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Control Techniques for Volatile Organic Compound Emissions from Stationary Sources

ACT

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Control Techniques for Volatile Organic Compound Emissions from Stationary Sources

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Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711
December 1992

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PREFACE

This is the third edition of a report originally published by the Department of Health, Education, and Welfare (HEW) titled, "Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (AP-68)." The first edition was published in March 1970 by the National Air Pollution Control Administration, a part of HEW. The second edition, was published by the U. S. Environmental Protection Agency in May 1978. It contained numerous changes from the original and was retitled "Control Techniques for Volatile Organic Emissions from Stationary Sources" (EPA-450/2-78-022) to better express the EPA's concern with pollutants other than hydrocarbons. This third edition incorporates the knowledge gained by the Agency during the years subsequent to 1978 and condenses it for easy reference.

1.0 SUMMARY

This document is a summary document containing general information on sources of volatile organic compound (VOC) emissions, applicable control techniques, and the impacts resulting from control applications. It references other documents which contain much more detailed information on individual sources and control techniques.

1.1 INTRODUCTION AND PURPOSE

In March 1970, the U. S. Department of Health, Education and Welfare published Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (AP-68) as one of a series of documents summarizing control techniques information for criteria air pollutants. Section 108(b) of the Clean Air Act (CAA) as amended in 1977 instructs the Administrator to review and modify these control techniques documents from time to time as appropriate:

> ". . . the Administrator shall, after consultation with appropriate advisory committees and Federal departments and agencies, issue to the States and appropriate air pollution control agencies information on air pollution control techniques, which information shall include data relating to the cost of installation and operation, energy requirements, emission reduction benefits, and environmental impact of the emission control technology. Such information shall include such data as are available on available technology and alternative methods of prevention and control of air pollution. Such information shall also include data on alternative fuels, processes, and operating methods which will result in elimination or significant reduction of emissions."

Additionally, Section 183(c) of the CAA as amended in 1990, provided:

> ". . . the administrator shall issue technical documents which identify alternative controls for all

categories of stationary sources of volatile organic compounds and oxides of nitrogen which emit, or have the potential to emit 25 tons per year or more of such air pollutant."

This third edition, incorporates new information on VOC emissions and technologies gathered during the development of national air emission standards under Section 111 and 112 of the CAA, during the preparation of control technique guidelines, alternative control technology documents, and other technical studies to aid States in developing VOC regulations, and during the review and comment period on the draft of this document by Federal and State agencies, industry and other public groups and individuals, and the National Air Pollution Control Technical Advisory Committee.

The CAA included this document primarily as a general reference for State and local air pollution control engineers. Based on the interest shown in this and previous editions by the industrial community, it will serve a much broader clientele. Because of the general nature of the document, it should not be used as the basis for developing regulations or enforcing them although it can be helpful as a basic reference from which to begin such an effort. It can be used to provide:

1) summary information and reference material on sources of oxidant precursors and control of these sources,
2) estimates of control costs, and
3) estimates of emission reductions achievable through control.

The costs presented in the text are the averages for a variety of differing industrial applications and consequently can be considered only rough estimates for any specific application. Actual costs for a particular installation may differ substantially from the average costs presented.

VOC is of concern because it contributes to lower atmospheric ozone formation, which in turn causes health and welfare effects. An estimate of nationwide VOC emissions is presented in Chapter 2.0, as is a brief discussion of the

mechanism by which photochemical oxidants (ozone) are formed in the lower atmosphere. The health effects associated with volatile organic and their secondary atmospheric reaction products are discussed in an EPA report Air Quality Criteria for Ozone and Other Photochemical Oxidants.

The techniques for control of VOC described in this report represent a broad spectrum of information from many technical fields. The devices, methods, and principles have been developed and used over many years and are constantly being revised and improved. These techniques vary in type, application, effectiveness, and cost. The "best technique" is to design and operate process equipment for maximum product yield, i.e., complete and efficient use of the raw materials being processed. Failing this, control equipment can be used to recover or destroy materials that otherwise would escape as air pollution.

Operating principles, design characteristics, disadvantages, applications, costs, and energy considerations for a variety of air pollution control equipment and other control techniques are described in Chapter 3.0.

Chapter 4.0 provides a more focused view of a number of industrial processes and source categories. Emission characteristics for each process are described. The control techniques that can be applied to reduce VOC from each process are reviewed. The proper choice of a method of controlling VOC emissions from a specific source depends on many factors, including the source characteristics. No attempt is made here to review all possible combinations of control techniques that may be used to reduce a certain emission.

As the title indicates, this report presents information on VOC control only for stationary sources. Information on control of emissions of VOC from mobile sources is available from the EPA's Office of Mobile Sources in Washington, D.C.

1.2 EMISSION SOURCES AND LEVELS

For purposes of this document, a volatile organic compound

(VOC) is any organic compound that participates in atmospheric photochemical reactions to form ozone. Nearly all organic react photochemically in the atmosphere to produce ozone and other oxidants, furthermore, as increasingly more information becomes available, we find many VOC's are individually toxic. Oxidants have long been associated with a variety of adverse health and welfare effects and were designated a criteria pollutant in 1971. Some organics are hazardous pollutants and may also be VOC (e.g., vinyl chloride and benzene) or be in the same emission stream as VOC. Therefore, controlling VOC often indirectly reduces hazardous pollutants. Therefore, volatile organic emissions are an important concern in the Agency's quest to protect the public health.

Figure 1-1 presents estimates of nationwide emissions of VOC for each general industrial (or source group) category for 1985. Notice that about two-thirds of volatile organic emissions from all sources are from stationary source. These estimates take into account Federal, State and local air pollution regulations. Also, it should be noted that the percentages shown in the bar graph are a function of how the sources are grouped together. A breakdown of each grouping is shown on Table 2-5 of Chapter 2.

1.3 CONTROL TECHNIQUES

The two methods commonly employed to reduce emissions of VOC's to the atmosphere are:

1. Installation of so called "add-on" control equipment to recover or destroy off-gas pollutants. Equipment to capture the emissions is often required in conjunction with add-on devices themselves.

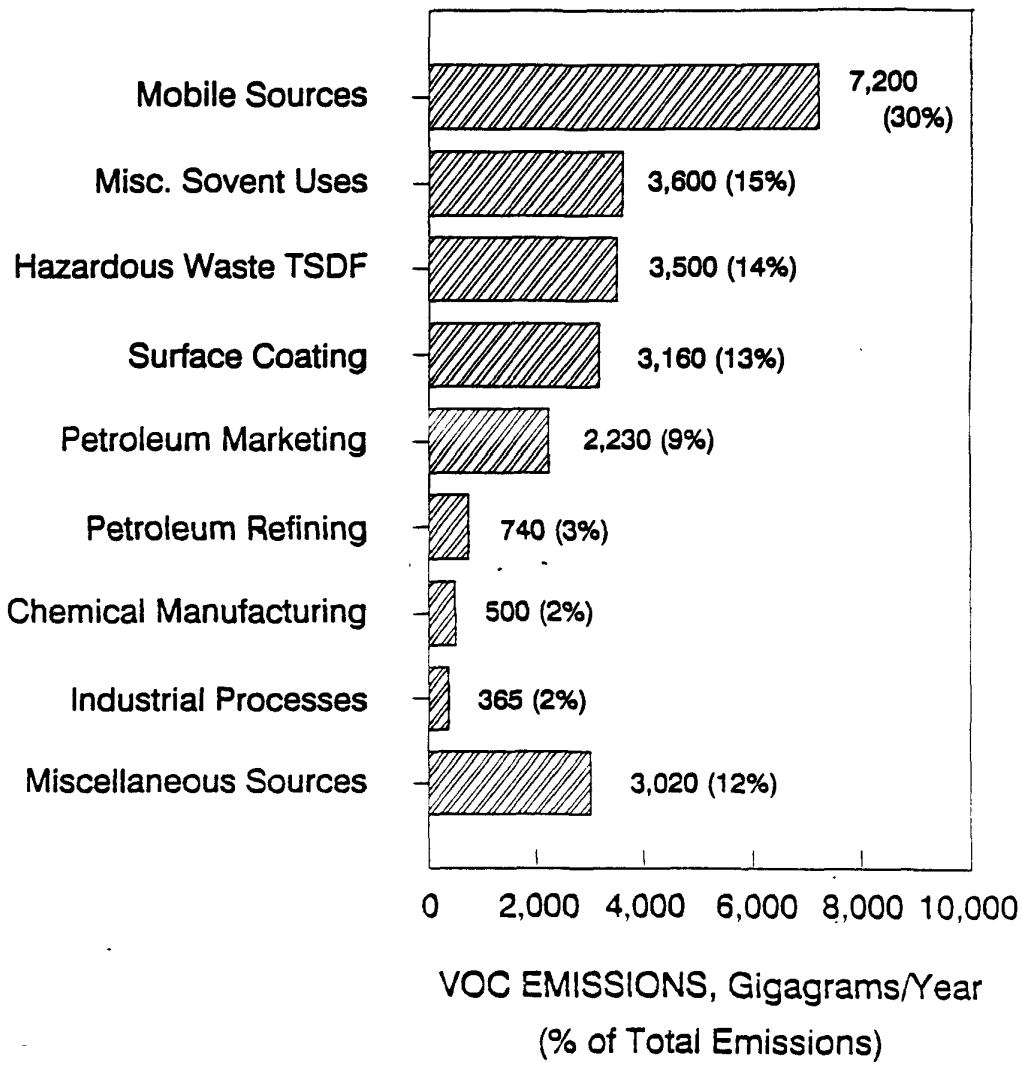
2. Changes in a process and/or raw material to eliminate or reduce generation of pollutants by the process.

1.3.1 Add-On Control Equipment

There are five widely used add-on control techniques for limiting emissions of VOC. These five are: combustion, adsorption, absorption, and condensation.

Figure 1-1. SOURCES OF VOC EMISSIONS AND 1985 NATIONAL VOC AIR EMISSION ESTIMATES

(Total = ~24,300 Gg/yr OR ~26,800,000 Tons/yr)



Tables 1-1 and 1-2 present a listing of these "add-on" control techniques including control levels achievable with some of these techniques, and critical design conditions. In the case of flares, boilers and thermal incinerators, emission testing on a variety of VOC streams has shown that if you meet the design conditions presented in the table, the VOC stream will be reduced by at least 98 percent. Adsorption equipment have been shown to achieve at least 95 percent removal efficiency, but the efficiency is dependent on the basic design parameters listed. As with adsorption equipment, catalytic incinerators, absorbers and condensers VOC control efficiencies are more dependent on the VOC streams characteristics. Thus for these techniques the equipment must be designed for each application.

Below is a general discussion of the operation principals for add-on equipment. A detailed discussion of each technology is presented in Chapter 3.

Combustion. Essentially all VOC will burn; hence combustion is the technique most universally applicable to reducing VOC emissions. Gases containing organic are usually burned if they have little recovery value or contain contaminants that make recovery unprofitable. Combustion devices include thermal incinerators, catalytic incinerators, boilers and process heaters.

Incinerators destroy pollutants through thermal or catalytic oxidation and control efficiencies should be at least 98 percent. Pollutant streams not capable of sustaining combustion may require additional fuel. Fuel costs can be at least partially offset by employing various methods of heat recovery. In addition, some pollutant streams can be directly vented into a process boiler's flame, thus reducing energy costs for the boiler and alleviating the need (or cost) of an add-on control device. Incineration has been successfully applied to aluminum chip dryers, petroleum processing and marketing operations, animal blood dryers, automotive brakeshoe debonding ovens, citrus pulp dryers, coffee roasters, wire enameling ovens, foundry core

Table 1-1. CONTROL TECHNOLOGIES THAT FORM THE BASIS OF STANDARDS

Type	Control Levels Achievable	Design Conditions to Meet Control Level	Comments
Flares	≥ 98%	° Flame present at all times - monitor pilot. ° Non-assisted Flares >200 Btu/scf heating value, and 60 ft/sec mas. exit velocity. ° Air and Steam Assisted Flares - >300 Btu/scf heating value, and max. exit velocity based on Btu content formula.	° Destroy rather than recovers organic. ° Smoking allowed for 5 min/2 hr. ° Not used on corrosive streams.
Boilers	≥ 98%	° Vent stream directly into flame.	° Destroys rather than recovers organic.
Thermal Incinerators	≥ 98%, or 20 ppm	° 1600°F Combustion temperature ° 0.75 sec. residence ° For halogenated streams 2000°F, 1.0 sec. and use a scrubber on outlet. ° Proper mixing	° Destroys rather than recovers organic. ° May need vapor holder on intermittent streams.
Adsorption	≥ 95%	° Adequate quantity and appropriate quality of carbon. ° Gas stream receives appropriate conditioning (cooling, filtering) ° Appropriate regeneration and cooling of carbon beds before breakthrough occurs.	° Most efficient on streams with low relative humidity.

TABLE 1-2. OTHER CONTROL TECHNOLOGIES THAT CAN BE USED TO MEET STANDARDS

Type	Critical Variables That Affect Control Level	Comments
Catalytic Incinerators	° Dependent on compounds, temp. and catalyst bed size.	° Destroys rather than recovers recovers organic. ° Technical limitations include particulate or compounds that poison catalysts.
Absorption	° Solubility of gas stream in the absorbent. ° Good contact between absorbent and gas stream	° Availability of absorbent. ° Disposal or recovery of absorbent and organic. ° Preferable on concentrated streams.
Condensation	° Proper design of the heat exchanger. ° Proper flow and temperature of coolant.	° Preferable on concentrated streams.

ovens, meat smokehouses, paint baking ovens, varnish cookers, paper printing and impregnating installations, pharmaceutical manufacturing plants, sewage disposal plants, chemical processing plants, and textile finishing plants.

Flares have historically been employed as safety devices to incinerate exhaust gases from petroleum refining and chemical manufacturing operations to prevent them from creating an explosion hazard within the facility. Because of their

simplicity and economy, flares are often used when disposing of gas streams which do not require supplemental fuel.

Adsorption. Adsorption is the use of a solid material to trap a gas. The material most commonly used is carbon, a highly porous material. Adsorption occurs in two ways: (1) physical adsorption, in which van der Waal's forces attract and hold gas molecules to the adsorbent surface, and (2) chemical adsorption, in which gas molecules are chemically bonded to the adsorbent. Additionally, within the capillaries of the porous solid, surface adsorption is supplemented by capillary condensation. The VOC is usually recovered by stripping the organic from the carbon by heating with steam.

Activated carbon is the most widely used adsorbent for recovering VOC. "Carbon adsorption" is usually more economical than combustion for the control of organic in low concentrations where the cost of supplemental fuel can be very high. Depending on the application, carbon adsorption efficiencies can be at least 95 percent. In addition, this control technique offers recovery of adsorbed organic which can be recycled to the process or used as fuel. Recovery and reuse has gained greater favor by industries as the price of petrochemicals has risen over the last decade.

Adsorption systems have been used successfully in the following industries: organic chemical processing, varnish manufacture, synthetic rubber manufacture, production of selected rubber products, pharmaceutical processing, graphic arts operations, food production, dry cleaning, synthetic fiber manufacture, and some surface coating operations.

Absorption. Absorption is the use of a liquid media to trap a gas. Absorption may be purely physical (organics simply dissolve in the absorbent) or chemical (organics react with the absorbent or with reagents dissolved in the absorbent). The generally low organic concentration of exhaust gases require long contact times and large quantities of absorbent for adequate emissions control rendering it a fairly expensive control

technique. Therefore, absorption is less desirable than adsorption or incineration, unless there is something unique offered by a process such as the absorbent is easily regenerated or can be used as a process make-up stream.

Absorption has been used to control organic vapors and particulates in waste handling and treatment plants, degreasing operations, asphalt batch plants, ceramic tile manufacturing plants, coffee roasters, chromium plating units, petroleum coker units, fish meal systems, chemical plants, and varnish and resin cookers.

Condensation. Condensation is the physical change from the vapor to liquid phase. Condensers operate in either of two ways: (1) the most common is a constant pressure system where the temperature of the gas stream is reduced to cause the desired condensable materials to liquify, or (2) less common is the technique of increasing the pressure of a gas stream to cause the combustible material to liquify. Condensation is also commonly applied to a gas stream to reduce VOC concentrations before the stream is routed to the other "add-on" devices spoken of earlier.

Condensers have been used successfully in bulk gasoline terminals, petroleum refining, petrochemical manufacturing, dry cleaning, degreasing, and tar dripping.

1.3.2 Process and/or Raw Material Changes.

In many manufacturing or processing operations, it may be possible to lower emission levels by changing the process or raw materials. For example, organic emissions from surface coating operations can be significantly reduced by using lower solvent coatings such as water-borne, higher solids, or powder coatings. Other examples of process and material changes improve the efficiency of the operation by increasing the yield on raw materials thereby eliminating the need for add-on control equipment. Typically, process or raw material changes require considerable research and testing of product quality, therefore these changes generally take several years to adopt. Twenty years ago, air pollution agencies attempted to reduce ambient

ozone levels by encouraging industry to substitute organic compounds they believed inert to the atmospheric chemical reactions that form ozone for the more photochemically reactive compounds previously used. Subsequently investigation has revealed this to be nearly futile since essentially all organics participate in photochemical reactions, although some are slower than others. Of those that do not react, many are inherently toxic and some have been implicated in the undesirable destruction of the stratospheric ozone layer.

1.4 REGULATORY STATUS

EPA has four ongoing control programs for reducing VOC emissions from existing and new stationary sources:

(1) New source performance standards (NSPS),

(2) National emission standards for hazardous pollutants (NESHAP),[1]

(3) Resource Conservation and Recovery Act (RCRA) air standards, and

(4) Publication of control technique guidelines (CTG).

The NSPS and NESHAP programs are authorized by Congress in the Clean Air Act as amended in 1977 and 1990 and codified in Section 111 and 112, respectively. The NSPS program focuses on new (rather than existing) sources of pollution to guard against new air pollution problems and provide results in long-term improvements in air quality as existing plants are replaced, modified or reconstructed to make an existing source subject to a NSPS. Congress authorized the Administrator to propose NSPS regulations for any category of stationary sources that "causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." NSPS are based on the best demonstrated control technology (BDT). In the language of Section 111, the standards of performance for

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[1] Reducing specific organic compounds which are listed as hazardous often reduces VOC emissions.

each affected facility "shall reflect the degree of emission limitation and the percentage reduction achievable through application of the best technological systems of continuous emission reduction which (taking into consideration the cost of achieving such emission reduction, any non-air quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated." Provided in Appendix D is a listing of the NSPS standards which have been promulgated, proposed, or are under development, and also provided are the appropriate dates, Federal Register cites and background information documents (BID's) for the standards. The BID documents provide a detailed description of the industry's emission sources, control techniques, control costs, and economic impact, and anticipated VOC emission reductions. The Act requires that NSPS standards be reviewed every 4 years to incorporate advancements in control technology.

Hazardous air pollutants (HAP) are regulated under Section 112. Standards developed prior to the passage of the 1990 CAA amendments defined a "hazardous air pollutant" as one which, in the judgment of the Administrator, "causes or contributes to air pollution which may reasonably be anticipated to result in an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness." The intent of those NESHAP standards is to protect the public health with an ample margin of safety. Some organic compounds which were listed as hazardous may also be VOC (e.g., vinyl chloride and benzene) or be in the same emission streams as VOC. The CAA amendments of 1990, defined "hazardous air pollutants" as any air pollutant listed in the CAA, and provided a list of them in Section 112(b). The 1990 CAA provisions on NESHAP standards are required to "require the maximum degree of reduction in emissions of "HAP" (so called, maximum achievable control technology standards -- MACT standards). As an alternative standard, the smaller area sources may be required to install generally available control technologies (GACT). In terms of VOC, standards developed under

Section 112 often indirectly reduce VOC as well as hazardous pollutant emissions. Appendix D provides a list of the NESHAP standards which have been proposed, promulgated, withdrawn, or are under development, and cites the appropriate BID's.

EPA is currently evaluating air emissions of VOC, particulates, and specific toxic substances from hazardous waste treatment, storage, and disposal facilities (TSDF) under the authority of Section 3004 of the Resource Conservation and Recovery Act and Sections 111 and 112 of the Clean Air Act. Like the NESHAP standards, controlling air emissions of hazardous wastes indirectly controls VOC emissions. Appendix D provides a list of the RCRA air emission standards that have been proposed and promulgated, and their BIDs.

The CAA requires each State in which the national ambient air quality standards (NAAQS) are exceeded to adopt and submit revised State Implementation Plans (SIP's) to EPA. Sections 172(a)(2) and (b)(3) of the Clean Air Act require that such "nonattainment" area SIP's require installation of reasonably available control technology (RACT) for select stationary sources. RACT defines the lowest emission limitation that a particular source is capable of meeting by the application of control technology that is reasonably available, considering technological and economic feasibility. The EPA required that States adopt RACT regulations for each specific category of stationary sources of VOC only after EPA has published guidance on control technology via a control techniques guideline (CTG) for that source category. Although CTG documents provide available information and data concerning the technology and cost of various control techniques, they are general in nature and are not able to fully account for variations within a stationary source category. The CTG's provide State and local air pollution control agencies with an initial information base (industry description, emission sources, control technology, emission reduction, control costs, and cost effectiveness) for proceeding with their own assessment of RACT for specific stationary

sources. Appendix D provides a listing of the CTG's published and under development.

2.0 CHARACTERISTICS OF VOLATILE ORGANIC EMISSIONS

2.1 DEFINITIONS *

The original of this report (AP-68) was titled Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources. Hydrocarbons are compounds containing only the elements hydrogen and carbon. "Organic solvents" was intended to include materials such as diluents and thinners which could also contain oxygen, nitrogen, sulfur, and halogens.

There are reasons for replacing "Hydrocarbon and Organic Solvents" with "Volatile Organic Compound" (VOC) in the title. There has been some confusion in the previous use of the term "hydrocarbons." Previously, the term "hydrocarbons" incorrectly referred to all organic chemicals. Many organics which are photochemical oxidant precursors are not hydrocarbons and are not used as solvent. To correct the previous confusion this report is titled Control Techniques for Volatile Organic Compound Emissions from Stationary Sources. A volatile organic compound (VOC) is defined as "any organic compound which participates in atmospheric photochemical reactions; or which is measured by a reference test method" (40 Code of Federal Regulations, Part 60.2).

Since its inception in 1970, the approach adopted by EPA to reduce photochemical (O_3) and other oxidants (O_x) in the ambient air has been based on unilateral control of one of its precursers VOC. From time to time EPA has listed in the Federal Register certain VOC's that a State may exempt from control by virture of it's negligibly low photochemical reactivity. All other organics are presumed reactive. This policy has and continues to be open to revision as new evidence develops that might justify reclassifying the reactivity of a specific VOC.

The EPA released its "Recommended Policy on Control of Volatile Organic Compounds" in 1977 (July 8, 1977, 42 FR 35314). That policy divided VOCs into three classes based on three criteria: photochemical reactivity, role in stratospheric O_3 depletion, and direct health effects.

The first class, shown in Table 2-1, includes those VOCs which by virtue of their negligible reactivity could be exempted from regulation. The second class, shown in Table 2-2, includes those VOCs which have low-photochemical reactivity and must be included in the ozone SIP inventories but their control has lower priority than that of the more reactive compounds. The third class, encompassing all VOCs other than those in Tables 2-1 and 2-2 includes those VOCs the control of which has relatively high priority.

Perchloroethylene (perc) was judged in 1977 to have photochemical reactivity comparable to those in Table 2-2 but was not included there because of its reported health effects. According to a more recent study (1983), perc is "judged to contribute less to the ambient photochemical O_3/O_x problem than an equal concentration of ethane"[1]. The EPA has formally proposed (October 24, 1983, 48 FR 49097) to reclassify perc with the organic compounds shown on Table 2-1, however a final decision has not been made. In addition, EPA has now formally announced (December 26, 1985, 50 FR 52880) the intent to add perc to the list of hazardous air pollutants. [For the purpose of this draft report, it is assumed that perc is not a VOC, thus its sources, emissions, and controls will not be further discussed.]

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* The current definition of VOC and list of non-VOCs are in part 51 of chapter I of title 40 of the Code of Federal Regulations.

TABLE 2-1. VOLATILE ORGANIC COMPOUNDS OF NEGLIGIBLE PHOTOCHEMICAL REACTIVITY THAT SHOULD BE EXEMPT FROM REGULATION UNDER STATE IMPLEMENTATION PLANS (JULY 8, 1977, 42 FR 35314)*

Methane
Ethane
1,1,1-Trichloroethane (Methyl Chloroform)[a]
Trichlorotrifluoroethane (Freon 113)[a]
Methylene Chloride[a]
Trichlorofluoromethane (Freon 11)[a]
Dichlorodifluoromethane (Freon 12)[a]
Chlorodifluoromethane (Freon 22)[a]
Trifluoromethane[a]
Chloropentafluoroethane (Freon 115)[a]
Dichlorotetrafluoroethane (Freon 114)[a]

[a] According to more recent EPA notices in the Federal Register (44 FR 32042, June 4, 1979, and 45 FR 48941, July 22, 1980), these compounds are of continuing concern to EPA over possible environmental effects and may be subject to future controls.*

TABLE 2-2. VOLATILE ORGANIC COMPOUNDS OF "LOW" PHOTOCHEMICAL REACTIVITY* (July 8, 1977, 42 FR 35314)

Propane
Acetone
Methyl Ethyl Ketone
Methanol
Isopropanol
Methyl Benzoate
Tertiary Alkyl Alcohols
Methyl Acetate
Phenyl Acetate
Ethyl Amines
Acetylene
N,N-dimethyl formamide

* The current definition of VOC and list of non-VOCs are in part 51 of chapter I of title 40 of the Code of Federal Regulations.

2.2 PHOTOCHEMICAL REACTIONS

Much research has been conducted concerning the causes and effects of photochemical smog. Investigations have revealed a complex series of chemical reactions take place in the atmosphere which result in high levels of photochemical oxidant (mostly NO_2 and ozone with smaller concentrations of peroxyacetyl nitrates and other peroxy compounds). These compounds produce haze, damage plant and animal life, and materials such as rubber, induce discomfort and are suspected to have toxic effects on man. Although specific volatile organics are inherently toxic, this text is devoted to a discussion of generic organic emissions, whose collective effect is most significant in their role as a precursor of photochemical oxidants.

A very simple, mechanistic description of the photochemical formation of ozone is shown in Equations 1 through 4.

$$NO_2 \xrightarrow{\text{Sunlight}} NO + O \qquad (1)$$

$$O + O_2 \xrightarrow{M} O_3 + M \qquad (2)$$

$$O_3 + NO \longrightarrow NO_2 + O_2 \qquad (3)$$

$$RO_x + NO \longrightarrow NO_2 + RO_y \qquad (4)$$

In these chemical equations M is a third body (usually N_2, O_2, or H_2O) stabilizing the molecule; R is an organic or inorganic radical; x = 1, 2, or 3; and y = x-1.

Reactions 1 through 3 are very rapid and their rates are nearly equal. At steady state conditions, ozone and NO are formed and destroyed in equal quantities. An equilibrium equation can be written relating the concentrations of O_3, NO, and NO_2:

$$[O_3] = k \frac{[NO_2]}{[NO]} \qquad (5)$$

This equation shows that any reaction which causes NO to be converted to NO_2 (Equation 4) will cause high NO_2 levels and high O_3 levels.

Hydroxyl and peroxy radicals are important atmospheric reactants which convert NO to NO_2. Hydroxyl radicals may react with CO or an organic compound to result in peroxy radicals which, by reacting with NO,

cause high levels of NO_2 and O_3. Additionally, some organic compounds (notably aldehydes) can photolize in the atmosphere to form radicals which participate in atmospheric reactions. Some of the organic radicals formed may react with NO_x to form nitrogenated organic pollutants, such as PAN.

The presence of highly reactive organic radicals can result in high oxidant levels within a few hours. These materials may be carried downwind great distances, thereby increasing ozone levels downwind from the pollutant source at a later time.

Volatile organics or oxidant precursors are emitted to the atmosphere from both natural and man-made sources. Globally, natural emissions appear to outweigh anthropogenic emissions. However, it is the high concentration of anthropogenic sources of volatile organics together with NO_x emissions from combustion processes in urban areas which give rise to the urban ozone problem. Wind and other climatalogical activities (transport mechanisms) may carry the ensuring oxidant formed into rural areas.

It is conceivable that natural phenomena may contribute to high oxidant levels. It has been suggested that terpenes emitted from heavily forested areas might act as precursors and react with naturally occuring NO_x to form ozone. It has also been postulated that intrusions of stratospheric ozone into the atmosphere might contribute to oxidant levels.

2.3 SAMPLING AND ANALYTICAL METHODS

The rationale for selection of specific sampling and analysis methods for the measurement of volatile organic emissions from stationary sources is addressed in two documents in the Guideline Series: "Measurement of Volatile Organic Compounds" (EPA-450/2-78-041, September 1979), and "Measurement of Volatile Organic Compounds - Supplement 1" (EPA-450/3-82-019, July 1982).

In considering test methods for VOC's, one must recognize that organic emissions normally occur as a mixture of (rather than a single) compounds. There is no simple quantitative method for a mixture. Several detection

techniques respond to organic compounds; however, the response can vary widely depending on the compound and will therefore, not likely be proportional to the total organic mass (or volume) of the mixture.

The principle concern when selecting a measurement method, is that it satisfies the intent of the appropriate emission standard by both using the correct sampling and analysis procedures, and expressing the results in a form consistent with the regulation. In some cases, the regulations are expressed in terms of the volatile organic content of a coating. In others, they restrict organic volume or mass concentrations, mass emission rates, or efficiency of the control device.

Table 2-3 lists the reference methods currently employed by EPA to measure VOC. Still other methods may be required to locate sampling points, standardize the measurements, and determine gas flowrates. Those methods are listed in Table 2-4.

2.4 CURRENT EMISSION LEVEL ESTIMATES

A list of VOC emission estimates by industry source category is presented in Table 2-5. These estimates by the EPA are based on data from a number of sources. The emission figures represent the nationwide combination of facilities (sources), both uncontrolled and controlled, and are based on local, State and Federal requirements on typical processes for each source category. These national emission estimates should be considered rough estimate largely because many estimates are ratioed up from "typical" plants, are dependent on how much EPA has studied a particular source and most estimates assume that required control equipment is properly inspected, operated and maintained. More specific information on their use and origin can be found in Chapter 4, where each source is discussed separately.

Mobile source emission estimates are also presented in Table 2-5 to present a comparison of stationary and mobile sources. As can be derived from the table, about two-thirds of VOC emissions is from stationary sources.

TABLE 2-3. THE ENVIRONMENTAL PROTECTION AGENCY REFERENCE METHODS FOR MEASUREMENT OF VOLATILE ORGANIC COMPOUNDS

Type of Measurement	Test Method (40 CFR Part 60, Appendix A)
1. Tank truck leaks, pressure and vacuum test.	Method 27
2. Fugitive emissions (leaks), ppmv as calibrated (reference compound in specified regulation).	Method 21
3. Solvent in surface coatings, weight of volatile organic compound per volume of solids.	Method 24
4. Solvent in ink, weight of volatile organic compound per volume of solids.	Method 24A
5. Total gaseous nonmethane organics, ppmv as carbon.	Method 25
6. Total organic carbon/flame ionization analyzer, ppmv as carbon.	Method 25A
7. Total organic carbon/nondispersive infra-red analyzer, ppmv as carbon.	Method 25B
8. Total nonmethane volatile organics/gas chromatography, ppmv as individual compounds.	Method 18

TABLE 2-4. THE ENVIRONMENTAL PROTECTION AGENCY REFERENCE METHODS TO DETERMINE THE FLOW OF A GAS

Type of Measurement	Test Method (40 CFR Part 60, Appendix A)
1. Sample and velocity traverse locations.	Method 1
2. Sample and velocity traverse locations - small stacks and ducts.	Method 1A
3. Stack gas velocity and flow rate, type S pitot tube.	Method 2
4. Gas flow rate, volume meter.	Method 2A
5. Gas flow rate, carbon balance.	Method 2B
6. Stack gas velocity and flow rate, standard pitot tube.	Method 2C
7. Gas flow rate - small pipes and ducts.	Method 2D
8. Gas analysis for CO_2, O_2, excess air, and dry molecular weight.	Method 3
9. Gas moisture content.	Method 4

TABLE 2-5. SOURCES OF VOLATILE ORGANIC COMPOUNDS

Source	1985 Estimated Emissions[a] Gg/yr	10^3 Tons/yr
PETROLEUM REFINERIES		
Equipment Leaks	370	409
Vacuum Producing Systems	44	49
Process Unit Turnaround	270	295
Cooling Towers	3	3
Wastewater Systems	55	60
	740	820
PETROLEUM MARKETING		
Oil and Gas Production Fields	226	250
Natural Gas and Natural Gasoline Processing Plants	76	84
Petroleum Liquid Storage[b]	668	736
Ship and Barge Transfer of Gasoline and Crude Oil	71	78
Bulk Gasoline Terminals[c]	172	190
Gasoline Bulk Plants[d]	180	200
Service Station Loading (Stage I)	256	280
Service Station Unloading (Stage II)	569	627
Vessel Cleaning	10	11
	2,230	2,460
ORGANIC CHEMICAL MANUFACTURE		
Process Vents	306	337
Storage and Transfer	45	50
Equipment Leaks	148	163
	500	550
INDUSTRIAL MANUFACTURING PROCESSES		
Paint and Varnish	12	13
Vegetable Oil	65	71
Pharmaceutical	50	55
Styrene-Butadiene Copolymer	NA[f]	NA[f]
Rubber Tire	40	44
Polymers and Resins	86	95
Synthetic Fibers	70	77
Plywood	2	2
Beer and Wine	2	2
Whiskey Warehousing	38	42
	365	400

TABLE 2-5. SOURCES OF VOLATILE ORGANIC COMPOUNDS (continued)

Source	1985 Estimated Emissions[a] Gg/yr	10^3 Tons/yr
APPLICATION OF PAINTS, INKS, AND OTHER COATINGS		
- SURFACE COATING		
Large Appliances	24	26
Magnet Wire	7	8
Automobiles and Light-Duty Trucks	64	70
Cans	68	75
Metal Coils	33	36
Paper, Film and Foil	175	193
Tapes and Labels	450	496
Magnetic Tape	8	9
Fabric Coating and Printing	70	77
Metal Furniture	95	105
Wood Furniture	200	220
Flat Wood Paneling	24	26
Other Metal Products	330	364
Large Aircraft	2	2
Large Ships and Boats	18	20
Plastic Parts (Business Machines)	5	6
Flexible Vinyl and Urethane	23	25
Architectural Coatings	360	397
Auto Refinishing	200	220
Others - Surface Coating	236	260
- GRAPHIC ARTS	467	514
- ADHESIVES	305	336
	3,160	3,490
OTHER SOLVENT USE		
Metal Cleaning	920	1,010
Petroleum Dry Cleaning	83	91
Cutback Asphalt Paving	195	214
Other Solvent Use[g]	2,400	2,645
	3,600	3,960

TABLE 2-5. SOURCES OF VOLATILE ORGANIC COMPOUNDS (continued)

Source	Estimated Gg/yr	1985 Emissions[a] 10^3 Tons/yr
OTHER MISCELLANEOUS STATIONARY SOURCES		
Fuel Combustion	2,100	2,300
Forest, Agricultural, and Other Open Burning	900	(990
Hazardous Waste Treatment, Storage, and Disposal Facilities	3,500	3,860
Publicly Owned Treatment Works (POTW's)	21	23
	6,520	7,190
TOTAL VOLATILE ORGANIC EMISSIONS FROM STATIONARY SOURCES	17,100	18,870
MOBILE SOURCES[e]		
Highway Vehicles	6,000	6,600
Off-Highway Vehicles	400	440
Rail	200	220
Aircraft	200	220
Vessels	400	440
TOTAL VOLATILE ORGANIC EMISSION FROM MOBILE SOURCES	7,200	7,920
TOTAL VOLATILE ORGANIC EMISSIONS	24,300	26,800

[a] 1985 EPA Estimates, due to data limitations all emission calculations may not be based on 1985 data. See Chapter 4 of this document for more information.

[b] Petroleum Liquid Storage - includes all storage facilities except those at service stations and bulk plants. .

[c] Bulk Terminals - emissions from loading tank trucks.

[d] Bulk Plants - emissions from storage and transfer.

[e] Estimates from "National Air Pollutant Emission Estimates (1940 - 1983), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA 450/4-84-028, December 1984.

[f] Not available.

[g] Estimates from End Use of Solvents Containing VOC, U.S. EPA, EPA-450/379-032, May 1979.

2.5 AIR QUALITY AND EMISSION TRENDS

EPA annually publishes a report on air quality and emission trends.[2] Improvements are reported for long-term (1975 through 1983) ozone levels. In summary, the report shows an 8 percent decrease in the average of the second-highest daily maximum 1-hour ambient ozone levels. VOC emissions were also reported to have decreased by 12 percent during the same time period.

2.6 REFERENCES

1. Dimitriades, B.; Gay, B.; Arnts, R.; and Selia, R. "Photochemical Reactivity of Perchloroethylene," U. S. Environmental Protection Agency, Environmental Sciences Research Laboratory, Research Triangle Park, North Carolina 27711, EPA-600/3-83-001, January 1983, pg. 46.

2. National Air Quality and Emissions Trends Report, 1983, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-450/4-84-029, April 1985.

3.0 CONTROL TECHNOLOGIES AND EQUIPMENT

Two methods employed commercially to control emissions of volatile organic compounds are:

1. installation of control equipment to destroy or extract the organic vapors from exhaust gases, and

2. changes to the process or raw materials that reduce or eliminate vapor emissions.

There are four major types of control equipment. They are based on combustion, adsorption, absorption, and condensation. These are discussed in Section 3.2 through 3.5, where operating characteristics of each are explained and the primary areas of application are indicated. Some representative estimates of capital and annualized costs are provided, along with energy requirements and environmental impact.

3.1 CAPTURE

Any control system that reduces volatile organic compound (VOC) emisssions from a process, has two fundamental components. The first is the containment or capture system, which is a single device or group of devices whose function is to collect the pollutant vapors and direct them into a duct leading to a control device. The second component is the control device, which reduces the quantity of the pollutant emitted to the atmosphere.

The efficiency with which vapors from a process are collected by the containment or capture system and delivered to the control device is called "Capture Efficiency" (CE). It is defined as "the fraction of all organic vapors generated by a process that is directed to an abatement or recovery device". "Control Device Efficiency" (CDE) is defined as "the ratio of the pollution destroyed or recovered by a control device to the pollution introduced to the control device." The "Overall Control

Efficiency" (OCE) is the product of the capture and control device efficiencies or

$$OCE = CE \times CDE \qquad \text{(Equation 1)}$$

For this reason a highly effective capture system is critical to achieving high levels of VOC emission control.[1]

There are three types of capture systems: local ventilation, partial enclosures, and total enclosures. Each of these are discussed below.

Local Ventilation Systems.[2] Local ventilation systems are the most common capture systems. They usually consist of one or more hoods such as floor sweeps, slotted ducts, and even certain kinds of partial enclosures. Capture efficiencies of these ventilatiion systems vary widely.

An efficient local ventilation capture system should maximize the collection of VOC emissions, minimize the collection of dilution air, and maintain an adequate ventilation rate in the work place. The factors important in designing an efficient capture system include:

1. Degree of turbulance;
2. Capture velocity; and
3. Selectivity of collection.

Although these factors are interdependent, each will be discussed separately.

Turbulence in the air around a VOC emission source is a serious impediment to effective collection. Turbulence dilutes the solvent laden air stream and contributes to the transport of VOC away from the capture device. The resulting increase in of dilution air increases the size and resultant cost of control equipment. Sources of turbulence that should be recognized and minimized include:

1. Thermal air currents;
2. Machinery motion;
3. Material motion;
4. Operator movements;
5. Room air currents; and
6. Spot cooling and heating of equipment.

Turbulence around hoods and exhaust vents should also be minimized. The coefficient of entry (C_e) is a measure of the degree of turbulence caused by the shape of the opening. A perfect hood with no turbulence losses would have a coefficient of entry equal to 1. Table 3-1 gives coefficients of entry for selected hood openings. Flanged or bell-mouthed hood openings reduce the pressure drop at the entrance which reduces turbulence, and, thereby, improves capture.

The velocity necessary to collect contaminated air and draw it into a capture device is called the capture velocity. At capture velocity, the inflow of air to the capture device is sufficient to overcome the effects of turbulence and, thereby, minimize the escape of contaminated air. Local ventilation systems require higher capture velocities than total or partial enclosures and result in larger quantities of air being ducted to the control device. Empirical testing of operating systems has been used to develop the guidelines for capture velocity presented in Table 3-2.

Selectivity describes the ability of the capture system to collect pollutants at their highest concentration by minimizing the inflow of clean air. A highly selective system will achieve a high capture efficiency using low airflow rates. Low airflow rates and the increased VOC concentration in the air stream result in control systems that are relatively economical to operate.

The best method of improving selectivity is to minimize the distance between the emission of source and the capture device. Selectiyity also can be enhanced by the use of flanges or bell-shaped openings on hoods and exhaust points. These features cause the airflow to be pulled more directly from the source of emissions. Less dilution air is pulled from behind and the sides of the hood.

Partial Enclosures. A partial enclosure is any rigid or semirigid structure other than a total enclosure, that partially surrounds or enshrouds a manufacturing process or other source of emissions. For example, it may be open on at least one side to provide unobstructed access

TABLE 3-1. COEFFICIENTS OF ENTRY FOR SELECTED HOOD OPENINGS[3]

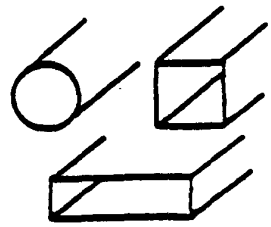
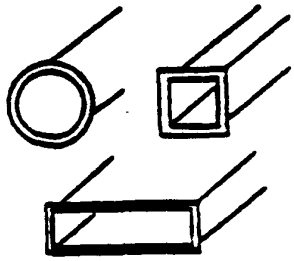
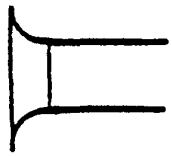
Hood type	Description	C_e
	Plain opening	0.72
	Flanged opening	0.82
	Bell mount inlet	0.98

TABLE 3-2. RANGE OF CAPTURE VELOCITIES[3]

Condition of dispersion of contaminant	Capture velocity, m/s (fpm)
Released with little velocity into quiet air	0.25-0.51 (50-100)
Released at low velocity into moderately still air	0.51-1.02 (100-200)
Active generation into zone of rapid air motion	1.02-2.54 (200-500)
Released at high initial velocity into zone of very rapid air motion	2.54-10.2 (500-2,000)

to the process equipment. (A total enclosure would be a partial enclosure if operated with an open door.) Because the partial enclosure only partially encloses the source of emissions, part of the VOC might not be contained (for ducting through a stack or into an oven), but rather might escape to the atmosphere as fugitive emissions. Examples are a tunnel open at one end, a spray booth open on one side or a room with an open doorway. The emissions may be vented through the drying oven and then to the control device or directly to the control device.

Total Enclosures.[1,4] The most effective emission capture system is a total enclosure that surrounds the emission source. The only openings are those which allow raw materials into the enclosure or that specifically allow air into prevent a buildup of organic vapors to hazardous exposure or explosive concentrations. A negative-pressure differential is maintained with respect to the outside of the enclosure to ensure that no air can escape through the limited openings.

A ventilation system can be designed so that the room containing the source(s) of emissions functions as a total enclosure. By closing all doors and windows, the room may be evacuated either by the draft from the oven(s) or by hoods and exhaust ducts. The room ventilation exhaust can be directed to the control device; it can be used as make-up air to any ovens which are served by a control device; or, it can be split between the two routes.

A total enclosure also may be designed as a small room surrounding the emission source or as a "glove box" shaped to conform roughly to the shape of the equipment. This design may preclude total emission capture at all times, however, because of turbulence or back drafts caused by the opening of enclosure doors during operation, if frequent worker access is necessary. If the pressure diffential between inside and outside the enclosure is adequate, fugitive losses would be minimal.

If frequent or continuous worker access is necessary, fresh air could be supplied directly to operators stationed within the enclosure. Another approach would be to have the total enclosure equipped with local

hoods and evacuated at a rate that maintains a safe concentration for the worker without requiring a fresh air supply system. The amount of air necessary to achieve this condition would be a function of the proximity of the hood(s) to the source(s) of emissions.

The VOC emissions that are contained by the glove box enclosure, as with the emissions from the large room, can be ducted to the oven to serve as make-up air or directly to a control device. When the captured emissions are used as oven make-up air, the total airflow to the control device is lower than that for systems that duct air from the process area to the control device through independent ductwork. In some cases, the draft from the oven opening at the substrate entrance may be sufficient to draw the captured emissions into the oven without the use of additional hoods and ducts. Using ventilation air as oven make-up increases the VOC concentration in the solvent laden air that is ducted to the control device; thus, the potential size of the control device required to treat the solvent laden air may be smaller.

