Because of the large variation in waste management unit process vent stream characteristics, a model unit approach was used to characterize this source on an industry-wide basis. A range of model unit cases was developed to represent typical process vent streams associated with currently operating waste management units. Table 4-1 presents the model unit parameters for each process vent case used in the analysis. The process vent stream model unit parameters selected for analysis in this document include those used in the development of Resource Conservation and Recovery Act (RCRA) air emission standards to characterize waste management unit process vents at treatment, storage, and disposal facilities (TSDF).[1] Also

TABLE 4-1. PROCESS VENT MODEL UNIT PARAMETERS

Case No.	Vent class	Total flow, scfm	Organic emission rate, lb/h	Operating hours, h/yr[a]	Constituent	Resulting organic concentration, volume %	Uncontrolled organic emissions, Mg/yr
1	D	8.3	0.40	4,160	ME CHI	0.3174	0.76
2	D	8.3	0.40	4,160	TOL	0.2933	0.76
3	D	8.3	0.40	4,160	1,1,1-TCE	0.2022	0.76
4	D	8.3	0.40	4,160	MEK	0.3742	0.76
5	D	8.3	4.20	4,160	ME CHI	3.3328	7.94
6	D	8.3	4.20	4,160	TOL	3.0792	7.94
7	D	8.3	4.20	4,160	1,1,1-TCE	2.1236	7.94
8	D	8.3	4.20	4,160	MEK	3.9291	7.94
9	D	8.3	10.60	4,160	ME CHI	8.4114	20.04
10	D	8.3	10.60	4,160	TOL	7.7714	20.04
11	D	8.3	10.60	4,160	1,1,1-TCE	5.3562	20.04
12	D	8.3	10.60	4,160	MEK	9.9163	20.04
13	D	1.2	0.17	2,080	ME CHI	0.9331	0.16
14	D	1.2	0.17	2,080	TOL	0.8621	0.16
15	D	1.2	0.17	2,080	1,1,1-TCE	0.5945	0.16
16	D	1.2	0.17	2,080	MEK	1.1000	0.16
17	D	1.2	0.42	2,080	ME CHI	2.3052	0.40
18	D	1.2	0.42	2,080	TOL	2.1298	0.40
19	D	1.2	0.42	2,080	1,1,1-TCE	1.4688	0.40
20	D	1.2	0.42	2,080	MEK	2.7176	0.40
21	D	1.2	1.20	2,080	ME CHI	6.5863	1.13
22	D	1.2	1.20	2,080	TOL	6.0851	1.13
23	D	1.2	1.20	2,080	1,1,1-TCE	4.1967	1.13
24	D	1.2	1.20	2,080	MEK	7.7647	1.13
25	D	1.2	5.00	2,080	ME CHI	27.4428	4.73
26	D	1.2	5.00	2,080	TOL	25.3548	4.73
27	D	1.2	5.00	2,080	1,1,1-TCE	17.4860	4.73
28	D	1.2	5.00	2,080	MEK	32.3528	4.73
29	D	0.6	0.08	2,080	ME CHI	0.8782	0.08
30	D	0.6	0.08	2,080	TOL	0.8114	0.08
31	D	0.6	0.08	2,080	1,1,1-TCE	0.5596	0.08
32	D	0.6	0.08	2,080	MEK	1.0339	0.08
33	D	0.6	0.24	2,080	ME CHI	2.6345	0.23
34	D	0.6	0.24	2,080	TOL	2.4341	0.23
35	D	0.6	0.24	2,080	1,1,1-TCE	1.6787	0.23
36	D	0.6	0.24	2,080	MEK	3.1059	0.23
37	D	0.6	1.00	2,080	ME CHI	10.9771	0.95
38	D	0.6	1.00	2,080	TOL	10.1419	0.95
39	D	0.6	1.00	2,080	1,1,1-TCE	6.9944	0.95
40	D	0.6	1.00	2,080	MEK	12.9411	0.95

(continued)

TABLE 4-1 (continued)

Case No.	Vent class	Total flow, scfm	Organic emission rate, lb/h	Operating hours, h/yr[a]	Constituent	Resulting organic concentration, volume %	Uncontrolled organic emissions, Mg/yr
41	D	26	7.00	4,160	TOL	1.6383	13.24
42	D	26	7.00	4,160	MEK	2.0905	13.24
43	D	26	7.00	4,160	1,1,1-TCE	1.1299	13.24
44	A	2,100	0.10	8,760	TCE	0.0002	0.40
45	A	2,100	0.50	8,760	TCE	0.0009	1.99
46	A	2,100	1.50	8,760	TCE	0.0027	5.97
47	A	2,100	5.00	8,760	TCE	0.0091	19.91
48	A	2,100	0.10	8,760	DCE	0.0002	0.40
49	A	2,100	0.50	8,760	DCE	0.0012	1.99
50	A	2,100	1.50	8,760	DCE	0.0037	5.97
51	A	2,100	5.00	8,760	DCE	0.0123	19.91
52	A	2,100	0.10	8,760	EDC	0.0002	0.40
53	A	2,100	0.50	8,760	EDC	0.0012	1.99
54	A	2,100	1.50	8,760	EDC	0.0036	5.97
55	A	2,100	5.00	8,760	EDC	0.0121	19.91
56	A	6,200	0.10	8,760	TCE	0.0001	0.40
57	A	6,200	10.00	8,760	TCE	0.0061	39.82
58	A	6,200	0.10	8,760	DCE	0.0001	0.40
59	A	6,200	10.00	8,760	DCE	0.0082	39.82
60	A	6,200	0.10	8,760	EDC	0.0001	0.40
61	A	6,200	1.50	8,760	EDC	0.0012	5.97
62	A	6,200	10.00	8,760	EDC	0.0081	39.82
63	A	14,500	0.50	8,760	TCE	0.0001	1.99
64	A	14,500	5.00	8,760	TCE	0.0013	19.91
65	A	14,500	10.00	8,760	TCE	0.0026	39.82
66	A	14,500	0.50	8,760	DCE	0.0002	1.99
67	A	14,500	5.00	8,760	DCE	0.0018	19.91
68	A	14,500	10.00	8,760	DCE	0.0035	39.82
69	A	14,500	0.50	8,760	EDC	0.0002	1.99
70	A	14,500	5.00	8,760	EDC	0.0017	19.91
71	A	14,500	10.00	8,760	EDC	0.0034	39.82

A = Air-stripper-type vents (i.e., high flow rates).
D = Distillation-type vents (i.e, low flow rates).
DCE = Dichloroethylene.
EDC = 1,2-Dichloroethane.
ME CHI = Methylene chloride.
MEK = Methyl ethyl ketone.
TOL = Toluene.
1,1,1-TCE = 1,1,1-Trichloroethane.
TCE = Trichloroethylene.

[a] Distillation-type units are assumed to operate one or two 8-h shifts per day and air-stripper-type units 24 h/day.

included in the model units examined in this document are a selection of process vent stream parameters previously established by EPA to evaluate the cost of controlling air emissions from air strippers used in groundwater remediation.[2] Selection of the process vent stream parameters is discussed below.

4.1.1 Emission Rates

Review of data on actual emission rates from waste management unit process vents (see Section 2.4) indicates that a model unit organic emission rate range of 0.1 to 10 lb/h is appropriate. Process vent organic emissions were found generally to fall into this range regardless of the type of distillation or stripping process involved.[3] Emissions data from batch distillation operations, steam strippers, thin-film evaporators, and air strippers were examined, and emission rates were found to be in this general range on a mass per unit time basis (e.g., pound/hour). The large range in process vent organic emissions reported in test data for TSDF is due to the variation in primary condenser collection (or recovery) efficiencies from unit to unit. The data also include test results from units using secondary condensers on primary condenser vents. Efficiencies for the secondary condensers tested were, in some cases, quite low, and emissions from these units also varied over the range reported above.

4.1.2 Flow Rates

Because of physical differences in the unit operations themselves, air stripping operations inherently have a much higher process vent volumetric flow rate than the distillation-type operations (i.e., batch stills, thin-film evaporators, and steam strippers). In addition, a primary condenser system is usually an integral part of most distillation operations. Condensers are needed to provide reflux in fractionating columns and to ultimately recover distilled products. With primary (or product recovery) condensers typically applied to distillation-type operations, process vent flow rates are even further reduced. Therefore, in Table 4-1, each process vent model unit is assigned a vent class that indicates that the vent is either representative of a distillation-type operation assumed to be equipped with a primary condenser as part of the process (i.e., the stream has a low total volumetric flow) or representative of an air stripping operation (i.e., the stream has a high exhaust flow rate). With higher flow rates, the organic concentrations associated with air strippers are considerably lower than the organic concentrations in distillation unit process vent streams.

To account for the contrast or bracketing of process vent flow rates at the two extremes (i.e., very high flows of over 2,000 scfm and very low flows of less than 10 scfm), the process vent model unit cases include analyses of both high and low flow rate units. It should be noted that emission levels for the model units cover the same basic range of about 0.1 to 10 lb/h of organics, regardless of vent flow rates. As can be seen by examining Table 4-1, seven flow rates were selected, based on site-specific data, to characterize process vents on waste management units. Four flow rates are used to represent distillation units with low overhead gas flows (e.g., exhaust gases from a primary condenser). Three flow rates are used to represent air stripper exhaust vents. For each of the flow rates, several organic emission rates were selected based on source test data from tests conducted for EPA. From the flow rate and emission rate data, the stream's organic concentration can be determined for each constituent.

4.1.3 Temperatures

Vent stream exhaust gas temperatures were also found to be in the same general range for both distillation-type process vents and air stripping process vents (i.e., 10 to 27 °C [50 to 80 °F]).[4] A model unit vent stream temperature of 16 °C (60 °F) was used in the analysis for air stripper vents (i.e., average ambient air temperature) and 24 °C (75 °F) for distillation-type vents (i.e., uncondensed overheads exhaust temperature).

4.1.4 Waste Constituents

The waste constituents selected for use in the analysis of waste management unit process vent emission controls are toluene, methyl ethyl ketone, 1,1,1-trichloroethane, methylene chloride, trichloroethylene, 1,1-dichloroethylene, and 1,2-dichloroethane. Of these, 1,1,1-trichloroethane and methylene chloride have been identified as nonreactive organic chemicals, i.e., non-VOC (45 FR 48941, July 22, 1980); however, all of the waste constituents are toxic chemicals. The constituents were selected for use in the analyses because the constituent properties are considered to span the range of values exhibited by organic constituents typically found in waste streams managed in distillation/stripping units. The chemical and physical properties relevant to the analyses are presented in Table 4-2.

The model unit constituents are grouped according to vent type or classification. The constituents that most typically occur in vents associated with distillation-type operations differ from those most frequently associated with air stripper process vents. Four chemicals are used in the distillation-type process vent analysis; these are toluene, methyl ethyl ketone, methylene chloride, and 1,1,1-trichloroethane. Three chemical constituents, trichloroethylene, 1,1-dichloroethylene, and 1,2-dichloroethane, were used in the air stripper process vent analysis.

The EPA conducted a review of the available information regarding waste stream organic constituents and concentrations as part of efforts to develop the RCRA TSDF air emission standards. The EPA TSDF Waste Characterization Data Base (WCDB),[5] information from numerous plant trip reports, and data from a limited number of emission test reports were used to characterize waste streams managed at TSDF and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites in terms of constituents and concentrations of components. Plant trip reports and emission test reports from site visits, conducted in connection with the evaluation of organic removal through treatment processes involving distillation (i.e., waste management units that have associated process vents), provided organic composition and concentration data for 22 waste stream cases at TSDF. In general, the waste streams were comprised of one or two major constituents with two or more minor constituents. The constituent that showed up most frequently in the site-specific data was toluene, which was reported as being present in about 55 percent of the streams examined. Other major constituents and their percent occurrence included methyl ethyl ketone (36 percent), acetone (32 percent), xylene (27 percent), ethyl benzene (36 percent), isopropyl alcohol (36 percent), methylene chloride (32 percent), 1,1,1-trichloroethane (45 percent), trichloroethylene (36 percent), chloroform (18 percent), tetrachloroethylene (18 percent), and carbon tetrachloride (23 percent).

TABLE 4-2. PROPERTIES OF CHEMICAL CONSTITUENTS USED IN PROCESS VENT IMPACTS ANALYSES

Constituent[a]	Molecular weight[b]	Vapor pressure, 25 °C, mm Hg[b]	Boiling point, °C[b]	Henry's law constant, atm-m^3/mol[b]	Heat of combustion, Btu/lb[c]
Methylene chloride	85.00	438	39.8	3.19×10^{-3}	2,280
Toluene	92.00	30	110.6	6.68×10^{-3}	18,280
1,1,1-Trichloroethane	133.40	123	81.0	3.00×10^{-2}	2,760
Methyl ethyl ketone	72.12	100	79.6	4.35×10^{-5}	14,580
Trichloroethylene	131.39	75	87.0	9.10×10^{-3}	3,280
1,1-Dichloroethylene	97.00	630.1	-99.8	1.50×10^{-2}	5,030
1,2-Dichloroethane	98.76	82	83.5	1.20×10^{-3}	4,740

[a] Methylene chloride, toluene, 1,1,1-trichloroethane, and methyl ethyl ketone were used in the analyses of the efficiency and cost effectiveness of controlling distillation-type process vents. Trichloroethylene, 1,1-dichloroethylene, and 1,2-dichloroethane were used in the analyses of the efficiency and cost effectiveness of controlling air stripping process vents.

[b] Source: U.S. EPA. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF)--Air Emission Models. Appendix D. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-87-026. December 1987.

[c] Source: Weast, R. C. (ed.). CRC Handbook of Chemistry and Physics. 56th edition. CRC Press. Cleveland, OH. 1975-1976. *p.* D-274 *through* D-279.

The most comprehensive source of waste information currently available is the TSDF WCDB. This data base, used to support the development of comprehensive air emission regulations for hazardous waste TSDF, was developed by merging five existing data bases:

- National Survey of Hazardous Waste Generators and Treatment, Storage, and Disposal Facilities (Westat Data Base)
- Industrial Studies Data Base (ISDB)
- Listing documentation of 40 CFR 261.32 hazardous wastes from specific sources (K waste codes)
- WET Model Hazardous Waste Data Base
- A data base created by the Illinois EPA.

An examination of information in the WCDB for D001 wastes and spent solvent wastes (i.e., wastes that are typically treated in distillation-type units) indicates the same general trend as the plant-specific data. The waste streams were composed of one or two major constituents with one or more minor constituents present in low concentrations. The major constituents identified included those found in the plant-specific data. This review led to the selection of the four constituents that were used in the analysis of distillation-type process vents.

The three chemical constituents used in the analysis of air stripper process vents were chosen as follows because they represent the range of volatilities of chemicals commonly air stripped. Trichloroethylene was selected because it was a volatile organic compound (VOC) commonly found in contaminated ground water at Superfund sites, air stripping is commonly used to remove it from contaminated water, and it has a midrange Henry's law constant.* Selection of the other two constituents was made after consulting the chemical data table in the Superfund Public Health Evaluation Manual (SPHEM) and reviewing the Superfund Records of Decision System (RODS) data base.[6] The constituent 1,1-dichloroethylene was

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*The Henry's law constant is a measure of the diffusion of organics into air relative to diffusion through liquids and is used in predicting emissions for aqueous systems. A high range Henry's law constant indicates that rapid volatilization will generally occur.

selected from the chemicals commonly air stripped as the VOC with a higher-range Henry's law constant, and 1,2-dichloroethane was selected as the VOC with a low-range Henry's law constant.

4.1.5 Operating Hours

The annual operating hours assigned to the process vent model units were based on results of EPA information requests, under RCRA 3007 authority, regarding actual waste stream distillation, steam stripping, and air stripping operations. Hours of operation for large distillation and steam stripping units treating waste streams were found to be best characterized as intermittent operation at two 8-h shifts per day, 5 days per week, and 52 weeks per year (i.e., 4,160 h/yr). Small- and medium-sized distillation and steam stripping units, those handling less than 100,000 gal of waste per year, were found typically to operate only one shift per day, 5 days per week, and 52 weeks per year (i.e., 2,080 h/yr).[7] On the other hand, most air strippers usually are operated 24 h/day, 365 day/yr (i.e., 8,760 h/yr).[8]

4.2 EMISSION REDUCTIONS USING ALTERNATIVE CONTROL TECHNOLOGIES

Emission control technologies applicable to waste management unit process vent organic emissions include condensers, carbon adsorbers, flares, incinerators, and scrubbers. Although the emission reduction potentially achievable by each control technology depends on the physical parameters associated with the process vent stream and the design and operation of the control device, the control technology options that are feasible for application to waste management unit process vents generally represent two levels of control: 95 percent control and 98 percent control.

Review of available information on the operations of TSDF indicates that condensers, carbon adsorbers, and incinerators are the most widely used air pollution control technologies and will be the technologies of choice to reduce process vent organic emissions (see Table 3-2). Properly designed and operated, each of these control technologies can achieve at least a 95-percent emission reduction for most situations. However, there are situations where a particular technology may not be applicable as a control method for a particular waste management unit process vent stream. For example, the efficiency of a condenser depends on the physical properties of the organics being condensed, the organic concentration in the vent stream, and the operating temperature of the condenser. As a result, condensers are not well suited for vent streams containing organics with low boiling points, high moisture content, large quantities of inerts (e.g., CO_2 or N_2), or low concentrations of organics (i.e., too low thermodynamically to support a liquid phase). Flares are not widely used to control waste management unit process vent emissions in part because these streams typically contain halogenated organics. Flares are not recommended for halogenated streams because of the corrosion caused by the products of combustion.