3.2 COMBUSTION CONTROL DEVICES

Combustion control devices include process heaters, boilers, flares, and thermal and catalytic incinerators. Combustion is a rapid, exothermic oxidation process which will convert VOC to water and carbon dioxide. Fuels and VOC contain carbon and hydrogen, which when burned to completion with oxygen, form carbon dioxide and water. Combustion control devices destroy any organic raw material or product in the offgas. Much of the thermal energy released by combustion in incinerators can be recovered with equipment such as recuperative heat exchangers or waste heat boilers, if desired.

3.2.1 Thermal Incinerators

3.2.1.1 Equipment and Operating Principles

Incineration destroys volatile organics by oxidizing them to carbon dioxide and water. Any VOC heated to a sufficiently high temperature in the presence of oxygen will burn or oxidize. Theoretical combustion temperatures vary depending upon the chemical structure of the VOC, incinerator residence time, and availability of oxygen in the proximity of the VOC (mixing). Properly designed incinerators include the following:

1. A sufficiently high design temperature for the combustion chamber to ensure rapid and complete oxidation.
2. Adequate turbulence to obtain good mixing between combustion air, VOC, and hot combustion products from the burner.
3. Sufficient residence time at incineration temperature for complete combustion.

A typical thermal incinerator consists of a refractory-lined chamber containing one or more burners. As shown in Figure 3-1a, the design provides for a thorough mixing of waste gas, combustion air, and hot combustion products from the burner. The gas mixture then passes into a combustion chamber (5) sized to allow complete combustion with a typical residence time of 0.3 to 1.0 second. Energy can be recovered from the hot flue gases in a heat recovery section (6). Energy so recovered can be used to preheat subsequent combustion air, offgas or both, to generate steam in a waste heat boiler, or for a variety of other uses such as providing process heat elsewhere in the plant, to heat

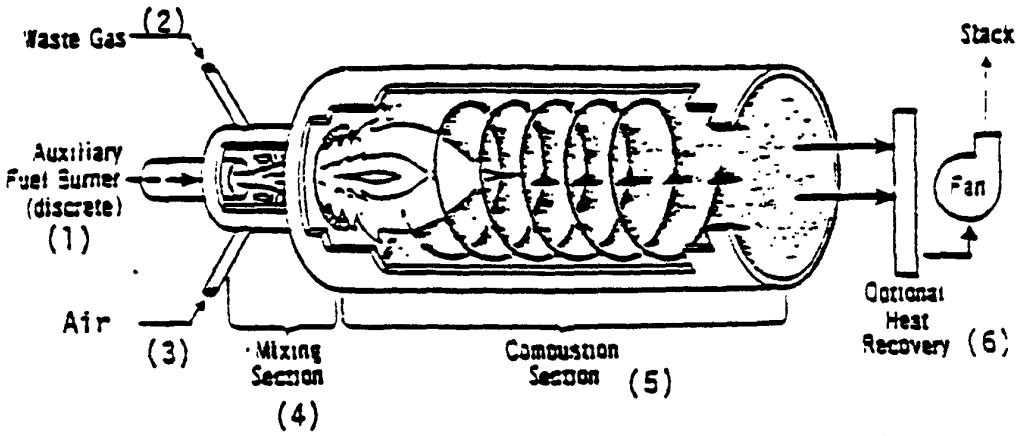


Figure 3-1.a Discrete burner, thermal incinerator.

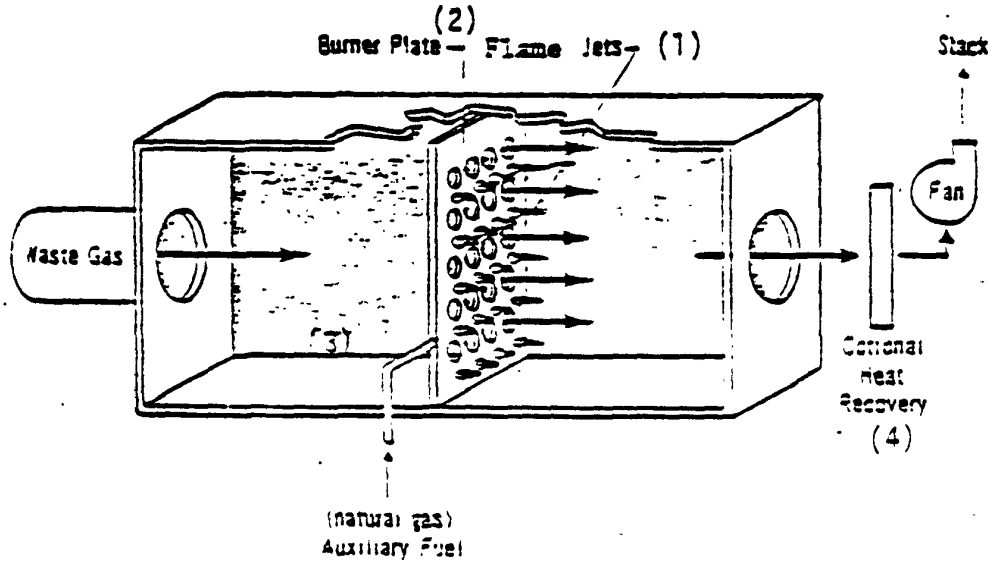


Figure 3-1.b Distributed burner, thermal incinerator.

ventilation air in wintertime, etc. If the waste gas is preheated, insurance regulations require the VOC concentration be maintained at or below 50 percent of the lower explosive limit (LEL) with proper instrumentation to prevent risk of fire or explosion.

A second type of thermal incinerator uses a distributed gas burner as shown in Figure 3-1b.[5] Tiny natural gas flame jets (1) on the burner plate (2) ignite the waste gas as it passes through the grid. The grid acts as a baffle for mixing the gases in the chamber (3). This design provides high efficiency and reportedly requires less fuel and a lower chamber temperature. The use of natural gas allows a shorter combustion section than a fuel oil fired incinerator.

Incinerator performance is affected by the heating value of the waste gas, the inert content, the water content, and the amount of excess combustion air. Combustion of waste gas with a heating value less than 1.9 MJ/scm (50 Btu/scf) usually requires auxiliary fuel to maintain the desired combustion temperature. Waste gas with a heating value above 1.9 MJ/scm (50 Btu/scf) will burn but it may need auxiliary fuel for flame stability. Auxiliary fuel requirements can be decreased if recuperative heat exchangers are installed to preheat combustion air.

When a waste gas contains entrained water droplets, additional auxiliary fuel is required to vaporize the water and raise it to the combustion chamber temperature. If the heat value or moisture content varies, then increased monitoring and control are required to maintain proper temperatures and removal efficiency.

To insure sufficient oxygen is present for complete combustion, incinerators are always operated with some excess air. The amount of excess air introduced may vary with fuel and burner type, but is kept low to avoid wasting fuel. Excess air increases flue gas volume and can require increases in the size and cost of the incinerator control system. Packaged, single unit thermal incinerators are available to control gas flow rates from about 0.14 scm/sec (300 scfm) to 24 scm/sec (50,000 scfm).

Thermal incinerators burning halogenated VOC typically require special materials of construction and additional control equipment to prevent release

of the corrosive combustion products. Flue gases are quenched to lower their temperature and are then often routed through absorption equipment to remove the corrosive gases. Failure to scrub the acid flue gases can result in corrosion problems in downstream equipment and on any plant equipment on which the stack gases impact.

VOC destruction efficiency depends upon design criteria, i.e., chamber temperature, residence time, inlet VOC concentration, compound type, and degree of mixing as previously discussed. An analysis of test results, along with kinetics calculations, indicate that for a nonhalogenated VOC, 98 percent destruction efficiency is achieved with a combustion temperature of 870°C (1,600°F) and a residence time of 0.75 seconds.[6]

At temperatures over 760°C (1,400°F), oxidation reaction rates are much faster than the mixing rates. The VOC destruction efficiency then become dependent upon the fluid mechanics within the combustion chamber. High efficiencies require rapid, thorough mixing of the VOC stream, combustion air, and hot combustion products from the burner.

Studies of thermal incinerator efficiency indicate that new incinerators using current technology can achieve 98 percent VOC destruction or a 20 ppmv compound exit concentration.[7] For vent streams with VOC concentration below approximately 2,000 ppmv, reaction rates decrease, maximum VOC destruction efficiency decreases, and an incinerator outlet concentration of 20 ppmv (volume, by compound), or lower, is achievable by all new thermal incinerators.[8] For vent streams with VOC concentration above approximately 2,000 ppmv, a 98 percent destruction efficiency is predicted for incinerators operated at 870°C (1,600°F) with 0.75 seconds residence time. For halogenated streams, 98 percent efficiency is predicted for incinerators operated at 1,100°C (2,000°F) with 1 second residence time.

Applications

Thermal incinerators can be used to reduce emissions from almost all volatile organic emission sources including reactor vents, distillation vents, solvent operations, and operations performed in ovens, dryers, and kilns. They can handle minor fluctutations in flow, however excess fluctations require the use of a flare. Presence of elements such as halogens or sulfur requires additional equipment such as scrubbers for acid gas removal.

3.2.1.3 Costs

Capital costs for thermal incinerators depend upon the following factors: (1) the fuel valve of the gas (2) the gas flowrate, (3) the fuel used, (4) the degree of heat recovery, (5) the residence time, and (6) the presence of contaminants. A thermal incinerator control system may consist of the following equipment: combustion chamber, recuperative heat exchanger, waste heat boiler, quench/scrubber system, and auxiliary equipment such as ducts, pipe rack, fans, and stack.

The Control Techniques Guideline Document for Air Oxidation Processes in the Synthetic Organic Chemical Manufacturing Industry[9] presents a series of capital cost equations which include purchase costs and retrofit installation costs for thermal incinerators, recuperative heat exchangers, ducts, fans, and stacks and support structures for the ductwork. Equations are available for two incineration temperatures, 870°C (1,600F) and 1,100°C (2,000°F). Equations are available both halogenated and non-halogenated streams. For halogenated streams, the purchase and retrofit installation costs of waste heat boilers and flue gas scrubbers are also included. The equations used capital costs data obtained from vendor quotations.[10] Total installed capital costs include such installation cost components as foundation, insulation, erection, instruments, painting, electrical, fire protection, engineering, freight and taxes. Capital costs increase as design flowrate increases and decrease as off-gas heating value increases.

For a process vent stream with a flowrate of 327 nm^3/min (11,500 scfm) and a heating value of 48 MJ/nm^3 (1,300 Btu/scf), the installed capital cost for the thermal incinerator is estimated at $2,300,000 in 1984 dollars.[11]

The annualized cost consists of direct operating and maintenance costs, and annualized capital charges. Direct operating and maintenance costs consist of operating and maintenance labor, replacement parts, utilities, fuel, and caustic. Utility requirements include electricity (for fans and pumps), and make-up water for operation of the quench system. Natural gas is needed to supplement the heating value of many vent streams and to maintain the pilot flame. Caustic may be required to neutralize acidic scrubber

water. Capital charges include annualized equipment costs, indirect costs for overhead, taxes, insurance, administration and capital recovery.

For the process vent stream cited above, annualized costs for the incinerator are $1,000,000 in 1984 dollars.[12]

3.2.1.4 Energy Requirements

The use of incineration typically requires supplemental fuel and electricity. Supplemental fuel is frequently required to support combustion. Electricity is required to operate pumps, fans, blowers, and instrumentation. Fans and blowers are needed to transport vent streams and combustion air. Pumps are necessary to circulate absorbent through scrubbers. Electricity generally accounts for less than 2 percent of the total energy impact, while fuel use accounts for the remainder.[13]

In general, supplemental fuel requirements depend on the organic content of the process gas stream, waste stream temperature, incineration temperature, and type of heat recovery employed. For halogenated vent streams with heat content values of less than 3.5 MJ/nm^3 (95 Btu/scf) and nonhalogenated streams with heat content values of less than 1.9 MJ/nm^3 (51 Btu/scf) the fuel requirement can be estimated at 0.33 MJ of natural gas heat per normal cubic meter of offgas (89 Btu/scf). For halogenated vent streams with heat content values of greater than 3.5 MJ/nm^3 (95 Btu/scf) and nonhalogenated streams with heat content values of greater than 1.9 MJ/nm^3 (51 Btu/scf) the amount of fuel required per normal cubic meter of offgas is equivalent to 10 percent of the offgas heating value.[14]

3.2.1.5 Environmental Impacts

Destruction of volatile organics with a thermal incinerator can produce secondary emissions, particularly nitrogen oxides (NO_x). Factors affecting the rate of NO_x formation during combustion include the following: the amount of excess air available, the peak flame temperature, the length of time that the combustion gases are at a peak tempeature, and the cooling rate of the combustion products.[15] A series of tests conducted at three air oxidation process units found incineration outlet NO_x concentrations ranging from 8 to 200 ppmv.[16] The 200 ppmv concentration is the maximum value that can be anticipated.

Combustion of halogenated VOC emissions may result in the release of halogenated combustion products to the environment. To ensure 98 percent destruction of halogenated VOC, incineration temperatures greater than 870°C are required. The HCl emissions generated at this temperature are removed by wet scrubbing, preventing the release of halogenated combustion products to the environment.

The use of scrubbers to control HCl emissions does result in a small increase in wastewater. Water use is estimated at 0.033 m^3/Kg (19.2 gal/lb) of halogen in the waste gas.[17] Effluent guidelines may also require pH adjustment prior to discharge to the plant effluent system. The scrubber wastewater is also likely to contain small quantities of organic compounds.

No significant solid wastes are generated by a thermal incinerator used for VOC destruction.

3.2.2 Catalytic Incinerators

3.2.2.1 Equipment and Operating Principles

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 VOC stream.

Figure 3-2 presents a catalytic incinerator. The waste gas (1) is introduced into a mixing chamber (3) where it is heated to approximately 320°C (~600°F) by the hot combustion products of the auxiliary burners (2). The heated mixture then passes through the catalyst bed (4). Oxygen and VOC 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 (5) before exhausting into the atmosphere.

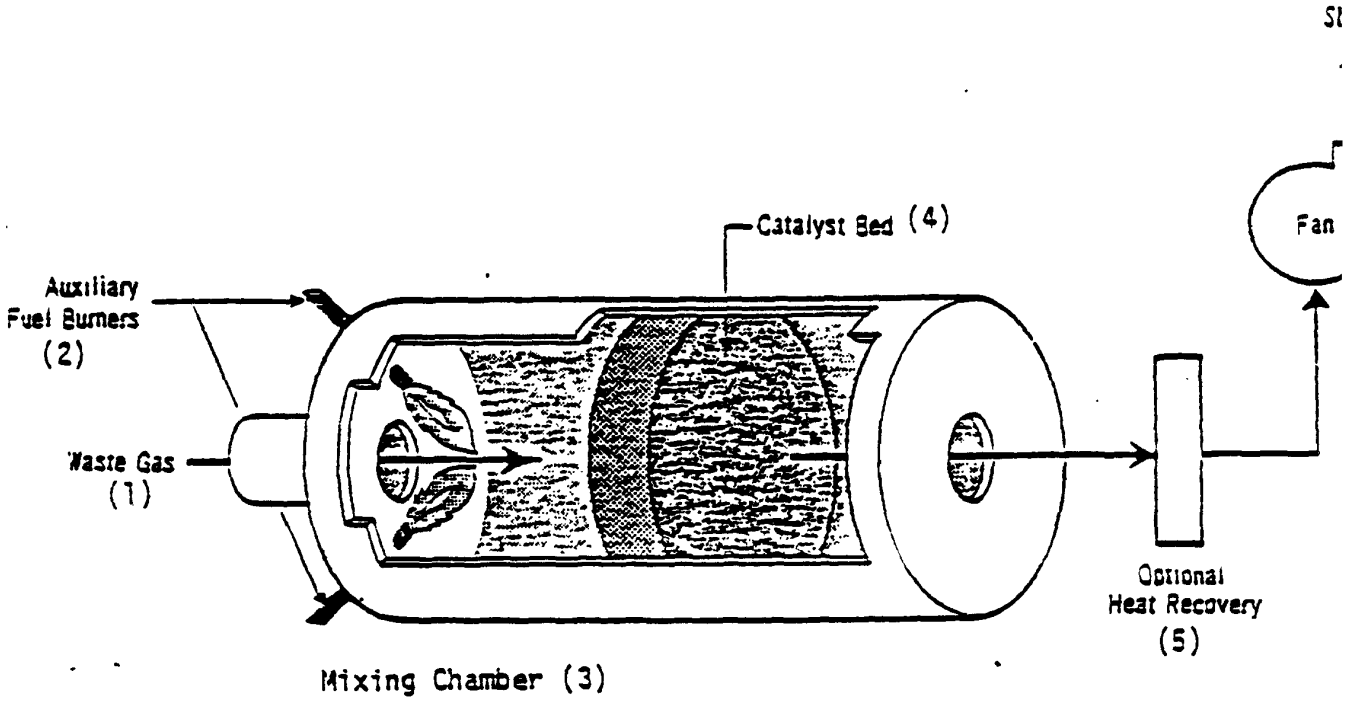


Figure 3-2 Catalytic oxidizer.

Combustion catalysts usually open 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. Offgas streams with high VOC concentrations can result in temperatures high enough to cause catalyst failure. In such cases, dilution air may be required. Accumulations of particulate matter, condensed VOC, or polymerized hydrocarbons on the catalyst can block the active sites and reduce efficiency. Catalysts can also be deactivated by compounds containing sulfur, bismuth, phosphorous, arsenic, antimony, mercury, lead, zinc, tin, or halogens. If these compounds deactivate the catalytic unit, VOC will pass through unreacted or be partially oxidized to form compounds (aldehydes, ketones, and organic acids) that are highly reactive atmospheric pollutants which can corrode plant equipment.

Catalytic incineration destruction efficiency is dependent on VOC 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 VOC destruction efficiency is strongly influenced by catalyst operating temperature. As space velocity increases, destruction efficiency decreases, and as temperature increases, VOC 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/sec (1,000 scfm) of offgas passing through the device can achieve 95 percent VOC destruction efficiency.[18] Destruction efficiencies of 98 percent or greater can be obtained by utilizing the appropriate catalyst bed volume to offgas flow rate.

Applications

Catalytic incineration has been applied to waste streams from a variety of stationary sources. Solvent evaporation processes associated with surface coating and printing operaions are a major source of VOC emissions, and catalytic incineration is widely used by many industries in this category. Catalytic incinerators have also been used to control emissions from varnish

cookers, foundry core ovens, filter paper processing ovens, plywood veneer dryers, and gasoline bulk loading stations.

The sensitivity of catalytic incinerators to VOC inlet stream flow conditions and catalyst deactivation, limit their applicability for many industrial processes.

3.2.2.3 Costs

Capital costs for catalytic incinerators are dependent upon the same variables as thermal incinerators (see Section 3.1.1.3). Cost data on catalytic incinerators are available in an EPA study[19] for seven waste-gas flows: 700, 2,000, 5,000, 10,000, 20,000, 50,000, and 100,000 scfm; for a destruction efficiency of 99 percent; and for no heat recovery, with a recuperative heat exchanger used to heat the waste gas and combustion air, and heat recovery with a waste-heat boiler used to produce steam. The cost data includes all indirect costs, such as engineering and contractors' fees and overheads.

Figure 3-3 presents the installed capital costs for a waste gas with heat content at 10 Btu/scf in air. Using Appendix B to update costs to May of 1984, capital costs for a 10,000 scfm waste-gas flow to a catalytic incinerator with heat exchanger and 99 percent destruction are $730,000.[20]

Annualized costs for a catalytaic incinerator include the same cost items presented in the discussion of thermal incinerators (see Section 3.2.1.3). For catalytic incinerators, catalyst replacement costs must be included. Catalysts can result in savings of about 40-60 percent in fuel costs as compared to thermal incinerators.

Annualized costs for the catalytic incinerator handling 10,000 scfm waste-gas discussed previously are $380,000[21] (in 1984 dollars).

3.2.2.4 Energy Requirements

Like thermal incinerators, catalytic incinerators typically require supplemental fuel and electricity. Where VOC concentrations are high enough, however, catalytic incinerators with recuperative heat exchangers require little or no fuel except for start-up. Fuel savings are due to the lower temperatures associated with catalytic incinerators. Gases which require heating to 750°C with no catalyst might be oxidized at 300°C with a catalyst.

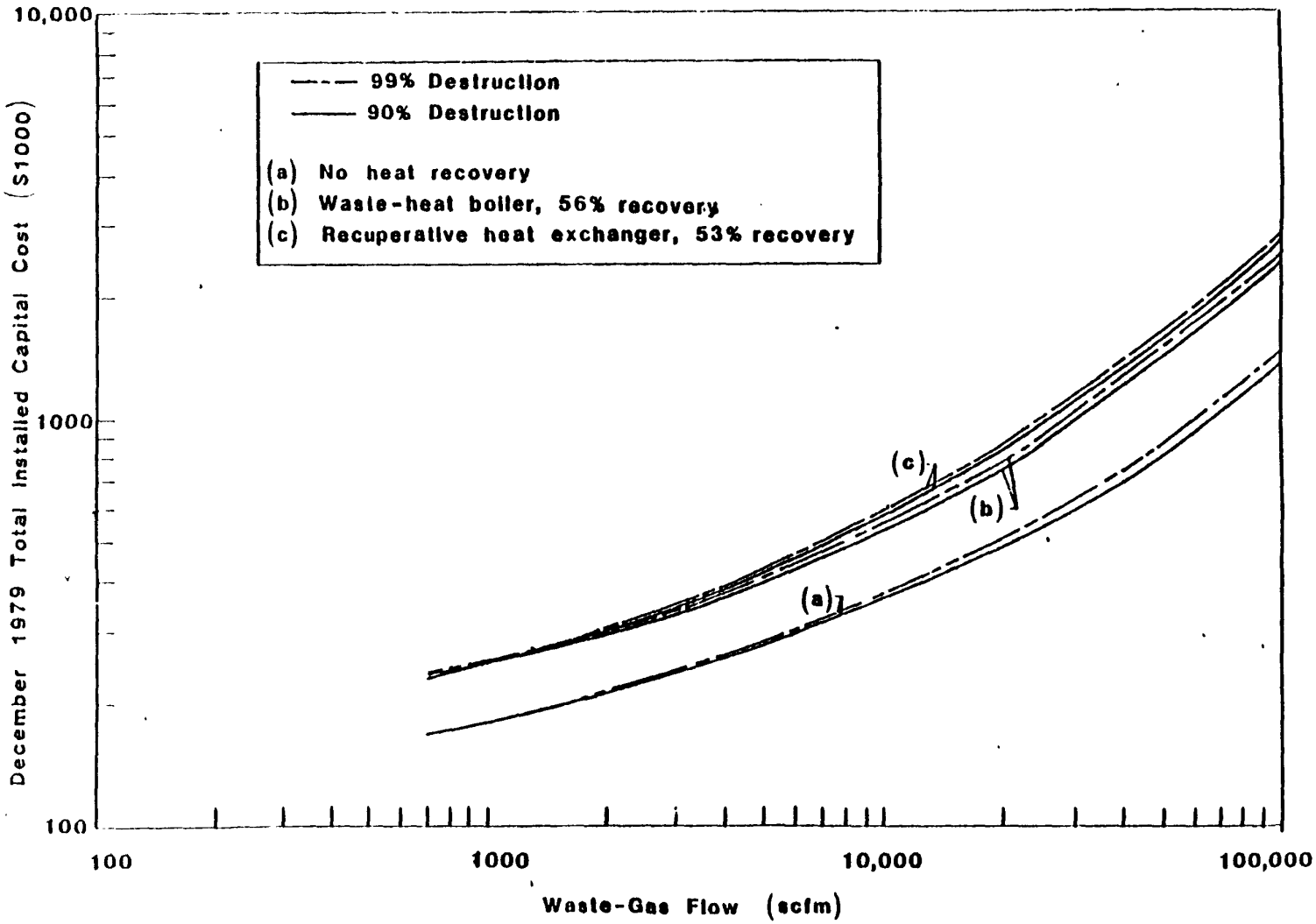


Fig. 3-3 Installed Capital Costs of Catalytic Oxidizer Systems for Waste Gas with a Heat Content of 10 Btu/scf in Air

3.2.2.5 Environmental Impacts

Environmental impacts for catalytic incinerators are similar to impacts presented in Section 3.2.1.5 for thermal incinerators. In addition, regeneration or replacement of the catalyst can present a secondary pollution problem. When the catalyst needs to be completely replaced, the used catalyst is treated as solid waste requiring proper disposal. Regeneration of the catalyst also requires proper disposal of any waste material that is produced.

3.2.3 Industrial Boilers and Process Heaters

3.2.3.1 Equipment and Operating Principles

Industrial boilers and process heaters can be used for VOC destruction. The waste gas is either mixed in with the fuel or fed in through a separate burner. A typical industrial boiler in the chemical industry is the watertube design fired by natural gas. In a watertube boiler, hot combustion gases contact the outside of heat transfer tubes, which contain hot water and steam. These tubes are interconnected by a set of drums that collect and store the heated water and steam. Energy transfer from the hot flue gases to water in the furnace water tube and drum system can be above 85 percent efficient. Additional energy can be recovered from the flue gas by preheating combustion air in an air preheater or by preheating incoming boiler feedwater in an economizer unit.

Forced or natural draft burners are used to thoroughly mix the incoming fuel and combustion air. If a process vent stream is combusted in a boiler, it can be mixed with the incoming fuel or fed to the furnace through a separate burner. In general, burner design depends on the characteristics of the fuel mix (when the process vent stream and fuel are combined) or of the characteristics of the vent stream alone (when a separate burner is used). A particular burner design, commonly known as a high intensity or vortex burner, can be effective for vent streams with low heating values (i.e., streams where a conventional burner may not be applicable). Effective combustion of low heating value streams is accomplished in a high intensity burner by passing the combustion air through a series of spin vanes to generate a strong vortex.[22]

Furnace residence time and temperature profiles vary for industrial boilers depending on the furnace and burner configuration, fuel type, heat input, and excess air level. A mathematical model has been developed that estimates the furnace residence time and temperature profiles for a variety of industrial boilers.[23] This model predicts mean furnace residence times of from 0.25 to 0.83 seconds for natural gas-fired watertube boilers in the size range from 4.4 to 44MW (15 to 150 x 10^6 Btu/hr). In boilers at or above the 44 MW size residence times and operating temperatures ensure a 98 percent VOC destruction efficiency. Units are designed to mix and burn all fuel efficiently. Furnace exit temperatures for this range of boiler sizes are at or above 1,200°C (2,200°F) with peak furnace temperatures occurring in excess of 1,540°C (2,810°F). Residence times for oil-fired boilers are similar to the natural gas-fired boilers described here.

Like boilers, process heaters take the heat produced by fuel combustion and transfer it by radiation and convection to fluids contained in tubular coils. Process heaters are used in the chemical industry to drive endothermic reactions. They are also used as feed preheaters and as reboilers for some distillation operations. Fuels used include natural gas, refinery off gases, and various grades of fuel oil. Gaseous fuels predominate.

In the design of process heaters, the radiant and convective sections are modified depending on the application considered. In general, the radiant section consists of the burner(s), the firebox, and a row of tubular coils containing the process fluid. Most heaters also contain a convective section in which heat is recovered from hot combustion gases by convective heat transfer to the process fluid.

Process heater applications in the chemical industry can be broadly classified with respect to firebox temperature as follows: (1) low firebox temperature applications such as feed preheaters and reboilers, (2) medium firebox temperature applications such as steam superheaters, and (3) high firebox temperature applications such as pyrolysis furnaces and steam-hydrocarbon reformers. Firebox temperatures within the chemical industry can range from about 400°C (750°F) for preheaters and reboilers to 1,260°C (2,300°F) for pyrolysis furnaces.[24]

A boiler or process heater furnace is comparable to an incinerator where the average furnace temperature and residence time determines 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.

As discussed in previous sections, firebox temperatures for process heaters show relatively wide variations depending on the application. Tests were conducted by EPA to determine the benzene destruction efficiency of five process heaters firing a benzene offgas and natural gas mixture. The units tested are representative of process heaters with low temperature fireboxes (reboilers) and medium temperature fireboxes (superheaters). Sampling problems occurred while testing one of these heaters, and as a result, the data for that test may not be reliable and are not presented. The reboiler and superheater units tested showed greater than a 98 percent overall destruction efficiency for C_1 to C_6 hydrocarbons. Additional tests conducted on a second super heater and a hot oil heater showed that greater than 99 percent overall destruction of C_1 to C_6 hydrocarbons occurred for both units.[25]

3.2.3.2 Applications

Industrial boilers and process heaters are currently used by industry to combust process vent streams from chemical manufacturing operations, and general refinery operations. Both devices are most applicable where high vent stream heat recovery potential exists.

Combustion of process vent strams can affect the performance of a boiler. The vent stream characteristics must be considered. Variable flow rates, variable heat contents, and the presence of corrosive compounds may require changes in operating methods but do not prevent use of a boiler as a control device.

The introduction of a process vent stream into the furnace of a boiler or heater could alter the heat transfer characteristics of the furnace. Heat

transfer characteristics are dependent on the flowrate, 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 vent 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 a process vent stream may affect the performance of the heat generating unit, and increase fuel requirements. Flame fluttering within the furnace could also result from variations in the process vent stream characteristics. Precautionary measures should be considered in these situations.

When a boiler or process heater is applicable and available, they are excellent control devices since they can provide at least 98 percent destruction of VOC in most cases. 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.

3.2.3.3 Costs

Capital costs for application of a boiler or process heater to control VOC typically assume the plant has an existing boiler which can be modified to accommodate the vent stream. Natural gas-fired watertube boilers are most common and boiler modifications include increasing the induced fan size and replacing the existing burner with one capable of burning a fuel and vent gas mixture. Total installed capital costs associated with a boiler combusting a 0.0123 scm/s (26 scfm) vent stream with a heating value of 494 Btu/scf are $32,000 (1984 dollars).[26] Capital costs include the pipes, fittings and compressors necessary to transport the vent stream from its source to the control device.

Annualized costs for a boiler include direct operating and maintenance costs, and annualized capital changes. In many cases, the energy recovery associated with combusting the vent stream results in a cost savings. For the vent stream discussed above, annualized costs are a net cost savings of $27,000 (in 1984 dollars).[27]

3.2.3.4. Energy Requirements

As noted earlier combustion of vent streams with high heat contents in boilers or process heatrs can result in a net energy savings. Savings result from decreased fuel consumption or increased steam production.

3.2.3.5. Environmental Impacts

The principal environmental impact associated with the use of boilers or process heaters is the increased nitrogen oxides emissions. Most units use natural gas as a primary or supplemental fuel. Data on NO_x emissions from gas-fired process heaters show NO_x concentrations from 76 to 138 ppmv. Typically, mechanical draft heaters with preheating emit more NO_x than furnaces without preheating and natural draft furnaces. Also, NO_x emissions are higher under typical excess air conditions (about 5.5 percent oxygen) than under low excess air conditions (about 3 percent oxygen).[28] Adding the process vent VOC results in an incremental increase in NOx.

3.2.4 Flares

A flare is a combustion control device which provides a safe and economical way of disposing of sudden releases of large amounts of gas. Flares are also used to combust continuous vent streams. Flares are used extensively to burn purged and waste products from refineries, excess gas production from oil wells, vented gas from blast furnaces, unused gas from coke ovens and waste and purge products from the chemical industry.

3.2.4.1 Equipment and Operating Principles

Flaring is an open combustion process. The air surrounding the flare provides the oxygen needed for combustion. Along with the oxygen, good combustion in flare requires adequate flame temperature, sufficient residence time in the combustion zone, and turbulent mixing.

Flares can be divided into two major types, with or without assist. Flares with assist include steam-assisted, air-assisted, and pressure-assisted.

Figure 3-4 indicates the primary elements of an elevated, steam-assisted flare. Process off gases are delivered to the flare through the collection header. The knock-out drum removes water or liquid hydrocarbons to prevent

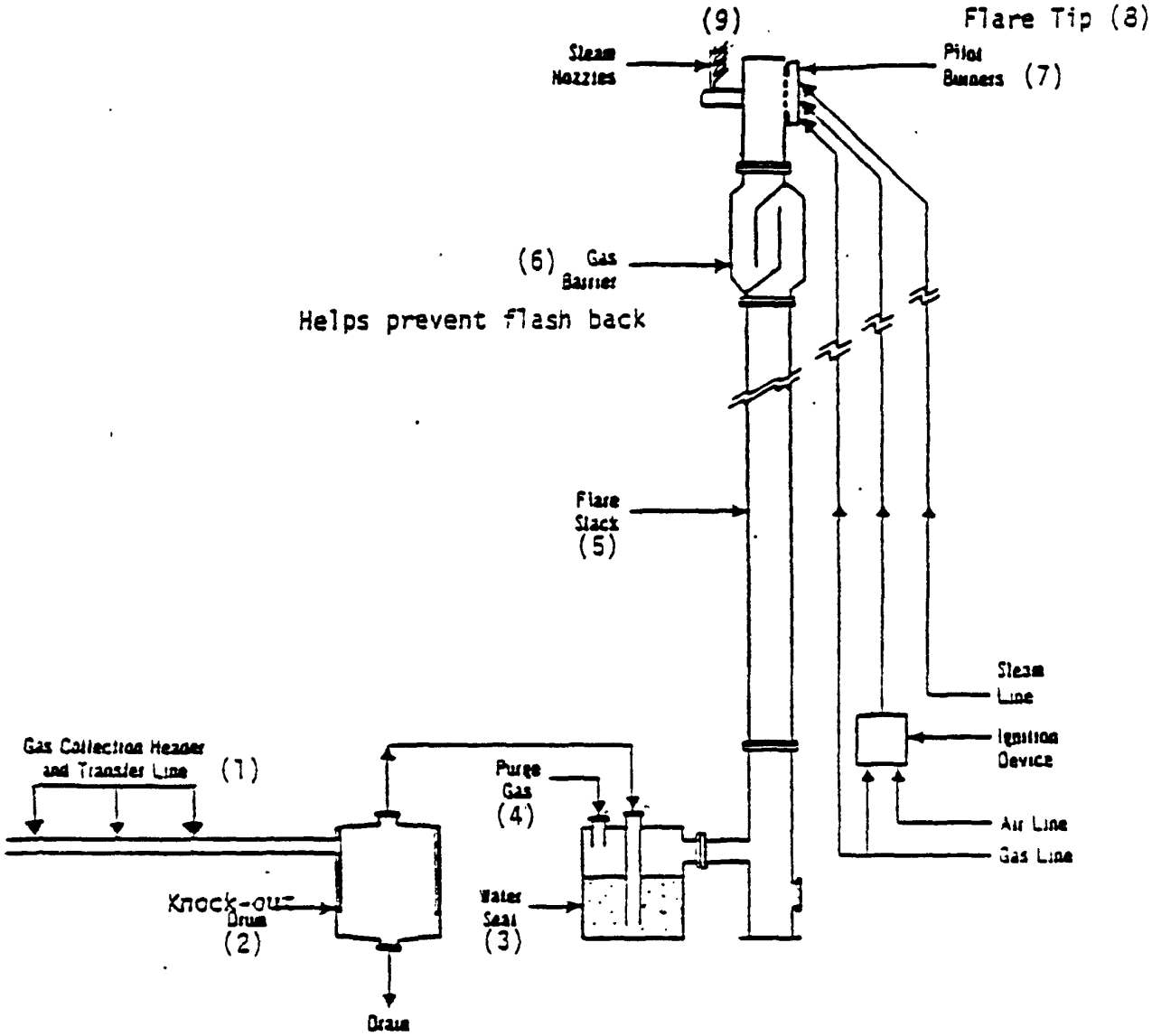


Figure 3-4 Steam-assisted elevated flare system.

problems in the flare combustion zone. Off-gases usually pass through a water seal and a gas barrier to prevent flame flashbacks during low gas flows.

Flashbacks are also prevented by controlled addition of a purge gas (N_2, CO_2, or natural gas). Careful control of the gas flow rate can prevent both flashbacks due to low flows and detached flames due to very high flows.

The gas stream enters at the base of the flame where it is heated by the already burning fuel and the pilot burners at the flare tip. The flare tips are designed to stably burn gases over a very wide range of flow rates and to suppress soot. For most fuels and flow rates, soot suppression requires that air be mixed into the flare at a faster rate than simple gas diffusion can supply. Steam-assisted flares use steam to increase gas turbulence in the flame boundary zones. The turbulence draws in more combustion air and improves combustion efficiency. By minimizing the cracking reactions that form carbon, the steam injection promotes smokeless operation. The steam requirement depends on the tip diameter, the gas composition, and the steam nozzle velocity. Typically, 0.15 to 0.5 kg of steam per kg of flare gas is required.[29] The injection of steam into a flare can be controlled either manually or automatically. Manually controlled flares require an operator to observe the flare and add steam as necessary to maintain smokeless operation. Steam consumption can be minimized by using devices which sense flame characteristics and adjust the steam flow rate to maintain smokeless operation.

In situations where steam is too expensive, flares then use forced air for combustion air and mixing. Air-assist is rarely used on large flares because the air flow is difficult to control when the gas flow is intermittent. About 0.8 hp of blower capacity is required for each 100 lbs/hr of gas flared.[30]

In a small percentage of flares, the system pressure, in conjunction with the nozzle design, provides the necessary gas turbulence. This type of flare is described as pressure-assisted. These flares have multiple burner heads staged to operate based on the quantity of gas released to the flare. With a high nozzle pressure drop, the energy of the flared gas provides the mixing necessary for smokeless operations. This type of flare is usually enclosed and located at ground level.

Typically, flares without assist burn gas continuously while steam-assisted flares are required for large volumes of gas released during emergencies.

Based on a series of flare combustion efficiency studies, EPA has concluded that 98 percent combustion efficiency can be achieved by steam-assisted and air-assisted flares combusting gases with heat contents greater than 11 MJ/nm^3 (300 btu/scf). In addition, steam-assisted and nonassisted flares must be designed and operated with an exit velocity either (a) less than 60 scf per second (fps), (b) less than 400 fps if the heat content of the gss being combusted is greater than 37 MJ/nm^3 (1,000 Btu/scf), or (c) less than a velocity determined by an equation based on the heat content if the gas being combusted is between 11 MJ/nm^3 and 37MJ/nm^3 (300 Btu/scf and 1,000 Btu/scf). Air-assisted flares must be designed and operated with an exit velocity less than a velocity determined by another equation based on the heat content of the gas being combusted in the flare.[31]

Flares are not normally operated at the very high steam to gas ratios that resulted in low efficiency in some tests because steam is expensive and operators make every effort to keep steam consumption low. Flares with high steam rates are also noisy and may be a neighborhood nuisance.

3.2.4.2 Applications

Estimates from 1980 reported 16 million ton/year of gas are flared in the United States. Blast furnace gas accounted for 60 percent by weight and 19 percent by heating value. Petroleum production gases accounted for 18 percent by weight and 32 percent by heating value.[32]

These values reflect the varied composition of gases flared in the United States. Gases flared from refineries, petroleum production, and the chemical industry are composed largely of low molecular weight VOC and have high heating values. Those flared from blast furnaces consist of inert species and carbon monoxide with a low heating value. Gases flared from coke ovens are intermediate in composition to the other two groups and have a moderate heating value.

For dilute gas streams, supplemental fuel costs can eliminate flares as a disposal alternative. Unlike incinerators, flares have no heat recovery capability.

In a typical installation, flares are designed to control the normal operating vents or emergency upsets which require release of large volumes of gases. Large diameter flares may control low volume continuous vent streams from operations such as distillation and also handle emergency releases. In refineries usually all process vents are combined in a common header which supplies fuel to boilers and process heaters. However, excess gases and fluctuations in flow in the header are flared.

An emission control device that can be used for almost any VOC stream with sufficient heat content, flares can handle fluctuations in VOC concentration, flowrate, and inerts content very easily. Gases containing high concentrations of halogen should not be flared to prevent corrosion of the flare tip or secondary pollution such as SO_2 or HCl.

3.2.4.3 Costs

Flare capital costs are dependent upon flare height and tip diameter. The tip diameter selected is a function of the combined vent streams and supplemental fuel flowrates, the combined gas temperature, mean molecular weight, and the assumed tip velocity. Flare height is selected to minimize the risk to workers. The flare height is selected so the maximum ground level heat intensity is 440 W/m^2 (140 BTU/hr $ft.^2$).

The Background Information Document for Proposed Standards on Reactor Processes in Synthetic Organic Chemical Manufacturing Industry[33] presents a capital cost equation for a flare as a function of flare height and tip diameter. The equation was generated by using a linear regression analysis of cost curves presented in an EPA report.[34] Adding in the ducting and fan costs results in the installed capital costs of the flare system.

As an example, for a reactor process vent stream with a medidan value flow rate (2.0 scm/m) and a median heat content (12 MJ/scm), installed capital costs for flare systems are $78,000 (in 1984 dollars).[35]

encountered gradually become saturated, i.e., all of the surface is covered with organic material. The subsequent carbon then is exposed to organics and it begins to adsorb. Over a period of time the saturation "front" travels through the bed until no active surface remains. At this time, "breakthrough" occurs, i.e., there is no further solvent reduction and the outlet organic concentration will equal the inlet. In reality, this doesn't happen quite so precipitiously. Because of channeling of gases through the bed and absence of perfection in contact between the carbon and organic vapor, the loss of adsorption efficiency is not instantaneous. The point at which removal efficiency first diminishes (the exhaust concentration begins to increase) is called the "break-point". In order to maximize vapor recovery, design and operating procedures considerations should require the adsorber be taken off-stream to be regenerated before the break-point is reached.

A schematic of the adsorption process is shown in Figure 3-5. The diagram shows how the concentration of VOC varies from the inlet to the exit of a carbon bed at three different times. The organic content of the bed, presented as percent of saturation, is shown as a function of distance along the bed. The curve at Time 1 represents conditions shortly after placing a regenerated bed on line. Conventional regeneration of a bed does not remove all of the adsorbed organics. For that reason, the entire bed retains a small amount of VOC after regeneration. This "heel" will result in some small amount of emissions when it is returned to service as the gas stream will strip these organics from the carbon nearest the outlet. This "base-line" effluent concentration is usually less than 10 ppm.[38] The exit VOC concentration from an adsorber is near zero during the first adsorbtion cycle when virgin carbon is used.[39]

The curve at Time 2 represents conditions part way through the adsorption cycle. A significant portion of the carbon bed is now saturated. The effluent VOC concentration, however, remains constant and low, typically, below 20 ppm. The length of the curve represents the interface within the bed between the layer of saturated carbon particles and the adjacent unsaturated ones, i.e., the transfer zone along which adsorption takes place.

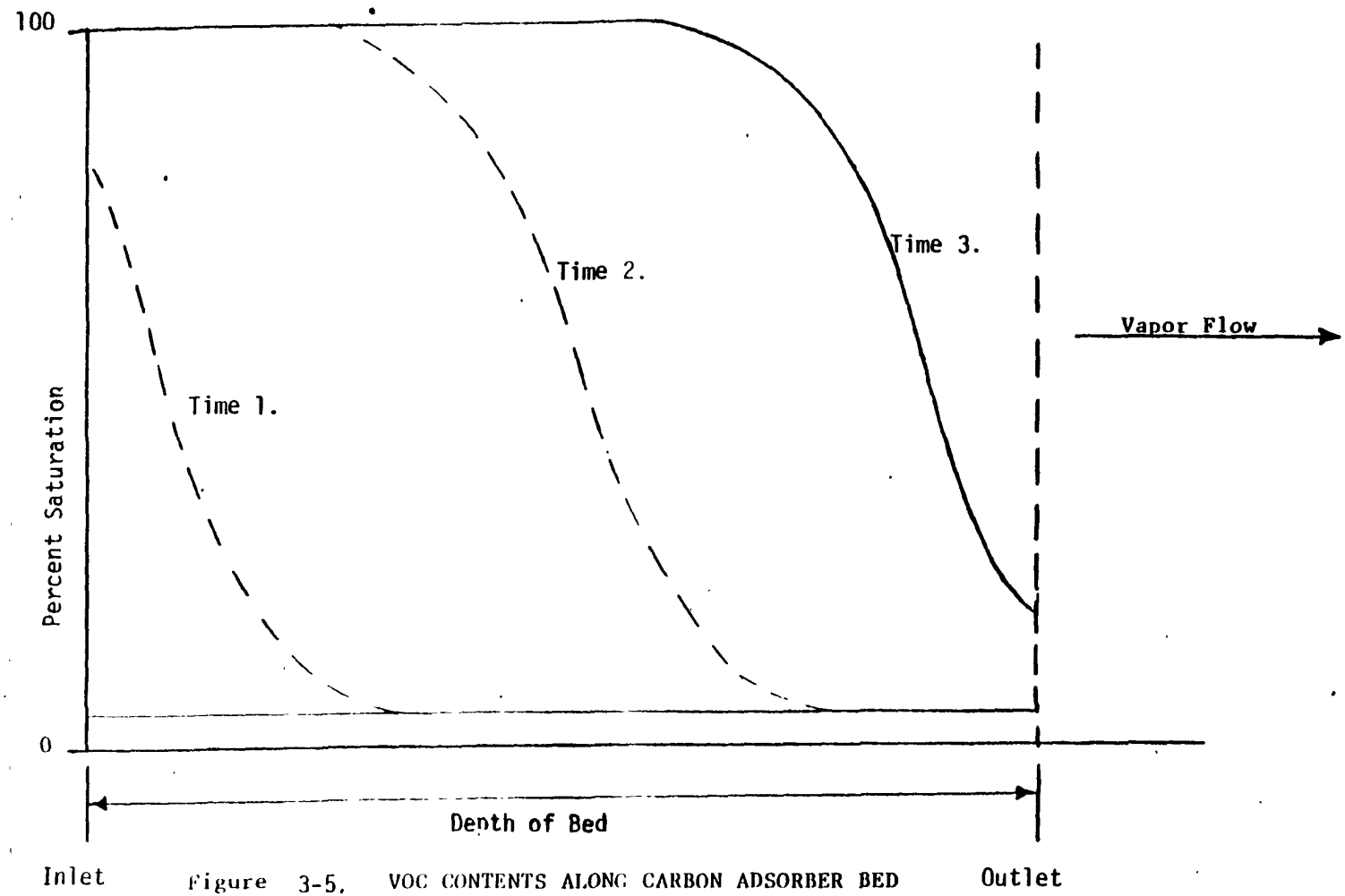


Figure 3-5. VOC CONTENTS ALONG CARBON ADSORBER BED

As more of the carbon becomes saturated, this transfer zone progresses through the bed until carbon at the outlet face of the adsorber begins to accept VOC. At this time the effluent concentration begins to increase, and "breakthrough" occurs. This is represented by the curve at Time 3 of Figure 3-5. Shortly before (and certainly no later than) the breakthrough point, a well operated adsorption system will remove that carbon bed from service by directing the VOC laden inlet stream to another carbon bed which has been regenerated since it last saw service. The saturated carbon must be regenerated to remove the VOC (or the carbon replaced) in preparation for future operation.

The adsorption capacity of carbon for various organics is not uniform. Generally, the adsorption capacity is inversely proportional to volatility. Initially, all organic vapors are adsorbed equally. With time, however, higher-boiling constituents will displace more volatile components. Of general interest, this displacement phenomena, which repeats for each vapor in a mixture, has seen limited use as a technique to separate specific organics from a mixture.

Conventional adsorption systems recover the organic vapors which are desorbed from the carbon during the regeneration cycle. Used or "spent" carbon beds are usually regenerated with low-pressure steam that is passed through the bed in the opposite direction of the gas flow during the adsorption cycle. The adsorption capacity of carbon is inversely proportional to temperature. Steam both heats the bed and strips the adsorbed organics. The organic adsorbate which remains on the carbon after regeneration (the heel) accounts for most of the difference between the saturated adsorption capacity and the operating capacity. The amount of heel which remains after regeneration is a function of the amount of steam used.[40]

A carbon adsorber bed may be fixed, moving, or fluidized. A typical fixed-bed adsorber system, with two adsorbtion units or beds, is shown in Figure 3-6. One adsorber cleanses the vapor-laden stream while the other is undergoing steam regeneration. The steam, contaminated with the pollutant vapors, is condensed after which the organics and water can be separated by gravity decantation or distillation. In some cases, the mixture is incinerated.

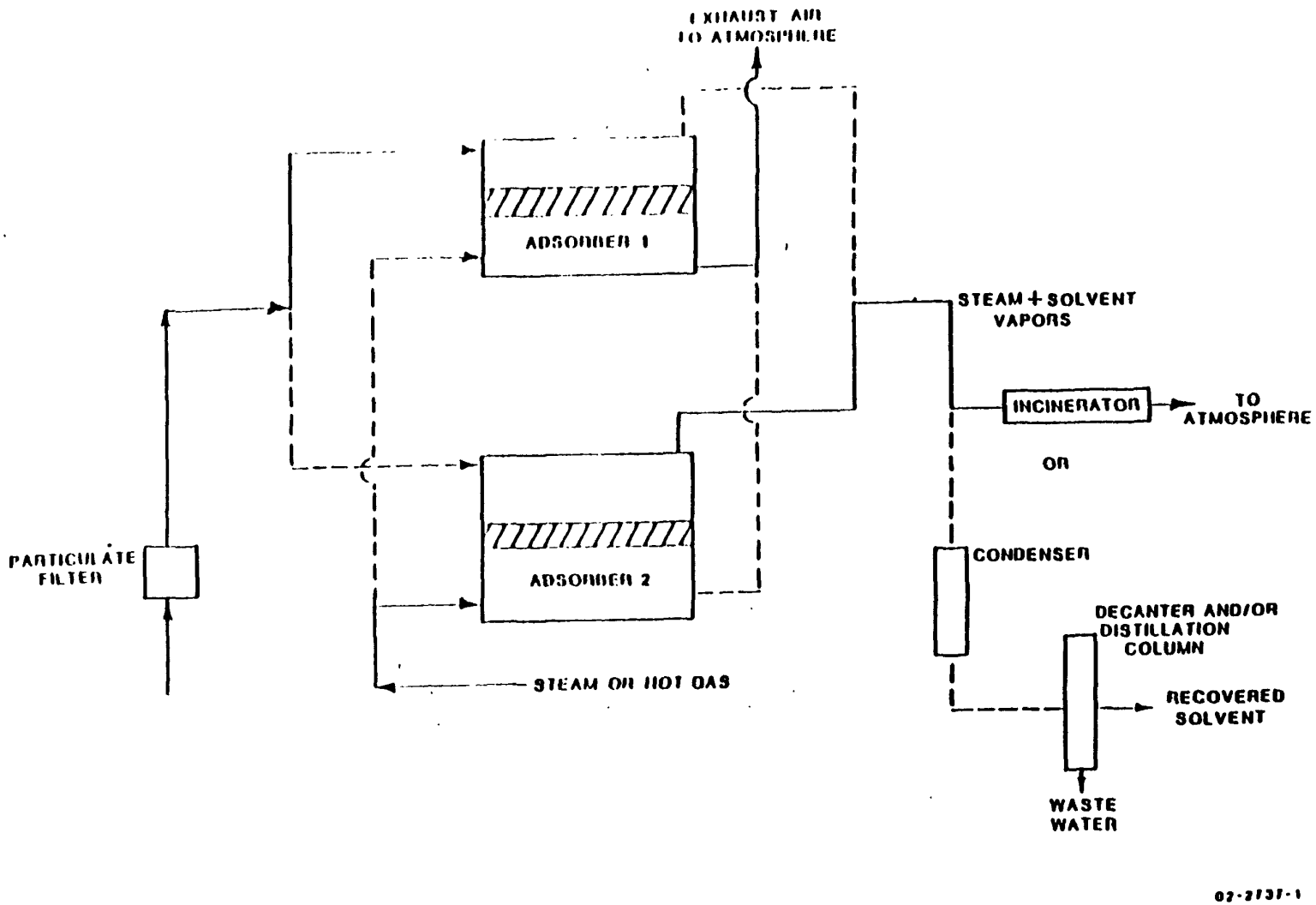


Figure 3-6. A TWO-UNIT FIXED BED ADSORBER

Although many two-unit adsorber systems are in use, three unit systems are becoming more common. Since adsorbative capacity is inversely proportional to temperature, for maximum efficiency, a bed must be cooled after regeneration before it is again placed in service. Inclusion of the third bed in the rotation sequence permits more time for a regenerated bed to cool. Some three bed systems place the cooling bed in service downstream of the bed in the primary adsorbtion cycle in order to recover emissions which otherwise would be lost as a result of breakthrough of the primary bed.

The simplest fixed-bed adsorber is a vertical cylindrical vessel fitted with horizonal perforated screens that support the carbon. Another is shaped like a cone. The cone allows more inlet and exit surface area for gas contact within a fixed vessel diameter thereby accommodating higher gas flow rates at lower pressure drops than would be available with a flat bed in the same vessel.

Moving bed adsorbers move the adsorbent into and out of the adsorption zone. Because of the continuous regeneration capability of a moving bed, a more efficient utilization of the adsorbent is possible than with stationary bed systems. Disadvantages include wear on moving parts, and attrition of the adsorbent.

In fluidized-bed systems, adsorption and desorption are carried out continuously in the same vessel. The system consists of a multistage, countercurrent, fluidized-bed adsorption section; a pressure-sealing section; and a desorption section. Nitrogen gas is used as a carrier to remove the solvent vapors. The regenerated carbon is carried by air from the bottom to the top of the column.

The solvent laden air (SLA) is introduced into the bottom of the adsorption section of the column and passes upward countercurrent to the flow of carbon particles. Adsorpton occurs on each tray as the carbon is fluidized by the SLA. The carbon falls down the column through a system of overflow weirs. Below the last tray, the carbon falls to the desorption section where indirect heating desorbs the organic compounds from the carbon; hot nitrogen gas passes through the bed countercurrent to the

carbon flow and removes the organic compounds. The desorption temperature is normally around 121°C (250°F) but can be raised to 260°C (500°C) to remove buildup of highboiling materials. The desorption section is maintained continuously at the temperature required to volatilize the absorbed compounds. The solvent and nitrogen mixture is directed to a condenser where the solvent can be recovered for reuse. The nitrogen is sent through the "secondary adsorber" (top layer of carbon in the desorption section), which removes residual solvent from the nitrogen, and is then recycled.

The microspherical particles of carbon used in a fluidized-bed are formed by spray-drying molten petroleum pitch. The carbon particles are easily fluidized and have strong attrition resistance. The adsorptive properties of carbon made this way are similar to those of other activated carbons.

The parameters considered in design of a fluidized-bed carbon adsorber system are:

1. Type of solvent(s);
2. SLA inlet concentration;
3. SLA flow rate;
4. Temperature of the inlet SLA;
5. Relative humidity of the inlet SLA;
6. Superficial bed velocity;
7. Bed pressure drop;
8. Rate of carbon flow;
9. Degree of regeneration of the carbon (bed); and
10. Condenser water outlet temperature.

The first five parameters are characteristics of the production process. The next two are design parameters for the adsorber. The next three are operating parameters. The rate of carbon flow is set by the operator to achieve desired control efficiency. Just as with fixed-bed, the dryer exhaust gas (the SLA) must be cooled before it reaches the adsorber in order to optimize the carbon's adsorbability. Pressure drop per stage

normally ranges from 1 to 2 kilopascals (kPa) (4 to 8 in. water), with six to eight stages required, depending on the application. The pressure drop across the entire bed is 6 to 16 kPa (24 to 64 in. water). The gas velocity through the adsorption section is as high as 1 m/s (200 fpm), which is two to four times that used in fixed bed adsorbers. For a given flow rate, this high gas velocity reduces the cross-sectional area of the bed.

The primary problem that may occur with operation of fluidized-bed adsorbers is fouling of the carbon. The same factors that affect fouling of carbon in fixed-bed adsorbers also affect the carbon used in fluidized-bed adsorbers. Corrosion is generally not a problem in fluidized-bed adsorbers; because stripping is by nitrogen rather than steam, the water content of the recovered solvent is low, typically 5 percent or less. The only water present in the recovered solvent is that which was adsorbed from the SLA. Thus, generally, the carbon adsorber need not be made of expensive corrosion-resistant materials. Bed fires are generally not a problem in fluidized-bed adsorbers because the relatively high superficial velocities and the intimate contact between the SLA and activated carbon eliminate the possibility of hot spot formation. However, hot spots can form, depending on the solvents adsorbed, if the bed is shut down before being completely stripped. Shutdowns resulting from mechanical problems could create conditions leading to potential bed fires.

A distillation system may not be required for a fluidized-bed adsorption system because of the low water content of the recovered solvent (less than 5 percent water by weight). Cleanup can be as simple as drying by the addition of caustic soda.

3.3.2 Applications

Processes that can be controlled by adsorption include VOC emissions from dry cleaning, degreasing, paint spraying, solvent extracting, metal foil coating, paper coating, plastic film coating, printing, fabric impregnation, and manufacturing of plastics, chemicals, pharmaceuticals, rubber, linoleum, and transparent wrapping.

Organics desorbed from the carbon are generally condensed and either reused directly or reprocessed. In some cases, such as controlling a mixture of organics emitted from a paint spray booth, it may be more practical to send the desorbed organics directly to an incinerator without ever condensing them. In this situation the adsorber acts as a "concentrator." The desorbed organic-laden stream is lower in volume and higher in organic concentration than the feed stream to the adsorber. This allows for use of a smaller incinerator with consequently lower capital and operating costs than if the feed stream were sent directly to an incinerator. Moving bed adsorbers have been used in Europe and Japan for this purpose and are now beginning to see similar use in this country.[41]

The preferential adsorption charactristics and physical properties of a variety of industrial adsorbents determine the appropriate applications of each type. Physical adsorbents can remove organic solvents, impurities, and water vapor from gas streams. Adsorbents may have an affinity for either polar or nonpolar compounds. Polar adsorbents such as silica gel and activated alumina are poor adsorbents for organics because of their strong affinity for water. Activated carbon is the most widely used nonpolar adsorbent. It will selectively adsorb organic vapors from gases even in the presence of water. A list of some of the organics for which activated carbon is known to be used is presented in Table 3-3.

Molecular sieves are also classed as physical adsorbents. Like silica gel and alumina, their strong affinity for water greatly limits their use for control of organic vapor emissions.

Soda lime, sometimes combined with activated carbon, has been used to chemisorb vapors such as ethanoic acid, acetonitrile, acrylonitrile, allyl chloride, and vinyl propyl disulfide. Some physical adsorbents are impregnated with chemically reactive compounds that react with vapor molecules after physical adsorption has occurred. Pollutant vapors that have been removed by impregnated adsorbents include ethylene, organic acids, mercaptans, olefins, phosgene, and thiophenol.

TABLE 3-3. ORGANIC COMPOUNDS CONTROLLED BY CARBON ADSORPTION[42]

1. Acetaldehyde
2. Acetone
3. Acetylene
4. Acrylonitrile
5. Ammonium Thiocyanate
6. Asphalt
7. Benzene
8. Benzoyl Chloride
9. Butanol
10. Butyl Acrylate
11. Carbon Tetrachloride
12. Cellosolve
13. Chloroform
14. Cumene
15. Cumene Hydroperoxide
16. Cyclohexane
17. 1,6-Diaminoloxane
18. Dibromochloropropane
19. p-Dichlorobenzene
20. Dichloroethylene
21. Diethyl Ether
22. Dimethyl Ketone
23. Ethanol
24. Ethyl Acetate
25. Ethyl Acrylate
26. Ethyl Mercaptan
27. Fluorazepam HCl
28. Fluoro-trichloromethane
29. Formaldehyde
30. Freon 11, 114ABS
31. Heptane
32. n-Hexane
33. Isopropanol
34. "Lactol"
35. Maleic Anhydride
36. Mercaptans
37. Methacrylic Acid
38. Methanol
39. Methyl Acetate
40. Methyl Bromide
41. Methyl Chloride
42. Methyl Chloroform
43. Methyl Ethyl Ketone
44. Methyl Formcel
45. Methyl Isobutyl Ketone
46. Methyl Methacrylate
47. Methylene Chloride
48. VM&P Naphtha
49. Naphthalene
50. CIO-Paraffin
51. Perchloroethylene
52. Phenol
53. Phosgene
54. Propane
55. Stoddard Solvent
56. Styrene
57. Terephthalic Acid-HNO_3
58. Toluene
59. Toluene Diisocyanate
60. Trichloroethane
61. trichloroethylene
62. Vinyl Chloride
63. Vinylidene Chloride
64. Xylene, meta & para
65. p-Xylengen
66. Xylol

In some specific situations the owner of an adsorbtion system may choose a regeneration system other than conventional steam regeneration. When making such a selection, the owner will likely evaluate the least cost method for ultimate recovery or disposal of the organics. Alternative regeneration systems include:[43]

1. Heated air or inert gas regeneration of the primary bed followed by a second adsorption with steam regeneration of the second bed.

2. Heated air or inert gas regeneration followed by solvent condensation at lowered temperature with recycle of noncondensibles through absorbent bed.

3. Regeneration by pressure reduction.

Under normal circumstances, the cost effectiveness of a carbon bed recovery system is inversely proportional to the organic concentration of the exhaust gas stream. There are some restrictions, however to the maximum concentration that can be fed to an adsorber. Safety considerations will likely preclude concentrations greater than 50 percent of the lower explosive limit. Also, the heat of adsorption must be considered because the heat released by adsorption may raise the temperature of the carbon bed high enough to cause spontaneous combustion.

After regeneration, a bed is normally cooled by passing clean air or the discharge from another bed through the carbon. If the time required for regenerating and cooling a bed is longer than the adsorption time for another bed then a satisfactory system will require at least three beds to assure a clean cool bed is available before breakthrough of the bed in service.

3.3.3.1 Capital Costs[44]

The capital cost for a carbon adsorber is a function of the ventilation rate, the type and mass emission rate of the pollutant, the length of the adsorption and regeneration cycle, and the adsorption capacity of the carbon at operating conditions. The key design parameters that determine the size of the carbon adsorber are the face velocity and the bed depth. The desired face velocity is approximately 80 to 100 feet per minute for most commercial and industrial applications involving solvent recovery. The depth of the beds may vary from 6 inches to 30 inches.

For air purification systems where the concentration of pollutants is on the order of 1 ppm or less, the desired face velocity is reduced to approximately 40 fpm and bed depths may be only 0.5 to 3 inches. For a given ventilation rate, the maximum desirable face velocity and the minimum practical bed depth determine the minimum volume of working bed of carbon that will be required.

For design purposes, the minimum working bed volume for minimum preselected cycle time can be determined from the adsorption isotherm for the particular adsorbent and adsorbate. The adsorption isotherm is a plot of the adsorption capacity at constant temperature as a function of the vapor pressure or the relative partial pressure of the adsorbate in the gas stream. Normally, the adsorption capacity of an adsorbent increases with increased vapor pressure and decreases with increased temperature. Using the appropriate adsorption isotherm, the adsorption capacity in pounds of adsorbate per pound of adsorbent can be obtained for the desired operating conditions. The adsorption capacity is then multiplied by a design factor of between 0.1 and 0.5 to determine a working capacity. A design factor of 0.25 can be used for preliminary sizing in most applications[45]. The weight of carbon for each bed is then determined by multiplying the organic emission rate in pounds per hour by the desired length of the adsorption cycle, in hours, and dividing by the working capacity in pounds of adsorbate per pound of adsorbent.

For example, assume that toluene vapors at 70°F are generated by a source at a rate of 6.15 lb/min and the inlet concentration to the adsorber is to be maintained at 25 percent of the lower explosive limit (LEL). The LEL for toluene in air is 1.29 percent or 3.07 lbs/1000 cu.ft.; hence, 25 percent of the LEL would be 0.32 percent or 0.768 lbs/1000 cu.ft. The vapor pressure of the toluene in air at a total pressure of 760 mm Hg is determined by multiplying the concentration (0.0032) by the operating pressure (760 mm Hg) to obtain a pressure of 2.4 mm Hg. Using the adsorption isotherm in Figure 3-7, the adsorption capacity in percent by weight at this vapor pressure is 35 percent or

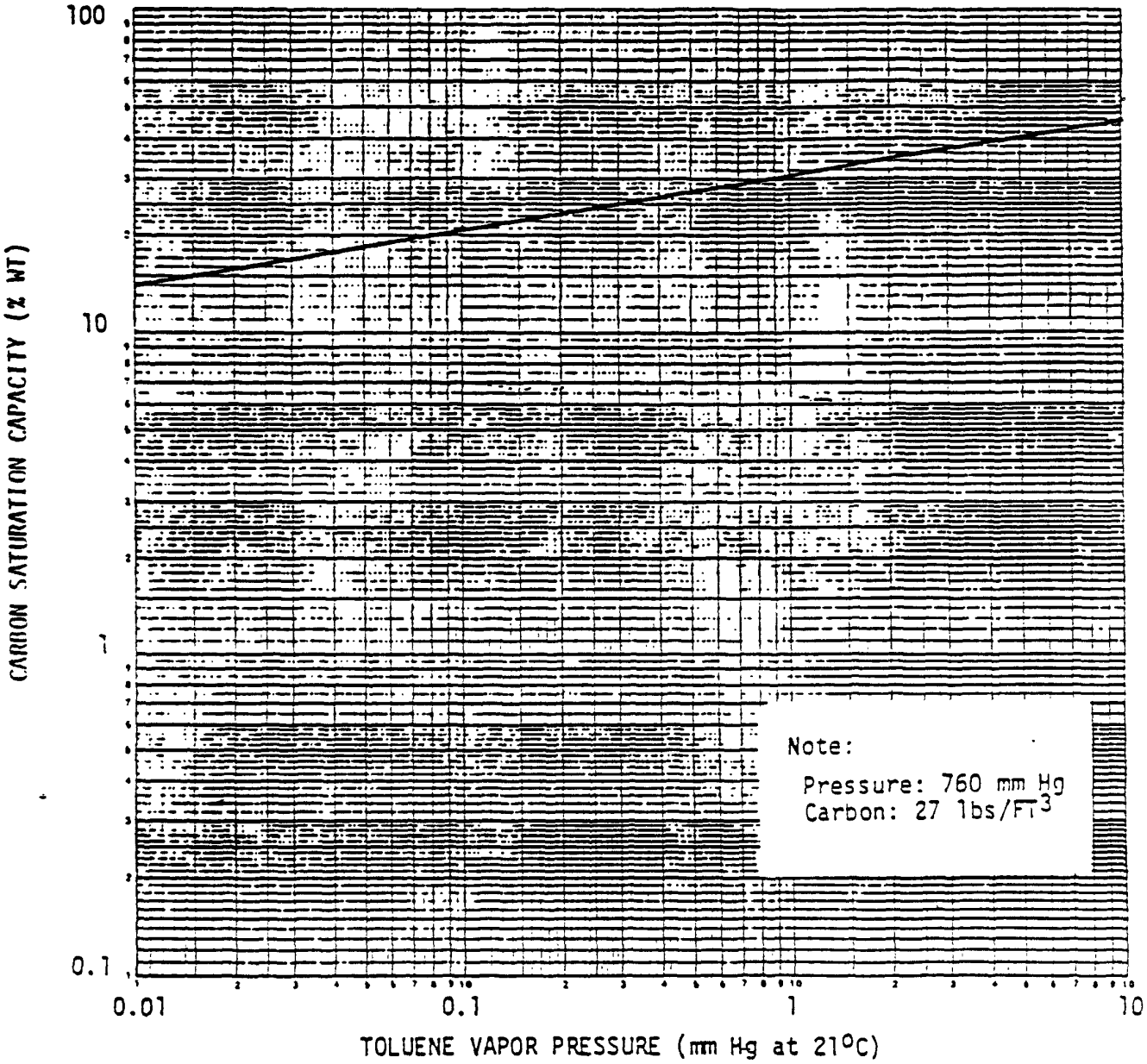


Figure 3-7. ADSORPTION ISOTHERM FOR TOLUENE [46]

0.35 lbs of toluene per lb. of carbon. Note that the adsorption isotherm is for operating temperatures of 21°C (70°F) and operating pressures of 760 mm Hg with a carbon adsorbent having a density of 27 lbs/ cu.ft. A working capacity of 8.75 percent is obtained by multiplying the adsorption capacity from Figure 3-7 by a design factor of 0.25. If the adsorption period is one hour per bed, then 369 lbs of toluene (6.15 lbs/min x 60 mn/hr) will be recovered per bed. The carbon requirements per bed will be 369 lbs/hr divided by 0.0875 lbs toluene/lb carbon or approximately 4200 lbs per bed with a one-hour adsorption cycle.

Adsorption isotherms for other hydrocarbons are available from handbooks and manufacturers' literature. These isotherms have been developed for many adsorbents operating at select pressures and temperatures.

The cost of carbon adsorbers are presented in Figures 3-8 and 3-9, as a function of total pounds of carbon in the unit. The total or gross number of pounds is determined by the adsorption rate and the regeneration rate of the carbon for the emission being controlled. A carbon adsorber will normally be a dual system with one bed on-line adsorbing while the second bed will be off-line regenerating. Variations in regeneration time are due to the type of solvent being desorbed and any specific drying and cooling requirements. Normally, one hour is the longest expected regeneration time. For some operations, such as dry-cleaning and solvent metal cleaning where working bed capacity is high, a longer adsorption phase may be desired. This is likely if steam capacity for desorption is not always available.

Figure 3-8 represents the cost of packaged units for automatic operation in commercial and industrial applications. Commercial applications would include dry-cleaning and solvent metal cleaning. Industrial applications, which include lithography and petrochemical processing, cost about 30 percent more than commercial requirements. Industrial requirements would include those beds designed for heavier materials which will require high steam or vacuum pressure designs and more elaborate controls to assure safety against explosions and prevent breakthrough. Figure 3-9 presents the cost of custom units, used mostly for industrial applications where the gas flow rate exceeds 10,000 acfm.

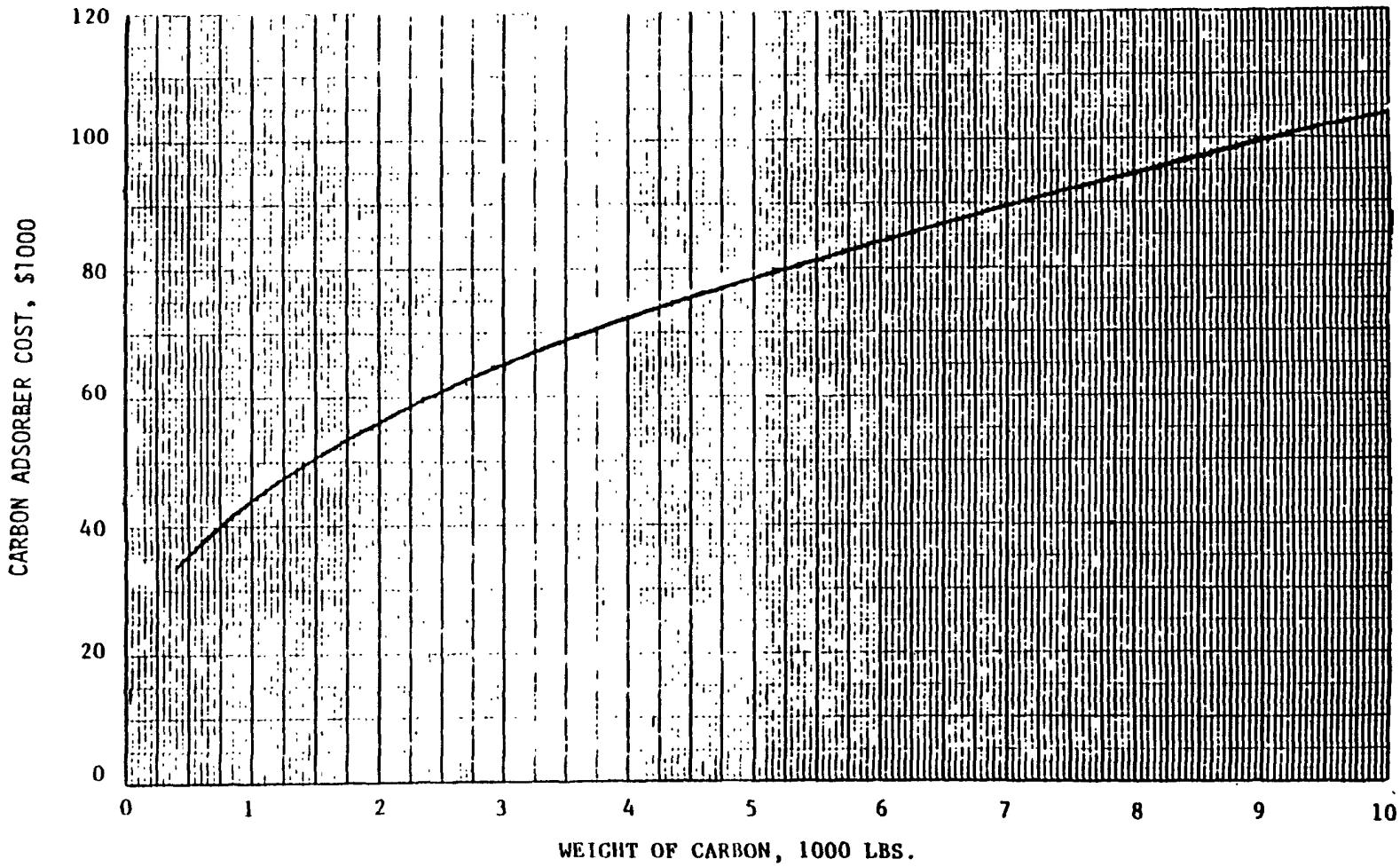


Figure 3-8. PRICES FOR PACKAGED STATIONARY BED CARBON ADSORPTION UNITS WITH STEAM REGENERATION[46]

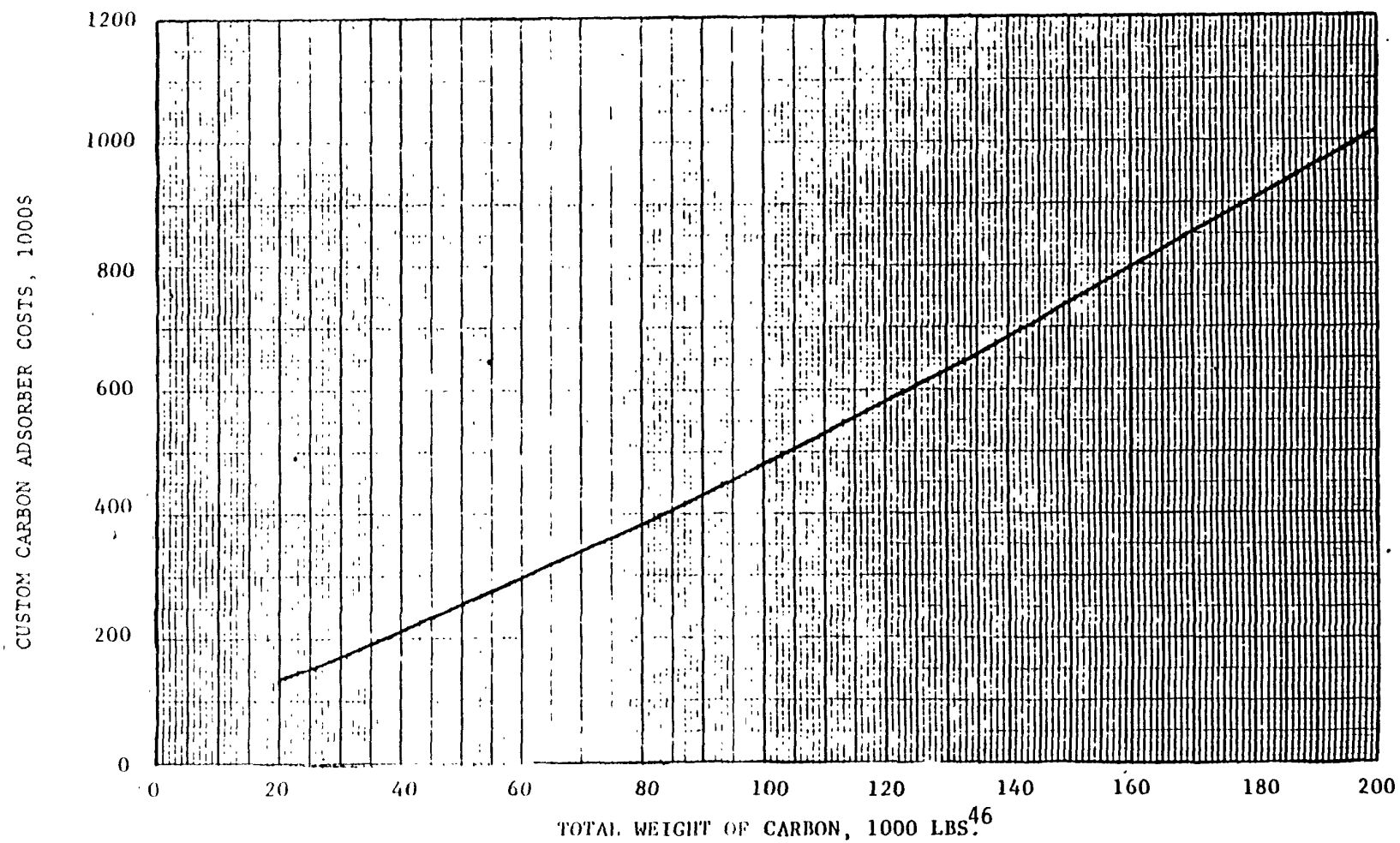


Figure 3-9. PRICES FOR CUSTOM CARBON ADSORPTION UNITS

3.3.3.2 Annualized Costs[47]

An estimate of annualized costs will have two components, operating costs and the annualized cost of the original capital investment. Table 3-4 provides a list of parameters and their use rate which may be used to estimate operating costs for a carbon adsorber including requirements for steam, cooling water, maintenance, electricity, and replacement carbon. These assumptions represent a composite of information obtained by the EPA from a variety of sources. To use the values in Table 3-4, independent variables required to estimate costs are the pollutant emission rate, estimated recovery efficiency, annual operating hours, exhaust gas rate, and the purchase price. Replacement of carbon requires the same quantity as the original capital installation.

In Table 3-4, the figure for steam consumption is based on both the sensible heat (energy necessary to heat the bed and vessel from the operating temperature (100°F) to the solvent boiling temperature) and the latent heat of vaporization (the energy required to evaporate the solvent from the bed). The latent heat is directly proportional to the quantity present. The sensible heat depends also on the amount of carbon and the design of the bed. For estimation purposes, a value of 4 lbs. per lb. solvent desorbed is a reasonably figure.

The cooling water requirement is proportional to the steam consumption rate in that it is used to condense and cool the regeneration steam. The electrical consumption presumes a pressure drop of 20 inches of water across the adsorber (a bed depth of 1.5 feet of 8-14 mesh carbon). The pressure drop through a carbon bed is a function of the carbon granule size, the size distribution, the packing of the bed, flow velocity and vessel configuration. Given a specific carbon bed, pressure losses through the bed are proportional to the square of the superficial face velocity.

The second major cost factor is a function of the original installed cost of the adsorber. This can be minimized by reducing the amount of waste gas to be treated (thus increasing the concentration of organics), thereby reducing the size of the adsorber needed.

TABLE 3-4 - TECHNICAL ASSUMPTIONS FOR ESTIMATION OF DIRECT OPERATING COSTS[47]

Item	Assumption	Reference
Steam Consumption	4 lb. per lb. pollutant recovered	MSA, DOW, STAUFFER, VIC
Cooling Water	12 gal. per 100 lbs. steam	SHAW
Electricity	5 HP per 1000 ACFM	STAUFFER, MSA
Maintenance	5% of equipment purchase cost	Compromise between DOW and MSA
Carbon Replacement	Replace original carbon every five years	STAUFFER, MSA

MSA - "Hydrocarbon Pollutant Systems Study" by MSA Research Corp., EPA Contract EHSD 71-72, January, 1973.

DOW - "Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations," EPA Contract 68-02-1329, Dow Chemical Co., June, 1976.

STAUFFER - Private communication from J. J. Harte, Stauffer Chemical Co. to Richard Schippers, EPA, April 11, 1977 on subject of carbon adsorber costs for control of ketones and toluene.

VIC - Private communication from J. W. Barber, VIC Manufacturing Co., to F. L. Bunyard, EPA, June 3, 1977.

SHAW - "Carbon Adsorption/Emission Control Benefits and Limitations," paper presented at Surface Coatings Industry Symposium, April 26, 1979.

Since almost all recovered organics have some value, a by-product credit should be included as part of the calculation of the annualized cost of control. Depending on the value of the recovered organic, this credit can have a substantial effect on the amortization rate of the capital costs of the equipment.

The annualized carbon adsorption costs for a plant producing rubber-coated industrial fabric (dip-coating process) are presented in Table 3-5.

3.3.3.3 Comparison to Incineration

Carbon adsorption is usually less costly than incineration for the control of organics in concentrations below 100 ppm because of the cost of supplemental fuel required for combustion. The cost of the carbon adsorption process, however, is adversely affected if the waste gas stream contains water-soluble compounds, or organics that are very difficult to desorb since, in the first case, an aditional purification step may be necessary to obtain maximum value for the adsorbate, and in the second case, the effective life of the carbon is decreased.

If the waste gas stream is sufficiently rich in organics to sustain combustion, then the operating costs for a combustion device can be very low, rendering an incinerator the most economical device. This is particularly true when the recovered organics would have little value. Once the decision is made to use an incinerator, incorporation of primary and/or secondary heat recovery will reduce the cost of incineration.[49]

3.3.4 Utility Requirements

An adsorption system requires steam (or hot gas) to regenerate the carbon and electricity to power pumps, fans and instrumentation. If the concentration of organics in the waste gas can be increased by reducing the volume of exhaust gas, energy costs for the fan will decrease. Figure 3-10 illustrates the effect of concentration on energy requirements for a typical dual fixed-bed adsorber operating at 100°F (38°C).[50]

When steam is used to regenerate the adsorption bed, it represents the majority of the total energy required for the adsorption system. The amount of steam needed is about 4 pounds per pound (4 kg/kg) of organic vapor adsorbed. Regeneration by steam leaves the bed wet; thus, some cooling of the gas is accomplished.

TABLE 3-5. TYPICAL COMPONENTS OF ANNUALIZED COSTS FOR CARBON ADSORPTION SYSTEMS[48]

Configuration

1. Dual fixed-bed adsorber operating at 95°F
2. Toluene recovery with condenser and decanter
3. Total carbon required: 2,160 lbs.
4. Total installed cost: $215,300

Gas Stream Characteristics

Flow	2,050 scfm
Concentration	25% LEL
Process Gas Temperature	200°F

Component	Annual Cost (1st Quarter 1984 dollars)
(1) Operating and maintenance labor plus materials: (6 percent of total installed cost)	$12,920
(2) Carbon replacement cost at 5-year life $\left(\frac{2160\ \text{lb}}{5} \times \$1.35 \text{ per lb.} = 583\right)$	$ 580
(3) Utilities:	
Electricity $\left(2550\ \text{acfm} \times \frac{5\ \text{hp}}{10^3\ \text{cfm}} \times \frac{0.746\ \text{kwh}}{\text{hp}} \times 2000\ \text{hr/yr} \times \frac{\$0.056}{\text{kwh}} \times 1.1 = \$1,170\right)$	$ 1,170

Table 3-5 (Continued)

Steam----------$ 4,870

$$\left(\frac{1.53 \times 10^5 \text{ lb. VOC}}{\text{yr}} \times \frac{4 \text{ lb. steam}}{\text{lb. VOC}} \times \frac{\$7.96}{1000 \text{ lbs. steam}} = \$4{,}870\right)$$

Cooling Water----------$ 600

$$\left(\frac{12 \text{ gpm}}{100 \text{ lbs. steam}} \times \frac{306 \text{ lb. steam}}{\text{hr.}} \times \frac{60 \text{ min.}}{\text{hr.}} \times \frac{2000 \text{ hr.}}{\text{yr.}} \times \frac{\$0.13}{1000 \text{ gal.}} = \$570\right)$$

(Water used to cool exhaust to 95° C = $30)

(4) Captial Recovery Charges----------$47,370

(22 percent of total installed cost)

(5) Recovered Solvent Credit----------$26,010

$$\left(76.5 \frac{\text{tons/VOC}}{\text{yr}} \times 2000 \text{ lb/ton} \times \frac{\$0.17}{\text{lb. VOC}} = \$26{,}010\right)$$

Net Annualized Costs----------$41,500

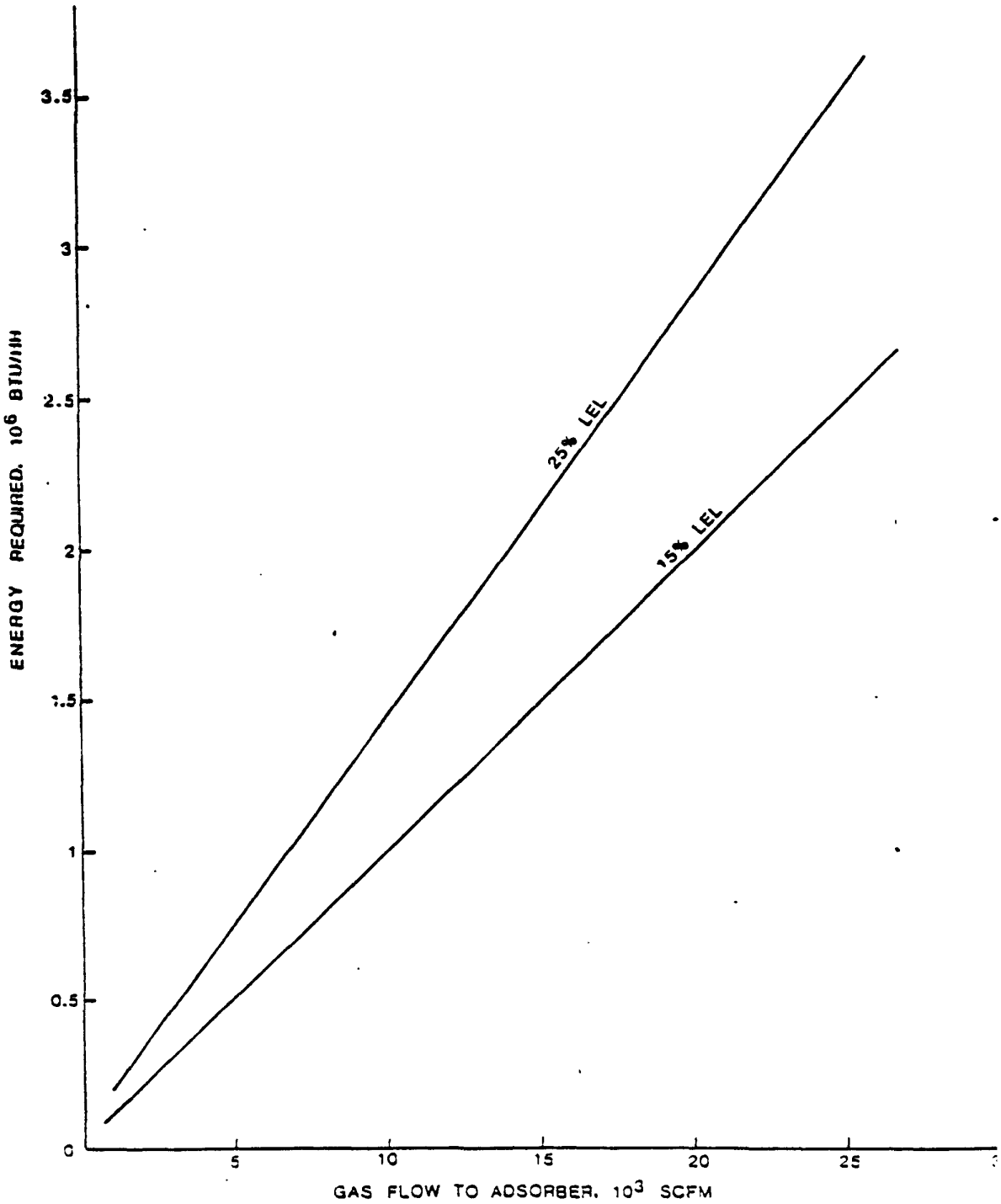


Figure 3-10. Energy Requirement for Adsorption-Solver Recovery System

One alternative to steam is use of a hot noncondensible gas; another is electrical resistance heating of the bed. The major energy requirements for these systems are for heating and transporting the noncondensible gas (usually air) or to power the resistance heating.

Waste gases from which the organics are to be removed are often from an oven or other heated source and are usually too hot for efficient adsorption and must first be cooled. This is usually accomplished in a heat exchanger with cooling water. The water requires pretreatment, hence, some minimal energy expenditure will be required then also.

A blower is used to force the gas through the adsorption bed. The amount of electricity consumed by the fan depends upon the exhaust gas rate and the resistance of the bed (type and configuration of the carbon bed).

If a bed is to be regenerated by steam (which is to be subsequently condensed) the adsorption system must provide for separation of the organics from the condensate as part of either the organic recovery or waste disposal system.

If a noncondensible gas is used for regeneration, the organics-laden regeneration gas can be incinerated directly or the organics can be separated from the gas by condensation, or a second adsorber. Energy requirements for an entire adsorption system are heavily dependent on the requirements for final treatment.