The 95-percent control efficiency alternative for waste management unit process vents is analyzed on the basis of applying a (secondary) condenser to the vent stream as the initial choice of control technology. This is because, in cases where condensation is feasible, condensers provide the most cost-effective means to control organic emissions from process vents. Condenser and other control technology cost effectiveness is discussed in more detail later in this chapter. Because the organic concentrations associated with air stripper process vent streams are typically quite low (i.e., less than 100 ppm), control devices involving condensation are not applicable to these streams. Condensers are generally not effective for gas streams containing less than 10,000 ppmv organics.[9] Because of the low organic concentration, condensation is not considered applicable for the model units used to characterize air stripping process vents (Model Unit Case Nos. 44 through 71).

Carbon adsorption was examined as an alternative control technology in the emission reduction and cost analyses. A well-designed, operated, and maintained adsorption system can achieve a 95-percent (by weight) control efficiency for all organics under a wide variety of stream conditions over both short-term and long-term averaging periods. The major factors affecting performance of an adsorption unit are temperature, humidity, organic concentration, volumetric flow rate, "channelling" (nonuniform flow through the carbon bed), regeneration practices, and changes in the relative concentrations of the organics admitted to the adsorption system. A review of plant data indicates that waste management unit process vent stream characteristics are typically within design limits for carbon adsorbers in terms of parameters such as gas temperatures, pressures, and velocities. The EPA does not support assigning a higher control efficiency (i.e., 98 percent as opposed to 95 percent) to carbon adsorption units applied to waste management unit process vents, particularly in light of the design considerations related to controlling multicomponent vent streams when the organic constituent mix is subject to frequent change.

Incineration also was examined as a control alternative in the emission reduction and cost analyses. However, as noted in Section 3.2.2.3, both the vent stream volumetric flow rate and the vent stream organic concentration can potentially limit the applicability of thermal incinerators as process vent control devices. Because several of the process vent model unit cases examined in this document (see Table 4-1) have a low volumetric flow rate (i.e., <10 scfm) and/or a low organic concentration, use of thermal incineration is not appropriate for all of the model units. In evaluating the applicability of thermal incinerators to the model unit cases, the desired control device efficiency was used as the decision criterion. Maximum achievable organic destruction efficiency decreases as inlet concentration decreases below 2,000 ppmv. Therefore, model unit cases with process vent stream organic concentrations that result in estimated control device efficiencies of less than 95 percent were judged inappropriate for application of thermal incinerators (as dedicated units) for the cost analysis. With an incinerator outlet concentration of 20 ppmv as the lowest achievable by all new thermal oxidizers, the 95-percent control efficiency corresponds to a minimum vent stream concentration of about 400 ppmv. This concentration limit was therefore used to evaluate the appropriateness of applying a thermal incinerator to each vent stream case.

The model unit volumetric flow rates (see Section 4.1) fall into two groups or vent classes. The high flow rates (Model Unit Case Nos. 44 through 71) are within typical thermal incinerator design specifications (i.e., >500 scfm) for minimal flow. However, because organic concentrations for these streams are below 400 ppmv, thermal incineration is not considered appropriate for these cases. For analysis of the low-flow model units (Model Unit Case Nos. 1 through 43), natural gas and air can be added to the stream to maintain the desired minimum temperature and residence time to compensate for application of an oversized incineration chamber. However, dilution of these vent streams to 500 scfm results in many of the process vent model unit cases having organic concentrations of less than 400 ppmv, the limit for acceptable control device efficiency. Therefore, thermal incineration is not considered applicable in many of these cases.

In general, a tradeoff exists between the higher capital costs of catalytic incinerators and the higher operating costs of thermal incinerators. Thermal units typically require more auxiliary fuel than catalytic units and operate at temperatures that are roughly 538 °C (1,000 °F) higher. This results in a disparity in operating costs that in some cases is enough to offset the higher capital costs of the catalytic incinerator. Other factors also should be considered when evaluating the applicability of thermal and catalytic incinerators for control of process vents. For example, the 98-percent level of destruction attained by thermal incineration may be difficult to reach by the catalytic system. The potential for fouling of the catalyst in a catalytic system could increase the operating expense of the unit because of the replacement cost of the catalyst. In addition, the fluid-bed catalytic incinerator capacity range has a higher minimum flow rate and lower maximum flow rate than the thermal (recuperative) incinerators (i.e., 2,000 vs. 500 scfm and 25,000 vs. 50,000 scfm, respectively) for commercially available packaged units. The limited availability of small packaged catalytic units limits their appropriateness for low flow-rate streams such as those model unit streams characterizing distillation process vent streams. Because of this and the potential for catalyst fouling by chlorine and other compounds in the waste stream, catalytic incineration was not included as a control device in this environmental and cost impacts analysis. However, catalytic incineration may be applicable for control of some waste management unit process vent streams, and this alternative can be examined on a case-by-case basis.

The emission reduction and cost analyses also include the option of venting the waste management unit process vent to an existing, in-use control device at the facility. Because the flow rates associated with the distillation-type process vents are low (e.g., <10 scfm), control devices such as fixed-bed carbon adsorption units, condensers, and incinerators would require only marginal excess capacity to accommodate introduction of the process vent stream. For the high flow-rate process vent streams (i.e., >2,000 scfm), the use of an existing, in-use control device such as a condenser or carbon adsorber is less likely. However, these streams are low organic concentration and consist principally of air; as a result, they can be used to substitute for auxiliary air in existing incinerators, boilers, or process heaters.

4.3 CONTROL COSTS

The capital and operating costs presented below include basic installed equipment costs and minimum expected operation and maintenance costs, which include operating labor requirements. Other direct or indirect costs associated with control of organic emissions from waste management unit process vent streams may be applicable depending on site-specific conditions. The following general assumptions were made in determining control costs:

- All costs are presented in second-quarter 1989 dollars.
- Electricity, gas, and water are readily available.
- The site is readily accessible by road or railway.
- No civil engineering work is required.
- Closed-vent system (i.e., piping and ductwork) and control devices are dedicated units (i.e., each device serves a single process vent stream and is not used to control other air pollution sources).
- A net salvage value determined by the heating value for the recovered organics is credited in computing the condenser and regenerable carbon adsorption system control costs.
- There is no salvage value for the used equipment at end of service life.

Except where noted, the following items were not included in the cost estimates:

- Design, engineering, and contingencies
- Treatability studies or pilot-scale testing
- Site work
- Installation of utility lines
- Storage tanks, auxiliary equipment, and supplies
- Heating of vent stream
- Ambient air monitoring.

4.3.1 Condensation

The control costs for the 95-percent level of control for the model unit cases that involve the use of condensers for organic emission control were estimated using a chemical engineering process simulator known as ASPEN (Advanced System for Process Engineering).[10] The chemical constituents and operating conditions that were used in the ASPEN runs are provided in Table 4-3 together with the condenser efficiencies that were calculated. The ASPEN condenser configuration consisted of (1) a floating-head, one-pass, shell-and-tube heat exchanger; (2) a refrigeration unit capable of producing chilled brine at a temperature of -29 °C (-20 °F); and (3) an optional primary water-cooled heat exchanger. The design of an optimum condenser system for a given emission control application requires the selection of a combination of equipment and operating conditions that will satisfy emission control requirements at minimum total annual cost. A change that reduces the cost of one element (e.g., condenser size) must often be balanced against the effect it has on other costs (e.g., refrigeration requirements). In this design effort, the cooling temperature of -29 °C (-20 °F) was set in ASPEN, and the heat exchanger size was allowed to vary. Lower coolant temperatures were not examined; chilled brine can be used down to -34 °C (-30 °F), and direct-expansion coolants such as chlorofluorocarbons can be used at temperatures below -34 °C (-30 °F). The final item, the water-cooled heat exchanger, is

TABLE 4-3. CONDENSER OPERATING CONDITIONS USED IN COST ANALYSIS AND CONDENSER CONTROL EFFICIENCIES PREDICTED FOR MODEL UNIT CASES

Case No.	Total flow, scfm	Inlet organic flow rate, Mg/yr	(lb/h)	Constituent	Condenser[a] efficiency, %	Emission reduction, Mg/yr
1	8.3	0.76	(0.40)	ME CHL	NC	0.0
2	8.3	0.76	(0.40)	TOL	45	0.34
3	8.3	0.76	(0.40)	1,1,1-TCE	16	0.12
4	8.3	0.76	(0.40)	MEK	NC	0.0
5	8.3	7.94	(4.20)	ME CHL	NC	0.0
6	8.3	7.94	(4.20)	TOL	95	7.54
7	8.3	7.94	(4.20)	1,1,1-TCE	95	7.54
8	8.3	7.94	(4.20)	MEK	87	6.91
9	8.3	20.04	(10.60)	ME CHL	44	8.82
10	8.3	20.04	(10.60)	TOL	98	19.63
11	8.3	20.04	(10.60)	1,1,1-TCE	97	19.44
12	8.3	20.04	(10.60)	MEK	95	19.04
13	1.2	0.16	(0.17)	ME CHL	NC	0.0
14	1.2	0.16	(0.17)	TOL	82	0.13
15	1.2	0.16	(0.17)	1,1,1-TCE	72	0.12
16	1.2	0.16	(0.17)	MEK	50	0.08
17	1.2	0.40	(0.42)	ME CHL	NC	0.0
18	1.2	0.40	(0.42)	TOL	82	0.33
19	1.2	0.40	(0.42)	1,1,1-TCE	89	0.36
20	1.2	0.40	(0.42)	MEK	80	0.32
21	1.2	1.13	(1.20)	ME CHL	26	0.29
22	1.2	1.13	(1.20)	TOL	97	1.10
23	1.2	1.13	(1.20)	1,1,1-TCE	96	1.08
24	1.2	1.13	(1.20)	MEK	95	1.07
25	1.2	4.73	(5.00)	ME CHL	87	4.12
26	1.2	4.73	(5.00)	TOL	98	4.64
27	1.2	4.73	(5.00)	1,1,1-TCE	98	4.64
28	1.2	4.73	(5.00)	MEK	98	4.64
29	0.6	0.08	(0.08)	ME CHL	NC	0.0
30	0.6	0.08	(0.08)	TOL	80	0.06
31	0.6	0.08	(0.08)	1,1,1-TCE	70	0.06
32	0.6	0.08	(0.08)	MEK	47	0.04
33	0.6	0.23	(0.24)	ME CHL	NC	0.0
34	0.6	0.23	(0.24)	TOL	95	0.23
35	0.6	0.23	(0.24)	1,1,1-TCE	90	0.22
36	0.6	0.23	(0.24)	MEK	83	0.19
37	0.6	0.95	(1.00)	ME CHL	58	0.55
38	0.6	0.95	(1.00)	TOL	98	0.93
39	0.6	0.95	(1.00)	1,1,1-TCE	98	0.93
40	0.6	0.95	(1.00)	MEK	96	0.92
41	26.0	13.24	(7.00)	TOL	95	12.58
42	26.0	13.24	(7.00)	MEK	95	12.58
43	26.0	13.24	(7.00)	1,1,1-TCE	95	12.58

ME CHL = Methylene chloride.
MEK = Methyl ethyl ketone.
NC = Neglible condensation achieved.
1,1,1-TCE = 1,1,1-Trichloroethane.
TOL = Toluene

[a] The condenser configuration consisted of a floating-head, one-pass, shell-and-tube exchanger and a refrigeration unit capable of producing chilled brine at a temperature of -29 °C (-20 °F).

necessary in some instances of volatile organic condensation to reduce the size of the refrigeration unit or to remove water vapor and avoid freezing problems. In this design effort, removal of water vapor prior to organics condensation is included to prevent ice buildup on heat transfer surfaces.

The ASPEN's cost correlation for heat exchangers, developed originally for plant-scale processes, does not extend to the low flows examined for distillation-type waste management unit process vents. Therefore, vendor quotes for condenser costs were added to the ASPEN to allow cost scaling by condenser area for the low-flow cases (i.e., the distillation-type vents, Model Unit Case Nos. 1 through 43). Model Unit Case Nos. 44 through 71 were not examined because of the low organic concentrations in the vent streams.

As shown in Table 4-3, in only 18 of the 43 model unit cases examined was a removal efficiency of 95 percent achievable at the condenser conditions examined (i.e., a coolant temperature of -29 °C [-20 °F]). Figure 4-1 presents a graphic comparison of achievable condenser efficiencies versus vent gas concentration for the four chemical constituents analyzed at the selected condenser operating conditions. This illustrates the point, made previously in the Chapter 3.0 discussion on condensers, that condensation is not universally applicable to all waste management unit process vents. Again, this is because the efficiency of vent condensers depends on the physical properties of the organics being condensed, the organic concentration in the vent stream, and the operating temperature of the condenser. It should also be pointed out that other condenser designs may achieve different efficiencies than those reported in this analysis. For example, if a coolant temperature of -34 °C (-30 °F) or less had been used instead of -29 °C [-20 °F], slightly higher efficiencies might have been attained for some of the model unit cases, but capital and operating costs would have increased significantly.

4.3.1.1 Condenser Capital Costs.[11] The design condenser area, as calculated by ASPEN, is used in estimating capital costs. A 25-percent overdesign factor was added to the calculated (theoretical) condenser area to determine the base equipment cost. Instrumentation costs were estimated at 10 percent of the base equipment cost. Sales tax and freight were

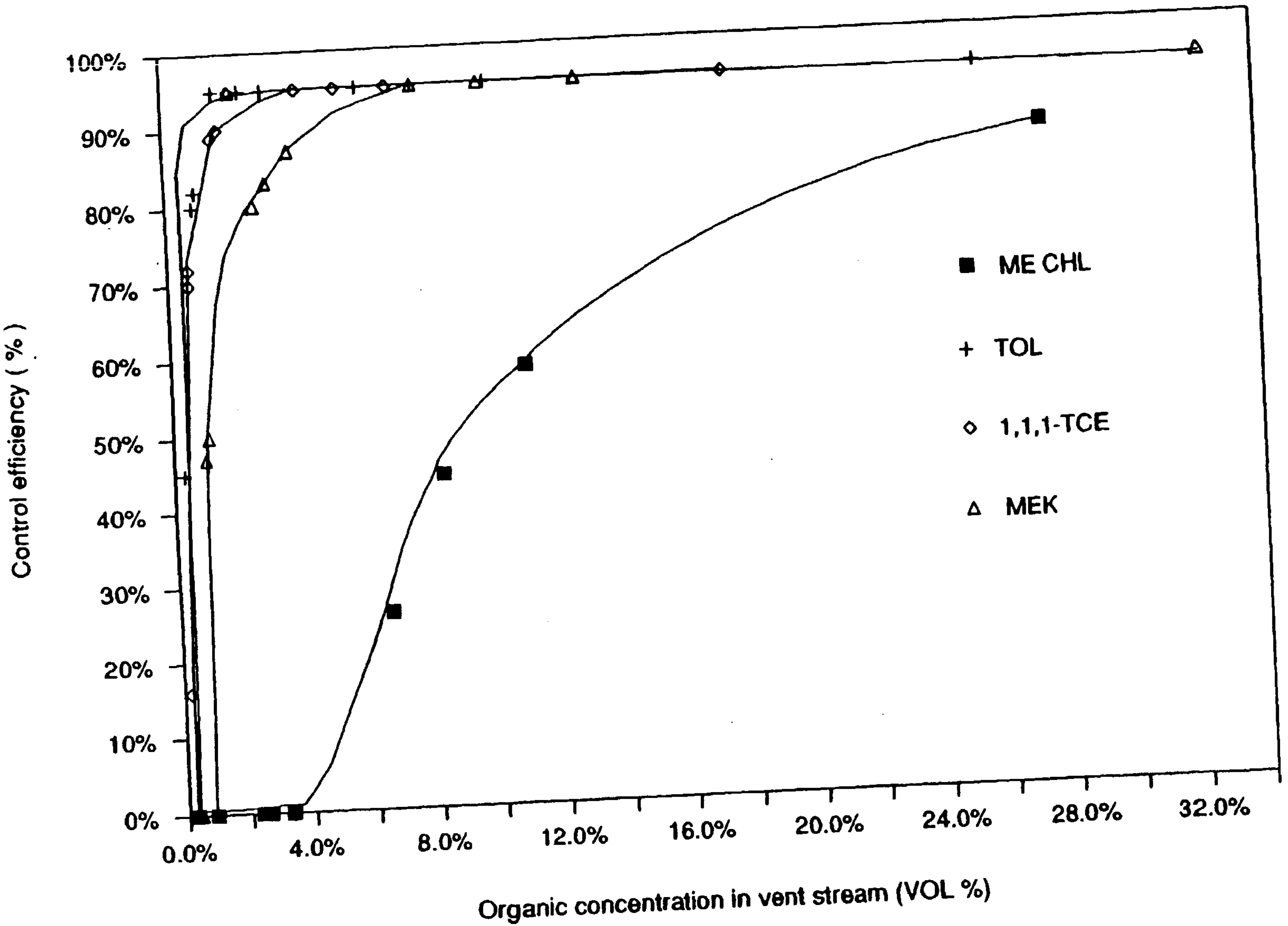

Figure 4-1. Condenser efficiency for distillation-type process vents as a function of organic concentration (Note: Condenser operating at a coolant temperature of -20°F.)

estimated at 8 percent of base equipment cost plus instrumentation costs. The purchased equipment cost was determined as the sum of the base equipment cost, instrumentation costs, sales tax, and freight. Total installation costs were estimated at 67 percent of the purchased equipment cost. Total capital investment for the condensers was calculated as purchase cost plus installation cost. The total capital investment, total annualized cost, and cost effectiveness (i.e., $/Mg of organic controlled) for this control technology alternative are presented in Table 4-4.

4.3.1.2 Condenser Annualized Costs.[12,13] The total annualized costs are the sum of the annual operating costs and the capital recovery costs. Annual operating costs consist of costs for electricity, labor, supervisory labor, labor overhead, taxes, insurance, administration, and maintenance parts. Capital recovery costs are calculated by multiplying total capital costs by the capital recovery factor of 0.16275 (10-percent capital recovery for a 10-year service life).