3.3.5 VOC Removal Efficiency and Environmental Impacts of Adsorption

VOC removal efficiencies of more than 95 percent can be achieved by carbon adsorption provided: (1) the adsorber is charged with an adequate quantity of high-quality activated carbon, (2) the gas stream receives appropriate preconditioning (e.g., cooling, filtering) before entering the carbon bed, and (3) the carbon beds are regenerated before breakthrough.[51]

An adsorption system poses two potential secondary pollution problems, disposal of both contaminated wastewater (steam condensate) and waste carbon. If the carbon bed is regenerated with steam, and some of the recovered organics are water soluable, then some separation is required to

minimize contamination of the condensate wastewater. If the waste gas stream contains particulates, they will plug the voids in the carbon bed, rendering it ineffective. This can be avoided by precleaning the gas feed stream, usually with a fabric filter, but perhaps with a small sacrificial carbon bed. The ultimate disposal of spent adsorbent is an environmental concern, but generally it will be returned to the manufacturer at infrequent intervals for screening and regeneration at very high (combustion) temperature in an inert atmosphere thereby rendering it suitable for recycle back to an adsorber for further service. This greatly reduces the rate at which carbon it must be transferred to a solid waste disposal site or burned.

3.4 ABSORPTION

Absorption is the process in which certain constituents of a gas stream are selectively removed by a liquid solvent. Absorption may be purely physical, in which the solute simply dissolves in the absorbent, or chemical, in which the gases react with the liquid absorbent or with reagents dissolved in the absorbent. The combined solvent and solute can then be further processed by stripping or desorbing to remove the solute. The recovered solvent is then available for reuse. In some cases the chemical product may be returned to storage without separation as in the case of hydrocarbon recovery of oil or gasoline.[52]

Low concentrations of organics in a waste gas stream will require long contact times and large quantities of absorbent for effective removal (emissions control). Absorption is therefore generally more expensive than adsorption or incineration. Absorption can be an attractive pollution control process if the absorbent is easily regenerated or the resulting solution can be used as a make-up stream.

3.4.1 Equipment and Operating Principles

The desirability of an absorption process for use as an emission control method depends on the ease with which organic vapors are removed by a readily available absorbent. In general, absorption is most efficient under the following conditions:[53]

1. the organic vapors are quite soluble in the absorbent,
2. the absorbent is relatively nonvolatile,
3. the absorbent is noncorrosive,
4. the absorbent is inexpensive and readily available,
5. the absorbent has low viscosity, and
6. the absorbent is nontoxic, nonflammable, chemically stable, and has a low freezing point.

Absorption requires intimate mixing of the vapor-laden gas and the liquid absorbent. A variety of absorption equipment has been designed to achieve good contact between the gas and the absorbent. Different types of

absorption equipment are packed towers, plate or tray towers, spray towers, and venturi scrubbers. Schematics of this equipment are shown in Figures 3-11 to 3-14.[54,55]

Packed towers can achieve high rates of absorption. A packed tower is a vertical cylinder filled with an irregularly-shaped packing material such as shown in Figure 3-15.[56] A liquid absorbent is introduced near the top of the tower through a distribution system above the packing in an attempt to assure wetting the entire packing surface. The absorbent flows by gravity down through the tower countercurrent to the waste gas introduced at the bottom of the tower. The concentration of the solute in the gas stream decreases as the gas rises through the tower because the absorbate is absorbed by the liquid absorbent as they contact in their countercurrent flow through the packing material. The height of packing required is a function of the affinity of the absorbate for the absorbent.

Plate or tray towers provide contact between the waste gas and liquid absorbent via a series of plates arranged in a step-like manner. Typically the plates are designed to retain a layer of liquid on top of each plate as the liquid spills down through the tower from plate to plate. The gas is forced to bubble up through the liquid to achieve intimate mixing at each plate. The bubbling is induced by holes in the plates through which gases rise to the top of the tower. The number of required plates is determined by the difficulty of the mass transfer operation and the desired degree of absorption.[57]

A spray tower is an empty chamber equipped with a series of nozzles which spray liquid across the cross section of the vessel. The waste gas is passed up through the sprays. The size of the spray droplets and their distribution affects the efficiency by determining available surface area for contact between two phases. One type of spray tower, a wash oil scrubber, can be used to control emissions from a storage tank in a by-product recovery plant.[58] Applications include light-oil and pure benzene storage tanks. The emissions enter the bottom of the tower and contact a spray of wash oil that is introduced into the top of the tower. Recent designs of wash-oil scrubbers

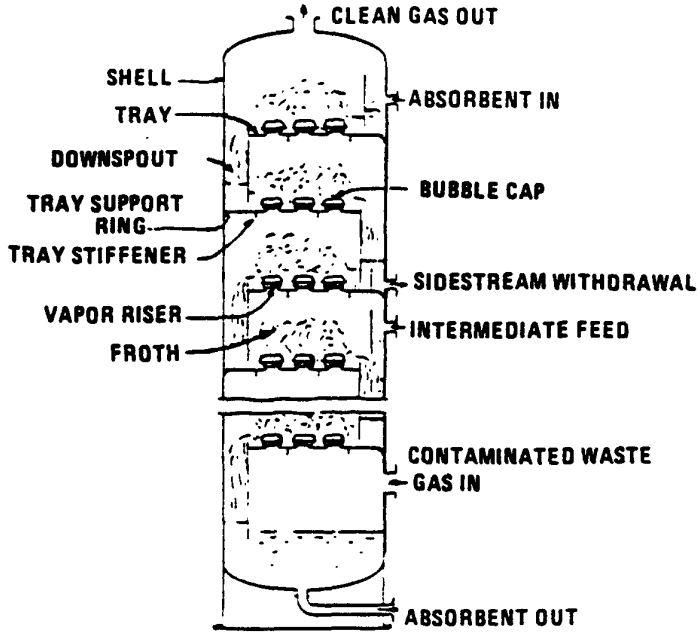


Figure 3-11. Schematic Diagram of a Bubble-Cap Tray Tower

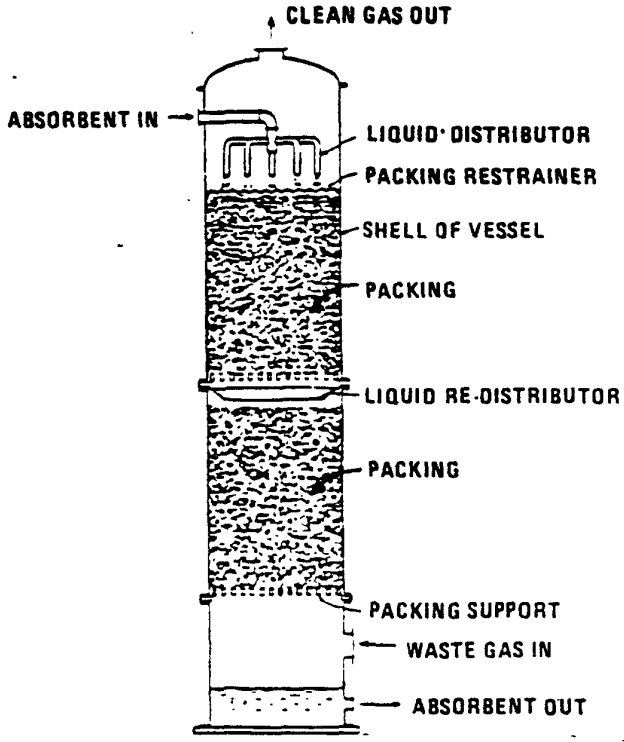


Figure 3-12. Packed Tower

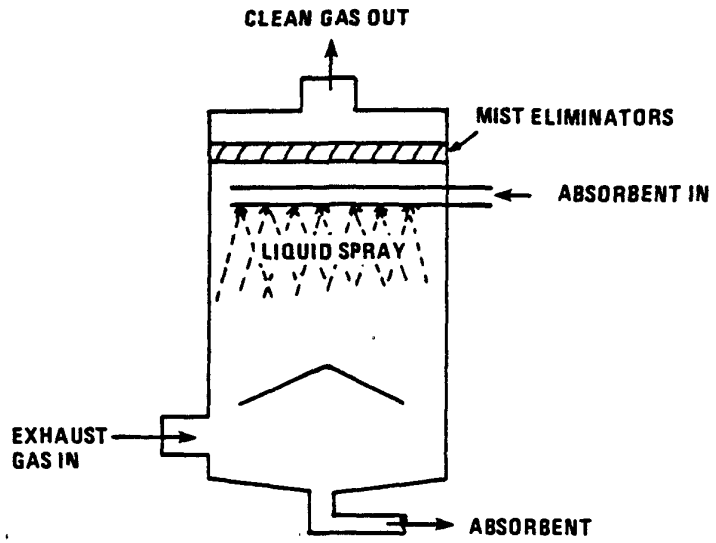


Figure 3-13. Spray Tower

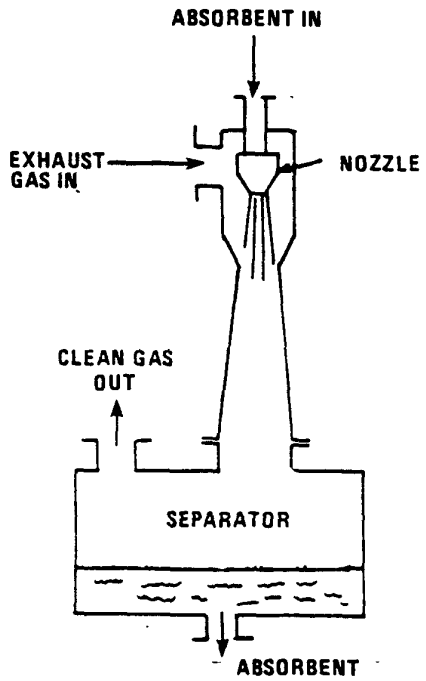


Figure 3-14. Venturi Scrubber

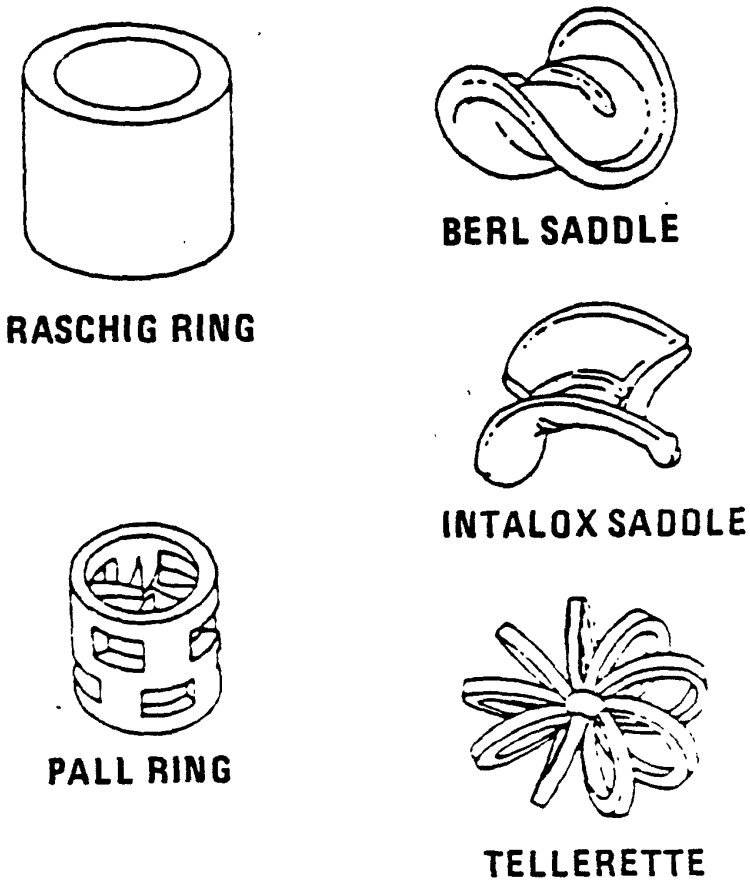


Figure 3-15. Commonly Used Materials for Tower Packing

accomplish contact by the use of single conical spray nozzles placed at two or three elevations in the tower. Spray towers do not suffer from restrictions to gas flow by accumulated residues commonly found in packed scrubbers.[59] Unfortunately, spray towers have the least effective mass transfer capability and thus, are generally limited to use for particulate removal and with high-solubility gases.[60]

A venturi scrubber is sometimes used to develop intimate contact between a liquid and a gas because of the unique properties of a venturi. The gas phase is drawn into the throat of a venturi by a stream of absorbing liquid sprayed into a convergent duct section. The effectiveness increases with increasing flow rate, as does the energy requirements. High gas velocities increase the effectiveness of the collision between the gas and liquid streams. Venturis have the advantage of obtaining a high degree of liquid-gas mixing, but have the disadvantage of short contact times.[61] Like spray towers, their more common use is for particulate removal or absorption of high solubility gases.

Due to the noted limitations of spray towers and venturi scrubbers, VOC control by gas absorption is generally limited to packed or plate towers. Packed columns are frequently used for handling corrosive materials, liquid with foaming or plugging tendencies, or where excessive pressure drops would result from use of plate columns. Packed columns are also less expensive than plate columns. Plate columns are preferred for large-scale operations where internal cooling is desired or where low liquid flow rates would inadequately wet the packing.[62]

3.4.2 Applications

The suitability of gas absorption as a VOC emission control method is generally dependent on the following factors:[63]

1. availability of a suitable solvent,
2. VOC removal efficiency required,
3. recovery value or terminal disposal cost of the VOC,
4. capacity required for handling vapors, and
5. VOC concentration in the inlet vapor.

Gas absorption as an emission control method may use water as a solvent for absorption of organic compounds that have high water solubility. Other solvents such as mineral oil or nonvolatile hydrocarbon oils are used for organic compounds that have low water solubility.[64] Absorption has been used to control VOCs from surface coating operations, waste handling and treatment plants, degreasing operations, asphalt batch plants, ceramic tile manufacturing plants, coffee roasters, chromium plating units, petroleum coker units, fish meal systems, smoke generators, and varnish and resin cookers.[65] Absorption is attractive if a significant amount of VOC can be recovered and if the recovered VOC can be reused. It is usually not considered when the VOC concentration is below 200-300 ppmv.[66]

3.4.3 Absorption Costs

Absorption costs vary widely and depend on many factors.[67] The estimated costs presented in Figure 3-16 represent the total investment, including all indirect costs such as engineering and contractors' fees and overheads, required for the purchase and installation of all equipment and materials. These are battery - limit costs. These costs are based on a new installation; no retrofit cost considerations are included. Retrofit is usually more costly. These costs apply to packed or tray columns in which the solvent is used on a once-through basis (see Appendix B). The annual cost is shown in Figure 3-17.[68]

It is emphasized that these cost figures are for illustrative purposes only. Each particular application of an absorption system will require an engineering analysis of performance requirements and gas stream characteristics before the costs can be estimated.[69] For more specific costing information, refer to Part XIII of the "Cost File" series published in Chemical Engineering Magazine.[70] Figures 3-16 and 3-17 are based on the parameters presented in Table 3-6.

3.4.4 Absorption Energy Requirements

The energy required for an absorber will vary greatly depending upon the type used. Energy is required for driving pumps and blowers, cooling water (primarily on a condenser if a stripper is used), and heat if regeneration of the absorbent is desired.

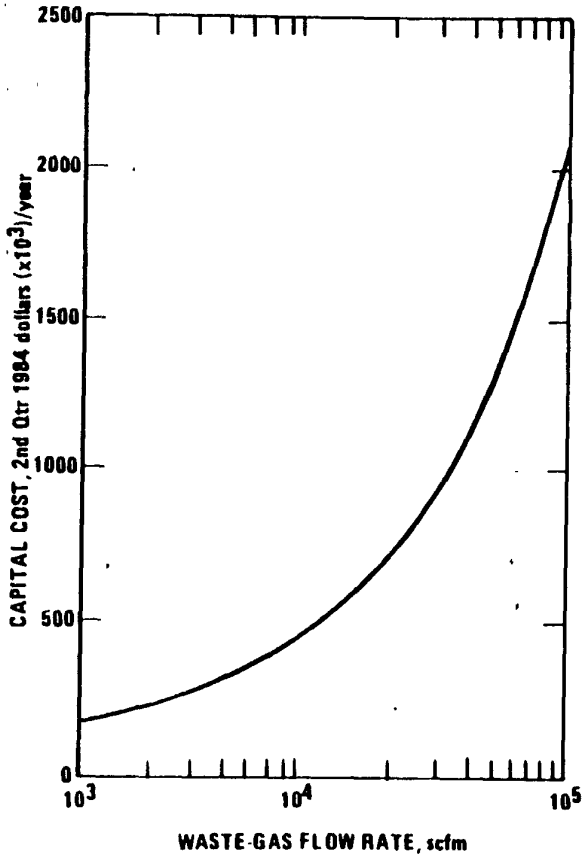


Figure 3-16. Installed Capital Cost vs Flow Rate for Complete Absorption System (No Stripper) With A Solute-Solvent System Operating at 99.0% VOC Removal Efficiency

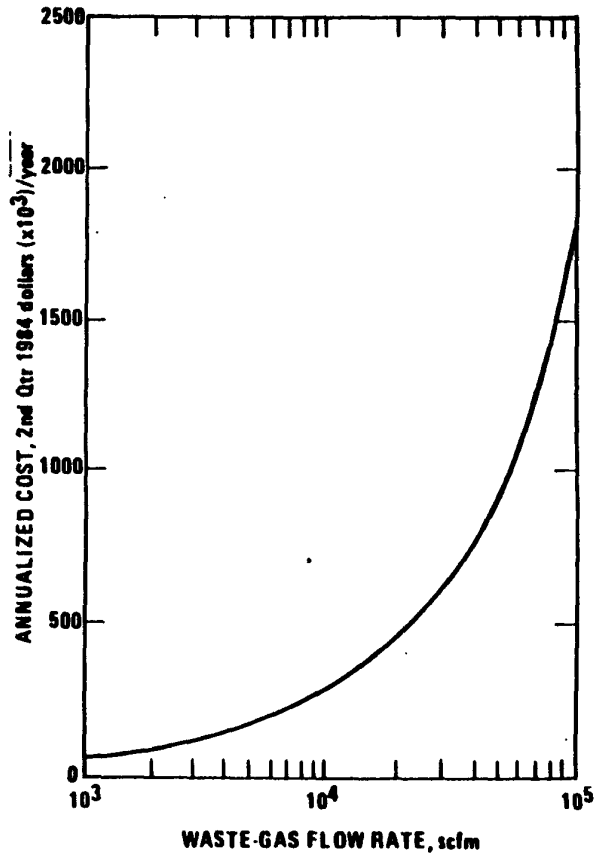


Figure 3-17. Annual Cost vs Flow Rate for Absorber Only (No Stripper) With A Solute-Solvent System Operating At 99.0% VOC Removal Efficiency

TABLE 3-6. Components Of The Annualized Cost Of An Absorption Unit

Gas Stream Characteristics	
Flow Rate	10,000 scfm
Concentration	0.5% (by weight) VOC
Equilibrium Curve Slope	2.0
Installed Capital Cost	$518,000
Direct Operating Costs	
Utilities	
Process water ($0.33/1,000 gal.)	$27,500
Electricity ($0.04/kWh)	$63,000
Wastewater treatment ($0.33/1,000)	$27,500
Maintenance, labor,and materials	$34,000[a]
Operating labor ($20/hr)	$17,500
Capital Charges	$110,000[b]
Net Annualized Costs	$279,500[c]

[a] Computed as 6.5 percent of installed capital cost.

[b] Calculated as 21 percent of installed capital cost. Based on 10 percent interest for 10 years plus 5 percent for taxes, insurance, and administrative charges.

[c] Computed as operating costs + capital charges. There is no VOC recovery credit for air containing 0.5 wt. percent of VOC.

Power requirements for pump operation are generally small compared to requirements for the blower.[71] Blower requirements are a function of the quantity of gas which must be treated and the pressure drop of the absorber. The energy required for a typical tower (plate or packed) as a function of gas flow rate is shown in Figure 3-18.[72]

3.4.5 VOC Removal Efficiency

Many factors in the design and operation of an absorber affect its performance, but two of the most important are solubility of the absorbate in the absorbent and intimacy of mixing between the two phases caused by the absorber.[73] For example, two important factors influence the rate and efficiency of benzene absorption in a wash-oil spray chamber. The first factor is the amount of benzene vapor absorbed by the wash oil at equilibrium. The second is the scrubber's contacting efficiency. One measure of this efficiency is the number of equilibrium stages provided by the scrubber.[74] The contacting efficiency increases as the number of stages increases.

In theory, a properly designed and operated scrubber can provide a benzene control efficiency of 95 percent or greater. The highest control efficiency known to have been demonstrated so far is 90 percent.[75]

3.4.6 Environmental Impact of an Absorption Process

Potential adverse environmental problems from an absorber include processing or disposal of the organic-laden liquid effluent, loss of absorbent to the atmosphere, and an increase for water use. The liquid effluent from some absorbers can be used elsewhere in the process. When this is not possible the absorbent effluent should be treated. Such treatment may include a physical separation process (decanting or distilling) or a chemical treating operation.

Sometimes regeneration may be accomplished by merely heating the liquid effluent stream to reduce the solubility of the absorbed organics and flash them from the absorbent. These concentrated organics can then be condensed or burned. If burned, emissions of SO_x, NO_x, or incomplete oxidation products of organics may result. The decision to burn will depend on the nature of the regenerated gas stream.

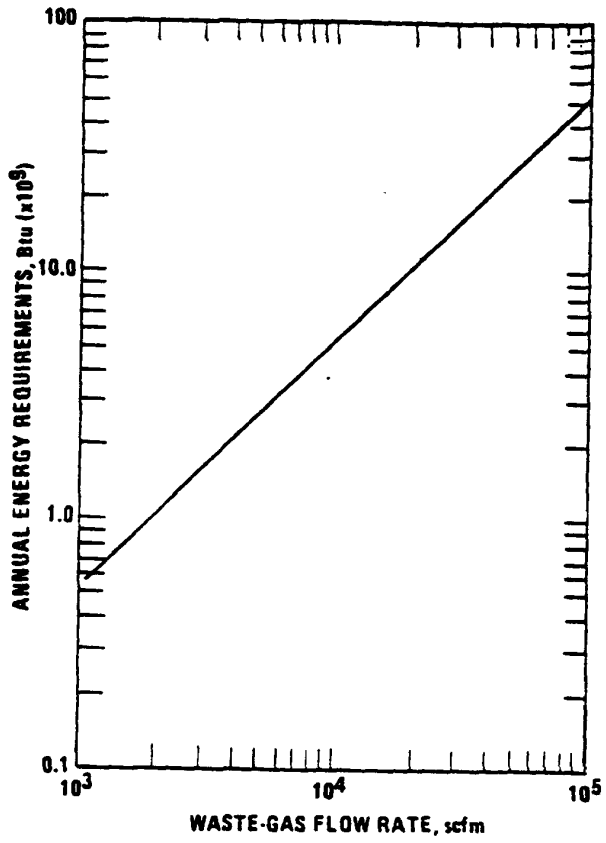


Figure 3-18. Annual Energy Requirements vs Flow Rate for Absorber Only (No Stripper) With A Solute-Solvent System Having An Equilibrium Curve Slope of 2.0 and Operating at 99.0% VOC Removal Efficiency.

The control of one volatile organic compound can result in emissions of another at an even greater rate when absorption is employed. For example, vapors of trichloroethylene can be substantially reduced in an air stream by absorption in a lean mineral oil; however, at ambient temperature the air stream leaving the absorber might contain some of the mineral oil.[76]

3.5 CONDENSATION

Condensation as an emission control method is often used in combination with other air pollution control equipment. Condensers may be located upstream of absorbers, carbon beds, or incinerators to reduce the VOC load entering the more expensive control devices.[77] A condenser can also be used to remove components that might cause corrosion, adversely affect the operation of downstream equipment, or to recover valuable components before burning the waste gas stream. When used as the only control technique, such as to limit emissions of gasoline vapor at bulk terminals, refrigeration is often required to achieve the low temperatures necessary to cause condensation.

3.5.1 Equipment and Operating Principles

In a vapor, condensation occurs when the partial pressure of a condensible component is equal to its vapor pressure. This may be accomplished by either increasing the pressure of the vapor, reducing the temperature of the vapor, or a combination of the two.

The two most common types of condensers are surface and contact condensers. Both operate at essentially constant pressure. The design of a surface condenser does not permit contact between the coolant and either the vapors or condensate. Condensation occurs on the walls that separate the two fluids. A contact condenser encourages intimate mixing of the fluids.

Most surface condensers are shell-and-tube heat exchangers like the one in Figure 3-19.[78] The coolant usually flows through the tubes and the vapor condenses on the outside tube surface. The condensate forms a film on the cool tube and gravity drains from the exchanger. Air-cooled condensers may be used. These are constructed with tubes with external surface fins through which air is blown. The vapor condenses inside the tubes.[79]

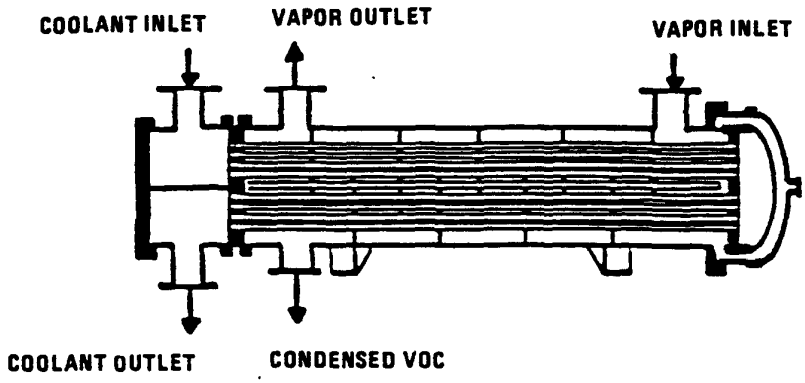


Figure 3-19. Schematic Diagram of a Shell-and-Tube Surface Condenser

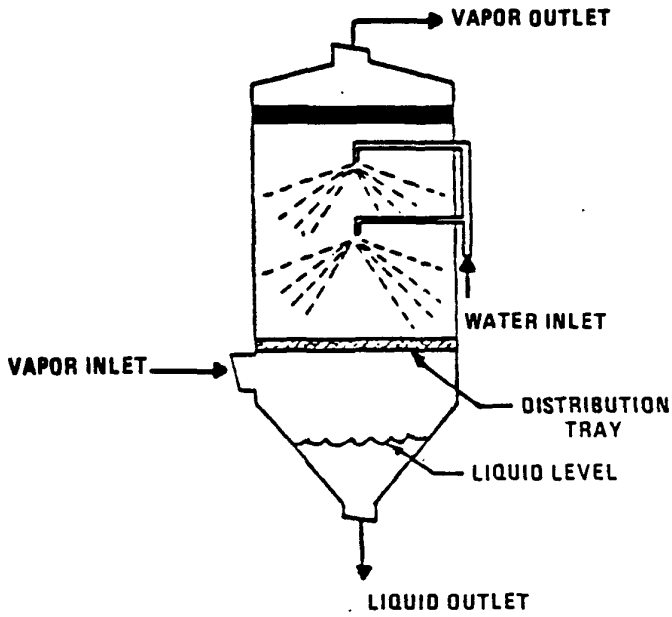


Figure 3-20. Schematic Diagram of a Contact Condenser.

Vapors are cooled in contact condensers by spraying 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 3-20.[80]

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 auxillary equipment and have greater maintenance requirements.

Refrigerated brine vapor recovery systems require the following equipment to produce the coolant for the vapor condenser: a refrigeration unit, a heat exchanger/evaporator, storage for the chilled and defrost brines, and a vapor condenser. To develop low temperatures, the refrigeration unit is normally a compound system (temperatures to approximately - 100°F) or a cascade multistage system (temperatures as low as - 250°F). Most petroleum products require temperatures of approximately - 110°F, consequently, cascade systems such as the one in Figure 3-21, are normally used.[81] In the cascade system, the condenser of one refrigeration stage acts as the evaporator for the second stage to produce a lower temperature. Below 32°F, moisture in the gas stream frosts and files the condensing surface. To remove the ice, the condenser must be periodically defrosted. For a continuous vapor recovery system, two condensers may be required, one condensing while the second is defrosting.[82]

Refrigeration systems are particularly well suited for applications for high value organics such as the recovery of hydrocarbon vapors from gasoline marketing operations. Such systems are sold as packaged units that contain all of the necessary piping, controls, and components. These are usually skidmounted with weather enclosure.[83] The size and cost of a refrigerated vapor recovery unit will depend on the operational schedule, process flow rate, load of VOC emissions, and the gas and liquid storage capacities desired.

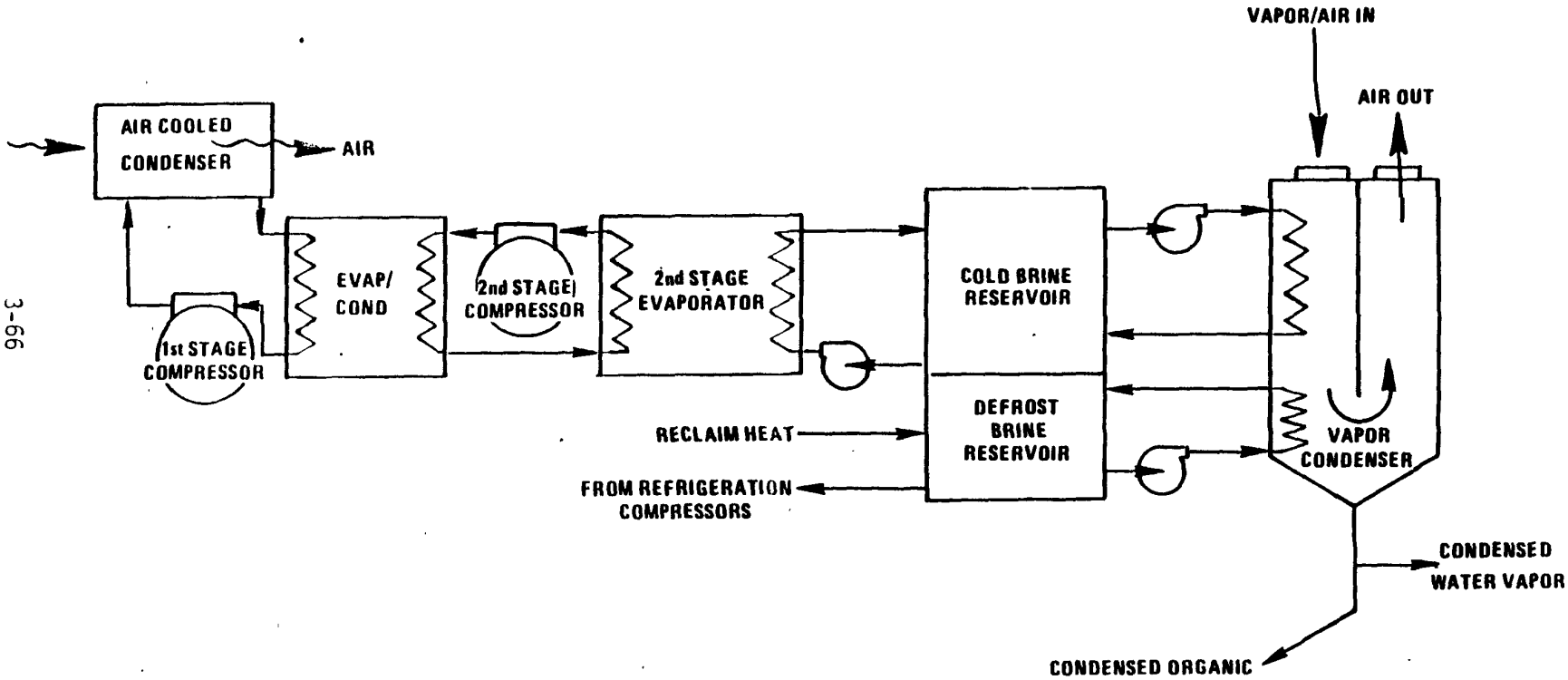


Figure 3-21. Cascade Refrigeration System for Vapor Recovery

A condensation system using a nitrogen-blanketed drying oven and a nitrogen-cooled heat exchanger is one type of system that has been used to recover VOC emissions from drying ovens at polymeric coating plants. Figure 3-22 presents a flow diagram of this condensation system. Nitrogen is used in the drying oven to permit operation with high solvent vapor concentrations without the danger of explosion. The nitrogen recycled through the oven is monitored and operated to maintain solvent vapor concentrations of 10 to 30 percent by volume. Solvents are recovered by sending a bleed stream of approximately 1 percent of the recycle flow through a shell-and-tube condenser. The liquid nitrogen is on the tube side, and the solvent-laden nitrogen passes over the outside of the tube surfaces. Vapors condense and drain into a collection tank. The nitrogen that vaporizes in the heat exchanger is recycled to the drying oven.[84]

A system now available from the Linde Division of Union Carbide Corporation uses liquid nitrogen to condense and recover vapors. Many plants presently use nitrogen at ambient temperature to blanket liquid-storage facilities for safety or purity purposes. The nitrogen is delivered and stored as a liquid and vaporized before use. Typically, the cooling potential of the liquid nitrogen is presently wasted. The Linde system uses the Joule-Thompson effect of the liquid nitrogen (en route to its being warmed to ambient temperature for use in blanketing) as a refrigerant for a condenser. At sites where the cryogen is already being used, such cooling is available at little or no additional cost. Even in cases where liquid nitrogen is not presently stored this condensation system may still be economical.[85]

3.5.2 Applications

Refrigerated condensers are being used for recovery of gasoline vapors at bulk gasoline terminals. The suitability of condensation for VOC emissions control is generally dependent on the following: VOC concentration in the inlet; the VOC removal efficiency required; the value of the recovered VOC; and the cost of the condenser required to handle the gas flow rate.[86]

A refrigerated condenser system may be used independently or in combination with another process. To recover organic vapors from transfer operations at gasoline terminals and bulk plants, refrigeration can be used to condense

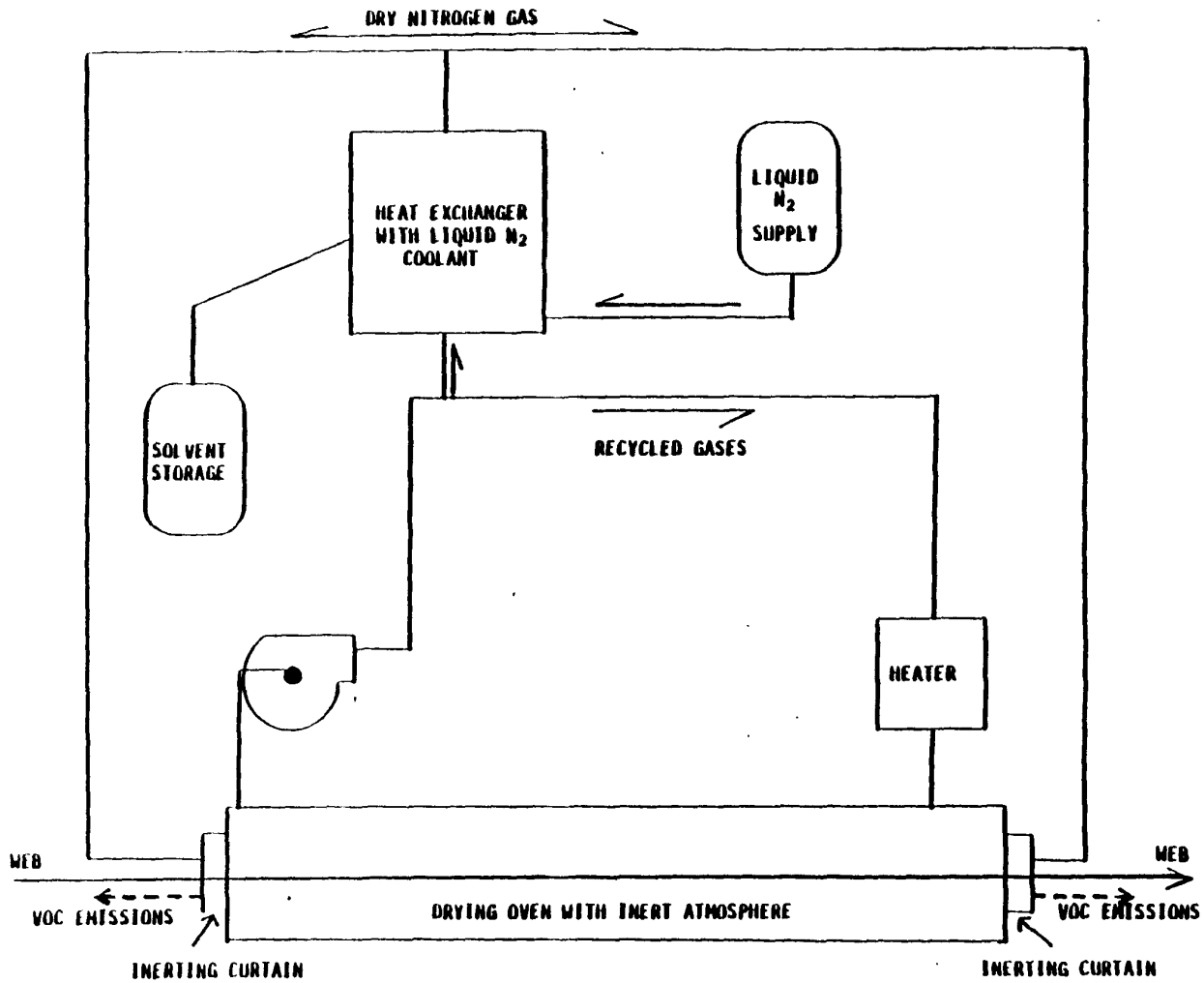


Figure 3-22. Schematic of Condensation System Using Nitrogen

the vapors at essentially atmospheric pressure or by compressing the vapors, requiring less refrigeration.[87] A primary condenser system is an integral part of any distillation operation. These condensers provide reflux for the fractionating columns. A secondary condenser may be used to remove even more VOC from the "noncondensible" vent stream which exits the primary condenser.[88]

Condensers have been used successfully (but usually in conjunction with other control equipment) in reducing organic emissions from petroleum refining, petrochemical manufacturing, asphalt manufacturing, coal tar dipping operations, degreasing operations, dry cleaning units, and sometimes the surface coating industry.[89]

3.5.3 Condensation Costs

The cost of a shell-and-tube surface condenser depends on the following:[90]

1. the nature and concentrations of the vapors in the waste gas,
2. the mean temperature difference between gas and coolant,
3. the nature of the coolant,
4. the desired degree of condensate subcooling,
5. the presence of noncondensible gases in the waste gas, and
6. the buildup of particulate matter on heat exchanger surfaces.

Using the above factors and standardized heat exchanger equations, the requisite contact area may be calculated from which the cost may be estimated. Generally, the capital cost for a surface condenser will be greater than for a contact condenser, although selection of a contact condenser will usually necessitate additional capital for treatment of the coolant effluent.

Annual and capital costs for refrigerated vapor recovery units for use at bulk gasoline terminals have been published by the EPA in a document on control of air pollution from the gasoline marketing industry.[91] These cost estimates are shown in Figures 3-23 and 3-24. All costs are indexed to second quarter 1984 dollars (see Appendix B). A negative annual cost indicates the profit associated with the control scheme.

The capital cost represents the total investment required to purchase and install a refrigeration unit. While the cost for installation at an existing facility may be slightly more than for a new one, the costs

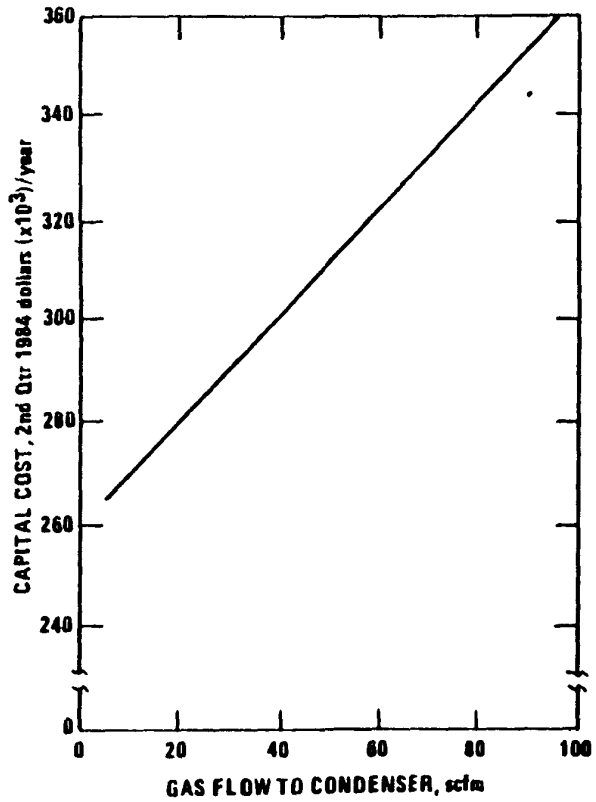


Figure 3-23. Installed Capital Cost vs Gas Flow Rate To A Condenser For A Refrigerated Vapor Recovery Unit

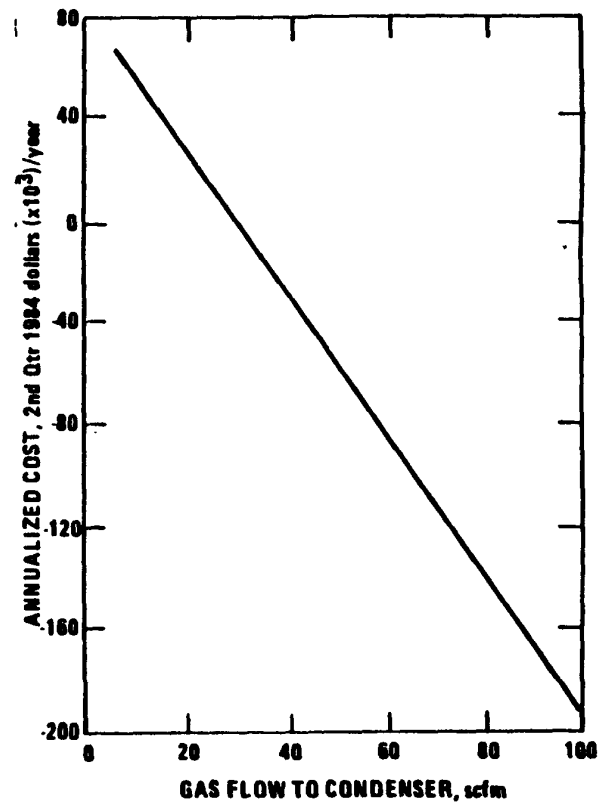


Figure 3-24. Annual Cost vs Flow Rate To A Condenser For A Refrigeration Vapor Recovery Unit

presented here are intended to represent the more expensive case. For a more detailed discussion of cost information, refer to Part XVI of the "Cost File" series published in Chemical Engineering Magazine.[92]

Some components of the annualized cost of operating a refrigerated vapor recovery unit are shown in Table 3-7. Utilities costs will depend on the inlet concentration of the organic; high recovery of gasoline can yield an annual savings. The increased price of gasoline over the past few years has made refrigerated condensers more profitable where high concentration of the valuable organic can be recovered.

TABLE 3-7 Components Of Annualized Costs For A Refrigeration Vapor Recovery Unit

Gas Stream Flow Rate	23.3 scfm ($.66 \frac{m^3}{min}$)
Installed Capital Cost	$280,000
Direct Operating Costs:	
Utilities	$23,000[a]
Maintenance	7,000[b]
Operating Labor	5,500
Capital Charges	59,500[c]
Gasoline Recovery (Credit)	($75,000)[d]
Net Annualized Costs	$20,000[e]

[a] Electricity @ $0.04/kWh.

[b] Maintenance as 2.5 percent of the capital cost.

[c] Calculated at 10 percent for 10 years plus 5 percent for taxes, insurance, and administrative costs.

[d] Gasoline valued at a wholesale price $0.31 per liter F.O.B. terminal before tax.

[e] Computed as operating cost + capital charges - gasoline recovery credits.

3.5.4 Energy Requirements for a Refrigerated Condenser

The refrigeration unit (that provides coolant to the condenser) and the pumps require electrical power. The amount, of course, is determined by the amount of refrigeration needed and the coolant temperatures required. The power required for a blower will be roughly proportional to the gas flow rate through the system and will therefore vary with the concentration and removal efficiencies selected.[93]

A contact condenser requires energy to chill the cold liquid, power the injection pumps, and the blower that moves the gas through the condensation zone. A surface condenser requires energy for a cooling water system or forced convection air cooler.[94]

Figure 3-25 shows the energy requirements for a refrigerated condenser system used to recover gasoline vapors at a bulk terminal as a function of vapor flow rates.[95] These costs are based on the electrical power required by the refrigeration unit.