The procedures and assumptions used by the ASPEN condenser design and costing algorithm in calculating the annual operating costs are described below. Electricity costs are calculated by multiplying the estimated electricity use by the price of electricity. Annual labor costs are calculated by multiplying the number of labor hours required by the labor wage rate. Supervisory (and administrative) labor is estimated at 15 percent of operating (or direct) labor costs. Total annual maintenance costs, including maintenance materials and maintenance labor, are estimated at 3 percent of total capital investment. Labor overhead equals 60 percent of the total of operating, supervisory, and maintenance labor. Finally, total annual labor costs equal the sum of operating (direct) labor, supervisory/administrative labor, maintenance labor, and labor overhead. The annual cost of taxes, insurance, and administration equals 4 percent of total capital investment. In addition, recovery credits are provided for the value of recovered organics captured by condensation using the net salvage value (i.e., heating value) of the recovered organics.

4.3.2 Carbon Adsorption

Carbon adsorption was also examined as the control technology for the emission reduction and cost analysis for the 95-percent organic reduction

TABLE 4-4. SUMMARY CONTROL COSTS FOR CONDENSER CONTROL ALTERNATIVE

Case No.	Vent class	Emission rate, lb/h	Constituent	Control device efficiency, %	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[a] $/Mg
1	D	0.40	ME CHI	NC	0.0	--	--	--
2	D	0.40	TOL	45	0.34	5,670	3,070	9,030
3	D	0.40	1,1,1-TCE	16	0.12	5,550	3,150	26,250
4	D	0.40	MEK	NC	0.0	--	--	--
5	D	4.20	ME CHI	NC	0.0	--	--	--
6	D	4.20	TOL	95	7.54	8,480	450	60
7	D	4.20	1,1,1-TCE	95	7.54	7,510	240	30
8	D	4.20	MEK	87	6.91	8,800	810	120
9	D	10.60	ME CHI	44	8.82	8,340	(150)	(20)
10	D	10.60	TOL	98	19.63	12,090	(4,190)	(210)
11	D	10.60	1,1,1-TCE	97	19.44	10,240	(4,520)	(230)
12	D	10.60	MEK	95	19.04	13,180	(3,700)	(190)
13	D	0.17	ME CHI	NC	0.0	--	--	--
14	D	0.17	TOL	82	0.13	2,040	2,380	18,310
15	D	0.17	1,1,1-TCE	72	0.12	1,940	2,360	19,670
16	D	0.17	MEK	50	0.08	1,990	2,390	29,880
17	D	0.42	ME CHI	NC	0.0	--	--	--
18	D	0.42	TOL	82	0.33	2,040	2,290	6,940
19	D	0.42	1,1,1-TCE	89	0.36	2,220	2,310	6,420
20	D	0.42	MEK	80	0.32	2,480	2,390	7,470
21	D	1.20	ME CHI	26	0.29	2,250	2,350	8,100
22	D	1.20	TOL	97	1.10	3,460	2,250	2,050
23	D	1.20	1,1,1-TCE	96	1.08	2,960	2,150	1,990
24	D	1.20	MEK	95	1.07	3,690	2,320	2,170
25	D	5.00	ME CHI	87	4.12	5,690	1,380	330
26	D	5.00	TOL	98	4.64	5,840	1,180	250
27	D	5.00	1,1,1-TCE	98	4.64	4,900	980	210
28	D	5.00	MEK	98	4.64	7,040	1,440	310
29	D	0.08	ME CHI	NC	0.0	--	--	--

(continued)

TABLE 4-4 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Control device efficiency, %	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[a] $/Mg
30	D	0.08	TOL	80	0.06	1,370	2,250	37,500
31	D	0.08	1,1,1-TCE	70	0.06	1,300	2,240	37,330
32	D	0.08	MEK	47	0.04	1,340	2,260	56,500
33	D	0.24	ME CHI	NC	0.0	--	--	--
34	D	0.24	TOL	95	0.23	1,710	2,260	9,830
35	D	0.24	1,1,1-TCE	90	0.22	1,540	2,220	10,090
36	D	0.24	MEK	83	0.19	1,740	2,280	12,000
37	D	1.00	ME CHI	58	0.55	2,130	2,200	4,000
38	D	1.00	TOL	98	0.93	2,710	2,150	2,310
39	D	1.00	1,1,1-TCE	98	0.93	2,410	2,100	2,260
40	D	1.00	MEK	96	0.92	3,140	2,260	2,460
41	D	7.00	TOL	95	12.58	4,320	(3,540)	(280)
42	D	7.00	MEK	95	12.58	3,750	(3,770)	(300)
43	D	7.00	1,1,1-TCE	95	12.58	2,950	(4,050)	(320)
44	A	0.10	TCE	NA	NA			
45	A	0.50	TCE	NA	NA			
46	A	1.50	TCE	NA	NA			
47	A	5.00	TCE	NA	NA			
48	A	0.10	DCE	NA	NA			
49	A	0.50	DCE	NA	NA			
50	A	1.50	DCE	NA	NA			
51	A	5.00	DCE	NA	NA			
52	A	0.10	EDC	NA	NA			
53	A	0.50	EDC	NA	NA			
54	A	1.50	EDC	NA	NA			
55	A	5.00	EDC	NA	NA			
56	A	0.10	TCE	NA	NA			
57	A	10.00	TCE	NA	NA			
58	A	0.10	DCE	NA	NA			
59	A	10.00	DCE	NA	NA			

(continued)

TABLE 4-4 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Control device efficiency, %	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[a] $/Mg
60	A	0.10	EDC	NA	NA			
61	A	1.50	EDC	NA	NA			
62	A	10.00	EDC	NA	NA			
63	A	0.50	TCE	NA	NA			
64	A	5.00	TCE	NA	NA			
65	A	10.00	TCE	NA	NA			
66	A	0.50	DCE	NA	NA			
67	A	5.00	DCE	NA	NA			
68	A	10.00	DCE	NA	NA			
69	A	0.50	EDC	NA	NA			
70	A	5.00	EDC	NA	NA			
71	A	10.00	EDC	NA	NA			

A = Air-stripper-type vents (i.e., high flow rates).
D = Distillation-type vents (i.e., low flow rates).
ME CHl = Methylene chloride.
DCE = Dichloroethylene.
EDC = 1,2-Dichloroethane.
MEK = Methyl ethyl ketone.
TOL = Toluene.
1,1,1-TCE = 1,1,1-Trichloroethane.
TCE = Trichloroethylene.
TCI = Total capital investment in second-quarter 1989 dollars.
TAC = Total annualized costs in second-quarter 1989 dollars per year; includes a credit for recovered organics.
NC = Negligible condensation.
NA = Not appropriate; condensation was not considered an appropriate or feasible control technology for the model unit vent stream.

[a] Cost effectiveness = TAC/emission reduction.

Source: Massachusetts Institute of Technology. ASPEN Technical Reference Manual. Volume 2. DOE/MC/16481-1202. DE82020201. Cambridge, MA. May 1982.

or control efficiency. Carbon adsorption costs were estimated using EPA's OAQPS Control Cost Manual (OCCM) (EPA 450/3-90-006, January 1990)[14] together with vendor price quotations. Carbon adsorption system costs were obtained from two leading manufacturers for both regenerative and nonregenerative carbon systems based on the model unit parameters such as volumetric flow rate and organic emission rate. These vendor costs were used for comparison with the costs estimated using the cost manual as a test for reasonableness.

When treating low organic concentration process vent streams with carbon adsorption technology, consideration must be given to the type of system required. Carbon adsorbers that make one-time use of the carbon (i.e., nonregenerative systems) or carbon adsorbers that regenerate the carbon onsite for reuse can have cost and/or technical advantages depending on the vent stream conditions. The organic concentration and flow rate where nonregenerative carbon use becomes preferable to a regenerative system on technical and economic grounds is very situation-specific. The information presented in this document is therefore a generalization, and specific comparisons are good only for the stated conditions.

The regenerative unit is fully automated and generally has low operating costs (mostly utilities); however, regenerative systems have a much higher initial capital cost and therefore incur large fixed costs due to capital recovery, maintenance, taxes, and insurance. On the other hand, the nonregenerative unit has a low initial capital cost, but high operating costs for carbon replacement or offsite carbon regeneration. In each case, the total annualized costs for each type of system (regenerative or nonregenerative) were compared to determine whether a regenerative or nonregenerative system should be used in the analysis. The system with the lowest total annualized cost is presented in the analysis results.

4.3.2.1 Carbon Adsorption Capital Costs.[15,16] The capital cost for a carbon adsorber is a function of the volumetric flow rate, the type and mass emission rate of the pollutant, the length of the adsorption and regeneration cycles, and the adsorption capacity of the carbon at operating conditions. Capital costs for the regenerative carbon system include the carbon tanks (two or three depending on stream conditions), carbon, fans, ductwork, organic vapor monitor, steam boiler, and air compressor. Capital costs for nonregenerative systems include ductwork, fans, organic vapor monitor, and carbon exchange setup charges (i.e., replacement contract charges). Equipment installation is also included as a percentage (i.e., 67 percent) of the purchased equipment costs. The total capital investment, total annualized cost, and cost effectiveness (i.e., \$/Mg of organic controlled) for this control technology alternative are presented in Table 4-5.

4.3.2.2 Carbon Adsorption Annualized Costs.[17,18] The annual operating costs for carbon adsorbers were estimated as follows. Utility costs were estimated using the equations in the OCCM. Maintenance labor was estimated at 0.5 h per shift at a cost of \$13.20/h, and maintenance materials were estimated at 100 percent of maintenance labor. Taxes and insurance and administration were each estimated at 2 percent of total capital cost (a total of 4 percent). Operating labor was estimated at 1 h/d at \$20/h (including labor overhead charges). Steam costs are calculated at 0.5 lb of steam required to strip 1.0 lb of carbon at a cost of \$6/1,000 lb of steam. Capital recovery costs are calculated by multiplying total capital costs by the capital recovery factor of 0.16275 (10 percent for 10 years). Carbon costs for nonregenerative systems are calculated using the working capacity of carbon for each constituent, the organic flow rate, and an average carbon cost of about \$2/lb (exchange cost).

4.3.3 Thermal Incineration

The cost analysis for the 98-percent level of control is based on the use of thermal incineration as the control technology for each waste management process vent model unit case. Catalytic incinerators and flares can also achieve 98-percent control but are not recommended for halogenated streams because such streams may cause corrosion, fouling, or scaling problems, significantly shortening the life of the control device or greatly increasing operating costs. Five of the seven constituents specified for the model unit cases are halogenated; therefore, thermal incinerators rather than catalytic incinerators are costed for the model

TABLE 4-6. SUMMARY CONTROL COSTS FOR CARBON ADSORPTION CONTROL ALTERNATIVE

Case No.	Vent class	Emission rate, lb/h	Constituent	Carbon system	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[a] $/Mg
1	D	0.40	ME CHI	N	0.72	1,180	19,870	27,650
2	D	0.40	TOL	N	0.72	1,180	26,730	37,200
3	D	0.40	1,1,1-TCE	N	0.72	1,180	14,290	19,890
4	D	0.40	MEK	N	0.72	1,180	24,410	33,970
5	D	4.20	ME CHI	R	7.54	227,000	69,810	9,260
6	D	4.20	TOL	R	7.54	227,000	69,810	9,260
7	D	4.20	1,1,1-TCE	R	7.54	227,000	69,810	9,260
8	D	4.20	MEK	R	7.54	227,000	69,810	9,260
9	D	10.60	ME CHI	R	19.04	217,000	62,430	3,280
10	D	10.60	TOL	R	19.04	217,000	62,430	3,280
11	D	10.60	1,1,1-TCE	R	19.04	217,000	62,430	3,280
12	D	10.60	MEK	R	19.04	217,000	62,430	3,280
13	D	0.17	ME CHI	N	0.15	1,180	8,440	55,280
14	D	0.17	TOL	N	0.15	1,180	11,360	74,400
15	D	0.17	1,1,1-TCE	N	0.15	1,180	6,070	39,750
16	D	0.17	MEK	N	0.15	1,180	10,370	67,910
17	D	0.42	ME CHI	N	0.38	1,180	20,770	55,060
18	D	0.42	TOL	N	0.38	1,180	28,070	74,410
19	D	0.42	1,1,1-TCE	N	0.38	1,180	14,180	37,590
20	D	0.42	MEK	N	0.38	1,180	26,250	69,590
21	D	1.20	ME CHI	R	1.08	218,000	66,910	61,950
22	D	1.20	TOL	R	1.08	218,000	66,910	61,950
23	D	1.20	1,1,1-TCE	R	1.08	218,000	66,910	61,950
24	D	1.20	MEK	R	1.08	218,000	66,910	61,950
25	D	5.00	ME CHI	R	4.49	226,000	67,380	15,010
26	D	5.00	TOL	R	4.49	226,000	67,380	15,010
27	D	5.00	1,1,1-TCE	R	4.49	226,000	67,380	15,010
28	D	5.00	MEK	R	4.49	226,000	67,380	15,010
29	D	0.08	ME CHI	N	0.07	1,180	3,970	55,250

(continued)

TABLE 4-6 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Carbon system	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[a] $/Mg
30	D	0.08	TOL	N	0.07	1,180	5,340	74,320
31	D	0.08	1,1,1-TCE	N	0.07	1,180	2,880	39,800
32	D	0.08	MEK	N	0.07	1,180	4,880	67,910
33	D	0.24	ME CHI	N	0.22	1,180	11,990	56,620
34	D	0.24	TOL	N	0.22	1,180	16,040	72,900
35	D	0.24	1,1,1-TCE	N	0.22	1,180	9,050	41,980
36	D	0.24	MEK	N	0.22	1,180	14,930	69,260
37	D	1.00	ME CHI	R	0.90	219,000	65,200	72,440
38	D	1.00	TOL	R	0.90	219,000	65,200	72,440
39	D	1.00	1,1,1-TCE	R	0.90	219,000	65,200	72,440
40	D	1.00	MEK	R	0.90	219,000	65,200	72,440
41	D	7.00	TOL	R	12.57	216,000	65,040	5,170
42	D	7.00	MEK	R	12.57	216,000	65,040	5,170
43	D	7.00	1,1,1-TCE	R	12.57	216,000	65,040	5,170
44	A	0.10	TCE	R	0.38	216,000	85,730	225,600
45	A	0.50	TCE	R	1.89	216,000	85,050	45,000
46	A	1.50	TCE	R	5.67	216,000	83,450	14,700
47	A	5.00	TCE	R	18.91	214,000	77,400	4,100
48	A	0.10	DCE	R	0.38	216,000	85,730	225,600
49	A	0.50	DCE	R	1.89	216,000	85,050	45,000
50	A	1.50	DCE	R	5.67	216,000	83,450	14,700
51	A	5.00	DCE	R	18.91	214,000	77,400	4,100
52	A	0.10	EDC	R	0.38	216,000	85,730	225,600
53	A	0.50	EDC	R	1.89	216,000	85,050	45,000
54	A	1.50	EDC	R	5.67	216,000	83,450	14,700
55	A	5.00	EDC	R	18.91	214,000	77,400	4,100
56	A	0.10	TCE	R	0.38	292,200	101,830	268,000
57	A	10.00	TCE	R	37.83	289,000	85,980	2,300
58	A	0.10	DCE	R	0.38	292,200	101,830	268,000
59	A	10.00	DCE	R	37.83	289,000	85,980	2,300

(continued)

TABLE 4-5 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Carbon system	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[a] $/Mg
60	A	0.10	EDC	R	0.38	292,200	101,830	268,000
61	A	1.50	EDC	R	5.67	291,000	99,450	17,500
62	A	10.00	EDC	R	37.83	289,000	85,980	2,300
63	A	0.50	TCE	R	1.89	445,000	141,150	74,700
64	A	5.00	TCE	R	18.91	460,000	137,500	7,300
65	A	10.00	TCE	R	37.83	460,000	128,980	3,400
66	A	0.50	DCE	R	1.89	445,000	141,150	74,700
67	A	5.00	DCE	R	18.91	460,000	137,500	7,300
68	A	10.00	DCE	R	37.83	460,000	128,980	3,400
69	A	0.50	EDC	R	1.89	445,000	141,150	74,700
70	A	5.00	EDC	R	18.91	460,000	137,500	7,300
71	A	10.00	EDC	R	37.83	460,000	128,980	3,400

A = Air-stripper-type vents (i.e., high flow rates).
D = Distillation-type vents (i.e., low flow rates).
ME CHI = Methylene chloride.
DCE = Dichloroethylene.
EDC = 1,2-Dichloroethane.
N = Nonregenerable carbon absorption system (e.g., carbon canisters).
MEK = Methyl ethyl ketone.
R = Regenerable, fixed-bed carbon adsorption system.
TOL = Toluene.
1,1,1-TCE = 1,1,1-Trichloroethane.
TCE = Trichloroethylene.
TCI = Total capital investment in second-quarter 1989 dollars.
TAC = Total annualized costs in second-quarter 1989 dollars per year.

[a] Cost effectiveness = TAC/emission reduction.

Note: The technical feasibility of using regenerable carbon adsorption systems for control of very low concentration streams is uncertain; the concentration at which regenerative systems are not considered to be technically feasible (i.e., capable of achieving the desired control efficiency) depends on the hydrocarbon being adsorbed and the flow rate, temperature, and relative humidity of the stream fed to the adsorber.

Source: U.S. Environmental Protection Agency, OAQPS Control Cost Manual. Fourth Ed. Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-90-006. January 1990.

unit cases to put the costs on a common basis. The total capital investment, total annualized cost, and cost effectiveness for those model unit cases for which a 95-percent or greater destruction efficiency is estimated to be achievable are presented in Table 4-6.