3.5.5 VOC Removal Efficiency

Condensers are operated at efficiencies between 50 and 95 percent.[96] Where solvent contamination is low and organic vapor concentration is relatively high, recovery efficiencies are reported greater than 96 percent. In cases where ambient air is mixed with the vapor and some contamination is present, efficiencies of about 90 percent are reported.[97]

For gasoline vapor recovery, refrigeration units have the capacity of recovering more than 90 percent of the organics when the gas entering the condenser consists of 35 percent gasoline vapors by volume. Refrigeration units will recover 70 percent of the organics when the gas entering the condenser consists of 15 percent gasoline vapor by volume.[98]

3.5.6 Environmental Impact of Condensers

Secondary environmental problems created by condensers include contamination of: (1) non-condensibles from surface condensers and refrigeration systems and (2) the liquid effluent from a contact condenser.

The non-condensible effluent from a surface condenser may be vented to the atmosphere or further processed (e.g., via incineration), depending on its composition. Since the coolant never contacts the condensate in a surface

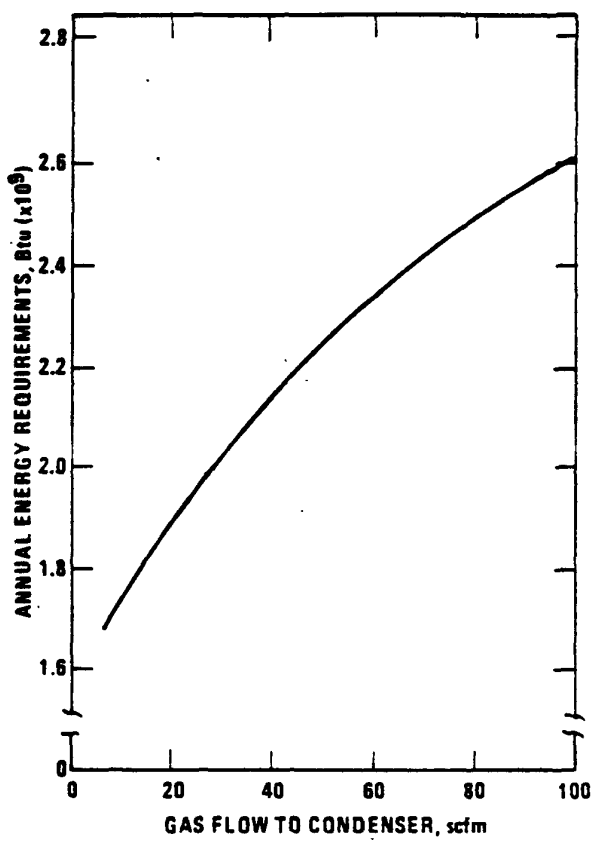


Figure 3-25. Annual Energy Requirement vs Gas Flow Rate To A Condenser For A Refrigeration Condenser (Gasoline Vapor Recovery System At A Bulk Terminal)

condenser, the recovered organic compounds are not contaminated and are usually reusable. It might not be economical to recover the condensate if more than one organic compound is present and their separation is costly. In such a case, proper treatment of the condensate is imperative before final disposal. This is also true of volatile organics recovered by a refrigerated condenser.

The condensate from a contact condenser is contaminated with the coolant liquid. The usual procedure is treatment of the waste stream to remove the organics and subsequent disposal. The amount of organic material entrained in the exiting wastewater will depend on the extent of treatment.[99]

3.6 OTHER CONTROL METHODS

3.6.1 Changes to the Process or Its Raw Materials

The control "option" most difficult to discuss is the variety of changes that can be made to a process or its raw materials which can reduce the emission rate.

A process change can be a very simple and often inexpensive measure such as closing an open vessel or trough from which solvents evaporate. It can also be more complicated such as replacement of open printing technology, reportedly not only reduces fugitive emissions from the ink fountain, but also permits much more precise control of the ink delivered to the substrate. It is reported that this has improved the quality of the print and reduced ink consumption thereby invoking both value to the printer and environmental benefits.

Other process changes with environmental benefits include installation of equipment to reduce breathing losses (from storage tanks that contain volatile organics) or replacement of steam jet ejectors with vacuum pumps thereby reducing the volume of exhaust gases and rendering abatement control less expensive. Another common change now being made in spray painting operations is the installation of new, more efficient spray techniques. As a result there is less waste, fewer emissions and resulting economies to the plant owner because of decreased paint costs. In addition to the efficiencies offered by electrostatic spraying techniques, many firms are installing robots to manage the spray equipment. Additional efficiencies are obtained because of the absolute repetitiveness offered by a robot. Waste motion and spray can be eliminated, ultimately resulting in even greater reductions of waste coatings and their VOC. The possibilities are endless and require an innovative analysis of the production process under scrutiny to determine the possibilities for improvement. One of the simplest changes to undertake, improvements in housekeeping and maintenance procedures, can have a dramatic effect on reducing emissions.

Routine inspections of pumps, valves, flanges and other fittings will allow more speedy identification of vapor and liquid losses. Rapid repair will minimize emissions and maximize product yield.

Changes in raw materials are much easier to conceptualize, but sometimes difficult to accomplish. One of the more noted successes of the last few years has been the change to hot melt adhesives to replace many of the solvent based materials previously applied by gravure rolls. Another change is the trend in many coating industries to convert to the use of low solvent paints and inks. Powder coatings, waterborne coatings, higher solids coatings are increasing their market share. All three products are replacing traditional coatings with solvent emissions several-fold greater.

Some raw material changes essentially eliminate organic emissions. An increasingly common example has been the transition to powder coatings. Powder coatings require no solvent and are applied as a dry powder. Sprayed electrostatically, the paint adheres to the substrate. When subsequently heated in an oven, the powder first melts and flows to gather to form a uniform film, then reacts to hardent into an esthetically pleasing and protective coating.

Other essentially zero emission raw materials include inks and coatings that are cured by ultraviolet or electron beam radiation. These liquid monomeric materials, which contain little or no solvent, react when the polymeric reaction is initiated by radiation.

3.6.2 Replacement of Organic Materials with Others Which are Less Photochemically Reactive

This technique of emission reduction was a major facet of the Los Angeles Air Pollution Control District's Rule 66 (now, "South Coast Air Quality Management District Rule 442") in force in the mid-60's. The use of so-called exempt solvents began to fade in 1977 when EPA published its Recommended Policy on Control of Volatile Organic Compounds (July 8, 1977, Federal Register, page 35314). That policy allowed continued use of Rule 66 type regulations by states during some interim transitional period as new regulations were developed to obtain real emission reductions.

The policy announced that research subsequent to enactment of the Los Angeles Rule had determined that essentially all organic compounds react photochemically to form ozone. The Los Angeles Rule was based on the photochemical reactivity of organics during experimental tests for a few hours (generally one "solar day" of about six (6) hours). When the "low photochemcially reactive" compounds identified by this test were exposed to photolysis for longer periods, they too reacted to form ozone. Rule 66, then, perhaps had successfully aided the Los Angeles Valley in ameliorating smog levels only at the expense of higher levels downwind.

This information led to EPA's policy that is founded on the nationwide transport phenomena of air pollutants. It makes little sense to permit substitution of slow (low photochemical reactivity) reacting organics for faster reacting ones if the result is transport of one metropolitan area's smog problem downwind to another place. EPA's policy declared essentially all organics reactive. The policy declared some exceptions, predominantly halogenated organics, which have negligible photochemical reactivity. Accompanying this declaration was a caution that although these materials do not react to produce ozone, some were suspected of being toxic and any decision to use them should consider such other environmental aspects. The cloud of uncertainty over some of these halogenated solvents has not yet cleared completely. In October 1984, the EPA published a final rule for manufacturers and processors of 1,1,1 trichloroethane that requires testing for "teratorgenic effects or, more appropriately, developmentally toxic effects." The caution in the 1977 policy statement to evaluate other potentially damaging environmental effects of halogenated solvents before substituting them for photochemically reactive ones seems no less important today than then.

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4.0 CONTROL TECHNIQUES APPLICABLE TO SOURCE CATEGORIES

This chapter provides a brief description of the emission rates and control technology for the major volatile organic compound (VOC) emission source categories. For each source category the following are described:

A. Process and Facility Description
B. Emission Sources and Factors
C. Control Techniques and Emission Reductions
D. Regulatory Status
E. Current National Emission Estimate
F. Capital and Annual Control Costs
G. References

This chapter relies heavily on the reference material developed under the present EPA emission control programs - NESHAP, NSPS and CTG documents. The reference documents should be reviewed to obtain a complete understanding of the subject matter. This chapter also provides the source of the national VOC emission estimates presented in Chapters 1 and 2.

All control costs (unless otherwise noted) have been updated to second quarter or May 1984 dollars to provide a rough estimate of cost in current dollars for comparing control costs with other source categories. The method for updating costs is presented in Appendix B.

4.1 PETROLEUM REFINERIES

4.1.1 Petroleum Refinery Equipment Leaks

A. Process and Facility Description

Petroleum refineries are facilities engaged in the production of gasoline, aromatics, kerosene, distillate fuel oils, residual fuel oils, and other products through the distillation of petroleum, or through the redistillation, cracking, rearrangement, or reforming of unfinished petroleum derivatives. Refineries are comprised of one or more processing units (equipment assembled to produce intermediate or final products). There are approximately 220 petroleum refineries operating in the United States (as of January 1, 1984), with a total crude capacity of about 2,522,000 m^3/calendar day (15,862,883 bbl/ calendar day).[1]

B. Emission Sources and Factors

Emissions of VOC from refineries can result when process fluids (either gaseous or liquid) leak from plant equipment. Potential leaking equipment include: pumps, compressors, valves, pressure relief devices, open-ended lines, sampling systems and flanges and other connectors. Emission factors for process equipment have been developed based on the results of several source testing studies. Emissions from petroleum refinery processing units can be estimated by multiplying emission factors for specific types of equipment by the number of equipment pieces in the process units. Refinery process unit emissions may range from about 80 to 500 Mg/yr (88 to 550 tons/yr) in the absence of regulatory controls. Emissions of VOC from a hypothetical refinery with 10 process units would be approximately 2,360 Mg/yr (2,600 tons/yr). Emissions from petroleum refinery equipment leaks are discussed in the background information documents for the proposed and promulgated new source performance standards (NSPS) for petroleum refinery fugitive emissions.[2,3]

C. Control Techniques and Emission Reductions

Two approaches are available to control refinery equipment leaks of VOC: (1) a leak detection and repair program and (2) the installation of specific controls or leakless equipment. The emission reduction efficiency of leak

detection and repair programs is dependent upon a number of factors including: (1) the monitoring method (visual, instrument, or soap solution); (2) leak definition; (3) frequency of inspections; (4) the time interval allowed between leak detection and subsequent leak repair; and (5) the emission reduction achieved by each successful repair. Leak detection and repair program control efficiencies are presented in Table 4.1.1-1.[4] The control estimates are based on available data on the occurrence and recurrence of leaking equipment and on the effectiveness of leak repair that are used in a model program that predicts control effectiveness using recursive equations developed for evaluating leak detection and repair programs. Control equipment can achieve control efficiencies approaching 100 percent. Examples of equipment controls include (1) venting emissions from pressure relief devices, pumps, and compressors to a control device (e.g., flare or process heater); (2) dual mechanical seals with barrier fluid systems for pumps and compressors; (3) caps, plugs, or second valves on openended lines; (4) closed purge sampling systems; and (5) sealed bellows valves.

TABLE 4.1.1-1. EMISSION FACTORS AND CONTROL EFFECTIVENESS[a]

		Controlled Emissions			
		Quarterly Monitoring		Monthly Monitoring	
Equipment Type/Service	Average Emission Factor, kg/hr	Emission Factor, kg/hr	Percent Reduction	Emission Factor, kg/hr	Percent Reduction
Valves -					
Gas	0.64	0.262	59.7	0.192	70.3
Light Liquid	0.26	0.098	62.7	0.072	72.5
Pumps - Light Liquid	2.7	0.78	70.9	0.45	83.3
Pressure Relief Devices - Gas	3.9	2.18	44	1.8	53

[a]Reference 2. Appendix F.

D. Regulatory Status

The EPA issued a CTG in June 1978 and set NSPS on May 30, 1984, (40 CFR 60 Subpart GGG) to control equipment leaks (fugitive emissions) of VOC in petroleum refineries. The CTG recommends quarterly leak detection and repair for valves, pressure relief devices, and compressors in gas/vapor service and annual leak detection and repair for pumps and valves in light liquid service. Pumps also would receive weekly visual inspections. The CTG additionally recommends that caps be installed on open-ended lines. The NSPS requires monthly leak detection for valves in gas/vapor and light liquid service and pumps in light liquid service. Pressure relief devices are subject to a no detectable emissions limit, compressors are to be equipped with a barrier fluid seal system that prevents leakage of VOC to atmosphere, sampling lines require closed purge systems, and caps be installed on open-ended lines. About 120 refineries (56 percent) are estimated to have implemented controls recommended by the CTG as required under State or local regulations.[1] By the end of 1984, 38 refinery process units are projected to be subject to the NSPS.[5]

E. Current National Emission Estimates

Total annual VOC emissions from petroleum refinery equipment leaks in 1984 has been estimated at 370,000 megagrams based on 1984 levels of control.[3,6] This estimate was derived by multiplying the total estimated number of refinery process units by process unit emission estimates. The nationwide emissions estimate assumes that 56 percent of the refineries are in nonattainment areas.[7]

F. Capital and Annual Control Costs

Capital and annual costs for controlling refinery equipment leaks are presented in Table 4.1.1-2 for a small and large process unit. These costs are estimated based upon control costs for individual equipment type multiplied by the number of each type of equipment in the process unit. The costs presented also include expenditures incurred for monitoring instruments.[7] A typical uncontrolled petroleum refinery (10 process units) would incur a capital cost of $161,000 and annual cost savings of $54,500 to comply with State and local regulations to control equipment leaks of VOC. The same refinery would incur about $1.2 million in capital costs and $140,000 in annual costs to comply with the NSPS requirements.[7]

TABLE 4.1.1-2. CAPITAL AND ANNUAL COSTS TO CONTROL REFINERY EQUIPMENT LEAKS[a]

Costs ($1,000)	CTG	NSPS
Capital Cost		
Small Unit[b]	4.7	43.6
Large Unit	27.2	237
Annual Cost		
Small Unit	(1.9)	3.7
Large Unit	(4.1)	25.7

Parentheses denote cost savings.

[a]Reference 7.

[b]A small and large unit correspond to Model Units A and C, respectively, from Reference 2.

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4.1.2 Petroleum Refining Vacuum Producing Systems

A. Process and Facility Description

Vacuum distillation columns can be a significant source of VOC from petroleum refineries. Vacuum is created within the vacuum distillation column by removal of non-condensible gases and process steam by steam jet ejectors or mechanical vacuum pumps. A steam nozzle in a jet ejector discharges a jet of high velocity steam across a suction chamber that is connected to the piece of equipment in which the vacuum is to be maintained. Mechanical vacuum pumps, although less popular than steam jet ejectors, are more energy efficient and produce a stream consisting almost entirely of hydrocarbons. The exiting steam (for steam jet ejectors) and any entrained vapors are condensed by direct water quench in a barometric condenser or by a surface condenser. In 1984 there were 165 refineries operating vacuum distillation units with a combined vacuum distillation charge capacity of 1,115,000 m^3/stream day (7,015,590 barrels/stream day).[1]

B. Emission Sources and Factors

All vacuum producing systems discharge a stream of non-condensible VOC while generating the vacuum. Steam ejectors with contact condensers also have potential VOC emissions from their hotwells. VOC emissions from vacuum producing systems that vent non-condensible hydrocarbons to atmosphere are estimated to be 145 kg/1,000 m^3 (51 lb/ 1,000 bbl) of refinery throughput.[2]

C. Control Techniques and Emission Reductions

VOC emissions from vacuum producing systems can be prevented by piping the non-condensible vapors to a control device (e.g., flare, incinerator) or compressing the vapors and adding them to refinery fuel gas. The hotwells associated with contact condensers can be covered and the vapors incinerated. Controlling vacuum producing systems in this manner will result in negligible emissions of hydrocarbons from this source.

D. Regulatory Status

The EPA issued a CTG in October 1977 recommending that refineries control vacuum producing system emissions by piping non-condensible vapors to a control device. It is estimated that 56 percent (123) of the existing petroleum

refineries have controlled vacuum producing system emissions as required under State regulations.[1,3]

E. Current National Emission Estimates

Emissions of VOC from petroleum refinery vacuum producing systems in 1984 have been estimated at 44,000 Mg/year (48,500 tons/year).[1-5] The nationwide emissions were estimated by multiplying the throughputbased emission factor by the nations' vacuum distillation charge capacity, and by an industry-wide utilization rate.

F. Capital and Annual Control Costs

For a typical 15,900 m^3 (100,000 bbl) per day throughput refinery, capital costs for piping vacuum producing system non-condensible hydrocarbons from surface condensers or mechanical vacuum pumps are estimated at $36,500. Capital costs for controlling emissions from contact (barometric) condensers and covering their hotwell area are estimated at $79,500. Recovering vapor producing system emissions would result in a net annualized cost savings estimated in excess of $100,000 per year.[2,5]

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1. Annual Refining Report, Oil and Gas Journal, Volume 82, Number 13, March 26, 1984.

2. Guideline Series - Control of Refinery Vacuum Producing Systems, Wastewater Separators, and Process Unit Turnarounds, U.S. Environmental Protection Agency, EPA-450/2-77-025, October 1977.

3. Overview Survey of Status of Refineries in the U.S. with RACT Requirements, U.S. EPA Contract No. 68-01-4147, Task No. 65 and 74, October 1979.

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4.1.3 Petroleum Refinery Process Unit Turnarounds

A. Process and Facility Description

Petroleum refinery process units (e.g., crude distillation unit, fluid catalytic cracking units) are periodically shut down and emptied for internal inspection and maintenance. The action of unit shutdown, repair, or inspection and start-up is termed a unit turnaround. In order for workmen to enter process vessels, vessel liquids are pumped to storage and vapors are purged (by depressurizing and flushing with water, steam, or nitrogen) and the vessel is ventillated. Refinery process unit turnarounds range in frequency from 6 months to 6 years. A typical process unit is shut down every 3 years.[1-4] It is estimated that in 1984, there were over 600 process unit turnarounds nationwide.[5]

B. Emission Sources and Factors

VOC emissions occur when vessels are purged to provide a safe interior atmosphere for workmen. Significant amounts of VOC are emitted by refineries that vent vessel vapors to atmosphere. These refineries release the vapors to atmosphere through a blowdown stack usually remotely located to ensure that combustible mixtures will not be released within the refinery. The emission factor for uncontrolled refinery process unit turnarounds 860 kg/10^3 m^3 (300 lb/10^3 bbl) of refinery throughput is based on engineering estimates.[6]

C. Control Techniques and Emission Reductions

VOC emissions from process unit turnarounds can be controlled by venting vessel vapors to a vapor recovery system or to a flare until the pressure in the vessel is as close to atmospheric pressure as practicable. The exact pressure at which the vent to atmosphere is opened will depend on the pressure drop of the disposal system. Most refineries depressurize a vessel almost to atmospheric pressure, then flood the vessel with steam before the vessel is opened to atmosphere.[1,2,3] In some refineries the hydrocarbon concentration within the vessel can range from 1 to 30 percent before the vessel is vented to atmosphere.[4] The emission factor for refineries that control process unit turnarounds by depressurizing to a control device is 15 kg/10^3 m^3 (5.2 lb/10^3 bbl) of refinery throughput.[6] Control of VOC emissions during a process unit turnaround can reduce emissions by 845 kg/10^3 m^3 (296 lb/10^3 bbl) of refinery throughput, or about 98 percent.

D. Regulatory Status

The EPA issued a CTG in October 1977 recommending that refineries pipe process unit turnaround emissions to a flare header system or to fireboxes.[6] It is estimated that about 56 percent (123) of the existing petroleum refineries are controlling process unit turnaround emissions as required under State regulations.[7,8]

E. Current National Emission Estimates

Nationwide emissions resulting from process unit turnarounds have been estimated at 267,000 Mg/yr (294,000 tons/yr). Nationwide emissions were estimated by multiplying the emission factors for controlled and uncontrolled refineries by an estimated throughput for refineries. It was assumed that the number of refineries in non-attainment areas is proportionate to refinery throughput in non-attainment areas.[6,8,9]

F. Capital and Annual Control Costs

Control costs for process unit turnarounds are based on piping purge vapors to a flare header system or control device for a typical 15,900 m^3/day (100,000 bbl/day) crude throughput refinery. The capital and annual costs of this system are estimated at $158,000 and $42,000, respectively. Although the annual costs assume no recovery credits, if all the emissions are recovered, the control method could provide an annual cost savings.[5,6]

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2. Letter with attachments from L. Kronenberger, Exxon Company U.S.A., to Don Goodwin, U.S. EPA, February 2, 1977.

3. Letter with attachments from I.H. Gilman, Standard Oil Company of California, to Don Goodwin, U.S. EPA, November 30, 1976.

4. Letter with attachments from R.E. Van Ingen, Shell Oil Company, to Don Goodwin, U.S. EPA, January 10, 1977.

5. Memorandum. Rhoads, T., Pacific Environmental Services, Inc., to S. Shedd, U.S. EPA, Derivation of Cost, Emissions, and Emission Reduction presented in the VOC Control Techniques Document. November 1985.

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9. Outlook: U.S. petroleum product usage, Hydrocarbon Processing, Volume 63, No. 11, November 1984.

4.1.4 Petroleum Refinery Cooling Towers

A. Process and Facility Description

Cooling towers dissipate heat from water used to cool process equipment such as reactors, condensers, and heat exchangers. Cooling water is circulated through process units and returned to a cooling tower where the water is cooled evaporatively by forced air circulation. A study of petroleum refineries found an average of 4 cooling towers per refinery.[1] It is estimated that there were 880 refinery cooling towers in the United States in 1984.[1,2]

B. Emission Sources and Factors

Emissions from cooling towers occur when petroleum fluids enter the cooling water from leaking heat exchanger tubes or from reuse of process wastewater in the cooling system. VOC's can be released to atmosphere at the top of the tower as cooling water vaporizes and from the bottom where cooled water collects prior to recirculation through the process water system. A "worst-case" estimate of average emissions developed from a study of 31 refinery cooling towers is 0.084 kg/1,000 m^3 water flow rate (0.0007 lb/1,000 gal).[3] A typical refinery indirect contact cooling tower with a water flow rate of 10,000 m^3/hr (2,600,000 gal/hr) would emit 7.4 Mg (8.2 tons) of VOC per year to atmosphere.

C. Control Techniques and Emission Reductions

Cooling tower VOC emissions are controlled by minimizing the amount of VOC entering the tower. One control technique is to eliminate the use of contaminated process water as cooling tower make-up. Another technique is to

monitor total organic carbon in the cooling water to detect early indications of small equipment leaks, and then find and repair them. Existing controls consist of equipment inspection and maintenance. A study of controlled cooling towers estimated emissions at 0.013 kg/1,000 m^3 water flow rate (0.11 lb/10^6 gal).[4] The emission reduction for control of a typical 10,000 m^3/hr cooling tower may be approximately 6.3 Mg/yr (6.9 tons/yr).

D. Regulatory Status

The EPA has not issued a CTG nor set NSPS standards to control emissions of VOC from cooling towers.

E. Current National Emission Estimates

The majority of refinery cooling towers do not emit significant quantities of VOC. A study of 31 refinery cooling towers found only 8 (26 percent) to have statistically significant emissions.[4] The total nationwide emissions of VOC from cooling towers has been estimated at 2,400 Mg/yr.[5] The nationwide estimate was derived by multiplying the total number of estimated cooling towers by an average sized cooling tower water flowrate and by a weighted average emission factor. The emission factor was based on the assumption that 26 percent of the cooling towers would have VOC controls in effect.

F. Capital and Annual Control Costs

Inspection and maintenance of refinery process equipment is already performed in many refineries. Costs are for labor to inspect and repair equipment and maintenance materials. Costs credits are received for product recovery and improved process operations. Increased plant safety is an additional benefit. Costs for monitoring equipment to detect organic contamination in water range between $6,000 and $17,000.[5,6]

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2. Annual Refining Report, Oil and Gas Journal, Volume 82, Number 13, March 26, 1984.

3. Assessment of Atmospheric Emissions from Petroleum Refining: Volume 3. Appendix B, U.S. Environmental Protection Agency, EPA-600/ 2-80-075c, April 1980.

4. Assessment of Atmospheric Emissions from Petroleum Refining: Volume 1, Technical Report, U.S. Environmental Protection Agency, EPA-600/2-80-075a, April 1980.

5. Memorandum. Rhoads, T., Pacific Environmental Services, Inc., to S. Shedd, U.S. EPA, Derivation of Costs, Emissions, and Emission Reduction Presented in the VOC Control Techniques Document. November 1985.

6. Instrumentation for Pollution Control Engineering, 9:1, 20-22, January 1977.

4.1.5 Wastewater Systems

A. Process and Facility Description

Wastewater is generated by a variety of sources in a petroleum refinery including cooling water, condensed stripping steam, tank draw offs and stormwater runoff. Oily water is usually collected by a segregated oily wastewater collection system. Wastewater enters the collection system by way of process drains. Process drains are connected directly to sewer lines which eventually lead to the wastewater treatment system.

The wastewater treatment system usually includes primary, secondary, and tertiary treatment processes. Primary treatment removes free oil, solids and emulsified oil using such processes as oil-water separators and air flotation units. Secondary treatment removes dissolved organics and reduces BOD and COD. Tertiary treatment provides final polishing of the wastewater before discharge.

B. Emission Sources and Factors[1]

The primary emission sources in the refinery wastewater system are process drains, oil-water separators and air flotation units. Wastewater entering secondary treatment processes downstream of the air flotation unit is low in volatile organic content. Although sources such as oxidation ponds, clarifiers and holding ponds are generally large area sources, emissions per unit surface area are low.

A common process drain is a straight section of pipe usually 10 to 15 centimeters (4-6 inches) in diameter. The pipe extends vertically to slightly above grade and connects directly to a lateral sewer below grade. Drain lines from refinery process units generally terminate just within, at, or slightly above the open mouth of the process drain. There is often more than one drain line depositing wastewater into a single process drain. A medium-sized refinery might have as many as a thousand process drains.

As part of a study to develop emission factors for fugitive sources in petroleum refineries, VOC emission measurements were made on process drains. The emission factor developed for refinery process drains is 0.032 kilograms VOC per hour per drain.

Oil-water separators are usually rectangular concrete basins in the ground. This type of separator is known as an API separator. Typical dimensions are 6 x 25 meters (20 x 80 feet) with a depth of 2.5 meters (8 feet). Free oil, having a specific gravity less than water, rises to the surface where it is skimmed at the downstream end of the separator. The recovered oil is then sent back to the refining process. Emissions from an uncovered separator are primarily affected by the wastewater temperature, ambient temperature, oil volatility, and the volume and oil content of wastewater. A relationship between percent loss of oil in the separator and the ambient temperature, influent wastewater temperature, and the 10 percent boiling point of the influent oil was developed from results of tests conducted by Litchfield. Typical wastewater conditions were used to estimate an emission factor of 420 kilograms VOC per million gallons of wastewater treated in an uncontrolled oil-water separator.

Dissolved air flotation uses dissolved gas to form bubbles in the wastewater. These bubbles become attached to suspended solids and emulsified oil in the wastewater and causes these substances to rise to the surface of the flotation chamber where they are removed. The emission factor for uncovered air flotation units is 15.2 kilograms VOC per million gallons of wastewater. This emission factor was developed from results of continuous monitoring of VOC from four air flotation units.

C. Control Techniques and Emission Reductions[1]

The control technique for reducing emissions from process drains involves the use of a water seal. One type of water seal is the P-leg water seal which is identical to the P-trap common to household kitchen sinks. The water in the P-leg isolates the sewer line from the atmosphere. The control efficiency of the water seal is estimated to be 50 percent.

Control technology for an oil-water separator is a fixed roof with vapors vented to a control device (e.g., flares) or a floating roof with a perimeter seal system (similar to an external floating roof tank). These control techniques can achieve an emissions reduction of approximately 97 percent.

Reasonable control technology for dissolved air flotation units is the installation of a well sealed fixed roof. The control efficiency is estimated to be 77 percent.

D. Regulatory Status

The EPA issued a CTG in 1977 recommending fixed roofs be installed on oil-water separators.[2] Approximately 85 percent of existing separators are equipped with some type of cover.

New source performance standards were proposed in 1986 (40 CFR, Part 60, Subpart QQQ) for controlling VOC emissions from process drains, oil-water separators and air flotation units. The proposed NSPS was an equipment standard requiring water seals on drains, fixed roofs with vapor collection on oil-water separators and fixed roofs on air flotation units.

E. National Emission Estimates

Emissions estimates for 1984 are 47.4 gigagrams per year (Gg/yr) from process drains, 7.5 Gg/yr from oil-water separators, and 0.6 Gg/yr from air flotation systems.[1]

F. Capital and Annual Control Costs

For a process unit of medium complexity (e.g., alkylation unit) having 44 drains, the total depreciable investment (TDI) for P-leg water seals is $10,700. Annual operating costs and capital charges are estimated to be $2,600.

For a 100 m^2 oil-water separator, the TDI for a fixed roof and vapor collection system is estimated to be $49,700. Annual costs are $27,400. The TDI for a floating roof with a double seal system is approximately $81,200. The annual costs are estimated to be $19,600.[3]

For a 70 m^2 dissolved air flotation unit, the TDI for a fixed roof is estimated to be $15,300 and the annual costs are approximately $3,800.

G. References

1. VOC Emissions from Petroleum Refinery Wastewater Systems - Background Information for Proposed Standards. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1984.

2. Control of Refinery Vacuum Producing Systems, Wastewater Separators and Process Unit Turnarounds - Guideline Series. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA 450/2-77-025, October 1977.

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4.2 PETROLEUM PRODUCTS - STORAGE, TRANSPORTATION, AND MARKETING

4.2.1 Oil and Gas Production Fields

A. Process and Facility Description

There are three basic operations involved in producing and processing crude oil and natural gas. The operations are (1) well drilling, (2) oil and gas separation, and (3) natural gas processing. Drilling is necessary to produce the crude oil and gas. The well-head gas/oil/water mixture is separated into crude oil for sale and transfer to pipeline companies, natural gas for sale and transfer to pipelines, and water for disposal/reinjection. Crude oil is stored at tank batteries prior to lease custody transfer. Natural gas may be processed to remove H_2S and CO_2 if necessary and processed to remove natural gas liquids if desired. Natural gas liquids removal is discussed in Section 4.2.2.

B. Emission Sources and Factors

Emissions from drilling operations occur when drilling muds are degassed. Drilling mud is pumped from a suction tank or mud pit to the drill string. The mud is returned to a shale shaker for cuttings removal, and finally to a settling pit and temporary storage in a sump pit. Some formation gases entrained in the mud will be emitted to the atmosphere in the shale shakers and mud pits, but most of the gas will be extracted by a degasser prior to reinjection. The average VOC emission rate per day per producing well being drilled ranges from 2.7 Kg/day (5.9 lb/day) for Alabama to 8.2 Kg/day (18.0 lb/day) for Colorado. The equation describing the VOC emissions (E, Kg per day) occurring during the drilling of an oil or gas well is as follows:[1]

$$E = VZPD + LT + MH$$

where:

E = VOC emissions, (Kg/day)

V = Volume of hole drilled, (M^3)

Z = Producing zone depth/well depth, (fraction)

P = Porosity of producing zone cutters, (fraction)

D = Density of oil/gas in producing zone, (Kg/m^3)

L = Leakage of oil/gas into drilling mud, (Kg/day)

T = Avg. producing zone exposed time, (day)

M = Oil-base mud emission, (Kg/day)

H = Avg. hole drilling time, (days)

Emission sources from the separation process or tank battery include storage tanks and equiment leaks. Production storage tanks commonly have a fixed roof and are of either bolted or welded construction. New tanks are primarily shop fabricated and of welded construction. VOC emissions from tank battery tanks are estimated to be approximately 1 Mg/yr/tank (1.1 tons/yr/tank).[2] Equations for estimating storage tank emissions are provided in EPA's publication AP-42. Major assumptions for emissions estimate are as follow: stored product is crude oil; tank volume (20,000 gallon); number of turnovers (36/yr); vapor pressure @ storage temperature (2.8 psia); tank diameter (15.5 ft); tank height (15 ft); and molecular weight (50 lb/lb mole). This estimate may overstate VOC emissions because the methane/ethane content of the gas vapors is not subtracted from the estimate.

Emissions of VOC from tank batteries can result when process fluids (either gaseous or liquid) leak from plant equipment. Potential leaking equipment includes: pumps, compressors, valves, pressure relief devices, open-ended lines and flanges, and other connectors. Emissions of VOC from a tank battery equipment in the absence of regulatory controls would be approximately 0.6 Mg/yr (0.66 tons/yr).[3] Emissions from equipment leaks are discussed in the background information document for the proposed NSPS[4] and the CTG[5] document for gas plant equipment leaks.

C. Control Techniques and Emission Reductions

Emissions from fixed roof tanks can be controlled by the installation of an internal floating roof and seals or by using a vapor recovery system. The control efficiency of internal floating roof systems ranges from 60 to 99 percent, depending on the type of roof and seals installed and on the type of organic liquid stored. Internal floating roof systems are not effective on bolted storage tanks because tank bolts affect the seals.

Several vapor recovery procedures may be used, including vapor/liquid absorption, vapor compression, vapor cooling, vapor/solid adsorption, or a combination of these. The overall control efficiencies of vapor recovery systems are as high as 90 to 98 percent.

Thermal oxidation or flaring is another method of emission control for fixed roof tanks; control efficiencies for this system can range from 96 to 99 percent.

Two approaches are available to control tank battery equipment leaks of VOC: (1) a leak detection and repair program and (2) the installation of specific controls or leakless equipment. The emission reduction efficiency of leak detection and repair programs is dependent upon a number of factors including: (1) the monitoring method (visual, instrument, or soap solution); (2) leak definition; (3) frequency of inspections; (4) the time interval allowed between leak detection and subsequent leak repair; and (5) the emission reduction achieved by each successful repair. Leak detection and repair programs may achieve control efficiencies up to 60 and 80 percent for pumps and valves, respectively, under a monthly monitoring program. Control equipment can achieve control efficiencies approaching 100 percent. Examples of control equipment include: (1) venting emissions from pressure relief devices, pumps, and compressors to a control device (e.g., flare or process heater); (2) dual mechanical seals with barrier fluid systems for pumps and compressors; (3) caps, plugs, or second valves or open-ended lines; and (4) sealed bellows valves.

D. Regulatory Status

There are no EPA regulations or guidelines which address VOC emissions from drilling operations or tank battery storage tanks and equipment leaks.

E. Current National Emission Estimates

Annual VOC emissions from tank battery storage and equipment leaks are estimated at approximately 175,000[2] and 51,000 megagrams per year in 1984, respectively. Tank battery storage estimate is based on a tank battery population of 84,000 with two tanks per tank battery.

F. Capital and Annual Control Costs[6]

For a new 20,000 gallon capacity storage tank, capital costs for an internal floating roof tank are estimated at approximately $7,800 (in 1984 dollars); deck and seal costs are $6,300 and $1,500, respectively. Annual operating costs and capital charges are estimated at approximately $1,760; a 20- and 10-year life were estimated for the deck and seal, respectively. A net annual savings of $200 for crude oil recovery would be realized; thus, reducing annual costs to $1,560.

G. References

1. Assessment of Oil Production VOC Sources, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/2-81-197 (NTIS #PB82108-176). 1982.

2. Memo from David Markwordt to File: Oil and Production Fields, March 1, 1985.

3. Source Category Survey Report, Onshore Production, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. March 19, 1980. Docket A-80-20-A II-A-13. p. 4-11.

4. Equipment Leaks of VOC in Natural Gas Production Industry - Background Information for Proposed Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/3-82-024a. December 1983.

5. Guideline Series - Control of Volatile Organic Compound Equipment Leaks from Natural Gas/Gasoline Processing Plants, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/3-83-007. December 1983.

6. Memo from David Markwordt to File: Oil and Production Fields, March 1, 1985.

4.2.2 Natural Gas and Natural Gasoline Processing Plants

A. Process and Facility Description

Natural gas and natural gasoline processing plants (gas plants) are facilities engaged in the separation of natural gas liquids from field gas, the fractionation of liquids into natural gas products (i.e., gasoline), or other operations associated with the processing of natural gas products. There are approximately 880 gas plants operating in the United States (as of January 1, 1984), with a total gas capacity of 1,970 Mm^3 (68,943.0 MMcfd) and throughput of 1,074 Mm^3 (37,576.8 MMcfd).[1]

B. Emission Sources and Factors

Emissions of VOC from gas plants can result when process fluids (either gaseous or liquid) leak from plant equipment. Potential leaking equipment include: pumps, compressors, valves, pressure relief devices, open-ended lines and flanges, and other connectors. Emission factors for process equipment have been developed based on the results of several source testing studies. Emissions from gas plant processing units can be estimated by multiplying emissions for specific types of equipment by the number of equipment pieces in the processing units. Equipment emission factors are presented in Table 4.2.2-1. Emissions of VOC from gas plants in the absence of regulatory controls may range from 30 to 300 Mg/yr (33 to 330 ton/yr).[2] Emissions from gas plant equipment leaks are discussed in the background information documents for the proposed and promulgated NSPS[3,4] and the CTG document for gas plant equipment leaks.[5]

C. Control Techniques and Emission Reductions

Two approaches are available to control gas plant equipment leaks of VOC: (1) a leak detection and repair program and (2) the installation of specific controls or leakless equipment. The emission reduction efficiency of leak detection and repair programs is dependent upon a number of factors including: (1) the monitoring method (visual, instrument, or soap solution); (2) leak definition; (3) frequency of inspections; (4) the time interval allowed between leak detection and subsequent leak repair; and (5) the emission reduction achieved by each successful repair. Leak detection and repair programs may achieve control efficiencies are presented in Table 4.2.2-1 for quarterly

and monthly monitoring programs.[3] Control equipment can achieve control efficiencies approaching 100 percent. Examples of control equipment include: (1) venting emissions from pressure relief devices, pumps, and compressors to a control device (e.g., flare or process heater); (2) dual mechanical seals with barrier fluid systems for pumps and compressors; (3) caps, plugs, or second valves on open-ended lines; and (4) sealed bellows valves.

TABLE 4.2.2-1 EMISSION FACTORS AND CONTROL EFFECTIVENESS[a]

Equipment Type/Service	Average Emission Factor kg/hr	Control Emission Reductions			
		Quarterly Monitoring		Monthly Monitoring	
		Emission Factor, Kg/hr	Percent Reduction	Emission Factor, Kg/hr	Percent Reduction
Valves	0.18	0.041	77	0.029	84
Relief Valves	0.33	0.12	63	0.10	70
Compressor Seals	1.0	0.18	82	-	-
Pump Seals	1.2	0.50	58	0.42	65

[a]Reference 3.

D. Regulatory Status

The EPA issued a CTG in February 1984 and set NSPS on June 24, 1985 (49 FR 26122), to control equipment leaks of VOC in gas plants. The CTG recommends quarterly leak detection and repair for pumps, valves, pressure relief devices, and compressors in gas/vapor or light liquid service. Pumps also would receive weekly visual inspections. The CTG recommends that caps be installed on open-ended lines. The NSPS requires monthly monitoring of valves and pumps and quarterly monitoring of pressure relief devices. The NSPS allows quarterly monitoring for valves not found leaking for 2 successive months. Compressors in natural gas liquids service would be equipped with seals having a barrier fluid system that prevents leakage of the process fluids to the atmosphere and caps are required for open-ended lines. An estimated 120 gas plants (14 percent) have implemented the controls recommended by the CTG as required under State or local regulations.

E. Current National Emission Estimates

Annual VOC emissions from gas plant equipment leaks has been estimated at 76,000 megagrams (84,000 tons) per year in 1984. The nationwide emissions estimate was derived by multiplying the total estimated number of gas plant process units by process unit emission estimates. The nationwide emission estimate assumes that 14 percent of the gas plants are in non-attainment areas.[6]

F. Capital and Annual Control Costs

Capital and annual costs for controlling gas plant equipment leaks are presented in Table 4.2.2- 2 for a small and large process unit. These costs are estimated based on control costs for individual types of equipment multiplied by the number of each type of equipment in the process unit. The costs presented include expenditures incurred for monitoring instruments.[6]

TABLE 4.2.2-2 CAPITAL AND ANNUAL COSTS TO CONTROL GAS PLANT EQUIPMENT LEAKS[a]

Costs ($1,000)	Capital Cost CTG	Capital Cost NSPS	Annual Cost CTG	Annual Cost NSPS
Unit Size:				
Small	15	24	5.4	8.5
Large	50	71	(9.0)	9.6

Parentheses denote cost savings.
[a]Reference 6.

G. References

1. Worldwide Gas Processing, Oil and Gas Journal, Volume 82, No. 29, July 16, 1984, p. 80.

2. Memorandum, T.L. Norwood, Pacific Environmental Services, Inc., to Docket A-80-20(B), Nationwide Emission Reductions and Costs of the Promulgated NSPS for Gas Plants (ESED Project Number 80/22), January 2, 1984.

3. Equipment Leaks of VOC in Natural Gas Production Industry Background Information for Proposed Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/ 3-82-024a. December 1983.

4. Equipment Leaks of VOC in Natural Gas Production Industry Background Information for Promulgated Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/ 3-82-0246. May 1985.

5. Guideline Series - Control of Volatile Organic Compound Equipment Leaks from Natural Gas/Gasoline Processing Plants, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/3-83-007. December 1983.

6. Memorandum. Rhoads, T., Pacific Environmental Services, Inc., to S. Shedd, U.S. EPA, Derivation of Cost, Emissions, and Emission Reductions Presented in the VOC Control Techniques Document. November 1985.

4.2.3 Petroleum Liquid Storage Tanks

A. Process and Facility Description

Organic liquids in the petroleum industry (petroleum liquids) are mixtures of chemicals having dissimilar true vapor pressures (for example, gasoline and crude oil). Petroleum liquids are stored in tanks having any one of three basic tank designs: fixed-roof, internal floating-roof, and external floating-roof. It is estimated that in 1983 there were a total of 44,300 petroleum storage tanks nationwide (with capacities greater than 40,000 gallons).[1]

A typical fixed-roof tank consists of a cylindrical steel shell with a permanently affixed roof. An internal floating-roof tank has both a permanently affixed roof and a cover that floats on the liquid surface (contact roof), or that rests on pontoons several inches above the liquid surface (noncontact roof), inside the tank. This roof rises and falls with the liquid level. The floating roof commonly incorporates flexible perimeter seals or wipers which slide against the tank wall as the roof moves up and down. An external floating-roof tank consists of a cylindrical steel shell equipped with a deck or roof which floats on the surface of the stored liquid, rising and falling with the liquid level. A seal (or seal system) attached to the roof, contacts the tank wall to cover the small annular space between the roof and the tank wall and slides against the tank wall as the roof is raised or lowered.

B. Emission Sources and Factors

Two types of emissions from fixed-roof tanks are breathing losses and working losses. The expansion of vapors in the tank due to changes in ambient temperature and pressure result in VOC emissions termed "breathing losses." Additional VOC emissions termed "working losses" result from vapors emitted from a tank as a result of filling and emptying operations. The total annual VOC emissions from a fixed-roof storage tank would be the sum of the breathing and working losses. The total annual VOC emissions from a large diameter (30 meter) and a small diameter (10 meter) fixed-roof storage tank are presented in Table 4.2.3.1.[2]

The emission estimates presented throughout this section are calculated using current emission formulae as presented in the fourth edition of the EPA publication AP-42.[3] The emission factor equation for fixed-roof tank

TABLE 4.2.3.1. FIXED-ROOF TANK EMISSIONS AND EMISSION REDUCTIONS OBTAINED WITH AN INTERNAL FLOATING-ROOF[a]
(Gasoline at 10 psi RVP)

Capacity (m^3)	Diameter (m)	Turnovers	FRT Emissions (Mg/yr)	$IFRT_{lm}$ Emissions (Mg/yr)	Emission Reduction (Mg/yr)	Percent Reduction
1,000	10.0	10.0	13.49	1.14	12.35	91.6
1,000	10.0	20.0	23.37	1.14	22.23	95.1
10,000	30.0	5.0	77.76	4.49	73.27	94.2
10,000	30.0	10.0	127.18	4.50	122.68	96.5

[a]Reference 2.

Nomenclature explanation - FRT = Fixed-roof tank
$IFRT_{lm}$ = Internal floating-roof tank (with a liquid-mounted primary seal).

TABLE 4.2.3.2. EXTERNAL FLOATING-ROOF TANK EMISSIONS AND EMISSION REDUCTIONS OBTAINED WITH A SECONDARY SEAL OVER A MECHANICAL SHOE SEAL[a]
(Gasoline at 10 psi RVP)

Capacity (m^3)	Diameter (m)	Turnovers	$EFRT_{ms}$ Emissions (Mg/yr)	$EFRT_{ms,ss}$ Emissions (Mg/yr)	Emission Reduction (Mg/yr)	Percent Reduction
1,000	10.0	10.0	4.06	0.22	3.84	94.6
1,000	10.0	20.0	4.06	0.22	3.84	94.6
10,000	30.0	5.0	12.16	0.65	11.51	94.6
10,000	30.0	10.0	12.17	0.66	11.51	94.6

[a]Reference 2.

Nomenclature explanation - $EFRT_{ms}$ = External floating-roof tank (with a mechanical shoe primary seal) $EFRT_{ms,ss}$ = External floating-roof tank (with a mechanical shoe primary seal and a rim-mounted secondary seal).

breathing losses is based on test data collected by the Western Oil and Gas Association, the Environmental Protection Agency, and the German Society for Petroleum Science and Carbon Chemistry. A comparison was made between the new test data in these reports and the breathing losses calculated by using the 1977 version of the emission factor equation in AP-42. It was determined from this comparison that the emission factor equation for fixed-roof breathing losses tended to over-predict and was therefore scaled downward.[4] The American Petroleum Institute sponsored a program to develop additional laboratory, pilot tank and field tank data on evaporative losses from internal and external floating-roof tanks. The mechanisms of evaporative loss were investigated and the effects of relevant variables were quantified, which resulted in the formulation of the current AP-42 emission factor equations.[5,6]

External and internal floating-roof tanks have similar sources of VOC emissions, known as "standing storage losses" and "withdrawal losses". Standing storage losses or seal losses for both external and internal floating-roofs can be the result of an improper fit between the seal and the tank wall which causes some of the liquid surface to be exposed to the atmosphere. Internal floating-roof tanks can also have standing storage losses through the openings in the deck required for various types of fittings (fitting losses); and through the nonwelded seams formed when joining sections of the deck material (deck seam losses). Withdrawal loss is the vaporization of liquid that clings to the tank wall and is exposed to the atmosphere when a floating-roof is lowered by withdrawal of liquid. Thus the total annual VOC emissions from either an external floating-roof storage tank or an internal floating-roof storage tank would be the sum of the standing storage loss and the withdrawal loss.

The total annual VOC emissions from a large and a small diameter internal floating-roof storage tank, equipped with a liquid-mounted primary seal, a bolted deck and controlled fittings are shown in Table 4.2.3.1.[2] The total annual VOC emissions from a large and a small diameter external floating-roof storage tank, equipped with a mechanical shoe primary seal are shown in Table 4.2.3.2.[2]

C. Control Techniques and Emission Reductions

Several methods are available to control VOC emissions from fixed-roof tanks: (1) the installation of an internal floating-roof and seal system, (2) a vapor recovery system (e.g., refrigerated vent condensers, carbon adsorption), and (3) a vapor destruction system (thermal oxidation). The emission reduction and percentage reduction which may be obtained with an internal floating-roof tank over a fixed-roof tank are shown in Table 1. Generally an internal floating-roof installed on a fixed-roof tank will reduce VOC emissions by 93 to 97 percent.[7] A carbon adsorption vapor control system is estimated to reduce VOC emissions by approximately 98 percent.[8] A thermal oxidation vapor control system is estimated to reduce VOC emissions by approximately 98 percent.[9,10] Standing storage loss emissions from external and internal floating-roof tanks are controlled by one or two separate seals. The first seal is called the primary seal, and the other, mounted above the primary seal, is called the secondary seal. There are three basic types of primary seal: (1) mechanical (metallic shoe), (2) resilient (non-metallic, either vapor-mounted or liquid-mounted), and (3) flexible wiper. A primary seal serves as a conservation device by closing the annular space between the edge of the floating-roof and the tank wall. Two types of secondary seal are currently available, shoe-mounted and rim-mounted. A liquid-mounted primary seal has a lower emission rate and thus a higher control efficiency than a vapor-mounted seal. Metallic shoe seals are commonly employed only on external floating-roof tanks and are more effective than vapor-mounted seals, but less effective than liquid-mounted seals. A secondary seal, be it in conjunction with a liquid- or vapor-mounted primary seal, provides an additional level of control.[11] The emission reduction and percentage reduction which may be obtained with a rim-mounted secondary seal over a mechanical shoe primary seal in an external floating-roof tank are shown in Table 4.2.3.2.[2]

D. Regulatory Status

The EPA issued CTG's in 1977 and 1978 and set NSPS in 1974 (40 CFR 60 Subpart K) and revised the NSPS in 1980 (40 CFR 60 Subpart Ka) to control VOC emissions from storage of petroleum liquids. Also, the NSPS for volatile organic liquid storage tanks which was proposed in 1984 (40 CFR 60 Subpart

Kb) included control of VOC emissions from storage of petroleum liquids. The CTG is applicable to fixed-roof storage tanks having a capacity greater than 150,000 liters (40,000 gal) and storing petroleum liquids which have a true vapor pressure greater than 10.5 kPa (1.5 psia). The CTG recommendations are stated in terms of equipment specifications and maintenance requirements. The installation of internal floating-roofs inside fixed-roof tanks is recommended. The CTG also recommends the use of alternative control equipment of equivalent efficiency.

Subpart K of the NSPS applies to storage tanks with a capacity greater than 151,416 liters (40,000 gal) and less than or equal to 246,052 liters (65,000 gal) which were constructed or modified after March 8, 1974 and prior to May 19, 1978. Also, it applies to storage tanks with a capacity greater than 246,052 liters (65,000 gal) which were constructed or modified after June 11, 1973 and prior to May 19, 1978. Subpart K requires that a storage tank be equipped with a floating-roof, a vapor recovery system, or their equivalent if the petroleum liquid being stored has a true vapor pressure greater than or equal to 10.5 kPa (1.5 psia) but less than or equal to 76.6 kPa (11.1 psia). Also, a storage tank is required to have a vapor recovery system or its equivalent if the petroleum liquid being stored has a true vapor pressure greater than or equal to 76.6 kPa (11.1 psia).

Subpart Ka of the NSPS applies to storage tanks with a capacity greater than 151,416 liters (40,000 gal) which were constructed or modified after May 18, 1978 and prior to July 23, 1984. For storage tanks which contain a petroleum liquid having a true vapor pressure greater than or equal to 10.5 kPa (1.5 psia) but less than or equal to 76.6 kPa (11.1 psia), Subpart Ka requires the use of: (1) an external floating-roof with primary and secondary seals, (2) an internal floating-roof on a fixed-roof tank, (3) a vapor recovery system, or (4) an equivalent system. If the storage tank contains a petroleum liquid having a true vapor pressure greater than 76.6 kPa (11.1 psia), Subpart Ka requires the use of a vapor recovery system.

Subpart Kb applies to petroleum storage tanks which were constructed or modified after July 23, 1984. A detailed description of the requirements in Subpart Kb are presented in Section 4.3.2.

E. Current National Emission Estimates

Total annual VOC emissions from petroleum liquid storage tanks has been estimated at 667,902 Mg/yr (736,240 tons/yr) in 1983. This estimate is based on projected new external floating-roof tanks being equipped with a vapor-mounted primary seal and a rim-mounted secondary seal and projected new internal floating-roof tanks being equipped with typical uncontrolled fittings.[12]

F. Capital and Annual Control Costs

The capital and net annualized cost to install an internal floating-roof equipped with a liquid-mounted primary seal on a new fixed-roof tank for either a small or a large size tank is shown in Table 4.2.3.3.[2,7] The capital and net annualized cost to install a secondary seal on a new external floating-roof tank for either a small or a large size tank is shown in Table 4.2.3.4.[2,7]

G. References

1. Pacific Environmental Services, Inc. Estimated Nationwide Petroleum Storage Tank VOC Emissions for the Years 1983 and 1988. Report to TRW Environmental Engineering Division, Research Triangle Park, North Carolina. Contract No. M23399JL3M. April 5, 1983. p. 20.

2. Memorandum. Gschwandtner, K., Pacific Environmental Services, Inc., to S. Shedd, U.S. EPA. Derivation of Cost, Emissions and Emission Reductions presented in the VOC Control Techniques Document. January 1986.

3. Compilation of Air Pollutant Emission Factors - Fourth Edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. AP-42. September 1985.

4. Petroleum Liquid Storage Vessels - Revision of AP-42 - Background Document, EPA Contract No. 68-02-3063, TRW Environmental, Inc., Research Triangle Park, North Carolina, May 1981.

5. Evaporation Loss From Internal Floating-Roof Tanks, Third Edition, Bulletin No. 2519, American Petroleum Institute, Washington, D.C., 1983.

6. Evaporation Loss From External Floating-Roof Tanks, Second Edition, Bulletin No. 2517, American Petroleum Institute, Washington, D.C., 1980.

TABLE 4.2.3.3. CAPITAL AND ANNUALIZED COST FOR AN INTERNAL FLOATING-ROOF INSTALLED IN A NEW FIXED-ROOF TANK[a]
(second quarter 1984 dollars)

Capacity (m^3)	Diameter (m)	Turn-overs	Total Capital Cost ($/Tank)	Total Annualized Cost ($/year)	Net Annualized Cost[b] ($/year)
1,000	10.0	10.0	15,015	4,100	147
1,000	10.0	20.0	15,015	4,100	(3,014)[c]
10,000	30.0	5.0	43,129	11,776	(11,671)[c]
10,000	30.0	10.0	43,129	11,776	(27,480)[c]

[a]Reference 2.

[b]Based on a product recovery credit of $0.21/liter for gasoline.

[c]Net annualized savings.

TABLE 4.2.3.4. CAPITAL AND ANNUALIZED COST FOR A SECONDARY SEAL INSTALLED IN A NEW EXTERNAL FLOATING-ROOF TANK WITH A MECHANICAL SHOE SEAL[a]
(second quarter 1984 dollars)

Capacity (m^3)	Diameter (m)	Turn-overs	Total Capital Cost ($/Tank)	Total Annualized Cost ($/year)	Net Annualized Cost[b] ($/year)
1,000	10.0	10.0	2,724	744	(484)[c]
1,000	10.0	20.0	2,724	744	(484)[c]
10,000	30.0	5.0	8,171	2,231	(1,452)[c]
10,000	30.0	10.0	8,171	2,231	(1,452)[c]

[a]Reference 2.

[b]Based on a product recovery credit of $0.21/liter for gasoline.

[c]Net annualized savings.

7. VOC Emissions from Volatile Organic Liquid Storage Tanks - Background Information for Proposed Standards. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. EPA-450/3-81-003a. July 1984. pp. 4-9.

8. Letter from McLaughlin, Nancy D., U.S. Environmental Protection Agency to D. Ailor, TRW, Inc. Comments on the benzene storage model plants package. May 3, 1979.

9. Letter and attachments from D.C. Mascone, EPA/CPB, to J.R. Farmer, EPA. June 11, 1980. Memo concerning thermal incinerator performance for NSPS.

10. U.S. Environmental Protection Agency. Organic Chemical Manufacturing Volume 4: Combustion Control Devices. Research Triangle Park, North Carolina. Publication No. EPA-450/3-80-026. December 1980.

11. Reference 7, p. 4-15.

12. Reference 1, p. 3 and 12.

4.2.4 Ship and Barge Transfer of Gasoline and Crude Oil

A. Process and Facility Description

Motor gasoline produced at petroleum refineries is transferred primarily by pipeline, ship, or barge to intermediate storage and bulk terminals. Various grades of gasoline are dispensed from refineries into barges at dockside loading terminals. From barge loading terminals, gasoline is delivered to bulk terminals.

Crude oil is imported to the contiguous 48 states via tanker and pumped to shoreside storage facilities. The crude oil is then transferred by pipeline or barge to refineries for processing.

B. Emission Sources and Factors[1]

Emissions from tanker and barge loading operations occur when gasoline or crude oil being loaded displaces the vapors in the vessel to the atmosphere. Loading is performed by connecting shoreside lines to the vessel header system; a loading arm is used to attach the flanged delivery lines to the vessel. Both tankers and barges have more than one tank to receive liquids; there is a vapor vent on each tank. During loading, ullage caps are opened for gauging to relieve vapors which simply are emitted to the atmosphere.

Emissions from tanker unloading operations occur when ballast being loaded displaces vapors in cargo tanks previously unloaded. Barges are not ballasted.

Emission rates for gasoline and crude loading and crude oil ballast emissions are summarized below:

	Loading		Ballast	
	(mg/l)	(lb/10^3 gal)	(mg/l)	(lb/10^3 gal)
	transferred		ballast water	
Barge				
Crude Oil	120	1.0	NA	NA
Gasoline	410	3.4	NA	NA
Tanker				
Crude Oil	73	0.61	129	1.1
Gasoline	215	1.8	100	0.8

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C. Control Techniques and Emission Reductions

Control techniques utilized to minimize emissions during tanker ballasting operations include: (1) segregated ballast and (2) simultaneous unloading and ballasting. Segregated ballast completely eliminates emissions because VOC vapors are not present in space dedicated to ballast. Simultaneous unloading and ballasting reduces emissions at port by displacing ballast emissions into the cargo space being unloaded.

Potential control techniques for barge loading operations include refrigeration, carbon adsorption, thermal oxidation, and flaring. Displaced vapors are vented directly to the control device. The control system requires a vapor collection header onboard the barge. Hatches must be closed during loading operations to maximize vapor collection. Assuming that the loading and collection system is vapor tight, the emission reduction using a thermal oxidizer or flare will be 98 and 90 percent, respectively. However, leakage may occur resulting in less than 100 percent capture. Based on gasoline terminal tests, the lowest leakage rate obtained was approximately 10 percent of the vapors, by requiring annual pressure tests and necessary maintenance; without test requirements the average vapor leakage loss was approximately 30 percent. Therefore, total emission reduction from loading operations could range from 88 to 68 percent for thermal oxidizers and from 81 to 63 percent for flares.

Safety issues associated with tanker and barge control are not discussed in this document.

D. Regulatory Status

There are no EPA regulations or guidelines which address tanker and barge loading and ballasting operations.

E. National Emission Estimates

National emission estimates in 1982 are estimated at approximately 60,000 metric tons (66,000 tons) of VOC from gasoline and crude petroleum barge loading operations and approximately 11,000 metric tons (12,000 tons) of VOC from crude petroleum and gasoline ballasting operations. National estimates are based on the volume of crude oil and gasoline transferred in 1982 as reported in the "Waterborne Commerce of the United States." Calendar Year 1982. DoA Corps of Engineers, WRSC-WCUS - 82-5. Ballast water was assumed to be 20 percent of tanker crude oil and gasoline unloaded.

F. Captial and Annual Control Costs

Capital and annual control costs are not available.

G. References

1. Compilation of Air Pollutant Emission Factors. Volume 1. Stationary Point and Area Sources. AP-42 Fourth Edition, September 1985. pp. 4.4-1 to 4.4-15.

2. Memo from David Markwordt, EPA, ESED, to Ship and Barge File. "Section 4.2.4 Ship and barge Transfer of Gasoline and Crude Oil." February 28, 1986.

4.2.5 BULK GASOLINE TERMINALS

A. Process and Facility Description

Motor gasoline produced at petroleum refineries is transferred primarily by pipeline, ship, or barge to intermediate storage at bulk gasoline terminals. Various grades of gasoline are dispensed through loading racks into tank trucks at bulk gasoline terminals. From terminals, the gasoline is delivered to bulk plants or to commercial or retail accounts (service stations). It is estimated that there were approximately 1,500 tank truck gasoline loading terminals in the United States in 1982.[1]

B. Emission Sources and Factors

Emissions from tank truck loading operations occur when gasoline being loaded displaces the vapors in the tank truck and forces the vapors to the atmosphere. The amount of transfer emissions are dependent on the vapor pressure of the product, product and tank temperature, condition of the tank, tank leakage, and loading method. Loading may be performed using either top splash or submerged loading methods, resulting in emissions at typical rates of 1,940 and 800 milligrams of VOC per liter (mg/l) of product loaded (or 16 and 6.7 lb/10^3 gal.), respectively (Reference 2 and assuming national average 12.6 RVP gasoline). Tank trucks returning with vapor, displaced from storage tanks at service stations or bulk plants which have installed vapor balance equipment, produce higher emission rates (1,335 mg/l or 11 lb/10^3 gal). Leaks from loading equipment, vapor collection equipment and tank trucks are also an emission source. The average VOC loss due to leakage from vapor collection equipment on gasoline tank trucks was found during emission tests to be 30 percent (ranges from 0 to 100 percent). Emissions from bulk terminal storage tanks are discussed and covered under the Petroleum Liquid Storage section of this Chapter.

C. Control Techniques and Emission Reductions

Control technology utilized to minimize emissions during tank truck loading includes: (1) switching from top loading to submerged loading, and (2) collecting displaced vapors, and routing the vapors to a vapor

- thermal oxidizers, refrigeration, and carbon adsorbers - can reduce these emissions to better than 35 mg/l.[3] A good maintenance and annual testing program can reduce leakage from vapor collection equipment on tanks trucks to 10 percent.[3]

D. Regulatory Status

The EPA issued a CTG in 1977 and set NSPS standards in 1983 (40 CFR 60 Subpart XX) to control emissions during tank truck loading at gasoline terminals.[4] The CTG recommends and the NSPS requires emissions from tank truck loading operations to be limited to 80 and 35 mg/l, respectively. In addition, the NSPS requires annual testing of tank trucks for leaks. There is also a CTG for tank trucks which recommends the same leak testing program.[5] Roughly two-thirds of the bulk gasoline terminals in 1982 are estimated to have installed vapor processors (required under State regulations).[6] The EPA is reviewing the need to regulate benzene and gasoline vapor emissions from all bulk gasoline terminals under Section 112 (see 49 FR 31706).

E. Current National Emission Estimates

The loading of tank trucks at bulk gasoline terminals has been estimated to emit 142,000 meagrams of VOC in 1983 based on 1982 control levels.

F. Capital and Annual Control Costs[6]

For a typical 950,000 liter per day throughput terminal, capital cost for installing a carbon adsorber and vapor collection equipment is estimated to be $324,000 (in 1982 dollars). Annual operating costs and capital charges are estimated to be $93,000. A net annual savings of $70,000 for gasoline recovery would be realized; thus, reducing the annual costs to $23,000.

G. References

1. National Petroleum News, 1983 Factbook Issue, Mid-June 1983, Volume 75, No. 7A.

2. Transportation and Marketing of Petroleum Liquids. In: Compliation of Air Pollution Emission Factors, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, July 1979.

G. References

1. National Petroleum News, 1983 Factbook Issue, Mid-June 1983, Volume 75, No. 7A.

2. Transportation and Marketing of Petroleum Liquids. In: Compliation of Air Pollution Emission Factors, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, July 1979.

3. Bulk Gasoline Terminals - Background Information for Proposed Standards -- and Promulgated Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA 450/3-80-038a and b. December 1980 and August 1983.

4. Guidelines Series: Control of Hydrocarbons from Tank Truck Gasoline Loading Terminals, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA 450/2-77-026, October 1977.

5. Control of Volatile Organic Compound Leaks from Gasoline Tank Trucks and Vapor Collection Systems, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-78-051, December 1978.

6. Evaluation of Regulatory Strategies for Gasoline Marketing Industry, U. S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., EPA 450/3-84-012a, July 1984. [This document is under public review and is subject to change. A revised document is scheduled to be released by the end of 1986.]

7. Preliminary information on reanalysis of analyses in Reference 6.

4.2.6 BULK GASOLINE PLANTS

A. Process and Facility Description

Motor gasoline is transferred by truck from bulk terminals to intermediate storage facilities, known as bulk gasoline plants or delivered directly to service stations. The gasoline delivered to bulk plants is again transferred into tank trucks and delivered to service stations and private accounts, such as farmers. The trend in recent years has been toward reducing the amount of gasoline passed through bulk plants. Approximately 25 percent of national gasoline consumption is passed through an estimated 15,000 bulk gasoline plants.[1,2]

B. Emission Sources and Factors[2,3]

Emissions from bulk plants occur when gasoline being loaded displaces the vapors displaced in the tank truck or storage tank and forces the vapors to the atmosphere (commonly called "working losses"). Emission factors for loading of tank trucks at bulk plants are the same as discussed previously for bulk terminals.

Temperature induced pressure differentials can expel vapor-laden air or induce fresh air into storage tanks (breathing losses) and result in an emission rate of roughly 228 mg/l (1.9 lb/10^3 gal.). Liquid transfers in and out of storage tanks create loading and draining losses which combined are called "working losses." Storage tank working losses result in emission rates of roughly 1,640 mg/l (13.7 lb/10^3 gal.)

C. Control Techniques and Emission Reductions

Control technology utilized to minimize emissions during tank truck and storage tank loading at bulk plants includes: (1) switching from top splash loading to submerged loading, (2) collecting displaced vapors from the loading of storage tanks and balancing the vapors back to the truck being unloaded, and (3) collecting displaced vapors from trucks being loaded and balancing the vapors back to the bulk plant's storage tank. Converting the loading equipment from top splash to submerged loading will reduce emissions by approximately 60 percent. Vapor balancing tank truck and storage tank transfers can reduce working loss emissions by 90 to 95 percent.[2] A good maintenance and annual testing program can reduce leakage from vapor collection equipment on tank trucks to 10 percent.

D. Regulatory Status

The EPA issued CTGs in 1977 and 1978 to control emissions from bulk plants and leakage from gasoline tank trucks and vapor collection systems, respectively.[4,5] The bulk plant CTG recommends installation of balance equipment for incoming and outgoing tank truck transfers. However, it does address that plants below 15,000 liters (about 4,000 gallons) per day of gasoline throughput may not be cost-effective in some situations.

Roughly 45 percent of the bulk plants in 1982 are estimated to have installed vapor balance systems on both the incoming and outgoing truck transfers (required under State and local regulations).[2] An additional 4 percent of the bulk plants have been estimated to have installed vapor balancing of only incoming truck transfers. Both of the above CTG's recommended checking for leakage from vapor piping and tank trucks with a combustible gas detector. Additionally, the tank truck CTG recommends an annual maintenance and pressure-vacuum testing program to reduce leakage from vapor collection equipment on gasoline tank trucks. The EPA is currently reviewing the need to regulate benzene and gasoline vapor emissions from all bulk plants under Section 112 of the Clean Air Act (see 49 FR 31706).

E. Current National Emission Estimates[3]

Emissions from truck loading and unloading operations, and storage tanks at bulk plants have been estimated to emit 180,000 megagrams (198,000 tons) of VOC in 1984 based on 1982 control levels.

F. Capital and Annual Control Costs [2]

For a typical 24,600 liter (6,500 gallons) per day throughput bulk plant, capital costs for installing vapor balance equipment on both the incoming and outgoing truck transfers are estimated to average about $28,540. Annual operating costs and capital charges are estimated to be $5,750. A net annual savings of $2,540 for gasoline recovery would be realized; thus reducing the annual costs to $3,210. Control costs vary due to the size and layout of the facility. For more information on cost varibility, References 2 and 4 should be consulted.

G. References

1. National Petroleum News, 1983 Factbook Issue, Mid-June 1983, Volume 75, No. 7A.

2. Evaluation of Regulatory Strategies for Gasoline Marketing Industry, U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., EPA 450/3-84-012a, July 1984. [This document is under public review and is subject to change. A revised document is scheduled to be released by the end of 1986.]

3. Preliminary information on reanalysis of Reference 2.

4. Guideline Series: Control of Volatile Organic Emissions from Bulk Gasoline Plants, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, N.C., EPA-450/2-77-035, December 1977.

5. Control of Volatile Organic Compound Leaks from Gasoline Tank Trucks and Vapor Collection Systems, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-450/2-78-051, December 1978.

4.2.7 SERVICE STATION STORAGE TANKS (STAGE I)

A. Process and Facility Description

Motor gasoline is transferred by truck from bulk storage facilities (bulk terminals or plants) to retail, public or private service stations. Various grades of gasoline are unloaded, usually by gravity, from tank trucks to underground storage tanks. The gasoline is again dispensed through pumps into gas tanks on vehicles. Vehicle refueling operations are discussed in the next section. It is estimated that there were approximately 421,000 service stations (not including an estimated 2.5 million agricultural outlets) in the U.S. in 1982.[1]

B. Emission Sources and Factors[1,2]

Two types of emissions occur from service station storage tanks breathing and working losses. Working losses occur when gasoline being unloaded from the tank truck displaces vapors in the storage tank (loading losses) and when fresh air is brought into the storage tank when small amounts of gasoline is pumped out of the storage tank (emptying losses). Later, this volume of fresh air becomes saturated with vapor (thus increasing in volume) and the additional vapor volume is expelled to the atmosphere through the storage tank vents. As discussed in the previous section on bulk terminals, many parameters influence the amount of losses and those emission factors discussed in the next few sentences are "typical" factors. Loading may be performed using either top splash or submerged loading methods, resulting in emissions (loading losses) of 1,690 or 1075 milligrams (14 or

9 lb/10^3 gal.) of VOC per liter (mg/l) of product loaded, respectively. Emptying losses are estimated to be roughly 120 mg/l (1 lb/10^3 gallons). Breathing losses occurring from temperature changes in the storage tank have not been quantified, but are believed to be insignificant since temperature fluctuations in underground tanks are small.

C. Control Techniques and Emission Reductions[1]

Control technology utilized to minimize emissions resulting from storage tank working losses include: (1) switching from top splash loading to submerged loading, and, (2) vapor balancing vapors displaced vapors from the storage tanks back into the truck tank delivering the gasoline. Converting loading equipment from top splash to submerged loading, by extending the length of the fill pipe, can reduce loading losses by approximately 60 percent. Installing piping and fittings for vapor balancing equipment can reduce emissions by 95 percent. Since the vapor balance system works on slight pressure in the storage tank and slight vacuum in the truck tank, all tanks and piping must be leak free or little emission reduction will be achieved. Although the emission leak rates have not been quantified, routine checking leaks with a combustible gas detector and annual tank truck vacuum testing is necessary.

D. Regulatory Status

The EPA issued a guidance paper in 1975 to control emissions from service station storage tanks.[3] This guidance paper recommends design parameters and equipment specifications for vapor balance equipment. In addition, EPA issued a CTG in 1978 to provide test procedures for tank trucks and vapor piping.[4] Roughly one-half of the service stations in 1982 are estimated to have installed storage tank vapor balance systems (required under State and local regulations).[1] The EPA is currently reviewing the need to regulate benzene and gasoline vapor emissions from all service stations under Section 112 of the Clean Air Act (see 49 FR 31706).

E. Current National Emission Estimates[2]

Emissions from storage tanks at service stations has been estimated to emit 256,000 megagrams (282,000 tons) of VOC in 1984 based on the 1982 control levels discussed above.

F. Capital and Annual Control Costs[1]

For a typical service station, capital costs for installing vapor balance equipment is estimated to be $1,698. Annual operating costs and capital charges are estimated to be $342. Unlike other gasoline marketing controls, no liquid recovery credit is assumed since recovered vapors are displaced back to the tank truck which returns the vapors to a bulk plant or bulk terminal.

G. References

1. Evaluation of Regulatory Strategies for Gasoline Marketing Industry, U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., EPA/3-84-012a, July 1984. [This document is under public review and is subject to change. A revised document is scheduled to be released by the end of 1986.]

2. Preliminary information on reanalysis of Reference 1 analysis.

3. "Design Criteria for Stage I Vapor Control Systems, Gasoline Service Stations," U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, November 1975.

4. Control of Volatile Organic Compound Leaks from Gasoline Tank Trucks and Vapor Collection Systems, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-450/2-78-051, December 1978.

4.2.8 VEHICLE REFUELING AT SERVICE STATIONS[1,2] (Stage II)

A. Process and Facility Description

Motor gasoline is transferred by truck from bulk storage facilities (bulk terminals or plants) to retail, public and private service stations. Various grades of gasoline are unloaded from tank trucks into underground storage tanks at service stations. (See previous section on service station storage tanks.) The gasoline is again dispensed through pumps and meters into gas tanks on vehicles (cars and trucks). It is estimated that there were approximately 421,000 service stations (not including an estimated 2.5 million agricultural outlets) in the U.S. in 1982.

B. Emission Sources and Factors

Emissions from vehicle refueling operations occur when gasoline being pumped into the vehicle gas tank displaces the vapors in the vehicle gas tank to the atmosphere by way of the open fill neck. Recent EPA testing has shown that refueling of a "typical" vehicle results in VOC emission rates of 1,552 milligrams per liter (mg/l) (12.9 lb/10^3 gallons) of gasoline transferred. Other EPA testing in the 1970's has shown that spillage of gasoline on the ground, side of vehicle, etc., accounts for VOC emissions of roughly 84 mg/l (0.7 lb/10^3 gal) transferred.

C. Control Techniques and Emission Reductions

Vehicle refueling emissions can be controlled by: (1) equipment installed at the service station which transfers the displaced vapors from the motor vehicle gas tank back to the underground storage tank (termed "Stage II Controls"), or (2) carbon canisters and a fill-pipe seal installed on the motor vehicle whereby the displaced vapors are adsorbed by the vehicles carbon canister as the gas tank is filled with gasoline (termed "onboard controls"). Both Stage II and onboard controls can be highly effective (as high as 95 and 98 percent, respectively). However, their high theoretical efficiencies are likely to be reduced during use (to as low as 62 percent for Stage II, depending on the level of enforcement, and to about 95 percent for onboard controls, given the expected level of tampering).

D. Regulatory Status

Stage II controls in 1984 are being used in 26 counties in California and the District of Columbia (required by local and State regulations), and are being considered for use by at least seven states. It is estimated that the installed Stage II controls control 9 percent of the national gasoline consumption. The EPA is currently reviewing the need for refueling controls in ozone nonattainment areas and the need to regulate benzene and gasoline vapor emissions from all vehicle refueling service stations under Section 112 and 202(a)(6) of the Clean Air Act (see 49 FR 31706). As part of the above review, EPA is reviewing which refueling control approach--Stage II or onboard controls--is the preferred control technology.

E. Current National Emission Estimates

Vehicle refueling at service stations has been estimated to emit 569,000 megagrams (627,000 tons) of VOC in 1984 based on 1982 control levels.

F. Capital and Annual Control Costs

For a 130,000 liter (34,000 gal.) per month throughput station (6-9 nozzles), average capital costs for installing Stage II controls is estimated to be about $11,500. Annual operating costs and capital charges are estimated to be $4,000. A net annual savings of $900 for gasoline recovery would be realized; thus, reducing the total annual costs to $3,100. Costs are dependent on the type of equipment used, number of nozzles and gasoline throughput.

The average fleet cost per vehicle for onboard systems is estimated to be $22. This would be the average cost to the purchaser of a new car or truck.

G. References

1. Evaluation of Regulatory Strategies for Gasoine Marketing Industry, U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., EPA-450/3-84-012a, July 1984. [This document is under public review and is subject to change. A revised document is scheduled to be released by the end of 1986.]

2. Preliminary information on reanalysis of Reference 1 analysis.

4.2.9 Vessel Cleaning

A. Process and Facility Description

Transportation vehicles--rail tank cars, tank trucks, and barges--are used to transport a wide variety of petroleum and chemical commodities from producer to consumer; as many as 70 commodities are transported by these carriers. Facilities which clean vessels are either: (a) independent shops, the business of which is cleaning vessels; (b) maintenance land service stations which clean vessels incidental to repair operations or prior to leasing; and (c) carrier facilities at shipping and receiving terminals or manufacturers or producers.

Prior to vessel cleaning, a determination of vessel contents is made to determine the appropriate cleaning technique. This determination is made by either checking the cargo history or performing lab tests on the vessel residuum or "heel." Vessels carrying hazardous chemicals or potentially explosive gases may have to be freed of gases prior to cleaning; this can be done by filling or flushing with water or pulling a vacuum or blowing air depending on the vessel. These vapors will be released directly to or treated prior to release to the atmosphere.

After vessels are made safe for cleaning, various cleaning agents are used to remove residuum from the vessels. Steam, water, detergents, caustic acid, and solvents may be employed in any number of combinations to clean the vessels. Steam hoses, pressure wands, and rotating spray heads may be used to apply cleaning agents to vessels. Wastewater from an estimated two-thirds of the installations is directed to municipal treatment systems. Approximately one-third of the existing facilities discharge directly to surface water streams with only some oil separation. Newer facilities are using combinations of one or more wastewater treatment methods such as gravity separation, equalization, emulsion breaking, dissolved air flotation, coagulation, aerated lagoons, trickling filter, activated sludge, activated carbon adsorption, biological treatment, etc., to control wastewater. Temporary holding tanks may be employed for wastewater prior to wastewater treatment or discharge.

B. Emission Sources and Factors

Emission sources at cleaning facilities include gas freeing prior to cleaning if necessary, vapor displacement during cleaning operations, holding tanks, and wastewater treatment systems. Emission factors for vapor displacement were estimated to be 24 mg and 58 mg per liter (0.0002 and 0.0005 lb per gallon) of cargo capacity for barges and railcar/tank trucks, respectively. These emission factors were calculated using the ideal gas law at 20°C (68°F) and assuming 10 and 50 percent saturation of the air vapor volume being expelled from the barges and railcar/tank trucks, respectively. The factor for railcar/tank trucks is a weighted average of emission factors for the top 50 organic chemical compounds produced in 1983. The factor for barges is a weighted average of emission factors for 13 of the largest VOC reported for 1982 in the "Waterborne Commerce of the United States," Calendar Year 1982, DoA Corps of Engineers, WRSC-WCUS - 82-5.

C. Control Techniques and Emission Reductions

Flares and thermal oxidizers are practical techniques for controlling cleaning vapor emissions because of their ability to handle many different types of compounds. Displaced vapors during cleaning are vented directly to the control device. The EPA has concluded that a combustion efficiency of 90 percent is attainable with a smokeless flare. Based on the EPA studies of thermal oxidizers (TO) systems, a 98 percent VOC reduction is attainable with a properly operated TO.

Assuming that the cleaning and collection system is vapor tight, the emission reduction using a thermal oxidizer or flare will be 98 and 90 percent, respectively. However, leakage may occur resulting in less than 100 percnt capture. Based on gasoline terminal tests, the lowest leakage rate obtainable was approximately 10 percent of the vapors, by requiring annual pressure tests and necessary maintenance; without test requirements the average vapor leakage loss was approximately 30 percent. Therefore, total emission reduction from cleaning operations could range from 88 to 68 percent for thermal oxidizers and from 81 to 63 percent for flares.

D. Regulatory Status

There are no EPA regulations or guidelines which address vessel cleaning operations.

E. National Emission Estimates

National emissions in 1982 are estimated at 10 metric tons of VOC from vapor displacement during cleaning operations.[1]

F. Capital and Annual Control Costs

Capital and annual costs are not available.

G. Reference

1. Memo, Markwordt to Vessel Cleaning File. February 8, 1985.

4.3. ORGANIC CHEMICAL MANUFACTURE

Standards development for VOC emissions from the manufacture of organic chemicals center on the synthetic organic chemical manufacturing industry (SOCMI) which uses 15 basic chemicals to produce over 7,000 intermediate and end-product chemicals.[1] Regulations focus on approximately 400 of the highest volume chemicals. The basic chemicals are derived primarily from crude oil, natural gas, and coal. Examples of basic chemicals include benzene, ethylene, propylene, and propane. Basic chemicals are used to produce hundreds of intermediate chemicals, which are subsequently used to manufacture end-product chemicals. Generally, each process level contains more chemicals than the preceding level, and process units manufacturing chemicals at the end of the production system generally have smaller capacities (in terms of production volume) than process units producing the basic materials. Also, the volatilities of the end-product chemicals are typically less than those of basic materials.

A SOCMI process unit uses two broad categories of processes to manufacture organic chemicals: conversion and separation. Conversion processes involve chemical reactions that alter the molecular structure of chemical compounds. Synthesis is a conversion process in which more complex compounds are formed by combining simpler compounds or radicals. Conversion processes comprise the reactor processes segment of a SOCMI plant. Separation processes often follow conversion processes and divide chemical mixtures into distinct fractions. Examples of separation processes are distillation, filtration, crystallization, and extraction.

SOCMI emissions have been divided into a number of groups according to emission mechanisms to make the development of NSPS more manageable. These major emission groups are process vents, equipment leaks, storage, and secondary. Sources within each SOCMI group are similar with respect to operating procedures, emission characteristics, and applicable emission control techniques. Process vents from chemical reactor processes have been divided into two subsets, air oxidation processes and reactor processes. Emissions from distillation operations is the other category of process vents.

4.3.1 Process Vents

4.3.1.1 SOCMI Reactor Processes

A. Process and Facility Description

Synthetic organic chemical manufacturing industry (SOCMI) emissions have been divided into a number of groups according to emission mechanisms to make the development of NSPS more manageable (See section 4.3)[2]. Reactor processes are part of several groups constituting process vent emissions. The focus of the reactor processes NSPS is all reactor processes other than air oxidation. The category covers 32 different types of chemical reactions used to produce about 180 high-volume chemicals.[3]

B. Emission Sources and Factors

Reactor VOC emissions include all VOC in process vent streams from reactors and associated product recovery systems. Process product recovery equiment includes devices such as condensers, absorbers, and adsorbers.

Reactor processes may use be either liquid phase reactions or gas phase reactions. Potential atmospheric emissions points include the following:

1. Direct reactor process vents from liquid phase reactors;

2. Vents from recovery devices applied to vent streams from liquid phase reactors (Raw materials, products, or by-products may be recovered from vent streams for economic or environmental reasons.);

3. Process vents from gas phase reactors after either the primary or secondary product recovery device (Gas phase reactors always have primary product recovery devices.); and

4. Exhaust gases from combustion devices applied to any of the above streams.

Some chemical production processes may have no reactor process vent to the atmosphere, while others may have one or more vent streams.

VOC emission characteristics vary widely between the different chemical reactions. For example, VOC emission factors range from 0 Kg/Gg of product (0 lb/ton of product) for pyrolysis reactions to 180,000 Kg/Gg of product (360 lb/ton of product) for chlorination reactions.

VOC emission characteristics also vary widely for process units using the same chemical reaction. Process units using chlorination reactions have VOC emission factors that range from 228 to 180,000 Kg/Gg (0.46 to 360 lb/ton). Process vent stream flow rates and heat values are not as variable. Flow rates range from 0 to 537 scm/min, and heating valves range from 0 to 537 normal cubic meters/min (nm^3/min)(0 to 19,000 standard cubic feet per minute (scfm)). Heating values range from 0 to 48 Megajoules (MJ) per nm^3 (0 to 1,300 Btu/scf)[4].

C. Control Techniques and Emission Reductions

Control technology for reactor VOC emissions is divided into two categories: noncombustion control devices and combustion control devices. Noncombustion control devices are generally gas treatment devices that recover VOC from process streams; combustion control devices are designed to destroy the VOC in the vent stream prior to atmospheric discharge. Combustion control devices may also recover energy.

Noncombustion control devices include adsorbers, absorbers, and condensers. Since VOC emission characteristics vary so widely between different reactor processes, no one noncombustion control device can always be installed. Adsorbers are not recommended for vent streams with high VOC concentrations, and absorbers are generally not used on streams with VOC concentrations below 200 to 300 parts per million by volume (ppmv). Condensers are not well suited for vent streams containing either low boiling point VOC or large inert concentrations. Control efficiencies vary from 50 to 95 percent for condensers and absorbers and up to 95 percent for adsorbers.

Combustion control devices include flares, thermal incinerators, catalytic incinerators, industrial boilers, and process heaters. Aside from the catalytic units, these devices can be applied to a wide variety of vent streams and can achieve 98 percent efficiency or greater if properly designed and operated. Combustion devices can adjust to moderate changes in flow rate and VOC concentration. Control efficiency is not greatly affected by the type of VOC present. Addition of a scrubber may be required to incinerate process vent streams containing halogenated or sulfonated compounds. These compounds can also cause corrosion problems with flare tips, boiler tubes, and other plant equipment.

D. Regulatory Status

The EPA is currently drafting NSPS standards to control emissions from the Synthetic Organic Chemical Manufacturing Industry (SOCMI) reactor processes. The recommended standards would require VOC emissions from new, modified, and reconstructed reactor process facilities to be reduced by 98 weight percent or to 20 ppmv, whichever is less stringent.

E. National Emission Estimates

The emissions of reactor processes are estimated to be 55,700 Mg per year (61,000 tons per year) in 1990 based on 1984 control levels. If the recommended standards are implemented, VOC emissions will be reduced by about 2,030 Mg per year (2,240 tons per year) in 1990.

F. Captial and Annual Control Costs

For an individual reactor process vent stream with median flow rate and median heat content, capital cost for installing a flare is estimated to be $81,000 (in 1984 dollars). Annualized cost is estimated to be $107,000. Reference 1 defines the median flowrate as 3.4 nm^3/mm (121 scfm). The median heat content is defined as 6.7 MJ/nm^3 (180 Btu/scf). The median VOC flowrate is 3.0 kg/hr (6.6 lb/hr). Reference 1 presents cost equations generated by a linear regression analysis of EPA cost curves. Flare costs are presented as a function of height and top diameter.

G. References

1. U.S. Environmental Protection Agency. Reactor Processes in Synthetic Organic Chemical Manufacturing Industry--Background Information for Proposed Standards. (Preliminary Draft) Research Triangle Park, N.C. March 1985.

2. Reference 1.

3. Memo from Fidler, K., Radian Corporation, to L. B. Evans, EPA. July 6, 1983. Identification of chemical production routes and unit processes expected to be used in the future to manufacture the 176 chemicals considered in the carrier gas Project.

4. Reference 1.

4.3.1.2 SOCMI Air Oxidation

A. Process and Facility Description

Air oxidation processes are part of several groups constituting process vent emissions from SOCMI. In air oxidation processes, one or more chemicals are reacted with oxygen supplied as air or air enriched with oxygen. This group also includes chemicals produced using a combination of ammonia and air or of halogens and air as reactants. Thirty-six chemicals identified as using air oxidation routes are shown in Table 4.3-1.[1] Plastics and textile fibers are the major end uses for the bulk of air oxidation chemicals.

B. Emission Sources and Factors

Air oxidation chemicals are produced with a large variety of reaction types. Air oxidation processes can be grouped together because they all vent large quantities of inert material containing VOC to the atmosphere. These inerts are predominantly nitrogen from the air which has passed through the reaction unreacted. The exact quantity of nitrogen and unreacted oxygen emitted is a function of the amount of excess air used in the production process.

Air oxidation reactions can be carried out in either liquid or gas phase. For liquid phase, liquid feedstock and catalyst are fed into a reactor. The reaction is carried out by passing air through this liquid mixture at a controlled temperature and pressure. After completion of the reaction, two streams come out of the reactor, liquid and gaseous. The liquid stream usually contains the desired product, which is taken to a product recovery system consisting of a series of different unit operations (e.g., distillation, crystallization, evaporation, etc.). The gaseous stream containing nitrogen, unreacted oxygen, carbon dioxide, and some VOC is condensed or cooled; then fed into the gas separator to recover the condensable compounds

TABLE 4.3-1. SOCMI CHEMICALS PRODUCED BY AIR OXIDATION

1. Acetaldehyde
2. Acetic Acid
3. Acetone
4. Acetonitrile
5. Acetophenone
6. Acrolein
7. Acrylic Acid
8. Acrylonitrile
9. Anthraquinone
10. Benzaldehyde
11. Benzoic Acid
12. 1,3-Butadiene
13. p-t-Butyl Benzoic Acid
14. n-Butyric Acid
15. Crotonic Acid.
16. Cumene Hydroperoxide
17. Cyclohexanol
18. Cyclohexanone
19. Ethylene Dichloride
20. Dimethyl Terephthalate
21. Ethylene Oxide
22. Formaldehyde
23. Formic Acid
24. Glyoxal
25. Hydrogen Cyanide
26. Isobutyric Acid
27. Isophthalic Acid
28. Maleic Anhydride
29. Methyl Ethyl Ketone
30. -Methyl Styrene
31. Phenol
32. Phthalic Anhydride
33. Propionic Acid
34. Propylene Oxide
    (tert butyl hydroperoxide)
35. Styrene
36. Terephthalic Acid

before venting it to the atmosphere or a control device. Vapor phase reactions have a similar sequence of steps. However, liquid feedstocks are first vaporized, then mixed with air in a mixing chamber prior to the reactor.

Atmospheric emissions originate at vents from the product recovery devices. Hourly emissions range from 0 to 2100kg/hr (0 to 4,600 lb/hr). Flowrates range from 24 to 3,600 Nm^3/min (850 to 127,000 scfm), and heating values range from 0 to 4 MJ/nm^3 (0 to 107 Btu/scf).

C. Control Techniques and Emission Reductions

Control technology options for air oxidation process vents are identical to options for reactor process vents (See Section 4.3.1.1C). Air oxidation process vents are typically too dilute for flares to be cost-effective control devices. Changes in flowrates, VOC concentrations, and waste stream contaminants associatd with air oxidation process emissions can reduce the efficiency of condensers, absorbers, adsorbers, and catalytic oxidizers. Thermal incinerators are therefore the only demonstrated VOC control which is applicable to all SOCMI air oxidation processes.