The background information document (BID) for the proposed standards for distillation operations in the Synthetic Organic Chemical Manufacturing Industry (SOCMI)[19] presents a series of capital cost equations that include purchase costs and installation costs for thermal incinerators, recuperative heat exchangers, ductwork, fans, and stacks and support structures for the ductwork. Equations are available for two incineration temperatures, 870 °C (1,600 °F) and 1,100 °C (2,000 °F), for application to either halogenated or nonhalogenated streams. For halogenated streams, the purchase and installation costs of waste heat boilers and flue gas scrubbers are also included. The equations use capital cost data obtained from vendor quotations. Heat and material balance also are analyzed to estimate annualized costs for incinerators and incinerator/scrubber systems. A FORTRAN computer program (the SOCMI incinerator/flare costing algorithm), which incorporates the incinerator cost equations, was used to generate both capital and annualized cost estimates for the model unit vent streams. The general design specifications that serve as the basis for the cost estimates are presented in Table 4-7.

The main data input file to the SOCMI incinerator/flare costing algorithm that was used to estimate thermal incineration costs included information on each process vent model unit case. The required information included vent stream flow rate (scfm), vent stream heating value (Btu/scf), organic flow rate (lb/h), halogenation status (halogenated or nonhalogenated), and stream molecular weight (lb/lb-mol). Table 4-1 lists vent stream flow rate, organic flow rate, and constituent for each model unit case examined in the analysis. The heat of combustion of each constituent also was needed to calculate vent stream heating value. Table 4-2 presents the heat of combustion for each of the seven constituents used in the model unit cases. In calculating each stream molecular weight, it was assumed that the nonorganic portion of each stream was air.

TABLE 4-6. SUMMARY CONTROL COSTS FOR THERMAL INCINERATION CONTROL ALTERNATIVE[a]

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[b] $/Mg
1	D	0.40	ME CHI	NA	--	--	--
2	D	0.40	TOL	NA	--	--	--
3	D	0.40	1,1,1-TCE	NA	--	--	--
4	D	0.40	MEK	NA	--	--	--
5	D	4.20	ME CHI	7.65	1,319,530	600,060	78,440
6	D	4.20	TOL	7.63	464,850	205,280	26,900
7	D	4.20	1,1,1-TCE	7.78	1,319,530	600,030	77,100
8	D	4.20	MEK	7.70	464,850	205,570	26,700
9	D	10.60	ME CHI	19.64	1,319,530	599,860	30,540
10	D	10.60	TOL	19.64	464,850	203,070	10,340
11	D	10.60	1,1,1-TCE	19.59	1,319,530	599,780	30,620
12	D	10.60	MEK	19.64	464,850	203,810	10,380
13	D	0.17	ME CHI	NA	--	--	--
14	D	0.17	TOL	NA	--	--	--
15	D	0.17	1,1,1-TCE	NA	--	--	--
16	D	0.17	MEK	NA	--	--	--
17	D	0.42	ME CHI	NA	--	--	--
18	D	0.42	TOL	NA	--	--	--
19	D	0.42	1,1,1-TCE	NA	--	--	--
20	D	0.42	MEK	NA	--	--	--
21	D	1.20	ME CHI	NA	--	--	--
22	D	1.20	TOL	NA	--	--	--
23	D	1.20	1,1,1-TCE	NA	--	--	--
24	D	1.20	MEK	NA	--	--	--
25	D	5.00	ME CHI	4.59	1,319,530	525,460	114,480
26	D	5.00	TOL	4.57	464,850	201,750	44,150
27	D	5.00	1,1,1-TCE	4.50	1,319,530	525,440	116,760
28	D	5.00	MEK	4.61	464,850	201,930	43,860
29	D	0.08	ME CHI	NA	--	--	--

(continued)

TABLE 4-6 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[b] $/Mg
30	D	0.08	TOL	NA	--	--	--
31	D	0.08	1,1,1-TCE	NA	--	--	--
32	D	0.08	MEK	NA	--	--	--
33	D	0.24	ME CHI	NA	--	--	--
34	D	0.24	TOL	NA	--	--	--
35	D	0.24	1,1,1-TCE	NA	--	--	--
36	D	0.24	MEK	NA	--	--	--
37	D	1.00	ME CHI	NA	--	--	--
38	D	1.00	TOL	NA	--	--	--
39	D	1.00	1,1,1-TCE	NA	--	--	--
40	D	1.00	MEK	NA	--	--	--
41	D	7.00	TOL	12.93	464,850	204,310	15,800
42	D	7.00	MEK	12.97	464,850	204,800	15,790
43	D	7.00	1,1,1-TCE	12.79	1,319,530	599,920	46,900
44	A	0.10	TCE	NA	--	--	--
45	A	0.50	TCE	NA	--	--	--
46	A	1.50	TCE	NA	--	--	--
47	A	5.00	TCE	NA	--	--	--
48	A	0.10	DCE	NA	--	--	--
49	A	0.50	DCE	NA	--	--	--
50	A	1.50	DCE	NA	--	--	--
51	A	5.00	DCE	NA	--	--	--
52	A	0.10	EDC	NA	--	--	--
53	A	0.50	EDC	NA	--	--	--
54	A	1.50	EDC	NA	--	--	--
55	A	5.00	EDC	NA	--	--	--
56	A	0.10	TCE	NA	--	--	--
57	A	10.00	TCE	NA	--	--	--
58	A	0.10	DCE	NA	--	--	--
59	A	10.00	DCE	NA	--	--	--

(continued)

TABLE 4-6 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr	Cost effectiveness,[b] $/Mg
60	A	0.10	EDC	NA	--	--	--
61	A	1.50	EDC	NA	--	--	--
62	A	10.00	EDC	NA	--	--	--
63	A	0.50	TCE	NA	--	--	--
64	A	5.00	TCE	NA	--	--	--
65	A	10.00	TCE	NA	--	--	--
66	A	0.50	DCE	NA	--	--	--
67	A	5.00	DCE	NA	--	--	--
68	A	10.00	DCE	NA	--	--	--
69	A	0.50	EDC	NA	--	--	--
70	A	5.00	EDC	NA	--	--	--
71	A	10.00	EDC	NA	--	--	--

A = Air-stripper-type vents (i.e., high flow rates).
D = Distillation-type vents (i.e., low flow rates).
DCE = Dichloroethylene.
EDC = 1,2-Dichloroethane.
ME CHl = Methylene chloride.
MEK = Methyl ethyl ketone.
NA = Not appropriate because of low vent stream volumetric flow rate or low vent stream organic content.
TAC = Total annualized costs in second-quarter 1989 dollars per year.
1,1,1-TCE = 1,1,1-Trichloroethane.
TCE = Trichloroethylene.
TCI = Total capital investment in second-quarter 1989 dollars.
TOL = Toluene.

[a] In all cases, the control device analyzed is a thermal incinerator, estimated to attain at least a 95-percent destruction efficiency.

[b] Cost effectiveness = TAC/emission reduction.

Source: U.S. Environmental Protection Agency. The SOCMI Incinerator/Flare Costing Algorithm. Distillation Operations in Synthetic Organic Chemical Manufacturing--Background Information for Proposed Standards. Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-83-005a. December 1983.

TABLE 4-7. INCINERATOR GENERAL DESIGN SPECIFICATIONS

Item	Specification
Emission control efficiency	98-percent destruction
Minimum incinerator volume[a]	1.01 m^3 (35.7 ft^3)
Incineration temperature	
• Low-temperature incineration	870 °C (1,600 °F)
• High-temperature incineration[b]	1,100 °C (2,000 °F)
Furnace residence times	
• Low-temperature incineration	0.75 s
• High-temperature incineration	1.00 s
Primary fuel requirement	Fuel required to maintain incinerator temperature with 18 percent excess air
Supplemental fuel requirement (h = vent stream heating value in MJ/Nm^3 (Btu/scf)	Required for flame stability
• $0 \leq h < 1.9$ ($0 < h < 50$)	Add 0.38 MJ/Nm^3 (10 Btu/scf)
• $1.9 < h < 3.7$ ($50 < h < 100$)	Add 10 percent of stream heating value
• $h \geq 3.7$ ($h \geq 100$)	No supplemental fuel required
Recuperative heat exchanger	Not applicable when vent stream heating value is sufficient to maintain design incinerator temperature
• Overall heat transfer coefficient	23 $W/m^2 \cdot K$ (4.0 $Btu/h \cdot ft^2 \cdot {}^\circ F$)
Scrubber system	Used when corrosive VOC is present
• Type	Packed tower
• Packing height	11.0 m (36.0 ft)
• Liquid/gas ratio	1,337 L/m^3 (10 gal/scf)
• Gas velocity	0.9 m/s (3.0 ft/s)
• Scrubber gas temperature	100 °C (212 °F)

[a] If calculated incinerator combustion chamber volume is less than 1.0 m^3 (35.7 ft^3), natural gas and air are added to maintain the design temperature and residence time for a 1.01-m^3 (35.7-ft^3) incinerator volume.

[b] Used when corrosive volatile organic compounds (VOC) are present due to the difficulty of achieving complete combustion of corrosive VOC at lower temperatures.

Source: U.S. Environmental Protection Agency. Distillation Operations in Synthetic Organic Chemical Manufacturing--Background Information for Proposed Standards. Office of Air Quality Planning and Standards. Research Triangle Park, NC. Publication No. EPA-450/3-83-005a. December 1983. p. 8-4.

4.3.3.1 Thermal Incineration Capital Costs. The design process vent flow rate is used in estimating capital costs. Packaged, single-unit thermal incinerators typically can be built to control streams with flow rates up to about 24 Nm^3 (50,000 scfm). Therefore, the number of incinerators required to destroy the vent gas organics is calculated by dividing the design flow rate by the maximum size incinerator flow rate. In the SOCMI incinerator/flare costing algorithm, the maximum incinerator flow rate for all halogenated streams equals 50,000 cfm. The maximum incinerator flow rate for nonhalogenated streams with heating values less than or equal to 52,000 Btu/ft^3 is 44,000 cfm. All nonhalogenated streams with heating values greater than 52,000 Btu/ft^3 have a corresponding maximum incinerator flow rate of 50,000 cfm. The greatest model unit flow rate is 16,400 cfm; therefore, none of the process vent model units would require more than one incinerator.

Total capital costs for the incinerators and supporting equipment consist of the sum of incinerator capital costs, additional duct length capital costs, and pipe rack capital costs. Installation costs include such components as foundation, insulation, erection, instruments, painting, electrical, fire protection, engineering, and freight and taxes. Working capital is not included as a cost. Incinerator capital costs are a function of design flow rate and the number of incinerators required. For halogenated streams with flows of less than 700 scfm, a waste heat boiler correction factor is subtracted from total capital costs. Additional duct length capital costs are a function of the number of incinerators, the design flow rate, and the amount of extra duct length. For the process vent model units, it was assumed that no extra duct length was needed. Finally, the pipe rack capital cost is a function of the pipe rack length.

The SOCMI incinerator/flare costing algorithm estimates capital costs for incinerators in December 1979 dollars, for duct in December 1977 dollars, and for pipe rack in 1982 dollars. Appropriate Chemical Engineering[20-23] indexes for chemical industry equipment were used to update the incinerator costs to second quarter 1989, and indexes for pipe, valves, and fittings were used to update the duct and pipe rack costs to second quarter 1989. Incinerator capital costs were scaled up by a factor of 1.4521, duct capital costs by a factor of 1.8188, and pipe rack capital costs by a factor of 1.2213.

Use of the SOCMI algorithm required that costs be scaled over a relatively long time, which has the potential for increasing the uncertainty of the derived values. More recent cost estimating protocols, such as the OCCM, are available for thermal incinerators but do not include the cost of flue gas scrubbers, which, because of the high percentage of chlorinated wastes in the model units, are a necessary part of the incineration system. The requirement for acid-gas scrubbers led to the use of the SOCMI procedure as the vehicle for estimating thermal incineration costs.

A simple test of the SOCMI algorithm as a means of estimating current incineration costs was conducted by using the OCCM to estimate the cost of an incinerator for one of the waste management process vent model units. The costs derived with the OCCM procedure were compared with the incinerator costs, exclusive of scrubber costs, derived with the SOCMI algorithm. The agreement between the two costs was reasonable, which would imply that the SOCMI algorithm generated representative and reasonable costs even though the costs were scaled over a relatively long time. Although the cost comparison is not rigorous and cannot be construed as a verification of the SOCMI algorithm, the good agreement between the two results provides a small measure of increased confidence in the validity of the incineration cost estimates derived from the SOCMI algorithm.

4.3.3.2 Thermal Incineration Annualized Costs. The total annualized costs are the sum of the direct operating and maintenance costs and the annualized capital costs. Direct operating and maintenance costs consist of utilities, labor, supervisory labor, labor overhead, taxes, insurance and administration, and maintenance parts. Utility requirements include electricity (for fans and pumps) and natural gas to supplement the heating value of many vent streams and to maintain the pilot flame. Annualized capital costs are calculated by multiplying total capital costs by the capital recovery factor of 0.16275 (i.e., 10 percent for 10 years).

The procedures and assumptions used in the SOCMI incinerator/flare costing algorithm to calculate the annual operating costs are described as follows. Natural gas costs are determined by multiplying the natural gas price by the amount of natural gas consumed. Similarly, electricity costs are calculated by multiplying electricity use by the price of electricity. Annual labor costs are calculated by multiplying the number of labor hours required per incinerator by the labor wage rate and by the number of incinerators required per vent stream. Supervisory labor is 15 percent of operating labor costs. Maintenance labor is equal to 3 percent of total capital costs. Labor overhead equals 80 percent of the total of operating, supervisory, and maintenance labor. Finally, total annual labor costs equal the sum of operating labor, supervisory labor, maintenance labor, and labor overhead. The annual cost of taxes, insurance, and administration equals 4 percent of total capital costs, and total annual maintenance costs equal 3 percent of total capital costs. The following table presents the cost factors used in calculating the annual operating costs.

Cost component	Cost factor, $	Reference
Natural gas	$3.34/10^9$ joules	24
Electricity	0.0472/kWh	25
Operating labor	14.60/h	26
Water	$1.00/10^3$ gal	27
Caustic soda	0.28/lb	28

In addition to the costs described above, the annual operating costs for incinerators for halogenated vent streams include a heat recovery credit, quench water, scrub water, and neutralization. The heat recovery credit is only applicable for streams with flows exceeding 700 scfm. When the vent stream flow rate exceeds 700 scfm, the heat recovery credit is a function of the operating flow rate and the price of natural gas. The annual costs of both quench and scrub water are a function of the price of water and the operating flow rate. Finally, neutralization costs are a function of the price of caustic and the operating flow rate.

4.3.4 Vent to Existing Control Device

In addition to analyzing the emission reduction and cost impacts based on the purchase and installation of new, dedicated add-on control devices for process vents, the costs for venting the process stream to an existing in-use control device were also estimated. Existing control devices capable of handling waste management process vent emissions include existing condensers, carbon adsorption units, and thermal or catalytic incinerators that have sufficient excess capacity to handle introduction of the vent stream. High flow-rate process vent streams can be substituted for auxiliary air in combustion devices such as incinerators, boilers, and process heaters. Table 4-8 presents the total capital investment, total annualized cost, and cost effectiveness (i.e., $/Mg of organic controlled) for venting to an existing control device.

4.3.4.1 Capital Cost to Vent to Existing Control Device. The capital cost for venting an existing process vent to an existing in-use control device includes the purchase costs and installation costs for vent piping and a flame arrestor. For each process vent model unit, 200 ft of vent piping and one flame arrestor were included; instrumentation costs were not included. The base equipment purchase costs are in second-quarter 1989 dollars. The total capital investment includes sales tax and freight, direct installation costs, and indirect installation costs.

Direct installation costs include foundation and supports, piping, electrical, handling and erection, painting, insulation, and site preparation and buildings. Indirect installation costs include engineering, construction and field expenses, contractor fees, startup and testing, and contingencies.

4.3.4.2 Annualized Cost to Vent to Existing Control Device. The total annualized costs to vent to an existing in-use control device consist of direct operating and maintenance costs and the annualized capital costs. It was assumed that the process vents were going into a negative static pressure header system to the existing control device; therefore, no flow-inducing device (e.g., fan) is necessary. A requirement of 1 h/yr of maintenance labor was estimated at a rate of $13.20/h and the cost of maintenance materials was calculated as 100 percent of the cost of

TABLE 4-8. SUMMARY CONTROL COSTS FOR VENTING TO AN EXISTING CONTROL DEVICE[a]

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr[b]	Cost effectiveness,[b] $/Mg
1	D	0.40	ME CHI	0.74	1,780	390	530
2	D	0.40	TOL	0.74	1,780	390	530
3	D	0.40	1,1,1-TCE	0.74	1,780	390	530
4	D	0.40	MEK	0.74	1,780	390	530
5	D	4.20	ME CHI	7.78	1,780	390	50
6	D	4.20	TOL	7.78	1,780	390	50
7	D	4.20	1,1,1-TCE	7.78	1,780	390	50
8	D	4.20	MEK	7.78	1,780	390	50
9	D	10.60	ME CHI	19.64	1,780	390	20
10	D	10.60	TOL	19.64	1,780	390	20
11	D	10.60	1,1,1-TCE	19.64	1,780	390	20
12	D	10.60	MEK	19.64	1,780	390	20
13	D	0.17	ME CHI	0.16	1,780	390	2,440
14	D	0.17	TOL	0.16	1,780	390	2,440
15	D	0.17	1,1,1-TCE	0.16	1,780	390	2,440
16	D	0.17	MEK	0.16	1,780	390	2,440
17	D	0.42	ME CHI	0.39	1,780	390	1,000
18	D	0.42	TOL	0.39	1,780	390	1,000
19	D	0.42	1,1,1-TCE	0.39	1,780	390	1,000
20	D	0.42	MEK	0.39	1,780	390	1,000
21	D	1.20	ME CHI	1.11	1,780	390	350
22	D	1.20	TOL	1.11	1,780	390	350
23	D	1.20	1,1,1-TCE	1.11	1,780	390	350
24	D	1.20	MEK	1.11	1,780	390	350
25	D	5.00	ME CHI	4.63	1,780	390	85
26	D	5.00	TOL	4.63	1,780	390	85
27	D	5.00	1,1,1-TCE	4.63	1,780	390	85
28	D	5.00	MEK	4.63	1,780	390	85
29	D	0.08	ME CHI	0.07	1,780	390	5,570

(continued)

TABLE 4-8 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr[b]	Cost effectiveness,[b] $/Mg
30	D	0.08	TOL	0.07	1,780	390	5,570
31	D	0.08	1,1,1-TCE	0.07	1,780	390	5,570
32	D	0.08	MEK	0.07	1,780	390	5,570
33	D	0.24	ME CHl	0.22	1,780	390	1,770
34	D	0.24	TOL	0.22	1,780	390	1,770
35	D	0.24	1,1,1-TCE	0.22	1,780	390	1,770
36	D	0.24	MEK	0.22	1,780	390	1,770
37	D	1.00	ME CHl	0.93	1,780	390	420
38	D	1.00	TOL	0.93	1,780	390	420
39	D	1.00	1,1,1-TCE	0.93	1,780	390	420
40	D	1.00	MEK	0.93	1,780	390	420
41	D	7.00	TOL	12.97	1,780	390	30
42	D	7.00	MEK	12.97	1,780	390	30
43	D	7.00	1,1,1-TCE	12.97	1,780	390	30
44	A	0.10	TCE	0.39	1,780	390	1,000
45	A	0.50	TCE	1.95	1,780	390	200
46	A	1.50	TCE	5.85	1,780	390	70
47	A	5.00	TCE	19.51	1,780	390	20
48	A	0.10	DCE	0.39	1,780	390	1,000
49	A	0.50	DCE	1.95	1,780	390	200
50	A	1.50	DCE	5.85	1,780	390	70
51	A	5.00	DCE	19.51	1,780	390	20
52	A	0.10	EDC	0.39	1,780	390	1,000
53	A	0.50	EDC	1.95	1,780	390	200
54	A	1.50	EDC	5.85	1,780	390	70
55	A	5.00	EDC	19.51	1,780	390	20
56	A	0.10	TCE	0.39	1,780	390	1,000
57	A	10.00	TCE	39.02	1,780	390	10
58	A	0.10	DCE	0.39	1,780	390	1,000
59	A	10.00	DCE	39.02	1,780	390	10

(continued)

TABLE 4-8 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	TCI, 1989 $	TAC, $/yr[b]	Cost effectiveness,[b] $/Mg
60	A	0.10	EDC	0.39	1,780	390	1,000
61	A	1.50	EDC	5.85	1,780	390	70
62	A	10.00	EDC	39.02	1,780	390	10
63	A	0.50	TCE	1.95	1,780	390	200
64	A	5.00	TCE	19.51	1,780	390	20
65	A	10.00	TCE	39.02	1,780	390	10
66	A	0.50	DCE	1.95	1,780	390	200
67	A	5.00	DCE	19.51	1,780	390	20
68	A	10.00	DCE	39.02	1,780	390	10
69	A	0.50	EDC	1.95	1,780	390	200
70	A	5.00	EDC	19.51	1,780	390	20
71	A	10.00	EDC	39.02	1,780	390	10

A = Air-stripper-type vents (i.e., high flow rates).
D = Distillation-type vents (i.e., low flow rates).
DCE = Dichloroethylene.
EDC = 1,2-Dichloroethane.
ME CHI = Methylene chloride.
MEK = Methyl ethyl ketone.
TAC = Total annualized costs in second-quarter 1989 dollars per year.
1,1,1-TCE = 1,1,1-Trichloroethane.
TCE = Trichloroethylene.
TCI = Total capital investment in second-quarter 1989 dollars.
TOL = Toluene.

[a] The existing control device could be a thermal or catalytic incinerator, carbon adsorber, boiler, process heater, condenser, or other device that can effectively accommodate addition of the process vent stream.

[b] No heat recovery or organic recovery credit is included.

maintenance labor. Overhead was estimated as 60 percent of the sum of maintenance labor and maintenance materials, and taxes, insurance, and administration costs were estimated as 4 percent of total capital investment. A capital recovery factor of 0.16275 (10 percent for 10 years) was used to calculate annualized capital costs.

4.4 COST EFFECTIVENESS OF CONTROL ALTERNATIVES

The three types of add-on control technologies examined in this chapter provide similar control levels (i.e., 95-percent versus 98-percent control). Therefore, for those facilities that are not covered by or are exempt from State and Federal requirements for control of waste management unit process vent emissions, the choice of a control technology is expected to be made on the basis of costs and cost effectiveness (i.e., the cost per ton of organic emission reduction). To obtain cost-effectiveness values, the total annualized cost of the control device is divided by the tons of organics removed per year. Tables 4-4, 4-5, and 4-6 present estimates of cost effectiveness for the various model unit cases for the three control technologies analyzed.

Table 4-9 presents a summary of the most cost-effective dedicated control device of the three analyzed for each model unit case capable of achieving at least a 95-percent emission reduction. As can be seen in the table, in all cases, either a condenser or carbon adsorber is more cost effective than a thermal incinerator.

In general, for those model unit process vent streams with emission rates of less than 1 lb/h, cost-effectiveness estimates for condensers (achieving a 95-percent emission reduction) are roughly half those for carbon adsorbers. Cost-effectiveness values for carbon adsorption and condensation decrease sharply as the emission rate increases from less than 1 lb/h to about 2 lb/h. From about 2 lb/h to about 10 lb/h, the cost-effectiveness values decrease gradually; at emission rate values greater than 10 lb/h, the cost-effectiveness values of these control technologies converge. At emission rates greater than 10 lb/h, cost-effectiveness values decrease only slightly as the emission rate increases.

TABLE 4-9. SUMMARY CONTROL COSTS FOR MOST COST-EFFECTIVE CONTROL DEVICE[a]

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	Type of control device	TAC, $/yr	Cost effectiveness, $/Mg
1	D	0.40	ME CHI	0.74	NC	19,870	27,650
2	D	0.40	TOL	0.74	NC	26,730	37,200
3	D	0.40	1,1,1-TCE	0.74	NC	14,290	19,890
4	D	0.40	MEK	0.74	NC	24,410	33,970
5	D	4.20	ME CHI	7.78	RC	69,810	9,260
6	D	4.20	TOL	7.78	C	450	60
7	D	4.20	1,1,1-TCE	7.78	C	240	30
8	D	4.20	MEK	7.78	RC	69,810	9,260
9	D	10.60	ME CHI	19.64	C	(150)	(20)
10	D	10.60	TOL	19.64	C	(4,190)	(210)
11	D	10.60	1,1,1-TCE	19.64	C	(4,520)	(230)
12	D	10.60	MEK	19.64	C	(3,700)	(190)
13	D	0.17	ME CHI	0.16	NC	8,440	55,280
14	D	0.17	TOL	0.18	NC	11,360	74,400
15	D	0.17	1,1,1-TCE	0.16	NC	6,070	39,750
16	D	0.17	MEK	0.16	NC	10,370	67,910
17	D	0.42	ME CHI	0.39	NC	20,770	55,060
18	D	0.42	TOL	0.39	NC	28,070	74,410
19	D	0.42	1,1,1-TCE	0.39	NC	14,180	37,590
20	D	0.42	MEK	0.39	NC	26,250	69,590
21	D	1.20	ME CHI	1.11	RC	66,910	61,590
22	D	1.20	TOL	1.11	C	2,250	2,050
23	D	1.20	1,1,1-TCE	1.11	C	2,150	1,990
24	D	1.20	MEK	1.11	C	2,320	2,170
25	D	5.00	ME CHI	4.63	RC	67,380	15,010
26	D	5.00	TOL	4.63	C	1,180	250
27	D	5.00	1,1,1-TCE	4.63	C	960	210
28	D	5.00	MEK	4.63	C	1,440	310
29	D	0.08	ME CHI	0.07	NC	3,970	55,250

(continued)

TABLE 4-9 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	Type of control device	TAC, $/yr	Cost effectiveness, $/Mg
30	D	0.08	TOL	0.07	NC	5,340	74,320
31	D	0.08	1,1,1-TCE	0.07	NC	2,860	39,800
32	D	0.08	MEK	0.07	NC	4,880	67,910
33	D	0.24	ME CHI	0.22	NC	11,990	55,620
34	D	0.24	TOL	0.22	NC	16,040	72,900
35	D	0.24	1,1,1-TCE	0.22	NC	9,050	41,980
36	D	0.24	MEK	0.22	NC	14,930	69,260
37	D	1.00	ME CHI	0.93	RC	65,200	72,440
38	D	1.00	TOL	0.93	C	2,150	2,310
39	D	1.00	1,1,1-TCE	0.93	C	2,100	2,260
40	D	1.00	MEK	0.93	C	2,260	2,460
41	D	7.00	TOL	12.97	C	(3,540)	(280)
42	D	7.00	MEK	12.97	C	(3,770)	(300)
43	D	7.00	1,1,1-TCE	12.97	C	(4,050)	(320)
44	A	0.10	TCE	0.39	RC	85,730	225,600
45	A	0.50	TCE	1.95	RC	85,050	45,000
46	A	1.50	TCE	5.85	RC	83,450	14,700
47	A	5.00	TCE	19.51	RC	77,400	4,100
48	A	0.10	DCE	0.39	RC	85,730	225,600
49	A	0.50	DCE	1.95	RC	85,050	45,000
50	A	1.50	DCE	5.85	RC	83,450	14,700
51	A	5.00	DCE	19.51	RC	77,400	4,100
52	A	0.10	EDC	0.39	RC	85,730	225,600
53	A	0.50	EDC	1.95	RC	85,050	45,000
54	A	1.50	EDC	5.85	RC	83,450	14,700
55	A	5.00	EDC	19.51	RC	77,400	4,100
56	A	0.10	TCE	0.39	RC	101,830	268,000
57	A	10.00	TCE	39.02	RC	85,980	2,300
58	A	0.10	DCE	0.39	RC	101,830	268,000
59	A	10.00	DCE	39.02	RC	85,980	2,300

(continued)

TABLE 4-9 (continued)

Case No.	Vent class	Emission rate, lb/h	Constituent	Emission reduction, Mg/yr	Type of control device	TAC, $/yr	Cost effectiveness, $/Mg
60	A	0.10	EDC	0.39	RC	101,830	268,000
61	A	1.50	EDC	5.85	RC	99,450	17,500
62	A	10.00	EDC	39.02	RC	85,980	2,300
63	A	0.50	TCE	1.95	RC	141,150	74,700
64	A	5.00	TCE	19.51	RC	137,500	7,300
65	A	10.00	TCE	39.02	RC	128,980	3,400
66	A	0.50	DCE	1.95	RC	141,150	74,700
67	A	5.00	DCE	19.51	RC	137,500	7,300
68	A	10.00	DCE	39.02	RC	128,980	3,400
69	A	0.50	EDC	1.95	RC	141,150	74,700
70	A	5.00	EDC	19.51	RC	137,500	7,300
71	A	10.00	EDC	39.02	RC	128,980	3,400

A = Air-stripper-type vents (i.e., high flow rates).
C = Condenser.
D = Distillation-type vents (i.e., low flow rates).
DCE = Dichloroethylene.
EDC = 1,2-Dichloroethane.
ME CHl = Methylene chloride.
MEK = Methyl ethyl ketone.
NC = Nonregenerable carbon adsorption system.
RC = Regenerable fixed-bed carbon adsorption system.
TAC = Total annualized costs in second-quarter 1989 dollars per year.
1,1,1-TCE = 1,1,1-Trichloroethane.
TCE = Trichloroethylene.
TOL = Toluene.

[a] Most cost-effective dedicated control device (condenser, carbon adsorber, or thermal incinerator) capable of achieving at least a 95-percent emission reduction.

4.4.1 Condensers

From a cost-effectiveness perspective, condensation should be the preferred control technology for application to waste management unit process vents regardless of emission rate. However, at emission rates of about 1 lb/h and less (a range where condensation clearly has significant cost-effectiveness advantages), condensation becomes less technically feasible of achieving the desired control efficiency of 95 percent. This is because condenser efficiency depends on, among other things, the organic concentration of the vent stream. At low emission rates, the concentration of organics can become too low thermodynamically to achieve a high control level. See Table 4-3 for condenser efficiencies.

Figure 4-2 shows the cost effectiveness of condensers as a function of the uncontrolled organic emission rate. For condensers achieving the 95-percent control level, the cost-effectiveness values did not seem to vary significantly by chemical species; i.e., for a particular constituent, if 95-percent condensation is technologically feasible, then the costs per ton of organics controlled are about the same regardless of the constituent.

4.4.2 Carbon Adsorbers

Carbon adsorption is generally more economical than thermal incineration for the control of organics in low concentrations. Thermal incineration with primary heat recovery is more economical than carbon adsorption at high organics concentrations unless the recovered organic is valuable and can be credited at market value. For both high and low volumetric flow rates, the cost effectiveness of nonregenerable carbon adsorption systems was determined to be more favorable than that for regenerable systems at mass emission rates of less than 1 lb/h. This is shown in Figure 4-3. As the organic emission rate increases from zero to 1 lb/h, the cost effectiveness increases for nonregenerable systems. The total annual cost for operation of a nonregenerable carbon adsorption system is directly proportional to the amount of organic captured (i.e., the organic emission rate). At an emission rate of about 1 lb/h, the cost-effectiveness values decrease as emission rate increases. The values of cost effectiveness for regenerable carbon adsorption systems show economies

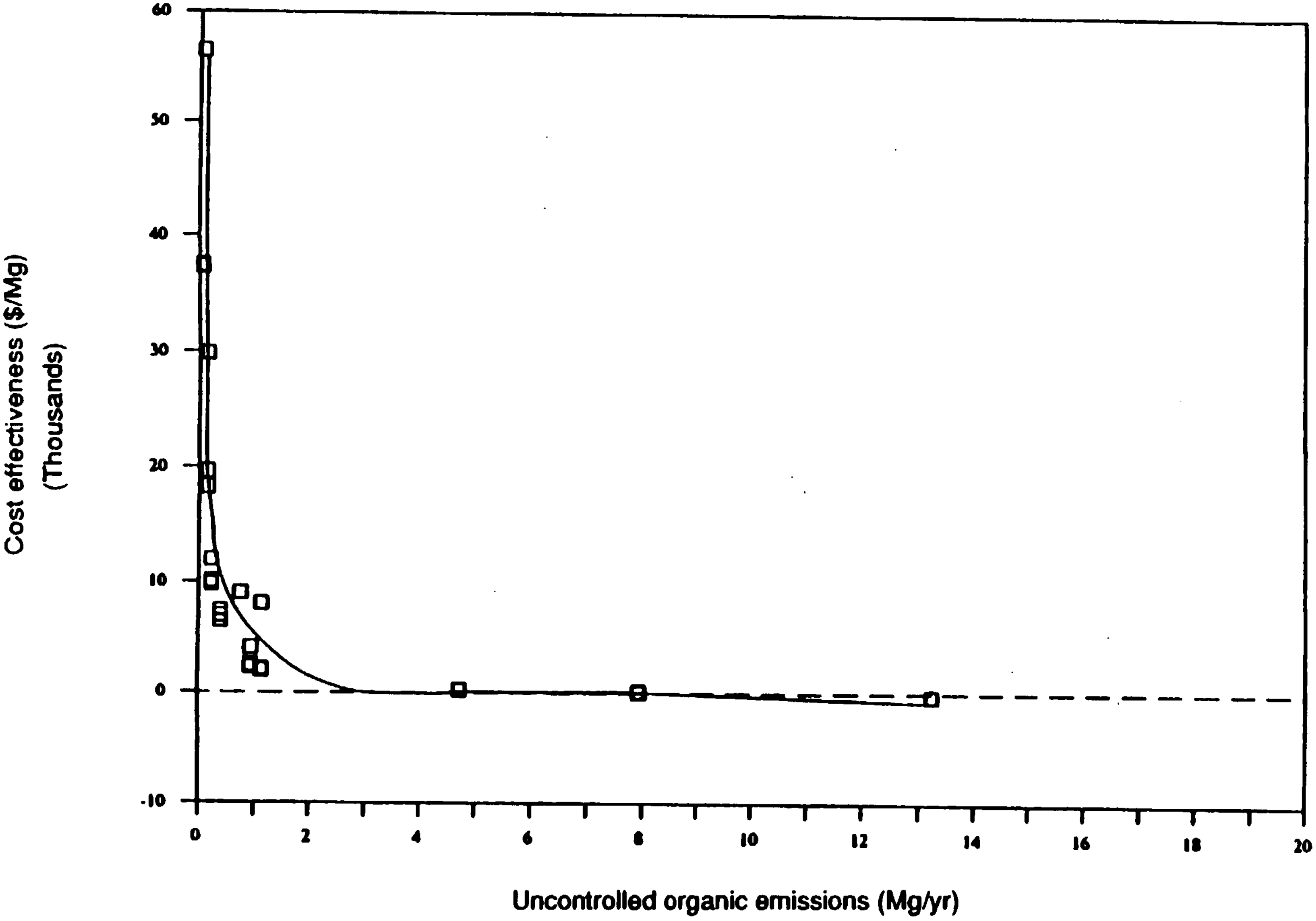

Figure 4-2. Cost effectiveness for condensers.