All new incinerators, if properly designed, adjusted, maintained, and operated, can achieve at least a 98 percent VOC reduction or 20 ppmv exit concentration, whichever is less stringent. This control level can be achieved by incinerator operation at conditions which include a maximum of 1600°F and 0.75 second residence time.

D. Regulatory Status

In October of 1983, EPA proposed NSPS standards to control emissions from the Synthetic Organic Chemical Manufacturing Industry (SOCMI) air oxidation processes. The recommended standards would require VOC emissions from new, modified, and reconstructed air oxidation process facilities to be reduced by 98 weight percent or to 20 parts per million by volume (ppmv), whichever is less stringent.

E. National Emission Estimates

The VOC emissions of air oxidation processes have been estimated at 110,000 Mg per year (121,000 tons per year) in 1984.

F. Current Capital and Annual Control Costs

For a VOC-rich stream with a heating value of 2.6 MJ/nm^3 (70 Btu/scf) and a flowrate of 456 nm^3 (16,000 scf) installed capital costs for a thermal incinerator system are estimated to be $1,200,000 (in 1984 dollars). Annualized cost is estimated to be $610,000.[2] Costs are proportional to the flowrate of the vent stream and inversely proportional to the net heating value. Reference 1 presents emission control costs and cost-effectiveness for various vent streams.

G. References

1. U.S. Environmental Protection Agency. Air Oxidation Processes in Synthetic Organic Chemical Manufacturing Industry - Background Information for Proposed Standards. Research Triangle Park, North Carolina. Publication No. EPA-450/3-82-001a. October 1983. p. 3-20.

2. Reference 2. p.8-21.

4.3.1.3 SOCMI Distillation Operations

A. Process and Facility Description

Distillation is a major processing step within the synthetic organic chemical manufacturing industry (SOCMI). Distillation is a unit operation used to separate one or more inlet feed streams into two or more outlet product streams, each product stream having component concentrations different from those in the feed streams. The separation concentrates the more volatile component in the vapor phase while the less volatile component concentrates in the liquid phase. Distillation systems can be divided into subcategories according to the operating mode, the operating pressure, the number of distillation stages, the introduction of inert gases, and the use of additional compounds to aid separation.[1]

B. Emission Sources and Factors

During operation of a distillation column, vapors separating from the liquid phase rise out of the column to a condenser. These vapors can contain VOC, water vapor, and noncondensibles such as oxygen, nitrogen, and carbon dioxide. The vapors and gases originate from vaporization of liquid feeds. dissolved gases in liquid feeds, inert gases added to assist in distillation, and air leaking into the column, especially in vacuum distillation. Most gases and vapors entering the condenser are cooled enough to be collected as a liquid phase. Noncondensibles 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.

Atmospheric emissions vary between different distillation systems. VOC emissions range from 0 to 1700 kg/hr (0 to 3,700 lb/hr). Flow rates range from 0.0001 to 18 nm^3/min (.004 to 640 scfm) and heating valves range from 0 to 180 MJ/nm^3 (0 to 4,800 Btu/scf).[2]

C. Control Techniques and Emission Reductions

VOC control techniques for distillation operations include both noncombustion and combustion control devices. Noncombustion devices may be attractive if a significant amount of usable VOC can be recovered. Though certain vent stream characteristics can limit the use of noncombustion devices

(See Sections 3.3 and 3.4), many condensers and absorbers are applied to distillation vent streams in the industry. Control efficiencies vary from 50 to 95 percent for condensers and up to 95 percent for adsorbers.

Combustion control devices are typically both capital and energy intensive. However, these devices are applicable to a wide variety of vent stream characteristics and all can achieve at least 98 percent destruction efficiency.[3]

D. Regulatory Status

In December of 1983, EPA proposed NSPS standards (40 CFR, Part 60, Subpart NNN) to control emissions from the Synthetic Organic Chemical Manufacturing Industry (SOCMI) distillation operations. The recommended standards would require VOC emissions from new, modified, and reconstructed distillation operations to be reduced by 98 weight percent.

E. National Emission Estimates

The VOC emissions of distillation operations have been estimated at 140 Gg per year (150,000 tons per year) in 1984.

F. Current Capital and Annual Control Costs

For an average individual distillation vent stream with a flow rate of 0.7 nm^3/min (25 scf/min) and a heating valve of 28 MJ/nm^3 (750 Btu/scf), installed capital costs for boiler, flare, and incinerator are $31,500, $53,200, and $345,000, respectively (in 1984 dollars). Annualized costs for flare and incinerator are $36,500 and $164,000 (in 1984 dollars). Use of a boiler results in a net annual savings of $26,600 due to reduced natural gas consumption. Costs increase with increasing vent stream flow rates and decrease with increasing vent stream heat values.

G. References

1. U.S. Environmental Protection Agency. Distillation Operations in Synthetic OSrganic Chemical Manufacturing - Background Information for Proposed Standards. Research Triangle Park, North Carolina. Publication No. EPA-450/3-83-005a. December 1983.

2. Reference 1.

3. Reference 1.

4.3.2 Volatile Organic Liquid Storage Tanks

A. Process and Facility Description

Five basic tank designs are used for storage of volatile organic liquids: fixed-roof, internal floating-roof, external floating-roof, variable vapor space, and pressure. It is estimated that in 1977 there were a total of 27,540 volatile organic liquid storage tanks nationwide.[1]

A typical fixed-roof tank consists of a cylindrical steel shell with a permanently affixed roof. An internal floating-roof tank has both a permanently affixed roof and a cover that floats on the liquid surface (contact roof), or that rests on pontoons several inches above the liquid surface (noncontact roof), inside the tank. This roof rises and falls with the liquid level. The floating roof commonly incorporates flexible perimeter seals or wipers which slide against the tank wall as the roof moves up and down. An external floating-roof tank consists of a cylindrical steel shell equipped with a deck or roof which floats on the surface of the stored liquid, rising and falling with the liquid level. A seal (or seal system) attached to the roof, contacts the tank wall to cover the small annular space between the roof and the tank wall and slides against the tank wall as the roof is raised or lowered. Variable vapor space tanks are equipped with expandable vapor reservoirs to accommodate vapor volume fluctuations attributable to temperature and barometric pressure changes. There are two classes of pressure tanks, low pressure (2-15 psig) and high pressure (up to 250 psig or higher). Pressure tanks are used for storage of organic liquids with high vapor pressures and are found in many sizes and shapes depending on the operating range of the tanks.

B. Emission Sources and Factors

Two types of emissions from fixed-roof tanks are breathing losses and working losses. The expansion of vapors in the tank due to changes in ambient temperature and pressure result in VOC emissions termed "breathing losses." VOC emissions termed "working losses" result from vapors emitted from a tank as a result of filling and emptying operations. The total annual VOC emissions from a fixed-roof storage tank would be the sum of the breathing and working losses. The total annual VOC emissions from a large diameter (10-

meter) and a small diameter (7 meter) fixed-roof storage tank are presented in Table 4.3.2.1.[2]

The emission estimates presented throughout this section are calculated using current emission formulae as presented in the fourth edition of the EPA Publication AP-42.[3] The emission factor equation for fixed-roof tank breathing losses is based on test data collected by the Western Oil and Gas Association, the Environmental Protection Agency, and the German Society for Petroleum Science and Carbon Chemistry. A comparison was made between the new test data in these reports and the breathing losses calculated by using the 1977 version of the emission factor equation in AP-42. It was determined from this comparison, that the emission factor equation for fixed-roof breathing losses tended to over-predict and was therefore scaled downward.[4] The American Petroleum Institute sponsored a program to develop additional laboratory, pilot tank and field tank data on evaporative losses from internal and external floating-roof tanks. The mechanisms of evaporative loss were investigated and the effects of relevant variables were quantified, which resulted in the formulation of the current AP-42 emission factor equations.[5,6]

External and internal floating-roof tanks have similar sources of VOC emissions, known as "standing storage losses" and "withdrawal losses". Standing storage losses or seal losses for both external and internal floating-roofs can be the result of an improper fit between the seal and the tank wall which causes some of the liquid surface to be exposed to the atmosphere. Internal floating-roof tanks can also have standing storage losses through the openings in the deck required for various types of fittings (fitting losses); and through the nonwelded seams formed when joining sections of the deck material (deck seam losses). Withdrawal loss is the vaporization of liquid that clings to the tank wall and is exposed to the atmosphere when a floating roof is lowered by withdrawal of liquid. Thus, the total annual VOC emissions from either an external floating-roof storage tank or an internal floating-roof storage tank would be the combination of the standing storage loss and withdrawal loss. The total annual VOC emissions from a large and a small diameter internal floating-roof storage tank, equipped with a liquid-mounted primary seal, a bolted deck and controlled fittings are also shown in Table 4.3.2.1.[2]

VOC losses occur in low pressure tanks during withdrawal and filling

TABLE 4.3.2.1. FIXED ROOF TANK EMISSIONS AND EMISSION REDUCTIONS OBTAINED WITH AN INTERNAL FLOATING ROOF[a]
(Cyclohexane at 2.0 psi TVP)

Capacity (m^3)	Diameter (m)	Turnovers	FRT Emissions (Mg/yr)	$IFRT_{lm}$ Emissions (Mg/yr)	Emission Reduction (Mg/yr)	Percent Reduction
200	7.0	20.0	2.54	0.37	2.17	85.6
200	7.0	40.0	4.47	0.37	4.10	91.7
1,000	10.0	10.0	6.81	0.49	6.31	92.8
1,000	10.0	20.0	11.64	0.50	11.14	95.7

[a]Reference 2.

Nomenclature explanation - FRT = Fixed-roof tank, $IFRT_{lm}$ = Internal floating-roof tank (with a liquid-mounted primary seal and controlled fittings).

TABLE 4.3.2.2. CAPITAL AND ANNUALIZED COST FOR AN INTERNAL FLOATING ROOF INSTALLED IN A NEW FIXED-ROOF TANK[a]
(second quarter 1984 dollars)

Capacity (m^3)	Diameter (m)	Turn-overs	Total Capital Cost ($/Tank)	Total Annualized Cost ($/year)	Net Annualized Cost[b] ($/year)
200	7.0	20.0	10,798	2,948	1,982
200	7.0	40.0	10,798	2,948	1,123
1,000	10.0	10.0	15,015	4,100	1,290
1,000	10.0	20.0	15,015	4,100	(859)[c]

[a]Reference 2.

[b]Based on a product recovery credit of $0.35/liter for cyclohexane.

[c]Net annualized savings.

operations when the pressure of the vapor space exceeds the pressure-vacuum vent setting and vapors are expelled. High pressure tanks are considered closed systems, with virtually no emissions. In the case of variable vapor space tanks, filling losses result when vapor is displaced by liquid during filling operations. Loss of vapor occurs only when the vapor storage capacity of the variable vapor space tank is exceeded.

C. Control Techniques and Emission Reductions

Several methods are available to control VOC emissions from fixed-roof tanks: (1) the installation of an internal floating-roof and seal system, (2) a vapor recovery system (e.g., refrigerated vent condensers, carbon adsorption), and (3) vapor destruction system (thermal oxidation). The emission reduction and percentage reduction which may be obtained with an internal floating-roof tank over a fixed-roof tank are shown in Table 1.[2] A carbon adsorption vapor control system is estimated to reduce VOC emissions by approximately 98 percent.[6] A thermal oxidation vapor control system is estimated to reduce VOC emissions by approximately 98 percent.[7,8] Standing storage loss emissions from external and internal floating-roof tanks are controlled by one or two separate seals. The first seal is called the primary seal, and the other, mounted above the primary seal, is called the secondary seal. There are three basic types of primary seals: (1) mechanical (metallic shoe), (2) resilient (nonmetallic either vapor-mounted or liquid-mounted), and (3) flexible wiper. A primary seal serves as a conservation device by closing the annular space between the edge of the floating-roof and the tank wall. Two types of secondary seal are currently available, shoe-mounted and rim-mounted. A liquid-mounted primary seal has a lower emission rate and thus a higher control efficiency than a vapor-mounted seal. Metallic shoe seals are commonly employed only on external floating-roof tanks and are more effective than vapor-mounted seals, but less effective than liquid-mounted seals. A secondary seal, be it in conjunction with a liquid- or vapor-mounted primary seal, provides an additional level of control.

D. Regulatory Status

The EPA proposed NSPS in 1984 (40 CFR 60 Subpart Kb) to control VOC emissions from storage of volatile organic liquids. Currently some State and

local regulations have adopted petroleum storage tank CTG recommendations for control of VOC emissions from VOL storage tanks. The NSPS requires one of the following: (1) a fixed-roof in combination with an internal floating-roof which incorporates either a liquid-mounted primary seal or two seals (primary and secondary) where the primary seal may be vapor-mounted and controlled fittings; (2) an external floating-roof tank with a liquid-mounted or metallic shoe seal and a continuous rim secondary seal (other detailed specifications are also required and may be read in the regulation); and (3) a closed vent system and a control device to reduce VOC emissions by 95 percent or greater. The requirements described above will apply to each storage tank either with a design capacity greater than or equal to 151 m^3 (40,000 gal) containing a VOL that has a maximum true vapor pressure equal to or greater than 3.5 kPa (0.5 psia) but less than 76.6 kPa (11.1 psia) or a storage tank with a design capacity greater than or equal to 75 m^3 (20,000 gal) but less than 151 m^3 (40,000 gal) containing a VOL that has a maximum true vapor pressure equal to or greater than 27.6 kPa (4.0 psia) but less than 76.6 kPa (11.1 psia). The NSPS additionally requires a closed vent system and control device to reduce VOC emissions by 95 percent or greater for storage tanks with a design capacity greater than or equal to 75 m^3 (20,000 gal) which contains a VOL that has a maximum true vapor pressure greater than or equal to 76.6 kPa (11.1 psia).

E. Current National Emission Estimates

Total annual VOC emissions from volatile organic liquid storage tanks has been estimated at 37,800 Mg/yr in 1983, based on 1977 tank population data and current State and local control levels. This emissions total includes an estimated 34,000 Mg/yr of VOC emitted by fixed-roof tanks and an estimated 3,800 Mg/yr of VOC from floating-roof tanks.[9]

F. Capital and Annual Control Costs

The capital and net annualized cost to install an internal floating-roof roof equipped with a liquid-mounted primary seal on new fixed-roof tank, for either a small or a large size tank, is shown in Table 4.3.2.2.[2]

G. References

1. VOC Emissions from Volatile Organic Liquid Storage Tanks - Background Information for Proposed Standards. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. EPA-450/3-81-003a. July 1984. p. 3-2.

2. Memorandum. Gschwandtner, K., Pacific Environmental Services, Inc., to S. Shedd, U.S. EPA. Derivation of Cost Emissions and Emission Reductions presented in the VOC Control Techniques Document. January 1986.

3. Compilation of Air Pollutant Emission Factors - Fourth Edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. AP-42. September 1985.

4. Petroleum Liquid Storage Vessels - Revision of AP-42 - Background Document, EPA Contract No. 68-02-3063, TRW Environmental, Inc., Research Triangle Park, North Carolina, May 1981.

5. Evaporation Loss from Internal Floating-Roof Tanks, Third Edition, Bulletin No. 2519, American Petroleum Institute, Washington, D.C., 1983.

6. Letter from McLaughlin, Nancy D., U.S. Environmental Protection Agency to D. Ailor, TRW, Inc. Comments on the benzene storage model plants package. May 3, 1979.

7. Letter and attachments from D.C. Mascone, EPA/CPB, to J.R. Farmer, EPA. June 11, 1980. Memo concerning thermal incinerator performance for NSPS.

8. U.S. Environmental Protection Agency. Organic Chemical Manufacturing Volume 4: Combustion Control Devices. Research Triangle Park, North Carolina. Publication No. EPA-450/3-80-026. December 1980.

9. Reference 1, p. 3-35.

4.3.3 SOCMI Equipment Leaks

A. Process and Facility Description

The synthetic organic chemical manufacturing industry (SOCMI) is comprised of facilities engaged in the production of one to several organic chemicals using one or more processes. These chemicals may represent final products or intermediate products which serve as feedstocks to yet other processes. There are over 2,000 chemical plants (as of 1984) operating in the United States. The 359 chemicals listed in the Organic Chemical Producers Data Base developed by EPA[1] represent the types of compounds manufactured by the industry.

B. Emission Sources and Factors

Emissions of VOC from the SOCMI can result when process fluids (either gaseous or liquid) leak from plant equipment. Potential leaking equipment include: pumps, compressors, valves, pressure relief devices, open-ended lines, sampling systems, and flanges and other connectors. Emission factors for process equipment presented in Table 4.3.3-1 have been developed based on the results of several source testing studies. Emissions from SOCMI process units can be estimated by multiplying the number of equipment pieces times the emission factors specific to the type of equipment. SOCMI process unit baseline emissions may range from about 30 to 300 Mg/yr depending upon the complexity (number and types of equipment) of the unit.[2] Emissions from the SOCMI equipment leaks are discussed in the background information documents for the proposed[1] and promulgated[2] new source performance standards (NSPS) for SOCMI and an additional information document on fugitive emissions of organic compounds.[3]

C. Control Techniques and Emission Factors

Two approaches are available to control SOCMI equipment leaks of VOC: (1) a leak detection and repair program and (2) the installation of specific controls or leakless equipment. The emission reduction efficiency of leak detection and repair programs is dependent upon a number of factors including: (1) the monitoring method (visual, instrument, or soap solution); (2) leak definition; (3) frequency of inspections; (4) the time interval allowed between leak detection and subsequent repair; and (5) the emission reduction achieved by each successful repair. The control efficiencies of leak detection

and repair programs are presented in Table 4.3.3-1. The control estimates are based on available data on the occurrence and recurrence of leaking equipment and on the effectiveness of leak repair that are used in a model program that predicts control effectiveness using recursive equations developed for evaluating leak detection and repair programs. Control equipment can achieve control efficiencies approaching 100 percent. Examples of equipment controls include: (1) venting emissions from pressure relief devices, pumps, and compressors to a control device (e.g., flare or process heater); (2) dual mechanical seals with barrier fluid systems for pumps and compressors; (3) caps, plugs, or second valves on open-ended lines; (4) closed purge sampling systems; and (5) sealed bellows valves.

Table 4.3.3-1. Emission Factors And Control Effectiveness[a]

Equipment Type/Service	Average Emission Factor, kg/hr	Controlled Emissions			
		Quarterly Monitoring		Monthly Monitoring	
		Emission Factor, kg/hr	Percent Reduction	Emission Factor, kg/hr	Percent Reduction
Valves -					
Gas	0.0056	0.0020	0.64	0.0015	0.73
Light Liquid	0.0071	0.0040	0.44	0.0029	0.59
Pumps - Light Liquid	0.0494	0.0333	0.33	0.019	0.61
Pressure Relief Devices - Gas	0.104	0.0580	0.44	--	--

[a]References 3 and 4

D. Regulatory Status

The EPA set NSPS on October 18, 1983, (40 CFR 60 Subpart VV) and issued a CTG in April 1984 to control equipment leaks of VOC in the SOCMI. The CTG recommends quarterly leak detection and repair for pumps, valves, compressors, and safety relief valves. Pumps would also be visually inspected weekly. The CTG recommends installation of caps on open-ended lines. The NSPS requires monthly leak detection for valves in gas/vapor and light liquid service. Pressure relief devices are subject to a no detectable emissions

limit, compressors are to be equipped with a barrier fluid seal system that prevents leakage of VOC to atmosphere, sampling lines require closed purge systems and open-ended lines should be capped. About half of the existing facilities are estimated to have implemented controls recommended by the CTG as required under State or local regulations. By the end of 1984, 645 SOCMI process units are projected to be subject to the NSPS.[1]

E. Current National Emissions Estimates

Total annual VOC emissions from the SOCMI in 1984 has been estimated at 148,000 megagrams. This estimate was derived by multiplying the total estimated number of SOCMI process units by process unit emission estimates. The nationwide emission estimate assumes that half of the process units are located in nonattainment areas.[2,5]

F. Capital and Annual Control Costs

Capital and annual costs for controlling SOCMI equipment leaks are presented in Table 4.3.3-2 for a small and large process unit to comply with State and local regulations (based on reference 2 recommendations) and NSPS requirements. These costs are estimated based upon control costs for individual equipment type multiplied by the number of each type of equipment in the process unit. The costs presented also include expenditures incurred for monitoring instruments.[3]

Table 4.3.3-2. Capital And Annual Costs To Control SOCMI Equipment Leaks

Costs ($1,000)	CTG[a]	NSPS[b]
Capital Cost		
Small Unit[c]	19.7	31.3
Large Unit	113	219
Annual Cost		
Small Unit	6.8	12.6
Large Unit	2.9	67.7

[a]Reference 4.

[b]Reference 2.

[c]A small and large unit correspond to Model Units A and C, respectively, from References 2 and 4.

G. References

1. VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry - Background Information for Proposed Standards. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-80-033a. November 1980.

2. VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry - Background Information for Promulgated Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina: EPA-450/3-80-033b. June 1982.

3. Fugitive Emission Sources of Organic Compounds -- Additional Information on Emissions, Emission Reductions, and Costs. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-82-010. April 1982.

4. Guideline Series - Control of Volatile Organic Compound Leaks from Synthetic Organic Chemical and Polymer Manufacturing Equipment. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-83-006. March 1984.

5. Memorandum. Rhoads, T., Pacific Environmental Services, Inc., to S. Shedd, U.S. EPA. Derivation of Cost, Emissions, and Emission Reductions presented in the VOC Control Techniques Document. November 1985.

4.3.4 VOL TRANSFER OPERATIONS[1]

A. Process and Facility Description

Volatile organic liquids (VOL) are transported from production facilities and bulk terminals to packaging plants, other processing plants, and users and bulk terminals by ships, barges, tank trucks and rail cars. Although motor gasoline is a VOL, it is not included in this discussion. (See Section 4.2 of this chapter.) Over 7,000 organic chemicals are being produced today. However, a small percentage of these compounds constitutes the major of industries output. Roughly 67 percent of the total production is represented by the top 50 chemicals produced. No data is available on the number or size of the organic chemical loading facilities.

B. Emission Sources and Factors

Emissions from transfer operations occur when organic chemicals being loaded displaces the vapors in the tank and forces the vapors to the atmosphere. Transfer losses are dependent on the condition of the tank before loading, loading method, product and tank temperature and vapor pressure of the product being loaded or previously loaded. No published reports have been found that presents a listing of emission factors for the variety of chemicals loaded. From industry contacts there seemed to be a consensus that most VOL's are being submerged filled, and vehicle tanks are in dedicated service or are usually cleaned before switching to other products. Also, if the VOL is a gas, loadings are performed under pressure and no emissions should occur. According to the above description of loading techniques and condition of tanks before loading and review of the information contained in AP-42[2], most vapor spaces in tank carrying VOL's would be 50 to 100 percent saturated. Transfer emissions then can be calculated using the ideal gas law.

C. Control Techniques and Emission Reductions

Control technology utilized to minimize emissions during tank truck loading includes: (1) switching from top loading to submerged loading, and (2) collecting displaced vapors, and routing the vapors to a vapor processor. Converting the loading equipment from top splash to submerged loading will reduce emissions by approximately 60 percent. Vapor processors - thermal

oxidizers, refrigeration, carbon adsorbers - should reduce emissions to better than 90 percent. A very small number of vapor processors (mostly thermal oxidizers) have been demonstrated on this source of emissions.

D. Regulatory Status

The EPA has not developed any guidance documents or have standards under development on this source. A few States and local agencies have requirements requiring 90 percent control at high throughput loading facilities.

E. National Emission Estimates

The loading of ships, barges, rail cars, and tank trucks is estimated to emit from 4,700 to 9,400 megagrams (5,200 to 10,400 tons) of VOC in 1983.[3] This estimate is based on the most recent production estimates for the top 50 organic chemical produced, and emission factors calculated using the ideal gas law and assuming a 50 to 100 percent saturation of the air-vapor volume being expelled from the tanks being loaded.

F. Capital and Annual Control Costs

No capital or annual control costs have been estimated at this time, however, control costs for thermal oxidizers should be simliar to those available in EPA documents for gasoline bulk terminals.[4]

G. References

1. Memorandum from Shedd, S., U.S. EPA/OAQPS to Durham, J., U.S. EPA/OAQPS, Pre-Phase 1 Report for VOL Transfer, August 27, 1982.

2. Transportation and Marketing of Petroleum Liquids. In: Compliation of Air Pollution Emission Factors, U.S. Environmental Protection Agency, Research Triangle Park, AP-42, July 1979.

3. Memorandum from Shedd, S., U. S. EPA/OAQPS to Branch File, File #84/21 - VOC CTD, Emission Estimate Update to August 27, 1982, Pre-Phase 1 Report for VOL Transfer, May 1985.

4. Bulk Gasoline Terminals - Background Information for Proposed Standards--and Promulgated Standards, U.S. EPA, RTP, North Carolina, EPA 450/3-80-038 a and b, December 1980 and August 1983.

4.4. INDUSTRIAL PROCESSES

4.4.1 Paint And Varnish Manufacturing

A. Process Description

The manufacture of paint and varnish requires three general steps. First, reactive organic compounds of low molecular weight called monomers are reacted or polymerized with the aid of heat and catalysts to produce a resin. In the second step the resin is developed further by reacting or "cooking" it with certain oils, or fatty acids or alcohols. Solvent is added to reduce the viscosity, and the resulting mixture is called the "vehicle." The third and final step is to blend pigments, driers and other additives with the resin or resin vehicle and make final viscosity adjustments for storage. Varnishes are generally not pigmented but they may contain dyes or stains.[1]

There are approximately 1,100 coating manufacturers; however, the top 15 firms account for 48 percent of the sales. The Bureau of Census has reported that 1.5 million cubic meters (410 million gallons) of original equipment coatings and 2.2 million cubic meters (590 million gallons) of architectural coatings and 0.6 million cubic meters (154 million gallons) of special purpose coatings were shipped during 1984.[2]

B. Emission Sources and Factors

VOC emissions occur from all three manufacturing steps identified above. Over the last decade the resin and varnish base cooking has migrated to the chemical plants that polymerized the resins. Emissions from these steps will therefore not be covered in this section. The manufacture of polymers and resins and related emissions and controls is covered in more detail in Section 4.4.5.

Emissions from grinding mixing, blending and final thinning of the paint or varnish occur usually from filling or charging the vessels, or as fugitives from leaking valves, and covers or charging ports left open inadvertently. Thinning tanks venting directly to atmosphere might emit 6 to 80 Mg/yr depending on size, frequency of charging solvents used, agitation rate and temperature. The remainder of the processes would

collectively contribute approximately half that amount. One estimate for a medium size paint plant has been put at 28 Mg VOC per year.

C. Control Techniques and Emission Reduction

Thinning tanks may be equipped with condensers that reduce emissions by over 95 percent during filling and agitation. The remaining emission reduction will depend on improving "housekeeping" measures such as repair of leaking valves and keeping lids and charging portholes closed and sealed.

A substantial reduction in emissions has and will continue to occur as an indirect result of EPA regulating VOC emissions from paint users. To comply with regulations, industrial paint users must use abatement equipment or coatings that release less solvent and other VOC when dried or cured. The latter is usually less capital intensive and often more desirable to the paint user. Resin and paint manufacturers have responded by developing low solvent paints for many end uses. Assuming that emissions from paint manufacturing are proportinal to the total solvent used by the paint manufacturing process, reduction of 30 to 95 percent have been achieved depending on the company's success at supplying new low solvent coatings.

D. Regulatory Status

The Agency has developed or assisted the States to develop numerous regulations for companies that apply paint, varnishes, and inks. All have resulted in indirect pressure on the manufacturers to develop new products which contain significantly less solvent. This will dramatically reduce the amount of solvent which each manufacturer processes and, again indirectly, reduce its emissions. The Agency has thus encouraged maximum expenditure on research and minimum investment in hardware which would become less, and perhaps prohibitively cost effective as solvent throughput through a plant decreases. Some States may limit the maximum daily emissions from a plant, others may choose to require leak detection and repair programs as discussed on page 4-18, or they may merely require good housekeeping measures such as tops or lids on all vessels.

E. National Emission Estimates

It is estimated that approximately 12,000 Mg VOC are emitted yearly.[3]

F. Capital and Annual Control Cost

Condensers, seals and other devices that restrict fugitive emissions (hence might be construed as control devices) are usually part of the process equipment. They are installed as safety and cost saving features, their role in of VOC controls is usually incidental. For that reason, capital and annualized control costs are considered negligible or non-existent for VOC control purposes.

G. References

1. Air Pollution Control Engineering and Cost Study of the Paint and Varnish Industry, U.S. Environmental Protection Agency, EPA-450/3-74-031, June 1974.

2. American Paint & Coatings Journal, April 29, 1985, page 9.

3. Memorandum from Crumpler, D., U.S. Environmental Protection Agency, to ESED File No. 84/21, Estimation of VOC Emissions from Paint Manufacturing and Reduction of Emissions due to Production of Low Solvent Coatings, May 31, 1985.

4.4.2 Vegetable Oil Processing

A. Process and Facility Description

In the United States, nearly all vegetable oil is extracted from soybeans, cotton, corn or peanuts. The processes and equipment used to manufacture vegetable oil are generally the same regardless of the type of seed being processed. The seed is cracked, dehulled and cooked before mechanically pressed to remove a portion of the oil prior to solvent extraction. The most common solvent used in commercial edible oil extraction systems is hexane. After solvent extraction, hexane and oil are separated by distillation and hexane is removed from the meal in a desolventizer toaster. Following desolventization, the meal is dried, cooled, ground and stored for transport. Following distillation, the vegetable oil is collected for refining while the solvent-water vapor is condensed, decanted, and the solvent is recycled for further use. Fresh solvent is added to the recycled solvent to replenish solvent lost during the process.

B. Emission Sources and Factors

Since soybean oil constitutes over 80 percent of the vegetable oil market most studies of emissions from vegetable oil manufacturing have been limited to soybean oil production. Therefore, the remainder of this section will apply directly to soybean oil but can generally be applied to all vegetable oil manufacturing.

Solvent vapors from the solvent extraction, distillation unit, solvent-water separator, solvent work tank and other indirect sources are transported by a blower to the main vent. The predominant technique for solvent recovery from the main vent is a cool water condenser followed by a mineral oil scrubber.

Assuming that all hexane lost during the process is eventually emitted to the atmosphere, the emission factor for soybean processing can be determined from solvent inventories. The average solvent loss for 64 plants operating in 1979 was 0.9 gallons per metric ton of soybeans processed.[1] The emission factor for soybean manufacturing is 2.3 kilograms VOC per metric ton of soybeans processed.

An approximate break-down of hexane loss by source is 5 percent from the main vent following the mineral oil scrubber, 41 percent from the meal dryer vent and 3 percent from the cooler vent. Approximately 2 percent of the hexane is lost to the crude oil that goes to refining and 27 percent is lost to the finished meal. Fugitive losses are estimated to be 22 percent of the total hexane lost to the atmosphere.[2]

C. Control Techniques and Emission Reductions

The three processess in soybean oil manufacturing plants that are amenable to control are the dryer, the cooler, and the main vent following a scrubber. These facilities all have ducted emissions. Currently, there are no plants controlling VOC from these vents. Both carbon adsorption and incineration have been investigated as control devices, but the National Soybean Processors Association (NSPA) doesn't consider either of these devices to be acceptable due to fire hazard. However, several well-operated modern soybean processing plants that have reduced fugitive emissions and reduced the amount of hexane in the meal leaving the desolventizer toaster report operating at an overall hexane loss of 1.4 kilograms per metric ton of soybeans processed.[2]

D. Regulatory Status

The EPA issued a CTG in 1978 recommending a control device on the main vent (e.g., mineral oil scrubber) and a control device on the dryer/cooler vent (e.g., carbon adsorber or incinerator).[3] In 1979, the CTG was rescinded pending further information that was to be provided upon completion of the field testing for the New Source Performance Standard (NSPS) project. But in 1980 all work was discontinued on the NSPS for VOC and particulate emissions from soybean oil extraction plants because no demonstrated control technology could be identified.[4]

E. National Emission Estimates

In 1980, eighty-nine soybean processing plants were in operation with a total capacity of 96,500 metric tons per day.[5] It was estimated that 80 percent of the capacity was utilized. The national emission estimate for soybean processing plants in 1980 is 64,800 metric tons of VOC.

F. References

1. Taken from confidential information received by EPA in 1979.

2. VOC and Particulate Emissions from Soybean Oil Extraction Plants - Background Information, Draft Chapter 6, April 1980. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

3. Control of Volatile Organic Emissions from Manufacture of Vegetable Oils - Guideline Series. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA 1450/2-78-035, June 1978.

4. Memo from Farmer, J. R., USEPA, to Don R. Goodwin, USEPA. July 2, 1980. Recommendation Memo - New Source Performance Standards for Soybean Oil Extraction Plants.

5. Memo from Parker, C. D., Research Triangle Institute, to Richard Burr U. S. EPA. May 27, 1980. Review of TRC Environmental Consultants Report, "National Vegetable Oil Processing Plant Inventory."

4.4.3 Pharmaceuticals Manufacture

A. Process and Facility Description

The pharmaceutical industry processess thousands of individual products including drugs, enzymes, hormones, vaccines, and blood fractions. There are approximately 800 pharmaceutical plants producing drugs in the United States and its territories. Production activities can be divided into the following four categories: chemical synthesis, fermentation, biologicals and botanicals, formulation, and packaging.

Synthetic pharmaceuticals are typically manufactured in a series of batch processes. Solid reactants and solvents are charged to a washed reactor where they are held, and sometimes heated. After the reaction is complete, any remaining unreacted volatile compounds and solvents are removed from the reactor by distillation and condensed. The pharmaceutical product is then transferred to a holding tank. Subsequent steps include washing, drying, and crystallization.[1]

Fermentation processes use microorganisms to produce certain pharmaceuticals, such as antibiotics. In these instances the reactor contains an aqueous nutrient mixture with living organisms such as fungi or bateria. The crude antibiotic is recovered by solvent extraction and is purified by essentially the same methods described above for chemically synthesized pharmaceuticals.

Biologicals and botanicals include pharmaceuticals produced by extraction from plant or animal tissues. Insulin is a biological drug extracted from hog or beef pancreas. The extraction process involves the use of a solvent.

Formulation and packaging consists of the formulation of bulk chemicals into tablets, capsules, ointments, and liquids. VOC emissions can occur during tablet drying and coating.

Organic chemicals are used as raw materials and as solvents. Typical chemicals include methanol, ethanol, isopropanol, acetone, acetic anhydride, methylene chloride, chloroform, amylacetate, cyclohexylamine, and toluene.

B. Emission Sources and Factors

When solvent is used in the manufacture of a pharmaceutical product, each step of the manufacturing process may be a source of solvent emissions. An approximate ranking of emission sources has been established for the synthesized pharmaceutical category. In the following list, the first four sources typically account for the majority of emissions: (1) dryers, (2) reactors, (3) distillation units, (4) storage and transfer, (5) filters, (6) extractors, (7) centifuges, and (8) crystallizers.[1] For the three other pharmaceutical categories, emissions are primarily associated with dryers, coaters, and extractors. Emission rates for uncontrolled reactors can vary from 0.0001 Mg/yr to 10 MG/yr (.00011 tons/yr to 11 tons/yr). Reference 1 presents emission rates for a variety of processes and operations.

C. Control Techniques and Emission Reductions

Applicable controls for all of the emission sources except storage and transfer are the following: condensers, scrubbers, and carbon adsorbers. Storage and transfer emissions can be controlled by the use of vapor return lines, conservation vents, vent scrubbers, pressurized storage tanks, and floating roof storage tanks. Thermal incinerators are a control option in certain instances. They are sometimes used in the industry to control odors from fermentation vessels. Although control efficiencies will vary with the specific process, greater than 90 percent control has been demonstrated.[2]

D. Regulatory Status

The EPA issued a CTG for synthesized pharmaceutical products in 1978. The CTG recommends regulation on a plant-by-plant basis after identification of operations with significant emissions.

Where an individual approach is not practical, the CTG presents guidelines for a generalized control program. The guidelines can be briefly summarized as follows:

1. For each vent from reactors, distillation operations, crystallizers, centrifuges, and vacuum dryers that emit 6.8 kg/day (15 lb/day) or more of VOC require surface condensers or equivalent controls. (Maximum condenser outlet gas temperatures are specified.)

2. For air dryers and production equipment exhaust systems that emit 150 kg/day (330 lbs/day) or more of VOC, require 90 percent emission reduction. For air dryers and production equipment exhaust systems that emit less than 150 kg/day (330 lbs/day), required emission reduction to 15 kg/day (33 lbs/day).

3. Pressure/vacuum conservation vents on tanks storing VOC with vapor pressure greater than 10 kPa (1.5 psi) at 20°C.

4. Ninety percent effective vapor balance or equivalent on deliverys to all tanks greater than 7,500 liters (2,000 gallons) for VOC liquids with vapor pressure greater than 28 kPa (4.1 psi) at 20°C.

5. Enclose all centrifuges and filters processing liquids with VOC vapor pressure of 3.5 kPa (0.5 psi) or more at 20°C.

6. All in-process tanks shall have covers.

7. For liquids containing VOC all leaks should be repaired as soon as practical.

E. National Emission Estimates

The manufacture of ethical (i.e., prescription) pharmaceuticals was estimated to emit 50,000 Mg/yr (55,000 tons/yr) of VOC in 1975. No data are available for proprietary (i.e., over-the-counter) pharmaceuticals. Seventy-three percent of the total emissions were attributed to chemical synthesis operations.[1]

F. Capital and Annual Control Costs

For a carbon adsorption system sized for 250 Kg/hr (550 lb/hr) VOC from a dryer, captial costs are $540,000 (in 1984 dollars). If the adsorber operates 16 hours per day, 7 days per week, annualized costs are $23,000 (in 1984 dollars).

Capital costs for a conservation vent on a 38 m^3 (10,000-gallon) storage tank are $700 (in 1984 dollars). Annualized costs without VOC recovery credits are $180. Credits for VOC emitted are dependent upon tank diameter but may be large enough to reduce the total annualized cost to a credit.

Chapter 5 of Reference 1 presents costs for a variety of control devices.

G. References

1. Guideline Series: Control of Volatile Organic Emissions from Manufacture of Synthesized Pharmaceutical Products, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-78-029, December, 1978.

2. Richard Crume, EPA, "Recommendation for Continuing Study of the Pharmaceutical Industry, "Memo to Robert Rosensteel, EPA,. November 24, 1982.

4.4.4 Rubber Products Manufacture

4.4.4.1 Styrene-Butadiene Copolymer Manufacture

A. Process and Facility Description

Styrene-butadiene copolymers(SBC) are used extensively in the manufacture of rubber tires, dipped goods, carpet underlay, adhesives, moldings, paper coatings, paints, and carpet back sizing. Most manufacturers use an emulsion polymerization process which provides an aqueous medium as a reaction site for the styrene and butadiene monomers. Emulsion products are sold in either a solid form, known as crumb, or a liquid form, known as latex. Crumb products are typically produced continuously in a train of reactors. Latex products are usually polymerized in a batch process.

B. Emission Sources and Factors

Table 4.4.4-1 presents emissions for an emulsion crumb model plant producing 136,000 Mg/yr (150,000 tons/yr) and an emulsion latex model plant producing 27,000 Mg/yr (30,000 tons/yr).

C. Control Techniques and Emission Reductions

Control techniques for the SBC industry include both add-on air pollution control devices and process modification. Applicable add-on equipment includes carbon adsorption, condensers, thermal and catalytic incinerators, and the compression of organic vapors into fuel manifolds. Applicable process modification consists of optimizing the steam stripping step in the emulsion crumb polymerization process.

D. Regulatory Status

No regulations have been issued on styrene-butadiene copolymers.

E. National Emission Estimates

No data are available on current VOC emissions associated with the manufacture of SBC.

F. Capital and Annual Control Costs

Installed capital costs represent total investment to install a thermal incinerator equipped with heat exchanges (70 percent recovery). Installed capital costs for the emulsion crumb model plant (see Table 4.4.4-2) are $360,000 (in 1984 dollars). Installed capital costs for the emulsion latex plant is $380,000 (in 1984 dollars). Annualized costs for the emulsion crumb and emulsion latex plants are $110,000 and $120,000, respectively (in 1984 dollars).

Table 4.4.4-1 Model Plant VOC Emissions

Process Production Rate	Facility	VOC Emissions Mg/yr
Emulsion crumb 136,000 Mg/yr	Monomer Recovery - absorbent	35
	Coagulation/blend tanks	57
	Dryers	328
Emulsion Latex 27,000 Mg/yr	Monomer removal - butadiene	224
	Monomer removal - styrene	4
	Blend tanks	3

G. References

1. U.S. Environmental Protection Agency. Control of Volatile Organic Compound Emissions from Manufacture of Styrene-Butadiene Copolymers. Preliminary Draft. Research Triangle Park, North Carolina. April 1980.

4.4.4.2 Pneumatic Rubber Tires

A. Process and Facility Description[1]

The tire manufacturing process generally consists of four main steps: (1) compounding of raw materials, (2) transforming the raw materials into tire components and preparing the components for assembly, (3) assembling the components, (tire building), and (4) molding, curing and finishing of the assembled components into the final product. Each of these steps is a potential source of VOC emissions.

During compounding, raw crumb rubber is combined with fillers, extenders, accelerators, antioxidants and pigments. This mixture is then transferred to roll mills which knead the material and form it into sheets.

Tire components are made in several parallel operations. Rubber stock and other raw materials, including wire and fabric, are used to make tire tread, sidewalls, cords, belts and beads. The major source of VOC emissions during this step is the evaporation of VOC's from solvent-based cements. A detailed presentation of the various operations in can be found in Chapter 3 of Reference 1.

Tire building is the assembly of the various tire components to form an uncured or "green" tire. The assembly takes place on a collapsible, rotating drum. Organic solvents may be applied to some tire components in this step to further "tackify" (make sticky) the rubber.

Green tires are then sprayed on the inside with lubricants and on the outside with mold release agents before molding and curing in automatic presses. Curing usually takes 20 to 60 minutes at a temperature of 100°C to 200°C. The cooled tire is finished with buffing and grinding operations.

In 1984, the rubber tire manufacturing industry consisted of approximately 60 plants nationwide.

B. Emission Sources and Factors[1]

Each of the four production steps may include one or more sources of VOC emissions. A detailed discussion on the individual emission sources and their estimated emission factors is provided in Reference 1.

Organic solvent-based green tire spraying, undertread cementing, sidewall cementing, tire building, tread end cementing, and bead cementing contribute 97 percent of the total VOC's emitted from tire production.

C. Control Techniques and Emission Reductions[1]

Emission control by either incineration or carbon adsorption is applicable to undertread cementing, sidewall cementing, automatic or manual tread end cementing, bead cementing and green tire spraying. With an 80 percent efficient capture system, emission reductions of 75 percent can be attained for each of these processes.

In addition to add-on control technology, there are low solvent use techniques which are applicable to several processes. Limiting the amount of solvent used during tread end cementing and bead cementing can effectively reduce emissions from these sources by as much as 85 percent. VOC emissions from water-based green tire sprays are 90 to 100 percent less than emissions from organic solvent-based sprays.

D. Regulatory Status

The EPA issued a guideline in 1978 which recommended that emission reductions ranging from 60 to 86 percent could be achieved at undertread cementing, tread-end cementing, bead dipping, and green tire spraying. These recommendations are based on carbon adsorption or incineration control technology. Use of water-based sprays could result in a 97 percent emission reduction from green tire spraying.[2]

The EPA proposed an NSPS in 1983 (48 FR 14). The proposed standards are structured so they can be met by low solvent use techniques or water-based green tire sprays without employment of a control device. The proposed

standards are given below:

Operation	Emission Limit[3] (grams VOC/tire)
each undertread cementing and each sidewall cementing operation	25* or 75 percent reduction
each tread end cementing operation	10
each bead cementing operation	10
each inside green tire spraying operation	1.2
each outside green tire spraying operation	9.3

*Low solvent use cut-off.

E. Current National Emission Estimates[1]

The 1985 emissions from the manufacture of rubber tire is estimated at 40,000 megagarams (44,000 tons) of VOC based on tire demand and the current level of emission control.

F. Capital and Annual Control Costs[1]

The capital and annual control costs for carbon adsorption, applied to the sidewall cementing facilities at a 30,000 tire per day plant, are estimated at $1,000,000 and $250,000, respectively (2nd quarter 1984 dollars). Control costs vary with production and solvent use rates. More detailed information is available in Chapter 8 of Reference 1.

G. References

1. Rubber Tire Manufacturing Industry - Background Information for Proposed Standards, EPA-450/3-81-008a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1981.