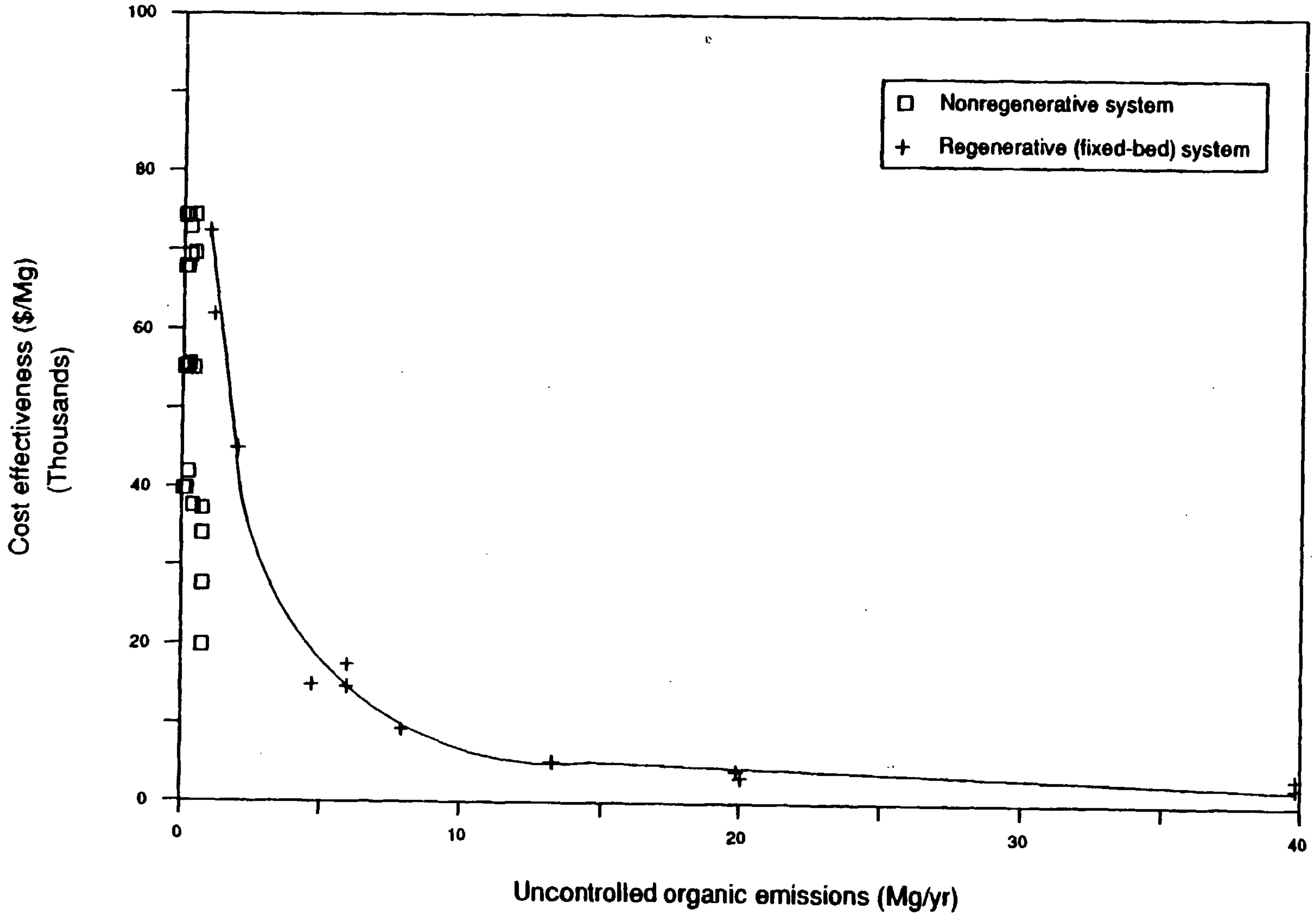

Figure 4-3. Cost effectiveness for carbon adsorbers.

of scale (i.e., the unit costs of operating the system decrease as the system size increases); therefore, the cost per ton of organic controlled decreases as the emission rate increases. For the model unit cases, differences in cost effectiveness for the various stream concentrations become almost insignificant at mass emission rates of about 5 lb/h.

4.4.3 Thermal Incineration

Cost-effectiveness estimates for thermal incineration of process vent streams show considerable variability in relation to emission rate. Figure 4-4 presents incineration cost-effectiveness estimates as a function of mass emission rate. For the process vent model unit cases examined, incineration was the least cost-effective control alternative. The difference in cost-effectiveness values for incineration and the other control technologies (at the same emission rate) decreases as the emission rate increases. Another factor that influences cost-effectiveness values of incinerators is the organic constituent; the presence of halogenated compounds requires special incinerator design considerations. Such compounds require higher combustion temperatures to achieve high destruction efficiencies. Also, because hydrogen chloride is a principal combustion product for such compounds, acid gas scrubbers are required. A comparison of the cost effectiveness of incineration of halogenated versus nonhalogenated compounds for the low flow-rate model units is also presented in Figure 4-4. As the figure indicates, the cost differential is less significant as the emission rate increases.

4.5 CROSS-MEDIA AND SECONDARY AIR POLLUTION AND ENERGY IMPACTS

The previously described control devices (i.e., condensers, carbon adsorbers, and thermal incinerators) all serve to reduce organic air emissions from TSDF process vents. However, these same control devices may as a result of operation generate other environmental pollutants. These new pollutants can be gaseous, solid, or liquid. Impacts resulting from emission of organic and nonorganic air pollutants are called "secondary air impacts." Impacts resulting from the creation of new liquid or solid waste are called "cross-media impacts."

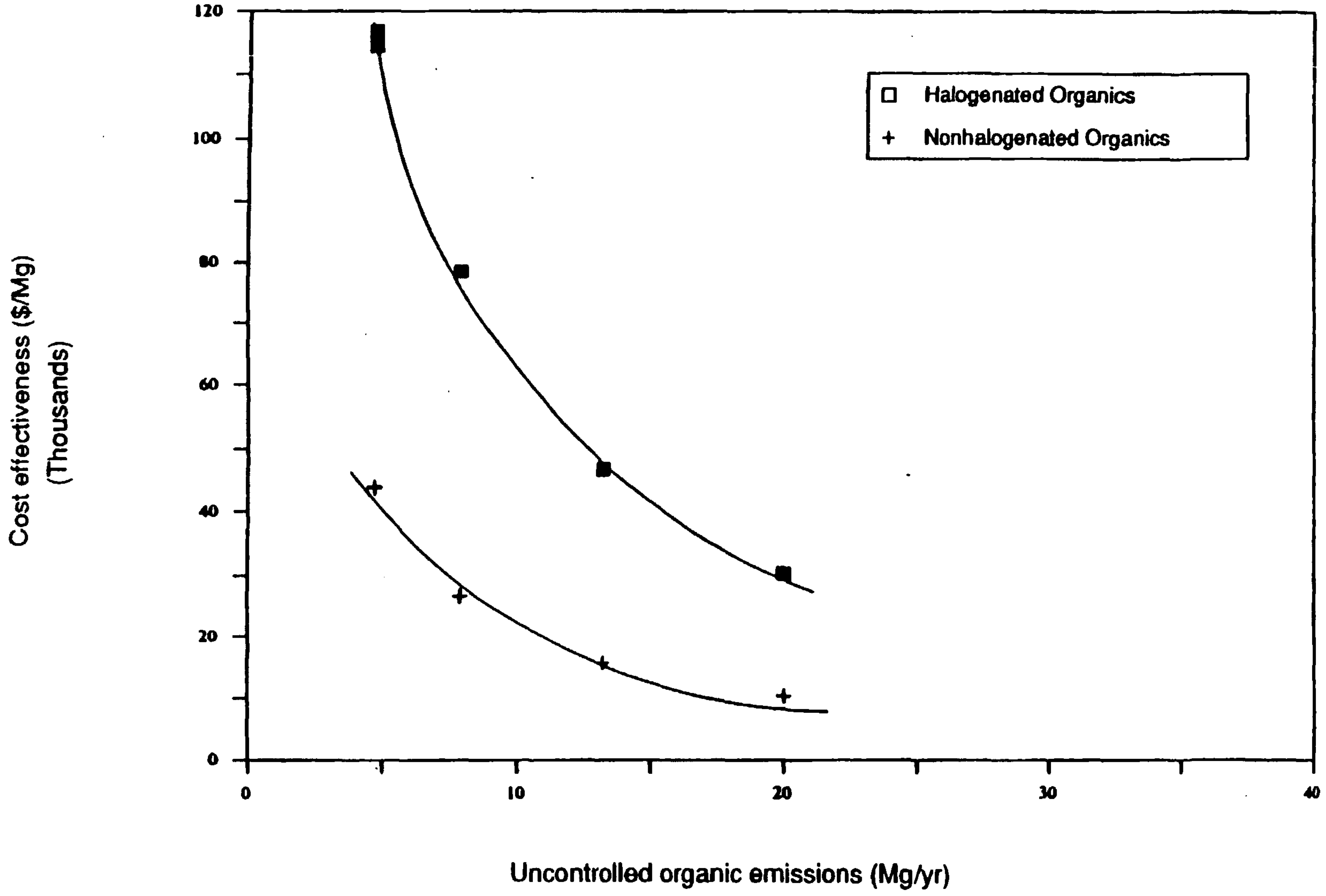

Figure 4-4. Cost effectiveness for thermal incinerators.

The determination of the environmental impacts for the various control technologies applicable to waste management unit emission sources should be made on a case-by-case basis. In some instances (e.g., waste solvent distillation), the by-products can be recycled, used for resale, or burned for fuel. In this case, no disposal problem or secondary environmental impacts would exist. However, some applications afford no other alternative but to dispose of the waste either by land disposal or wastewater treatment, thereby imposing a cross-media impact.

Secondary air impacts are characteristic of combustion control devices because nonorganic air pollutants are commonly formed during operation of the control device. In addition, air emissions, wastewater discharges, and solid waste from non-TSDF sources (e.g., industrial boilers and utility power plants) may also be created because these facilities provide the electricity and process steam needed to operate the air pollution control devices applied to the waste management unit process vents.

The human health and environmental benefits gained from the organic emission reduction achievable by applying a particular control technology to a process vent emission source can and should be evaluated relative to the secondary air and cross-media impacts the control technology creates as a result of operation. Therefore, it is necessary that secondary air and cross-media impacts be estimated and evaluated to the extent possible. This section identifies the types of environmental impacts associated with the control technologies previously discussed in Chapter 3.0 and provides rough estimates of both secondary pollutants and cross-media impacts for each of the process vent model unit cases examined.

4.5.1 Condenser Environmental Impacts

It is unlikely that the use of surface condensers for waste management unit process vent organic air emission control will produce significant cross-media impacts or secondary emissions with the exception of any impacts produced by utilization of electricity (e.g., power needed to run the refrigeration unit or to pump the coolant and condensate). The coolant does not contact the condensate and can therefore be recycled or reused. If the condensate contains a water fraction, then this contaminated water will require treatment of some type. Whether the noncondensibles exiting the condenser will be vented to the atmosphere or further processed is for the most part contingent upon the organic concentration of the noncondensibles exiting the condenser. If the condensed organics cannot be recycled or reused, they must be stored, treated, and disposed of as a solid (or hazardous) waste. Cross-media impacts resulting from the use of condensation as a control technology for the model unit process vent streams were estimated for each process vent model unit stream and are presented in Table 4-10. These estimates assume that all condensed organics will require solid waste disposal and that water from the condensate will go to wastewater treatment. Energy consumption associated with condensation (e.g., power required to operate the refrigeration unit, pump) will depend on the design and operation of the condenser. These utility requirements were estimated using a chemical engineering process simulator known as ASPEN (see Section 4.3.1). Of the estimates made, the worst case found the energy consumed to be on the order of 4,000 kWh/yr. In most cases, energy requirements were found to be small and are considered negligible.

4.5.2 Carbon Adsorption Environmental Impacts

Removal of organic compounds from process vent gases using carbon adsorption systems can produce cross-media impacts. Specific cross-media impacts include the disposal of both the organic/steam mixture from desorption of the saturated carbon when regenerated and the solid waste generated from the replacement of spent carbon. The extent of these impacts, for the most part, will be determined by the type of adsorption system used (e.g., fixed-bed carbon adsorption versus carbon canisters), the method of adsorbent (i.e., carbon) regeneration utilized (e.g., thermal swing-steam stripping versus pressure swing-vacuum desorption), and whether the spent carbon canister is recycled or discarded (landfilled).

Low-pressure steam is a common regenerating gas for adsorption systems and is expected to be utilized with most fixed-bed carbon adsorbers used for organic air emission control of process vents. This provides a hot, low concentration gas. Both of these factors enhance desorption.

TABLE 4-10. MODEL UNIT CROSS-MEDIA IMPACTS FOR CONDENSERS

Case No.	Cross-media impacts: Wastewater,[a] gal/yr	Cross-media impacts: Solid waste,[b] Mg/yr
1	332	0.0
2	332	0.34
3	332	0.12
4	331	0.0
5	320	0.0
6	321	7.54
7	325	7.54
8	318	6.91
9	300	8.82
10	303	19.63
11	312	19.44
12	294	19.44
13	24	0.0
14	24	0.13
15	24	0.12
16	24	0.08
17	18	0.0
18	18	0.33
19	18	0.36
20	18	0.32
21	22	0.29
22	22	1.10
23	23	1.08
24	22	1.07
25	16	4.12
26	17	4.64
27	19	4.64
28	15	4.64
29	12	0.0
30	12	0.06
31	12	0.06
32	12	0.04
33	10	0.0
34	10	0.23
35	10	0.22
36	10	0.19
37	10	0.55
38	11	0.93
39	11	0.93
40	10	0.92
41	1,240	12.58
42	1,240	12.58
43	1,240	12.58

[a] Condensed water vapor.

[b] Condensed organics.

During regeneration, the gas stream leaving the top of the adsorber will contain desorbed organics. If the organic is not soluble in water, a condenser-decanter can be used. The recovered organic material and expended steam condensate are normally the only liquids discharged from adsorption systems. The water obtained may be either discarded or reused for steam. In either case, it would require treatment prior to disposal or reuse. In some cases, recovered organics can be utilized (e.g., recycled to the original process or used for resale), and no disposal problem per se would exist. If the organic is not of a usable quality, it could be burned as a fuel to produce heat plus steam for regeneration, or it could be further enriched by chemical processing (distillation, etc.). Combustion of the organic as a fuel may provide a lower monetary return than reuse as a chemical in the process. When combustion is used, a check should be made to be certain no excessive amounts of hazardous substances (e.g., secondary air emissions) would be generated and released as a result of noncombustibles, incomplete combustion, and/or combustion products.

Products removed from the adsorber cannot be separated from the steam regeneration fluid by decantation if they are soluble in water. In these instances, a more complex recovery procedure is needed. This could be a distillation process if system cost and product values are favorable.

An onsite boiler is expected to supply the required steam for most fixed-bed carbon adsorber regeneration. The production of the steam needed for this regeneration creates secondary air emission impacts due to the boiler air emissions. It is anticipated that these impacts will primarily be an increase in nitrogen oxides (NO_x) and carbon monoxide (CO) emissions because natural gas or distillate fuel oil fuel is typically used in industrial boilers.

Spent adsorbent from nonregenerable systems must be disposed of upon removal, and regenerable system adsorbent does deteriorate and requires replacement periodically. These materials must be handled and disposed of in a safe and environmentally acceptable manner. To some extent, adsorbed gas molecules will be present on all spent adsorbents and must be considered for flammability and toxicity. Often, spent organic adsorbents can be disposed of safely and conveniently in a controlled combustion facility.

If spent carbon from an air pollution control application is determined to be a hazardous waste, it can be disposed of in a hazardous waste landfill. If it is determined to be nonhazardous, it may be possible to dispose of the spent carbon in a municipal solid waste landfill, depending on the policies of that particular landfill site. More often, however, it will be returned to the manufacturer for regeneration and then recycled back to an adsorber for reuse. Recycling spent carbon in this manner reduces the amount of solid waste generated by the control technology and submitted to a solid waste disposal site or a combustion facility.

Because the disposal of spent adsorbent is an environmental concern, estimates of the environmental impacts resulting from the disposal of spent carbon were developed for the model units based on a worst-case scenario. This worst-case assumption includes the following conditions: (1) for regenerative systems, the carbon life is 2 years; (2) for nonregenerative systems, the carbon life is equivalent to the time required for breakthrough.

The quantity of solid waste produced using carbon adsorption on the model unit process vent streams was estimated using a working capacity of 0.07 lb of organic per pound of carbon. Furthermore, the system for regenerative carbon adsorption was assumed to consist of two units operating in parallel, each having an adsorption cycle length of 8 h. Significant quantities of solid waste were calculated for both the regenerative and nonregenerative systems and are shown in Table 4-11. (Note: The solid waste impact estimates include both the spent sorbent and the organics adsorbed in the case of nonregenerative systems. Solid waste impact estimates for regenerative systems include the spent sorbent and the organic recovered from the regeneration process.)

The use of regenerative carbon adsorption systems also impacts water quality. Steam is used in the regeneration of activated carbon at the site. The resulting mixture of steam and organics, depending on the solubility of the organic in water, generally will be separated from the wastewater either by use of a condenser-decanter or some other more complex recovery procedure. In some cases, the separated organic may be reused (e.g., recycled, resold), and the water reused for steam; no environmental

TABLE 4-11. MODEL UNIT CROSS-MEDIA AND ENERGY IMPACTS FOR CARBON ADSORBERS

Case No.	Control device	Energy impacts	Cross-media impacts	
		Steam generation,[a] 1,000 Btu/yr	Wastewater, gal/yr	Solid waste, Mg/yr
1	CA-N	NA	NA	13.33
2	CA-N	NA	NA	13.33
3	CA-N	NA	NA	13.33
4	CA-N	NA	NA	13.33
5	CA	99,677	8,373	0.26
8	CA	99,677	8,373	0.26
9	CA	251,567	21,133	0.65
13	CA-N	NA	NA	2.83
14	CA-N	NA	NA	2.83
15	CA-N	NA	NA	2.83
16	CA-N	NA	NA	2.83
17	CA-N	NA	NA	7.00
18	CA-N	NA	NA	7.00
19	CA-N	NA	NA	7.00
20	CA-N	NA	NA	7.00
21	CA	14,239	1,196	0.07
25	CA	59,332	4,984	0.30
29	CA-N	NA	NA	1.33
30	CA-N	NA	NA	1.33
31	CA-N	NA	NA	1.33
32	CA-N	NA	NA	1.33
33	CA-N	NA	NA	4.00
35	CA-N	NA	NA	4.00
36	CA-N	NA	NA	4.00
37	CA	11,866	996	0.06
44	CA-N	NA	NA	7.02
45	CA	24,987	2,099	0.03
46	CA	74,963	6,297	0.09
47	CA	249,879	20,991	0.30
48	CA-N	NA	NA	7.02
49	CA	24,987	2,099	0.03
50	CA	74,963	6,297	0.09
51	CA	249,879	20,991	0.30
52	CA-N	NA	NA	7.02
53	CA	24,987	2,099	0.03
54	CA	74,963	6,297	0.09
55	CA	249,879	20,991	0.30
56	CA-N	NA	NA	7.02
57	CA	499,758	41,982	0.61
58	CA-N	NA	NA	7.02
59	CA	499,758	41,982	0.60
60	CA-N	NA	NA	7.02

(continued)

TABLE 4-11 (continued)

		Energy impacts	Cross-media impacts	
Case No.	Control device	Steam generation,[a] 1,000 Btu/yr	Wastewater,[b] gal/yr	Solid waste,[c] Mg/yr
61	CA	74,963	6,297	0.09
62	CA	499,758	41,982	0.61
63	CA-N	NA	NA	35.10
64	CA	249,879	20,991	0.30
65	CA	499,758	41,982	0.61
66	CA-N	NA	NA	35.10
67	CA	249,879	2,099	0.30
68	CA	499,758	41,982	0.61
69	CA-N	NA	NA	35.10
70	CA	249,879	20,991	0.30
71	CA	499,758	41,982	0.61

CA = Carbon adsorber.

CA-N = Nonregenerable carbon adsorber.

NA = Not applicable.

[a] Steam required for regeneration of the fixed-bed carbon adsorption units.

[b] Expended steam condensate resulting from regeneration of the fixed-bed carbon adsorption unit.

[c] Spent adsorbent plus desorbed organics.

impact would result. A worst-case assumption (i.e., the desorbed organics are neither reusable nor resaleable and must be disposed of as solid waste and the water [condensed steam] must be sent to a wastewater treatment unit) is made in the estimation of the solid waste and wastewater impacts shown in Table 4-11. A steam usage value of 4 lb of steam per pound of solvent desorbed was used to estimate the quantity of wastewater generated.[29] Table 4-11 presents the wastewater impacts estimated for the model units under the conditions noted above. The use of nonregenerative systems (assuming the life of the canister is equal to its breakthrough time) does not result in any wastewater impacts.

The energy impacts resulting from the use of carbon adsorption to control emissions are the energy required for steam for regeneration of the carbon and electricity to power pumps, fans, and instrumentation. Energy impacts are dependent on control device operating conditions such as electricity source, fuel type, and spent carbon practices. The energy needed to produce the steam for regeneration represents the majority of the total energy required for an adsorption system. Therefore, energy impact estimates for carbon adsorbers using the model units only consider the energy required to produce the steam for regeneration. The energy impacts from electricity required to power pumps, fans, and instrumentation are considered negligible. In addition, the following operating conditions are assumed: steam is supplied at a pressure of 65 psia and is generated by a boiler fueled by oil operating at approximately 80 percent overall efficiency.[30] Table 4-11 presents the energy impacts estimated for the model unit process vent streams.

4.5.3 Thermal Incineration Environmental Impacts

While thermal incinerators are used to prevent air pollution, thermal incinerators themselves exhibit an air pollution potential and can produce cross-media impacts and secondary emissions depending on how they are operated. It is possible to create a major pollution problem when burning any waste gas if the waste gas is not burned with sufficient air for combustion. Improper operating conditions can result in CO generation. If proper combustion conditions are observed (i.e., correct air-to-fuel ratio; sufficient mixing, adequate residence time, and peak flame temperature; and proper cooling rate of combustion products), essentially all the carbon present in the waste gas should end up as carbon dioxide (CO_2). All the hydrogen should result in water as a product of combustion, and unburned hydrocarbons should be minimal if not zero.

NO_x emissions from thermal incinerators are another secondary pollutant impact produced by thermal incinerators. Nitrogen oxides have two sources: nitrogen in the fuel and the reaction between atmospheric nitrogen and oxygen at high temperatures. One problem encountered in reducing emissions from combustion sources is the fact that modifications that reduce carbon monoxide and hydrocarbon emissions generally increase NO_x emissions and vice versa (see Table 4-12).

As noted above, some adverse effects on air quality can be associated with the use of combustion devices to control organic emissions from waste management unit process vents. Pollutants generated by the combustion process (i.e., SO_2, CO, and particularly NO_x) may have an unfavorable impact on ambient air quality. Secondary air pollutant emissions resulting from the incineration of the model unit process vent streams were estimated for each vent stream case. Using the AP-42 emission factors for natural gas combustion, the quantities of SO_2 and CO generated were found to be relatively insignificant. The NO_x emissions were estimated using an emission factor developed from thermal oxidizer test data gathered at incinerators controlling process vent organic emissions.[31] These estimates are presented in Table 4-13.

There is increasing concern about hydrogen chloride (HCl) emissions from incinerators, owing to the growing amount of halogenated polymers (e.g., polyvinyl chloride [PVC]) and halogenated solvent (e.g., methylene chloride) used in chemical processes and therefore potentially present in waste streams. In addition, hydrogen fluoride (HF) emissions arise from the combustion of fluorinated hydrocarbons. Water scrubbing appears to be an effective means of controlling these acid gases (HCl, HF). An increase in wastewater, however, will result from the wet scrubbing of these gases. The scrubber wastewater may require neutralization (addition of a caustic) before being released into the wastewater treatment and disposal system. The salts produced from the neutralization, though small, must be disposed

TABLE 4-12. EFFECT OF MODIFICATIONS IN OPERATION ON EMISSIONS

Change in operation	Effect on CO and HC emissions	Effect on NO_x emissions
Increase excess air	Decrease	Increase, then gradually decrease
Increase flame temperature	Decrease	Rapid increase
Increase residence time at high temperature	Decrease	Small increase

CO = Carbon monoxide.

HC = Hydrocarbons.

NO_x = Nitrogen oxides.

Source: Engdahl, R. B., and R. E. Barrett. Fuels and Their Utilization. In: Engineering Control of Air Pollution. Volume IV of Environmental Sciences: An Interdisciplinary Monograph Series on Air Pollution, Stern, A. C. (ed.). New York, Academic Press. 1977. p. 379-419.

TABLE 4-13. MODEL UNIT SECONDARY AIR POLLUTION, CROSS-MEDIA, AND ENERGY IMPACTS FOR THERMAL INCINERATORS

	Energy impacts		Secondary emissions	Cross-media impacts
Case No.	Gas use, 100 J/yr	Electric use, 1,000 kWh/yr	NO_x, kg/yr	Wastewater, 1E+6 gal/yr
5	16.0	26	3.3	20.7
6	6.1	8	3.3	0.0
7	16.0	26	3.3	20.7
8	2.2	8	3.3	0.0
9	15.9	26	3.3	20.7
10	1.5	8	3.3	0.0
11	16.0	26	3.3	20.7
12	1.7	8	3.3	0.0
25	8.0	13	0.2	1.5
26	1.1	4	0.2	0.0
27	8.0	13	0.2	1.5
28	1.2	4	0.2	0.0
41	1.9	8	10.3	0.0
42	2.0	8	10.3	0.0
43	15.9	26	10.3	64.9

of as hazardous waste. Therefore, thermal incineration does produce a solid waste impact.

The amount of wastewater (used to remove the acid gas contained in the thermal incinerator outlet stream) was estimated for each model unit case analyzed and is shown in Table 4-13. The quantities generated are, in most cases, relatively small and for most plants would not affect waste treatment or sewer capacity. However, the water used as a scrubbing agent will need to be neutralized, prior to discharge or reuse, by adding caustic (NaOH). The salt formed in the neutralization step must be purged from the system and properly eliminated (e.g., direct wastewater discharge or salt recovery). There are no other significant solid wastes generated as a result of control waste management unit process vents by thermal incineration.

The use of an incinerator to control organic emissions from waste management unit process vents results in a net energy usage for the model vent cases because supplemental fuel is needed to support combustion and promote flame stability. The determination of fuel use for select model unit cases was made as a part of the SOCMI Incinerator/Flare Costing Algorithm. These supplemental fuel requirements (in the form of natural gas) are also presented in Table 4-13. Electrical energy is required to operate the pumps, fans, blowers, and instrumentation that may be necessary to control organics using an incinerator. Electrical energy requirements as estimated by the costing model are presented in Table 4-13 as well.

4.6 REFERENCES

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APPENDIX A

SUMMARY OF SITE-SPECIFIC PROCESS AND EMISSION TEST DATA FROM DISTILLATION/STEAM STRIPPING UNITS AT TSDF

TABLE A-1. SUMMARY OF SITE-SPECIFIC PROCESS AND EMISSION TEST DATA FROM DISTILLATION/STEAM STRIPPING UNITS AT TSDF

Facility	Process	Material processed	(% Organics)	Feed rate (L/min)	Vent location	Gas flow rate (L/s)	Organic conc. (ppmv)	Organic emissions[a] (g/s)	Organic emissions[a] (Mg/yr)[b]	Organic emissions[a] (lb/h)	Emission factor (g/kg organic feed)
Plant A	TFE	Mixed chlor. xylenes	86	23	Condenser (P)	0.0014	9,900	0.00001	0.0016	0.0008	2.6
Plant B1	BD	Aqu. MEK (30,000 L)	6	37	Condenser (P)	0.64	68,000	0.186	2.8	1.47	6.0
Plant B2	BD	Aqu. acetone (11,000 L)	23	24	PA tank	0.4	2,100	0.006	0.078	0.04	0.18
					Condenser (P)	<1.3	<630	NA	<0.04	NA	NA
					Rec. tank	<0.8	760	0.002	0.03	0.016	0.02
Plant C	TFE	Acetone w/xylene	>83	27	Condenser (P)	NA	20 (0.06 mg/L)		Negligible		
Plant D1	BSS	Aqu. xylene MEK (1,260 L)	26	8	Condenser (P)	0.11	6,800	0.0029	0.043	0.02	0.08
Plant D2	BSS	1,1,1-Trichlo. MEK (897 L)	74	6	Condenser (P)	0.063	10,600	0.0036	0.052	0.03	0.05
					Miscible solvent tank	NA	5,100	0.0004	0.005	0.003	0.006
Plant E	SS	Aqu. nitro-benzene	Low	498	Condensate tank[c]	0.16	2,000	0.0026	0.03	0.02	NA
Plant F	SS	Aqu. method chloride	low	19	Gravity separator[c]	1.0	21,000	0.13	2.0	1.06	NA
Plant G	SS	Aqu. eth. dichloride	0.6	816	Secondary condenser	3.1	65,800	0.63	9.4	5.0	7.7
					Primary condenser	NA	NA	NA	NA	NA	NA
Plant H	SS	Chlorinated solvents	0.6	40 (41.6)	Primary condenser	0.95	394,000	1.2	18	9.5	NA
					Secondary condenser[d]	0.20	437,000	0.26	3.8	2.0	NA
					Solids decanter	0.70	394,000	2.3	34.8	18.4	NA

See notes at end of table.

(continued)

TABLE A-1 (continued)

Facility		Process	Material processed	(% Organics)	Feed rate (L/min)	Vent location	Gas flow rate (L/s)	Organic conc. (ppmv)	Organic emissions^a			Emission factor (g/kg organic feed)
									(g/s)	(Mg/yr)^b	(lb/h)	
Plant I		TFE 2 units	Waste solvents^e	High	20 (300 gal/h)	3rd condenser	NA	NA	0.01	0.4	0.1^f	0.04
Plant J		BD	Aqu. organic solvents (25,400 L)	3-10	6	Condenser (P)	NA	NA	NA	NA	NA	NA
						Distill. recvr.	(Vented to incinerator)					
Plant K		TFE 2 units	Aqu. xylene & IPA	20	NA	Condenser	NA	35 mg/L	NA	NA	NA	NA
Plant L		SS(B)	Organ. solv. & waste fuels (500 gal) (1,892 L)	NA 5	12.6 (250 gal/h)	Condenser (P) through distill. recvr.	NA	NA		NA	NA	NA
Plant M (E)		TFE CD BD	No process data, only cost, has "backup" condenser (2nd condenser)									
Pilot-scale test		TFE	Refinery sludge		0.87↔ 1.5	Primary condenser	1) 0.004 2) 0.017	>10,000 (BTX) >10,000 (BTX)	NA NA	NA NA	NA NA	NA NA
Plant N		TFE$_B$	Paint thinners^g (batch)	78	14.3	Condenser (P)	NA	NA	NA	NA	NA	NA
Plant N		BD	Chlorinated solvents (3,785 L)	High	5	Condenser (P)	NA	NA	NA	NA	NA	NA
Plant O		TFE & BD	Waste solvents	188,000 gal/wk treated			NA	NA	NA	NA	NA	NA
Plant P	1	BD	Waste sol. non-chl. (10,000 gal)	High	32	Condenser (P)	NA	NA	NA	NA	NA	NA
Plant P	2	BD	Chloro. solv. (3,000 gal)	High	6.3	Condenser (P)	NA	NA	NA	NA	NA	NA

See notes at end of table.

(continued)

TABLE A-1 (continued)

Facility	Process	Material processed	(% Organics)	Feed rate (L/min)	Vent location	Gas flow rate (L/s)	Organic conc. (ppmv)	Organic emissions[a] (g/s)	Organic emissions[a] (Mg/yr)[b]	Organic emissions[a] (lb/h)	Emission factor (g/kg organic feed)
Plant Q	TFE	Chloro. solv. (1,700 L)	High	6.3-7.5 (100 gal/h)	Condenser (P)	NA	0.06 mg/L	NA	NA	NA	NA
Plant Q	BD										
Plant R	TFE(B)	Waste sol. Tol, MEK, (15,000 L)	65-100	5-15	Condenser (P)	NA	NA	NA	NA	NA	NA[h]
Plant S	SS	Nitrobenzene Nitrotoluene	High	NA	Condenser vent tank	0.16	7.0 mg/L	0.001	0.02	0.01	NA
Plant T	TFE	Halogenated waste solvents (4,000-6,000 gal/batch)	High	NA	Secondary condenser	NA	NA	NA	NA	NA	NA
Plant U	BD1 BD2 SS	Chlorinated degreasing wastes		250 gal/h at 3-4 h 25 gal/h 250 gal/h		NA	NA	NA	NA	NA	NA
Plant V	TFE	Chlorinated organics (2%) 98% waste solvent (nonchloro) (3,000 gal/6-7 h)		450 gal/h	Demister & condenser	NA	NA	NA	NA	NA	NA

BD = Batch distillation.
BSS = Batch steam stripping.
CD = Continuous distillation.

NA = Not available.
SS = Steam stripping.
TFE = Thin-film evaporator.

[a] Organic emissions are the sum of the individual constituent emissions for the detectable compounds.

[b] Based on 4,160 hours operation per year.

[c] Condenser vented through tank.

[d] Secondary condenser efficiency was negligible.

[e] Acetone, toluene, xylene, methylene chloride, et al. at 3.4 x 10^6 gal/yr.

[f] Estimated only.

[g] Acetone, toluene, MEK, xylene, isopropanol, et al.

[h] Some ambient air data available.

Source: Memorandum from Zerbonia, R., RTI, to Colyer, R., EPA/SDB, and Lucas, R., EPA/CPB. October 19, 1987. Evaluation and development of emission factors for (TSDF process) vents. RCRA Docket Item: F-89-AESF-S0021.

APPENDIX B

SUMMARY OF AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE

TABLE B 1. SUMMARY OF AVAILABLE DATA ON AIR STRIPPER LOADINGS AND PERFORMANCE

Facility/location							Air stripper design and operation					
Name	City	State	Water[a] flow (gal/min)	Pollutant[b]	Conc. (ug/l)	Pollutant loading[c] (kg/yr)	Column diam. (ft)	Packing ht. (ft)	No. of cols.	Air flow[d] (ft³/min)	Air-to-water ratio[d]	Reported removal eff. (%)[e]
Confidential - Stover(1)			200[f]	BZ	1,000[f]	381.6	4	20	1	2,700[f]	100	100[f]
				TOL	1,000[f]	381.6						100[f]
				XYL	1,000[f]	381.6						100[f]
				VO	3,000	1,144.7						100
Confidential - Stover(2)			600[f]	BZ	10,000[f]	11,446.8	4	25	2	4,000[f]	50	99.9[f]
				XYL	5,000[f]	5,723.4						99.8[f]
				EBZ	5,000[f]	5,723.4						99.8[f]
				EDC	1,000[f]	1,144.7						99[f]
				VO	21,000	24,038.4						99.8
Unidentified	Scottsdale	AZ	3,700	TCE	200[h]	1,411.8	10	14	1	25,000	50	99[h]
Unidentified	City of Scottsdale	AZ	7	VOC	130,000	1,738.1						98
Hughes Aircraft	Tucson	AZ	4,200[f]	TCE	800[f]	6,410.2	9/9	6/25	3/3	4,800[f]	30[f]	99.4[f]
				TCA	100[f]	801.3						99.6[f]
				EDC	200[f]	1,602.6						99[g]
				VO	1,100	8,814.1						99.3
AMD, Inc.	Sunnyvale	CA	175[h]	VOC	2,000[h]	667.7						99.5[h]
Baldwin Park	Valley County	CA	970	TCE	710[h]	1,313.9	8	18	1	4,000	30	99[h]
				PCE	330	610.7						99
				VO	1,040	1,924.6						99
Unidentified	South Chesire	CT	1,700	TCE	100[h]	324.3	9 x 8	26	1	8,000	35	99[h]
CT American Water Co.		CT	300	TCA	75	42.9	4.5					70
Private Industry		CT	200	TCE	20,000[h]	7,631.2	4					99.9
Unidentified	Ft. Pierce	FL	350[h]	TCE	11.3[h]	7.5	4	16	1	2,000	50[f]	99[h]
				PCE	76[h]	50.7						99[h]
				VO	87.3	58.3						99
Unidentified	Port Malabar	FL	1,000[f]	VOC	57[h]	108.7	9 x 9	12	1	9,000[f]	70	99[h]

(continued)

TABLE B-1 (continued)

Facility/location							Air stripper design and operation					
Name	City	State	Water^a flow (gal/min)	Pollutant^b	Conc. (ug/l)	Pollutant loading^c (kg/yr)	Column diam. (ft)	Packing ht. (ft)	No. of cols.	Air flow^d (ft^3/min)	Air-to-water ratio^d	Reported removal eff. (%)^e
Sydney Mine	Hillsborough County	FL	150^f	EDC	24^h	6.9	4		1	4,700^f	220^f	100^h
				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	6,000^h	641.0			1			98^f
Acton Water District	Acton	MA	417^h	TCA	25^h	19.9	5.5	20	1	3,000	50	99
				DCE	25^h	19.9						99
				TCE	10^h	8.0						99
				VO	60	47.7						99
Site A		MI	1,400^h	TCE	4,000^h	10,683.7				8,000^h	40	99.8^h
				TCA	300^h	801.3						100^h
				VO	4,360	11,645.2						99
Site B		MI	155^h	CF	1,500^i	440.0	3	45	1	1,300^h	60	99.9^h
				MCL	ND							
				EDC	ND							
Verona Well Field	Battle Creek	MI	1,900^h	EDC	5^h	18.1	10	40	1	5,600^f	20	100^h
				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	200,000	28,617.1			1	10,000	1,000	ND
				MCL	20	2.9						ND
				PCE	4,700	672.5						ND
				TCA	150	21.5						ND
				EDC	8.9	1.3						ND
				CF	15	2.1						ND
				VO	204,893	29,317.3						ND

(continued)

TABLE B 1 (continued)

Facility/location Name	 City	State	Water^a flow (gal/min)	Pollutant^b	Conc. (ug/L)	Pollutant loading^c (kg/yr)	Air stripper design and operation Column diam. (ft)	 Packing ht. (ft)	 No. of cols.	 Air flow^d (ft^3/min)	 Air-to-water ratio^d	 Reported removal eff. (%)^e
Whitaker Site	Minneapolis	MN	60	TOL	23,000	2,194.0			1	270	40	ND
				EBZ	14,000	1,336.6						ND
				XYL	63,000	6,056.7						ND
				VO	90,000	8,686.1						ND
Monroe Auto	Cozad	NE	1,940	TCE	800^f	2,220.7	6		1	10,000	40^f	90
Unidentified	Rockaway	NJ	1,400	TCE	260^h	887.7	9	26	1	37,600	200	100^h
				MTBE	60^h	133.6						95^h
				DIPE	60^h	133.5						99^h
				VO	350	934.8						99.1
Unidentified	Rocky Hill	NJ	36	TCE	80^h	6.3	6	10	2	2,600	80^h	99
Unidentified	Mountainside	NJ	826	TCE	$1,000^h$	1,192.4	5 x 4	28	1	3,300	40	99^h
				PCE	100^h	119.2						90^h
				VO	$1,100^h$	1,311.6						98.2^h
Unidentified	Plainfield	NJ	$3,600^f$	PCE	200^f	1,373.6	12 x 10	24	1	19,200	40^f	99.6^f
Danville Water Dept.	Danville	NJ	600	TCA	6^h	4.8	9	26	1	4,000	60^f	100^h
				PCE	7^h	6.7						86^h
				VO	12	11.4						91.8
E. Hanover Water Dept.	East Hanover	NJ	750	TCE	50^h	71.5	7 x 13.8	4.5	1	6,000	60^f	78^h
South Brunswick TWP	Brunswick	NJ	1,100	TCE	76^h	167.4	7	10	1	13,000	90^f	99^h
				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	1.7	1.5					96
Unidentified	Queens	NY	3,000	PCE	300^h	1,717.0	12 x 7	16	1	16,000	40	97^h
				TCE	100^h	572.3						90^h
				VO	400	2,289.4						95.3
Unidentified	Garden City Park	NY	1,200	PCE	90^h	206.0	7.5	18	1	6,600	36	94^h

(continued)

TABLE B-1 (continued)

Facility/location							Air stripper design and operation					
Name	City	State	Water[a] flow (gal/min)	Pollutant[b]	Conc. (ug/l)	Pollutant loading[c] (kg/yr)	Column diam. (ft)	Packing ht. (ft)	No. of cols.	Air flow[d] (ft^3/min)	Air-to-water ratio[d]	Reported removal eff. (%)[e]
Unidentified	Brewster	NY	600	PCE EDC TCE VO	110[h] 49[h] 17[h] 176	125.9 56.1 19.5 201.6	4.8	17.8	1	3,000	38[f]	99[h] 99[h] 99[h] 99
Unidentified	New Hyde Park	NY	2,400	TCE PCE VO	300[h] 100[h] 400	1,373.6 457.9 1,831.5	12 x 7	21	1	12,000	40	97[h] 98[h] 96.3
Unidentified	Lake Success	NY	2,400	TCE	30	137.4	7 x 12	21	1	14,000.	41	97
Unidentified	Floral Park	NY	3,000	TCE TCA VO	300[h] 50[h] 350	1,717.0 286.2 2,003.2	12 x 7	10	1	16,000	40	97[h] 95[h] 96.7
Unidentified	Northport	NY	1,300	PCE	450[h]	1,116.1	6	16	1	5,200	30	99[h]
Citizens Water Supply	Great Neck, Long Island	NY	2,000	BZ PCE TCE VO	200[h] 55[h] 40[h] 295	763.1 209.9 152.6 1,126.6	10	24	1	21,400	80[f]	99[h] 99[h] 99[h] 99
EPA Region II	Hicksville	NY	100	MEK	1,000	190.8	3.5					99
Unidentified	Zanesville	OH	300	TCE DCE VO	15,000 3,000 18,000	8,586.1 1,717.0 10,302.2	4	20	1	1,850	46	97 97 97
Unidentified	Hatboro (#1)	PA	215	TCE MTBE DIPE EDC PCE VO	300[h] 130[h] 20[h] 15[h] 10[h] 475	123.1 53.3 8.2 6.2 4.1 194.8	5.5	25	1	6,300	220	99[h] 99[h] 95[h] 99[h] 98[h] 98.8
Unidentified	Upper Merion (#3)	PA	690	TCE	15[h]	19.7	4.5	10	1	1,400	15	95[h]

(continued)

TABLE B-1 (continued)

Facility/location								Air stripper design and operation				
Name	City	State	Water[a] flow (gal/min)	Pollutant[b]	Conc. (ug/l)	Pollutant loading[c] (kg/yr)	Column diam. (ft)	Packing ht. (ft)	No. of cols.	Air flow[d] (ft^3/min)	Air-to-water ratio[d]	Reported removal eff. (%)[e]
Unidentified	Warrington	PA	120	TCE	130[h]	29.8	2.7	18	1	600	30	97[h]
Unidentified	Hatboro (#2)	PA	278	TCE	300[h]	169.1						99[h]
				EDC	80[h]	42.4						99[h]
				PCE	10[h]	5.3						95[h]
				VO	390	208.8						98.9
lycoming Ck. Well Field	Williamsport	PA	4,180	TCE	350[h]	2,783.1	10/10	23/23	2/2	58,000	100	99[h]
				PCE	10	79.6						ND
				DCE	10	79.5						ND
				VO	370	2,942.1						ND
Superior Tube Co.	Norristown	PA	65	TCE	9,000	1,118.1	1.5 - 3		3	300	30	98
Tysons Dump	Upper Merion	PA	5[h]	1,2,3-TCP	30,000[h]	298.4			1	170[h]		99[h]
				XYL	17,000[h]	189.1						98[h]
				TOL	210[h]	2.1						ND
				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	47,614	472.8						ND
Upper Merion Res. (#1)	Upper Merion	PA	13,900	TCE	20	630.4	12	14	2	27,900	16	90
Unidentified	Chesapeake	VA	9,000	CF	77[h]	1,322.1	13.7	30	2	54,100	45	48[h]
				CHBrC12	38[h]	818.1						81[h]
				CHBr2Cl	34[h]	583.8						60[h]
				CHBr3	8[h]	137.4						44[h]
				VO	155[h]	2,881.4						58.1
Unifirst		VT	24[h]	PCE	126[h]	5.7						98.5[h]

(continued)

TABLE B-1 (continued)

Facility/location							Air stripper design and operation					
Name	City	State	Water[a] flow (gal/min)	Pollutant[b]	Conc. (ug/L)	Pollutant loading[c] (kg/yr)	Column diam. (ft)	Packing ht. (ft)	No. of cols.	Air flow[d] (ft^3/min)	Air-to-water ratio[d]	Reported removal eff. (%)[e]
City of Tacoma	Tacoma	WA	3,500	1,1,2,2-TCA	300[h]	2,003.2	12	23	5	145,000	300	95[h]
				TCE	130[h]	868.1						99[h]
				DCE	100[h]	667.7						99[h]
				VO	530	3,539.0						96.7
Unidentified	Wausau (#1)	WI	2,000	TCE	72[h]	274.7	9.3	24.5	1	16,000	30	98[h]
				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	995.9						97.0
Unidentified	Hartland	WI	1,000	TCE	240[h]	457.9	9	26.0	1	8,700	60	99[h]

ND = No data.

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

[b] Pollutant abbreviations used are:

BZ = Benzene
CHLBZ = Chlorobenzene
CF = Chloroform
DCE = Dichloroethylene
DIPE = Diisopropylether
EBZ = Ethylbenzene
EDC = Ethylene dichloride or dichloroethane
MCL = Methylene chloride
MEK = Methyl ethyl ketone
MTBE = Methyl-tertiary-butyl-ether
2-MPH = 2-Methylphenol
PCE = Perchloroethylene or tetrachloroethene
TOL = Toluene
TCA = Trichloroethane
TCE = Trichloroethylene
1,2,3-TCP = 1,2,3-Trichloropropane
VO = Total volatile organics (calculated as the sum of pollutants reported)
VOC = Volatile organic compounds (provided by facility rather than calculated)
XYL = Xylene

[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 h/yr 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 startup.

Source: U.S. Environmental Protection Agency. Air Stripping of Contaminated Water Sources--Air Emissions and Controls. Control Technology Center. Research Triangle Park, NC. Publication No. EPA-450/3-87-017. August 1987.

APPENDIX C

ESTIMATES OF UNCONTROLLED EMISSIONS FROM AIR STRIPPERS

TABLE C-1. ESTIMATES OF UNCONTROLLED EMISSIONS FROM AIR STRIPPERS

Facility/location						
Name	City	State	Air flow (ft^3/min)	Pollutant[a]	Pollutant conc. in air[b] (ppmv)	Air emissions[c] (kg/yr)
Confidential - Stover(1)			2,700	BZ	3.00	381.6
				TOL	2.56	381.6
				XYL	2.21	381.6
				VO	7.76	1,144.7
Confidential - Stover(2)			4,000	BZ	60.77	11,435.4
				XYL	22.34	5,712.0
				EBZ	22.34	5,712.0
				EDC	4.75	1,133.2
				VO	110.19	23,992.6
Unidentified	Scottsdale	AZ	25,000	TCE	0.69	1,397.7
Unidentified	City of Scottsdale	AZ		VOC	ND	1701.4
Hughes Aircraft	Tucson	AZ	4,800	TCE	16.43	6,371.8
				TCA	2.03	797.3
				EDC	5.54	1,586.5
				VO	23.99	8,755.6
AMD, Inc.	Sunnyvale	CA		VOC	ND	664.4
Baldwin Park	Valley Country	CA	4,000	TCE	4.02	1,300.8
				PCE	1.51	604.6
				VO	5.53	1,905.3
Unidentified	South Chesire	CT	8,000	TCE	0.50	321.1
CT American Water Co.		CT		TCA	ND	30.0
Private Industry		CT		TCE	ND	7,623.6
Unidentified	Ft. Pierce	FL	2,000	TCE	0.05	7.5
				PCE	0.25	50.2
				VO	0.30	57.7
Unidentified	Port Malabar	FL	9,000	VOC	0.20	107.7

(continued)

TABLE C-1 (continued)

Facility/location			Air flow (ft^3/min)	Pollutant[a]	Pollutant conc. in air[b] (ppmv)	Air emissions[c] (kg/yr)
Name	City	State				
Sydney Mine	Hillsborough County	FL	4,700	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	3,000	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	10,662.3
				TCA	ND	801.3
				VO	ND	11,528.8
Site B		MI	1,300	CF	4.7	439.6
				MCL	ND	ND
				EDC	ND	ND
Verona Well Field	Battle Creek	MI	6,500	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	10,000	TCE	2.47	1,998.6
Unidentified	Rockaway	NJ	37,500	TCE	0.22	667.7
				MTBE	0.06	126.9
				DIPE	0.08	132.2
				VO	0.34	928.8
Unidentified	Rocky Hill	NJ	2,600	TCE	0.03	5.3

(continued)

TABLE C-1 (continued)

Facility/location						
Name	City	State	Air flow (ft^3/min)	Pollutant[a]	Pollutant conc. in air[b] (ppmv)	Air emissions[c] (kg/yr)
Unidentified	Mountainside	NJ	3,300	TCE	4.43	1,180.5
				PCE	0.32	107.3
				VO	4.75	1,287.8
Unidentifed	Plainfield	NJ	19,200	PCE	0.71	1,368.1
Denville Water Dept.	Denville	NJ	4,000	TCA	0.01	4.8
				PCE	0.01	5.7
				VO	0.03	10.5
E. Hanover Water Dept.	East Hanover	NJ	6,000	TCE	0.11	54.4
South Brunswick TWP	Brunswick	NJ	13,000	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
Unidentified	Queens	NY	16,000	PCE	1.04	1,665.5
				TCE	0.40	515.1
				VO	1.44	2,180.6
Unidentified	Garden City Park	NY	5,600	PCE	0.35	193.7
Unidentified	Brewster	NY	3,000	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	12,800	TCE	1.29	1,332.4
				PCE	0.32	412.1
				VO	1.61	1,744.5
Unidentified	Lake Success	NY	14,000	TCE	0.12	133.2

(continued)

TABLE C-1 (continued)

Facility/location			Air flow (ft³/min)	Pollutant[a]	Pollutant conc. in air[b] (ppmv)	Air emissions[c] (kg/yr)
Name	City	State				
Unidentified	Floral Park	NY	16,000	TCE	1.29	1,665.5
				TCA	0.21	271.9
				VO	1.50	1,937.4
Unidentified	Northport	NY	5,200	PCE	2.12	1,104.9
Citizens Water Supply	Great Neck, Long Island	NY	21,400	BZ	0.75	755.5
				PCE	0.10	207.8
				TCE	0.09	151.1
				VO	0.93	1,114.3
EPA Region II	Hicksville	NY		MEK	ND	168.9
Unidentified	Zanesville	OH	1,860	TCE	55.70	8,327.6
				DCE	15.39	1,665.6
				VO	71.09	9,993.1
Unidentified	Hatboro (#1)	PA	6,300	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	1,400	TCE	0.17	18.8
Unidentified	Warrington	PA	500	TCE	0.71	28.9
Unidentified	Hatboro (#2)	PA		TCE	ND	167.6
				EDC	ND	42.0
				PCE	ND	5.0
				VO	ND	204.6

(continued)

TABLE C-1 (continued)

Facility/location					Pollutant conc. in air[b]	Air emissions[c]
Name	City	State	Air flow (ft^3/min)	Pollutant[a]	(ppmv)	(kg/yr)
Lycoming Ck. Well Field	Williamsport	PA	56,000	TCE	0.61	2,765.3
				PCE	ND	ND
				DCE	ND	ND
				VO	ND	ND
Superior Tube Co.	Norristown	PA	300	TCE	45.11	1,093.7
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	27,900	TCE	0.21	477.3
Unidentified	Chesapeake	VA	54,100	CF	0.16	634.6
				CHBrC12	0.09	500.7
				CHBr2Cl	0.05	350.3
				CHBr3	0.01	60.4
				VO	0.32	1,548.0
Unifirst		VT		PCE	ND	5.6
City of Tacoma	Tacoma	WA	145,000	1,1,2,2-TCA	0.13	1,903.0
				TCE	0.07	859.4
				DCE	0.08	661.1
				VO	0.28	3,423.5

(continued)

TABLE C-1 (continued)

Facility/location Name	City	State	Air flow (ft^3/min)	Pollutant[a]	Pollutant conc. in air[b] (ppmv)	Air emissions[c] (kg/yr)
Unidentified	Wausau (#1)	WI	16,000	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	6,700	TCE	0.84	463.3

ND = No data. Insufficient data available to calculate this value.

[a] Pollutant abbreviations used are:

BZ = Benzene
CHLBZ = Chlorobenzene
CF = Chloroform
DCE = Dichloroethylene
DIPE = Diisopropylether
EBZ = Ethylbenzene
EDC = Ethylene dichloride or dichloroethane
MCL = Methylene chloride
MEK = Methyl ethyl ketone
MTBE = Methyl-tertiary-butyl-ether
2-MPH = 2-Methylphenol
PCE = Perchloroethylene or tetrachloroethane
TOL = Toluene
TCA = Trichloroethane
TCE = Trichloroethylene
1,2,3-TCP = 1,2,3-Trichloropropane
VO = Total volatile organics (calculated as the sum of pollutants reported)
VOC = Volatile organic compounds (provided by facility rather than calculated)
XYL = Xylene

[b] Pollutants concentration in air calculated from air flow rate 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 °F.

[c] Air emissions calculated from pollutant loading and reported removal efficiency based on 8,400 h/yr operation.

Source: U.S. Environmental Protection Agency. Air Stripping of Contaminated Water Sources--Air Emissions and Controls. Control Technology Center. Research Triangle Park, NC. Publication No. EPA-450/3-87-017. August 1987.