2. Control of Volatile Organic Emissions from Manufacture of Pneumatic Rubber Tires, EPA-450/2-78-030, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1978.

3. Standards of Performance for New Stationary Sources; Rubber Tire Manufacturing Industry, Federal Register, Vol. 48, No. 14, January 20, 1983.

4.4.5 Polymers and Resins Manufacture

The polymers and resins industry includes operations that convert monomer or chemical intermediate materials into polymeric or copolymeric products. Sixteen of the major polymers types manufactured in the United States are:

Acrylics	Polyester Fibers
Alkyds	Polypropylene
High-Density Polyethylene	Polystyrene
Low-Density Polyethylene	Polyvinyl Acetate
Melamine Formaldehyde	Polyvinyl Alcohol
Nylon 6	Styrene-Butadiene Latex
Nylon 66	Unsaturated Polyester Resins
Phenol Formaldehyde	Urea Formaldehyde

The total process emissions from the polymer manufacturing industry are approximately 86,000 megagrams of VOC per year (1983 estimate). About 75 percent of these emissions come from the following sources.

1. Polypropylene
2. Polyethylene
3. Polystyrene
4. Polyester resin, also known as poly(ethylene terephthalate), or PET

There are approximately 130 plants in the United States that manufacture polymers and resins.

4.4.5.1 Polyethylene, Polypropylene, Polystyrene, and Polyester Resin

A. Process and Facility Description [1,2]

The manufacture of each of these polymers may be considered as a five-step operation:

(1) raw materials storage and preparation, (2) polymerization reaction, (3) materials recovery, (4) product finishing, and (5) product storage.

The first, raw materials storage and preparation includes methods of storing monomers and other raw materials to be used in the polymerization reaction. In preparation for the next step, raw materials may be dried and still other purification steps may be taken. Raw materials are then routed to the polymerization reactor.

In the reactor, raw materials and catalyst are combined with other processing materials, as appropriate, to produce the polymer. Reactor conditions, such as temperature and pressure, are specific for each product. After polymerization, any unreacted raw materials are recovered and returned to storage. The polymer is routed to "product finishing".

The product finishing stage of the polymerization process may include extruding and pelletizing, cooling and drying, introduction of additives, shaping operations and curing operations. The polymer is then ready for "product storage and shipping". The final step, "product storage and shipping" takes place in storage containers and associated solids transfer equipment.

B. Emission Sources and Factors

Pollutant emissions from the polymers and resins manufacturing process may be considered in two categories: (1) process emissions, those that can be anticipated based on the process flow diagram and, (2) fugitive emissions, those that can be identified only by sampling procedures.

The major sources of process emissions are vents and product recovery systems. Process emissions vary dramatically, both in composition and flow, depending on the process. Some streams may have a VOC concentration of less than 1 percent, others essentially 100 percent. Most are of relatively high concentration. Some emissions are continuous. Others are

intermittent. A more detailed description of the emissions sources and factors for thirteen different production processes used in the manufacture of polypropylene, high and low density polyethylene, polystyrene, and poly (ethylene terephtalate) (polyester resin) is presented in reference 2. Fugitive VOC emissions result when process fluids leak from the plant equipment. Sources include valves, pump seals, compressor seals, safety or relief valves, flanges, sampling connections, and open-ended lines. Fugitive emission factors are discussed in reference 2.

C. Control Techniques and Emission Reductions[2]

The control techniques for process emissions may be characterized by two broad categories: combustion or recovery techniques. The four major combustion devices applicable to process emissions are flares, thermal or catalytic incinerators, and boilers. These four devices are all expected to provide a destruction efficiency of 98 percent or greater. The three major recovery devices are condensers, adsorbers and absorbers. Recovery devices permit many organic materials to be retained and, in some cases, reused in the process. A recovery efficiency of 95 percent or greater can be expected from the application of any of these devices.

Two approaches are available to reduce fugitive VOC emissions by the polymers and resin industry. The first is a leak detection and repair program requires periodic inspections in which leaking fugitive emissions sources are located and repaired at specific intervals. The second is a preventive approach whereby fugitive emissions are either captured and vented to a control device or eliminated through the installation of specified controls or "leakless" equipment.

D. Regulatory Status

The EPA issued a control techniques guideline in 1983 to specify reasonable control technology (RACT) for the control of VOC emissions from manufacture of high-density polyethylene, polypropylene, and polystyrene resins. The following emission reductions or limitations are considered representative of RACT:[1]

(1) For polypropylene plants using liquid phase processes: a 98 weight percent reduction (or reduction to 20 ppm) of continuous VOC emissions from the polymerization reaction section (i.e., reactor vents), the material recovery section (i.e., decanter vents, neutralizer vents, slurry vacuum/filter system vents, by-product and diluent recovery operations vents), and the product finishing section (i.e., dryer vents and extrusion and pelletizing vents).

(2) For high-density polyethylene plants using liquid phase slurry processes: a 98 weight percent reduction (or reduction to 20 ppm) of continuous VOC emissions from the material recovery section (i.e., ethylene recycle treater vents or, if ethylene recycle is not used, emissions from the flash tank) and the product finishing section (i.e., dryer vents and continuous mixer vents).

(3) For polystyrene plants using continuous processes: an emission limit of 0.12 kg VOC/1,000 kg product from the material recovery section (i.e., product devolatilizer system, including the devolatilizer condenser vent and the solvent recovery unit condenser vent).

Standards of performance for stationary sources of VOC's from process and fugitive emission sources in the polymers and resins industry are currently being developed.[2] The new source performance standard, which will cover segments of the polypropylene, polyethylene, polystyrene and poly(ethylene terephthalate) manufacturing processes, is expected to reduce VOC emissions by almost 3,000 megagrams per year. This is about a 42 percent reduction of emissions that would be expected from the affected facilities if there were no NSPS.

E. Current National Emission Estimate[1]

The total process emissions from the manufacture of polypropylene, polyethylene, polystyrene, and poly(ethylene terephthalate) are approximately 65,000 megagrams of VOC per year (1983 estimate).

F. Capital and Annual Control Costs[1]

Control costs estimates are for 98 percent VOC destruction by either thermal incinerators or flare control of the combined continuous emission streams from the liquid-phase polypropylene process. The cost analysis is based on a fluidized bed dryer with emissions of 0.6 kg VOC/1000 kg of product. The total installed capital cost is approximately $735,000 for a thermal incinerator system and $90,000 for a flare system. The annualized cost is about $218,000 per year for an incinerator system and $80,000 per year for a flare. These numbers for this typical operation are given for illustrative purposes. Costs for the whole range of polymer processes are given in reference 1. Detailed costs discussions also constitute a chapter of reference 2.

G. References

1. Control of Volatile Organic Compound Emissions from Manufacture of High-Density Polyethylene, Polypropylene, and Polystyrene Resins, EPA-450/3-83-008, U. S. Environmental Protection Agency, Research Triangle Park, N.C., November 1983.

2. Polymer Manufacturing Industry - Background Information for Proposed Standards - Preliminary Draft, EPA 450/3-83-019a, U. S. Environmental Protection Agency, Research Triangle Park, N.C., September 1983.

4.4.6 Synthetic Fibers

A. Process and Facility Description [1,2]

Synthetic fibers are manufactured as continuous filaments (which may then be chopped into staple) of modified cellulose or man-made polymers. They are used to manufacture carpets, apparel, industrial textiles, rope, tires, cigarette filters, and composite materials. There are three broad manufacturing classifications: melt spinning, solvent spinning, and reaction spinning.

In the melt-spinning process, a thermoplastic polymer is heated to above its melting point and is forced (extruded) through a spinneret (a group of orifices). The filament solidifies as it is quenched in a stream of cool air or other medium. Typical polymers suitable for melt spinning are polyesters, nylons and polyolefins. Melt-spinning accounts for the preponderance of synthetic fiber production in the U. S. with 2,300,000 Mg (5.0 billion lbs) produced in 1983. There are approximately 130 plants engaged in melt-spinning.

Solvent spinning can be subdivided into two types of processes, wet or dry. Both first require the polymer to be dissolved in a suitable solvent at a ratio of about three parts solvent to one part polymer. In wet spinning, the polymer solution is extruded through a spinneret that is submerged in a liquid that extracts the solvent, thereby precipitating the polymer filament. In dry spinning the polymer solution is extruded into a zone of heated gas that evaporates the solvent leaving the polymer filament behind.

A third process, reaction spinning, is much like wet spinning. A low molecular weight fluid "prepolymer" is extruded into a bath containing a co-reactant which causes formation of the filament by polymerization. This process is minor tonnage-wise and henceforth will be included in the discussion of the wet spinning process.

Typical polymers suitable for solvent spinning are acrylics, modacrylics, acetates, triacetates, rayon and spandex. Approximately 1,400,000 Mg (3.0 billion lb) of solvent-spun fiber were produced in the U.S. in 1983

at approximately 20 plants.

Once spun, all fibers undergo post-spinning processing. It may involve one or more of the following: washing, stretching, cutting (into staple), crimping, twisting, drying and finally packaging.

B. Emission Sources and Factors

Solvents are not used in melt-spinning; therefore, all VOC emissions are due to unreacted monomer and oils applied to the filaments as they emerge from the spinneret. Emissions may occur in the exhaust from the quenching step or any of the post-spinning processing steps that require steam, hot water, or dry heat. The monomer concentrations are usually quite low. The lubricating oils have rather low vapor pressures and often condense into a visible aerosol. VOC emission factors for melt-spinning are given below:

Polymer	Uncontrolled Emissions (Kg/Mg fiber)
Nylon 6	2
Nylon 66	0.8
Polyester	2
Polyolefins	5

An average size plant will produce approximately 100 Mg fiber per year so plant emissions would range from 0.1 to 0.5 Mg per year. Solvent spinning involves such large quantities of solvent that even though efficient solvent recovery is essential to each process, substantial emissions still occur. Typical emission points are fugitive leaks from mixers and filters, wet-(and reaction-) spinning baths, the fiber as it emerges from the dry-spinning cabinet or wet-spinning bath, and subsequent processing steps that require steam, hot water or dry heat. Emission factors for the most common solvent-spinning processes are given below.[1]

Type of Fiber	Emission Factor (kg/Mg Fiber)
Wet spun Acrylic & Modacrylic	40
Dry Spun Acrylic	45
Dry Spun Modacrylic	140
Cellulose Acetate Cigarette Filtration Tow	120
Cellulose Acetate Textile Yarn	145
Dry Spun Spandex	10
Wet (Reaction) Spun Spandex	150

More detailed information about specific process steps can be found in Reference 1.

C. Control Techniques and Emission Reductions [1,3]

Melt spinning and the associated post-spinning processes, if controlled at all, are usually served by fabric filters, rotoclones, scrubbers or electrostatic precipitators. Since the uncontrolled emission rates are small, controls are installed at the plant's discretion. Removal efficiencies have not been determined by EPA. The textile industry has reported reductions of similar types of emissions by 70 to 95 percent.[4]

For economic purposes, most of the solvent used in the solvent spinning process is normally recovered either from the dry-spinning spin cell, or the wet-spinning spin bath. The method of recovery depends on the solvent and its concentration in the process stream from which it is recovered. Dry spinning solvents are recovered with packed or plate tower scrubbers using water as the scrubbing medium. Carbon adsorption is used for some solvents. Distillation is necessary to separate the water and solvent. Normally, 90 percent of the solvent used in the spinning step is recovered and recycled. Most of the remainder of the recoverable solvent, about 10 percent of the total solvent feed to the process, can be recovered by enclosing filters and the post-spinning

processing steps and ventillating the exhaust to a scrubber or carbon adsorber. These exhaust streams might be merged with streams from the spinning step or controlled individually. VOC emission reduction achievable from these points would be expected to also range from 90 to 95 percent.

D. Regulatory Status

Regulations for existing plants are nonexistent or very general in scope, employing a ceiling, or guideline, similar to the technique used by the old Los Angeles County Rule 66, i.e., 40 lbs per day. A new source performance standard was promulgated by EPA on April 5, 1984. It is applicable only to plants that solvent-spin fibers. The standard for facilities that produce acrylic fibers is 10 kilograms VOC per megagram of total solvent used. The standard for facilities that produce nonacrylic fibers is 17 kilograms per megagram. Compliance is determined on a 6-month rolling average basis. There are no regulations specific to melt-spinning processes.

E. National Emission Estimates

Emissions from melt spinning and associated postspinning processes were estimated at 4,600 Mg for 1983. Solvent spinning emissions (excluding carbon disulfide (CS_2) and (H_2S) from rayon) for that same year were 64,390 Mg. Emissions of CS_2 and H_2S from rayon production were estimated at 5,400 Mg.

F. Capital and Annual Control Cost

There are no regulations for the melt spinning processes. The EPA therefore has not estimated the cost effectiveness of controlling those emissions. The capital cost for using a refrigerated condensation aerosol removal system has been estimated at $550,000 (1984) for a 5,000 scfm exhaust from a textile plant.[4] The types of emissions and their concentrations would be similar to a melt spinning plant. Annualized costs were not estimated.

The cost of control for solvent spinning process will vary due to the variety of spinning technologies and postspinning processing steps that arise from the variety of fibers that are produced. The table below

reflects typical capital and annualized costs (May 1984) for models of the most common processes and likely control strategies.

Fiber	Plant Size Gg/yr	Spinning Process	Control Strategy used for Estimating Costs	Capital Costs Million Dollars	Annualized Costs Million Dollars
Acrylic	45	Wet	Scrubber/Distillation Train	98	76
Acrylic	45	Dry	Scrubber/Distillation Train	93	68
Mod-Acrylic	20	Dry	Scrubber/Distillation Train	60	34
Cellulose Acetate	23	Dry	Scrubber or Carbon Adsorber/Distillation Train	88	40
Cellulose Acetate	23	Dry	Carbon Adsorber/ Distillation Train	117	45

For more information on capital and annualized cost, refer to reference 1.

G. References

1. Synthetic Fiber Production Facilities - Background Information for Proposed Standards, EPA-450/3-82-011a, October 1982.

2. Chemical & Engineering News 62(8), 1984, p.24.

3. Zerbonia, R., and G. Lantham, Source Category Survey Report - Synthetic Fibers Industry, Pacific Environmental Services, Inc. EPA Contract No. 68-02-3060, February 14, 1980.

4. Control of Hydrocarbon Emissions from Cotton and Synthetic Textile Finishing Plants, EPA 600/2-83-041, May 1983.

4.4.7 Plywood Manufacture

A. Process and Facility Description[1]

Plywood is a product composed of layers of wood veneer glued together with an adhesive. The grain of each successive layer is placed at right angles to give the product strength in two directions. Softwood plywood is constructed using veneers from coniferous or needlebearing trees. Emissions from hardwood veneer processing are insignificant compared to emissions from softwood processes. In January 1980, an estimated 267 facilites were manufacturing softwood plywood and veneer in the continental United States. By January 1982, many mills were closed, either temporarily or permanently.

Four steps used in the production of plywood are listed below:

(1) Green process - log conditioning, followed by peeling into green veneer;

(2) Veneer drying;

(3) Veneer patching and grading, lay-up and glueing, and pressing to make plywood;

(4) Sizing and finishing of the plywood.

B. Emission Sources and Factors[1]

The primary sources of VOC emissions in this industry are the veneer dryers. Veneer dryers emit condensible organic compounds. The rate of uncontrolled emissions from a veneer dryer is a function both of the characteristics of the wood and of the dryer and operating conditions. Veneer dryers emit approximately 1.1 kilograms per thousand square meters (10^3M^2) VOC/10^3M^2 of 1-cm thick plywood produced[2].

Fugitive emissions can comprise a significant portion of the total from a veneer dryer. The main factors affecting the quantity of fugitive emissions are the type of dryer, the condition of the door seals and end baffles, and stock damper settings.

C. Control Techniques and Emission Reductions

Stack emissions from plywood veneer dryers can best be controlled by add-on equipment. Wet scrubbing and incineration are the most common control techniques presently used The most commonly employed wet scrubbing

process consists of multiple spray chambers in series. The control efficiency is generally less than 50 percent for this system. Incineration has the potential to reduce dryer emissions by more than 90 percent. Based on the performance of combustion equipment elsewhere, incineration of all dryer exhausts in a fuel cell incinerator, or furnace could achieve VOC removal efficiencies of greater than 90 percent from wood-fired veneer dryers.

Control techniques for minimizing fugitive emissions include maintenance of door seals, dryer skins, tops, and end baffles; proper balancing of air flows; and use of end-sealing sections.

D. Regulatory Status

There are no Federal regulations for plywood plants but one or more States have regulations.

E. Current National Emission Estimate[3]

National VOC emissions from plywood production are estimated at approximately 1,700 megagrams per year.

F. Capital and Annual Control Costs[1]

Boiler incineration control for a plywood plant with a single steam-heated dryer is estimated to have an installed cost of $199,000 and total annualized costs of $103,000. These costs are for a typical situation; however, there are different configurations for plywood plants depending on the number of dryers and whether the dryers are steam heated or wood fired. Reference 1 contains a more complete discussion of costs.

G. References

1. Control Techniques for Organic Emissions from Plywood Veneer Dryers, EPA-450/3-83-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1983.

2. Plywood Veneer and Layout Operations. In: Compilation of Air Pollutant Emission Factors, Third Edition. AP-42, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1977.

3. Emission estimate based upon 1981 softwood plywood production data provided by the National Paint and Coatings Association, Inc.

4.4.8 Beer and Wine Production

A. Process and Facility Description

Beer and wine are alcoholic beverages made by fermentation. Beer production begins with malting. Barley is malted by adding moisture and heat until germination occurs. Wine production begins with stemming and crushing of grapes. Fermentation is the next step for both beverages. During fermentation, specially cultivated yeasts convert the malt sugar or grape sugar into ethanol and carbon dioxide. Additional production steps include storage, clarification, pasteurization, and packaging. Beer production also includes recarbonation.

B. Emission Sources and Factors

VOC emissions from beer making are primarily associated with the spent grain drying and are estimated to be 1.31 kg/Mg (3.2 lb/ton) of grain handled.[1] The volatile organics consist principally of ethanol. All emissions during fermentation are collected for the carbon dioxide. Emissions from other brewry operations are minor. Emission factors are not available.

For wine making, VOC emissions are due to ethanol entrainment in the CO_2 produced during fermentation. For fermentation at 27°C (80°F), ethanol emissions range from 574 g/kl (4.8 lb/thousand gallons) for white wine to 862 g/kl (7.2 lb/thousand gallons) for red wine.[1] VOC emissions are expected from other operations, though no testing data are available.

C. Control Techniques and Emission Reductions

VOC emissions due to spent grain drying could be controlled by mixing the dryer exhaust with the combustion air of a boiler.[1] VOC destruction efficiency would be 95 percent or greater.

VOC control techniques have not been implemented by the wine industry.

D. Regulatory Status

Presently there are no EPA, state, or local air regulations directed specifically at controlling VOC emissions from beer or wine making.

E. National Emission Estimates

VOC emissions associated with beer production were estimated at 360 Mg/yr (400 tons/year) in 1982.

VOC emissions due to wine production were estimated at 1,300 Mg/yr (1,400 tons/yr) in 1983. Emissions estimates are based on emission factors. No test data are available.

F. Current Capital and Annual Costs

No cost information is available.

G. References

1. U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. Research Triangle Park, North Carolina. Publication AP-42. April 1981.

2. Predicasts, Inc., Predicasts Basebook, Cleveland, Ohio, 1984.

4.4.9 Whiskey Warehousing

A. Process and Facility Description

The manufacture of whiskey involves two distinct operations--the production of unaged whiskey from cereal grains and the maturation of this whiskey by storage in charred white oak barrels. Production steps include grain milling, cooking, malting, fermentation, and distillation. Following production, whiskey must be aged by storage in charred oak barrels to produce an alcoholic beverage with the traditional taste and aroma of whiskey.

Since production steps account for only a small percentage of total VOC emissions, this source category will focus on whiskey warehousing operations.

B. Emission Sources and Factors

During warehousing, there are two sources of VOC emissions--evaporation from the barrel wood during storage and evaporation from the saturated wood after the barrel is emptied. Storage evaporation occurs when liquid diffuses through the barrel staves and heads via the wood pores or travels by capillary action to the ends of the barrel staves. Evaporation from emptied barrels occurs when the saturated barrels are stored after emptying. The combined emissions from both sources are 3.2 kg ethanol lost/barrel-yr.[1] A barrel consists of 55 proof-gallons and a proof-gallon is defined as one U.S. gallon containing 50 percent by volume ethanol or any volume of liquid containing an equivalent amount of ethanol.

C. Control Techniques

Two methods for reduction of warehouse emissions have been investigated: (1) carbon adsorption and (2) an alternate aging system. Use of a carbon adsorption system would require closing the warehouse and ducting the interior to a skid-mounted package system. The carbon adsorption system should recover 85 percent of the ethanol allowing for maximum ethanol losses. An alternate system of aging--using sealed stainless steel vessels--is under development. Perfection of such a system with no reduction in whiskey quality would essentially eliminlate all ethanol losses. The EPA issued a cost and engineering study on VOC emissions from whiskey warehousing in April 1978.

D. Regulatory Status

No Federal regulations have been issued on whiskey warehousing. Over 90 percent of whiskey warehousing occurs in five states--Kentucky, Indiana, Illinois, Maryland, and Tennessee. None of these States have regulated these emissions.

E. National Emission Estimate

The national emission estimate is 38,170 Mg/yr based on 11.9 million barrels stored in June 1976. the estimate is based on emission factors derived from aggregate loss data obtained from the IRS.

F. Capital and Annual Costs

For a 50,000-barrel warehouse, capital cost for a carbon adsorption system to control warehouse emissions is $190,000 (in 1984 dollars). Total annual costs after alcohol recovery and resale are $5,600. Costs were developed from vendor quotes.

G. References

Cost and Engineering Study--Control of Volatile Organic Emissions from Whiskey Warehousing, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-78-013, April, 1978.

4.4.10 Other Industrial Processes

A major problem which impedes the Nation's progress in its goal of reducing ambient levels of ozone is the extremely large number of industries for which VOC regulations must be developed; almost every industrial activity is a source of organic emissions. As a result, a regulatory program that will ultimately achieve and maintain the ambient air quality standard is necessarily extensive and complex. Appendix A provides a list of many industrial operations that use and emit VOC. Even it, however, is far from complete. For example, many metal-forming operations such as casting, forging, rolling (of aluminum foil), and machining also use and emit organic lubricants. Ultimately, regulatory programs will be required for many more industrial processes before the air over all of America will have ozone contamination levels that are less than the national ambient air quality standard.

4.5 APPLICATION OF PAINTS, INKS, AND OTHER COATINGS

Introduction

Activities by the Environmental Protection Agency in 1977 have had a profound and continuing influence on the coating industry. In May of that year the Agency published its first volume of guidance for States to develop regulations. This guidance was contained in a series of reports that are now uniformly referred to as "CTG's" (Control Techniques Guidelines). These reports strongly influenced the ensuing State regulations that limit emissions from large segments of the original equipment manufacturers that use large volumes of coatings. Born of the environmental movement and nurtured by the energy shortage of the later 1970's, the search to develop coatings that contain less solvent has almost become a way of life for the coating manufacturing industry. Large companies have dropped entire product lines because the large investments required for research made it prudent to specialize in certain types of coatings or coatings for certain types of customers. The industry was shaken from a lethargy common to many large mature industries. Suddenly, innovation and exploration of new paint chemistry became paramount as customers placed pressure on suppliers to provide low-solvent coatings that would preempt the only alternative, purchase of capital-intensive abatement equipment. The results of the research are becoming increasingly evident in the marketplace as more companies come into compliance by use of new coatings applied with new application equipment. Often, having made the transition, both the coaters and coating manufacturers are finding economic advantages in use of the low-solvent coatings that were not expected. These include low transportation costs and less warehousing requirements (because of the more concentrated coatings), less waste disposal problems because of improvements in application equipment, lower insurance rates, and more desirable working conditions because of the decrease in solvent.

A survey[1] in April of 1984 revealed that 63 percent of the finishers that responded had changed their coatings in the last 3 years and 51 percent

of that group ascribed their motivation to environmental regulations. A subsequent survey[2] revealed that 61 percent of the responders intended to change coatings within the next 5 years. Of that group, almost half, 49 percent, ascribed environmental regulations as the major factor in their decision.

Similarly, manufacturers of ink have explored new ink technologies. Waterborne inks are being used to a greater extent than ever before. The industry also alleges that newer ink technology has reduced the solvent: solids ratio of inks and the resin: pigment ratio of the solids portion of the ink. Both changes would reduce emissions.

The printing industry has also made equipment changes that reduce fugitive emissions. Many companies now cover ink cans that formerly remained open. Ink fountains at some plants have been replaced by closed ink systems and doctor blades. One company has developed an air driven pump for the ink can that does not heat the ink as it is recycled. By operating cooler, the solvent does not evaporate as rapidly and the amount of make-up solvent required decreases.

The EPA has published two references that are critical to understanding the Agency's program for reducing emissions from coating operations. The first is a glossary of terms[3] which standardizes the vocabulary for this segment of environmental control. The second contains instructions and forms that manufacturers and applicators may use to certify the VOC content of their coatings.[4]

References

1. Industrial Finishing, April 1984, pg. 9.

2. Industrial Finishing, September 1984, pg. 9.

3. Glossary for Air Pollution of Industrial Coating Operations, Second Edition, EPA-450/3-83--013R, December 1983.

4. Procedures for Certifying Quantity of Volatile Organic Compounds Emitted by Paint, Ink, and Other Coatings, EPA-450/3-84-019, December 1984.

4.5.1 SURFACE COATING

4.5.1.1 Large Appliances

A. Process and Facility Description[1]

Large appliance products include kitchen ranges, ovens, microwave ovens, refrigerators, freezers, washers, dryers, dishwashers, water heaters, and trash compactors. A "large appliance surface-coating line" consists of the coating operations for a single assembly line within an appliance assembly plant. Typically, the metal substrate is first cleaned, rinsed in a phosphate bath, and oven dried to improve coating adhesion. If a prime coat is necessary, the part may be dipped, sprayed, or flow-coated and dried in a curing oven. Subsequently, the topcoat is applied, usually by spray. The freshly-coated parts are conveyed through a flashoff tunnel to evaporate solvent and cause the coating to flow out properly. After coating and flashoff, the parts are baked in single or multipass ovens at 150-230°C.

There are approximately 170 plants in the United States that manufacture large appliances.

B. Emission Sources and Factors

A surface coating line has three main sources of emissions. Major emissions occur at the application (spray booth) area, flashoff area, and the curing oven. Fugitive emissions occur during mixing of coatings.[2] The uncontrolled emission factor for an organic borne coating containing 25-volume percent solids (75-volume percent organic solvent) is 0.66 kilograms of VOC per liter of coating (minus water)* consumed.[3] An emission estimate of 50 megagrams of VOC per year is reasonable for the average appliance plant.[3]

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*Equivalent to 0.66 kilograms of VOC per liter of coating consumed for an organic borne coating that contains no water.

C. Control Techniques and Emission Reductions[1]

Control techniques used in the large appliance surface coating industry include converting to low solvent coatings, improving transfer efficiency with state-of-the-art equipment, or incineration. Changing from traditional to high-solids or waterborne coatings can reduce VOC emissions from prime coating operations by 70 percent and 92 percent, respectively. Use of electrodeposition to apply the prime coat can reduce emissions by 94 percent over conventional spray prime coat operations. Emissions from top-coat application can be reduced by use of waterborne, high-solids or powder coatings, giving reductions of 80 percent, 70 percent, and 99 percent, respectively, from levels typical of high VOC coatings.

Transfer efficiency is the ratio of the amount of coating solids deposited onto the surface of the coated part to the total amount of coating solids used. Improvments in transfer efficiency decreases the volume of coating that must be sprayed to cover a specific part, thereby decreasing the total VOC emission rate a proportional amount.

Historically, the large volumes of air used to ventilate open spray booths and flashoff areas made it prohibitively expensive to incinerate emissions from these sources. Incineration of VOC emissions in the curing oven exhaust, however, has been feasible, primarily because concentrations are higher. Incineration of the curing oven exhaust can reduce overall emissions from the large appliance surface coating line by about 15 percent.

D. Regulatory Status

The EPA issued a guideline to assist States in developing regulations for this industry in 1977 and set NSPS standards for it in 1980 (40 CFR 60 Subpart SS). The recommended emission limit for existing plants is 0.34 kilograms of VOC per liter of coating minus water (2.8 lb VOC/gallon coating minus water). This limit is based on the use of low solvent organic borne coatings.[2] The NSPS requires that emissions be limited to

0.90 kilograms of VOC per liter of applied coating solids. It is based on a 62-volume percent solids coating applied at a transfer efficiency of 60 percent.[1]

E. National Emission Estimates

It has been estimated that surface coating of large appliances resulted in emissions of approximately 24,000 megagrams of VOC[4] in 1981.

F. Capital and Annual Control Costs[1]

Higher solids, waterborne and powder coatings are available which will meet the standards and can be used for approximately the same cost as conventional high-solvent coatings. In some cases companies can save as much as $360,000 annually by switching to low solvent coatings.[2] Costs estimates for switching coatings are highly dependent on the particular installation. A case-by-case analysis should be performed on each installation when switching coatings.

G. References

1. Industrial Surface Coating: Appliances - Background Information for Proposed Standards - and Promulgated Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/3-80-037a and b, November 1980 and October 1982.

2. Guideline Series: Control of Volatile Organic Emissions from Existing Stationary Sources Volume V: Surface Coating of Large Appliances, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, May 1983.

3. Compilation of Air Pollutant Emission Factors, Third Edition. Supplement No. 14, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, May 1983.

4. Based on information provided by the National Paint and Coatings Association, Inc., Washington, D.C., 1981 data.

4.5.1.2 Magnet Wire

A. Process and Facility Description[1]

Magnet wire coating is the process of applying a coating of electrically insulating varnish or enamel to aluminum or copper wire for use in electrical machinery. The uncoated wire is unwound from spools and passed through an annealing furnace to make the wire more pliable and to burn off oil and dirt left from previous operations. The wire passes from the furnace to the coating applicator. At a typical applicator, the wire acquires a thick coating by passage through a coating bath. The wire is then drawn vertically through an orifice or coating die which scrapes off excess coating and leaves a thin film of the desired thickness. The wire is routed from the coating die into an oven where the coating is dried and cured. A typical oven has two zones. The wire enters the drying zone, held at 200°C, and exits through the curing zone, held at 430°C. A wire may pass repeatedly through the coating applicator and oven to build a multilayered coating. After the final pass through the oven, the wire is rewound on a spool for shipment. There are approximately 30 plants nationwide which coat magnet wire.

B. Emission Sources and Factors

The oven exhaust is the most important emission source in the wire coating process. Solvent emissions from the applicator are low due to the dip coating technique. A typical uncontrolled wire coating line emits about 12 kilograms of VOC per hour. It is not unusual for a wire coating plant to have 50 ovens, therefore an uncontrolled plant could easily emit more than 90 megagrams of VOC per year.[1,2]

C. Control Techniques and Emission Reductions[1]

Incineration, either thermal or catalytic, is the most common control technique for emissions from wire coating operations. Essentially all solvent emissions from the oven can be directed to an incinerator with a combustion efficiency of at least 90 percent. Equivalent emission reductions achieved through coating reformulations would require replacement of conventional solvent-borne coatings with either high-solids coatings (greater than 77 percent solids by volume) or waterborne coatings

(i.e., 29 volume percent solids, 8 volume percent organic solvent, 63 volume percent water). Use of powder coatings, hot melt coatings or waterborne emulsions, which contain little or no organic solvent, would eliminate VOC emissions.

D. Regulatory Status[1]

The EPA issued a guideline (CTG) in 1977 which recommends emissions from wire coating ovens be limited to 0.20 kilograms of VOC per liter of coating (minus water). This limit was based on use of incineration control although conversion to a low solvent coating that yields equivalent reductions would be an acceptable alternative.

E. National Emission Estimates

Coatings used for insulating of magnet wire in 1983 are estimated to have contained 22,000 megagrams of VOC.[3] Since many magnet wire lines already use incinerators, it is estimated that less than 7,000 Mg per year of VOC was actually emitted.

F. Capital and Annual Control Costs[1]

The capital and annual costs of a facility which exhausts 10,000 scfm that controls VOC emissions by incineration with primary heat recovery are approximately $325,000 and $170,000, respectively. The costs are for a typical size magnet wire facility; however, line sizes vary and the cost of the control equipment will be a function of the number of coating lines served by a single piece of control equipment. See reference 1 for a more complete discussion of costs.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume IV: Surface Coating for Insulation of Magnet Wire, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-77-033, December 1977.

2. Magnet Wire Coating. Compilation of Air Pollutant Emission Factors, Third Edition, Supplement NO. 15, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, January 1984.

3. Based on information provided by the National Paint and Coatings Association, Inc.

4.5.1.3 Automobiles and Light-Duty Trucks

A. Process and Facility Description[1]

The automobile and light-duty (less than 8,500 pounds gross vehicle weight) truck assembly industry receives parts from a variety of sources and produces finished vehicles ready for sale to vehicle dealers. The automobile and light-duty truck coating process is a multistep operation performed on an assembly line producing up to 90 units per hour. There were about 65 automobile or light-duty truck assembly plants in the United States in 1984.

Body surfaces to be coated are cleaned with various materials which may include solvents to remove oil and grease. Then a phosphating process prepares the surface for the prime coat. The primer is applied to protect metal surfaces from corrosion and to ensure good adhesion of the topcoat. Primer may be solvent-based or waterborne. Solvent-based primer is applied by a combination of manual and automatic spraying, flow coat or dip processes. Waterborne primer is most comon now and is most often applied in an electrodeposition (EDP) bath. The prime coat is oven cured before further coating. When EDP is used to apply primer, the resulting film may be too thin and rough to compensate for all surface defects, so a guide coat (primer-surfacer) is usually applied and oven-cured before the topcoat application. Recent developments in EDP technology produce a thicker dry film which in some cases elminates the need for the guide coat.

On some vehicles an additional coating called a chip guard or anti-chip primer is applied along the bottom of the doors and fenders. These flexible urethane or plastisol coatings help protect susceptible parts of the coated vehicle from damage by stones or gravel.

The topcoat (color) is then applied by a combination of manual and automatic spraying. The topcoat requires multiple applications to ensure adequate appearance and durability. An oven bake may follow each topcoat application, or the individual coats may be applied wet-on-wet with a final oven bake.

The painted body is then taken to a trim operation area where vehicle assembly is completed. Some additional coating may be done in a final off-line repair step if needed to correct paint defects or damage.

Single coating (not clearcoated) lacquer and enamel topcoats have traditionally been used in this industry. Since 1980, the entire domestic auto industry has been converting to a composite, two coating, topcoat system which consistes of a thin layer of a highly pigmented basecoat followed by a thick layer of clearcoat. These two coating systems are referred to as basecoat/clearcoat. They can provide higher gloss and better chemical resistance than conventional single coating topcoats, especially for metallic colors. Some domestic manufacturers are switching all of their colors to basecoat/clearcoat while others are using basecoat/clearcoat for metallic colors only. The switch to basecoat/clearcoat was prompted by the use of basecoat/clearcoat on virtually all imported metallic colored cars.

B. Emission Sources and Factors[2]

Solvent emissions occur in the application and curing stages of the surface coating operations. The application and curing of the prime coat guide coat and topcoat accounted for a majority of the VOC emitted from most assembly plants in the past. Over the last ten years, conversions to lower VOC content coatings and more efficient application equipment has reduced the contribution of these operations to total plant-wide VOC emissions at many assembly plants. Final topcoat repair, cleanup, adhesives, sound deadeners, and miscellaneous coating sources account for the remaining emissions. Approximately 70 to 90 percent of the VOC emitted during the application and curing process is emitted from the spray booth and flashoff areas, and 10 to 30 percent from the bake oven. Typical emission ranges for major automobile surface-coating operations are summarized in the table below:

Coating	Kg VOC/Vehicle	lb VOC/Vehicle
Prime Coat		
Solvent-borne spray	1.8-3.6	4-8
Electrodeposition	0.5-1.4	1-3
Guide Coat		
Solvent-borne spray	0.5-1.8	1-4
Waterborne spray	0.5-0.8	1-2
Topcoat		
Solution lacquer	13.6-22.7	30-50
Dispersion lacquer	5.9-9.1	13-20
Conventional enamel	5.0-10.0	11-22
Higher solids enamel	2.3-5.0	5-11
Waterborne enamel	1.6-2.7	3.5-6

C. Control Techniques and Emission Reductions[1]

Use of waterborne EDP coatings is the most common control technique for prime coats. Waterborne guide coats and topcoats have been used in three plants.

Since 1980, the industry and its suppliers have focused primarily on developing higher solids solvent-borne enamels and improving transfer efficiency. Most of the coating development work has been directed toward basecoat/clearcoat coatings. Low solids, high VOC content basecoat/clearcoat materials have been used since the mid-1960's, especially on metallic-colored imported cars. Higher solids basecoat/clearcoat topcoats have been developed to help meet VOC emission regulations and match the appearance of imported vehicles. These coatings are in use at many plants, including two of the plants that used waterborne topcoats. (The third plant that used waterborne topcoats has closed.)

New coating application systems are also being installed in assembly plants. Electrostatic, automatic and robot spray equipment are being used to improve transfer efficiency, quality and productivity.

Add-on control devices are also applicable in this industry. Thermal incineration can reduce VOC emissions from bake oven exhausts by at least 90 percent. Pilot studies in the United States have proven that carbon

adsorbers can efficiently reduce spray booth exhaust emissions. Several manufacturers are actively considering installation of carbon adsorption on some spray booth exhausts to meet VOC emission limitations and for odor control.

D. Regulatory Status

The EPA issued a guideline (CTG) in 1977. The guideline contained recommendations which were expressed in terms of the VOC content of the various coatings and were based upon waterborne coatings then in use for primer, guide coat and topcoat; and solvent-borne coatings for final repair. Later guidance suggested associating a baseline transfer efficiency of 30 percent with the recommendations for guide coat and topcoat. This later recommendation was based on the results of transfer efficiency tests conducted at two plants using waterborne guide coat and topcoat.

The CTG recommendations are summarized below:

	CTG Recommendation Kg VOC/liter (lb/gal) coating less water		Later Guidance Kg VOC/liter (lb/gal) solids applied	
Operation				
Prime coat	0.15	(1.2)		
Guide coat	0.34	(2.8)	1.8	(15.1)
Topcoat	0.34	(2.8)	1.8	(15.1)
Final repair	0.58	(4.8)		

An NSPS was promulgated in 1980 (40 CFR 60 Subpart MM). These standards are summarized below:

	Emission Limit Kg VOC/liter (lb/gal) solids applied	
Affected Facility		
Prime coat	0.16	(1.3)
Guide coat	1.40	(11.7)
Topcoat	1.47	(12.2)

A revision to the prime coat NSPS was proposed on July 29, 1982 (47 FR 146). This revision has not yet been made final. The purpose of the revisions is to better describe the emission characteristics of the

best demonstrated technology (cathodic electrodeposited primer) under a variety of operating conditions.

E. National Emission Estimates

The surface coating (prime coat, guide coat, topcoat and final repair) of automobiles and light-duty trucks is estimated to have resulted in VOC emissions of approximately 64,000 megagrams (70,000 tons) in 1984.[4]

F. Capital and Annual Control Costs

The cost of controlling topcoat bake oven and spray booth emissions with incinerators or carbon adsorbers varies with the VOC and solids content of the coatings used, ventilation rates, production rates, and other plant specific factors.

G. References

1. Automobile and Light-Duty Truck Surface Coating Operations - Background Information for Proposed Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/3-79-030, September 1979.

2. Letter from Fred W. Bowditch, Motor Vehicle Manufacturers Association to Jack R. Farmer, U.S. EPA, September 13, 1985.

3. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles and Light-Duty Trucks, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-77-008, May 1977.

4. Based on information provided by the National Paint and Coatings Association, Inc.

4.5.1.4 Cans

A. Process Description

There are two major types of cans. Coating application methods used by can manufacturers vary with the type of can. The coatings used depend on the type of can and the type of product to be packed in the can.

A "three-piece" can is made from a cylindrical body and two end pieces. A large metal sheet is first roll coated with both an exterior and an interior coating, then cut to size, rolled into a cylinder (body) and sealed at the side seam. A bottom end piece formed from coated metal is then attached to the body. The can interior may then be spray coated before the can is filled with a product and sealed with the top end piece.

A "two-piece" can body and bottom is drawn and wall ironed from a single shallow cup. After the can is formed, exterior and interior coatings are applied by roll coating and spraying techniques, respectively. The can is then filled with product and the top end piece is attached.[1]

The metal can industry consists of over 400 plants nationwide.[2] In recent years there has been a dramatic shift from three-piece cans to two-piece cans. Almost all beverage cans and many food cans are now two-piece.

B. Emission Sources and Factors

Solvent emissions from can coating operations occur from the application area, flashoff area, and the curing/drying oven. Typical per plant, annual emissions from can coating operations were estimated in 1977 to vary from 13 megagrams (14 tons) for the end sealing operation to 240 megagrams (264 tons) for coating two-piece cans.[2] Since then, increased use of low VOC content waterborne coatings, especially for two-piece beverage cans has reduced emissions considerably.

Emissions vary with production rate, VOC content of coatings used, and other factors. More detailed information on the annual emissions from individual coating operations in can manufacturing plants is presented in Reference 4.

C. Control Techniques and Emission Reductions

Emission reductions of up to 90 percent can be achieved by incinerating

emissions from can coating operations. Substitution of waterborne or high-solids coatings for conventional coatings can reduce VOC emissions by 60 to 90 percent at many of these operations.[1,3]

D. Regulatory Status

The EPA issued a guideline in 1977 which recommends separate VOC emission limits for the different steps in the can coating process. Although generally based on abatement techniques, the emission limits were expressed in terms of the VOC content of the coating to encourage development and use of low solvent coatings.

Can Coating CTG Recommendations[1]

Affected Facility	Recommended Limitation	
	kg per liter of coating minus water	lb per gallon of coating less water
	0.34	2.8
Sheet basecoat (exterior and interior and overvarnish; two-piece can exterior (basecoat and overvarnish)		
Two and three-piece can interior body spray, two-piece an interior end (spray or roll coat)	0.51	4.3
Three-piece can side-seam spray	0.66	5.5
End sealing compound	0.44	3.7

The EPA set new source performance standards in 1983 (40 CFR 60 Subpart WW) which limit VOC emissions from two-piece beverage can surface coating operations as follows:

(1) 0.29 kilograms VOC per liter (2.4 pounds per gallon) of coating solids from each exterior base coating operation except clear base coating.

(2) 0.46 kilograms VOC per liter (3.8 pounds per gallon) of coating solids from each over-varnish coating and each clear base coating operation,and

(3) 0.89 kilograms VOC per liter (7.4 pounds per gallon) of coating solids from each inside spray coating operation.[4,5]

E. National Emission Estimate

It has been estimated that surface coating of cans resulted in emissions of 68,000 megagrams (75,000 tons) of VOC in 1981.[7]

F. Capital and Annual Control Costs[3]

A can coating facility with a 5,000 scfm exhaust stream using either thermal or catalytic incineration (with primary heat recovery), or carbon adsorption (with credit for recovered solvent at fuel value), would require a capital expenditure ranging from $190,000 to $240,000 and have annualized costs from $60,000 to $110,000 (2nd quarter dollars). Control costs vary with production rate and other factors. More detailed informatin is presented in Chapter 8 of Reference 3.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks. EPA-450/2-77-008, OAQPS No. 1.2-073, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. May 1977.

2. U. S. Industrial Outlook 1983. U. S. Department of Commerce, Washington, D. C. January 1983.

3. Beverage Can Surface Coating Industry - Background Information for Proposed Standards, EPA-450/3-80-036a, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. September 1980.

4. Beverage Can Surface Coating Industry - Background Information for Promulgated Standards, EPA-450/3-80-03b. U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. August 1983.

5. Standards of Performance for New Stationary Sources; Beverage Can Surface Coating Industry. Proposed Rule. Federal Register, Vol 45, No. 230, November 26, 1980.

4.5.1.5 Metal Coils

A. Process and Facility Description[1]

The metal coil coating industry applies coatings to metal sheets or strips that come in rolls or coils. The metal strip is uncoiled at the beginning of the coating line, cleaned and then pretreated to promote adhesion of the coating to the metal surface. When the coil reaches the coating application station, a coating is applied, usually by rollers, to one or both sides of the metal strip. Some coil coatings are applied by electrodeposition. The strip then passes through an oven to cure the coating and is then water or air quenched. If the line is a "tandem" line, the metal strip passes through a second sequence of coating applicator, oven and quench station. Finally, the coil is rewound for shipment or further processing. In 1980, there were 109 plants containing an estimated 147 coil coating lines in the United States.

B. Emission Sources and Factors1

Approximately 90 percent of the total VOC content of the coating evaporates in the curing ovens. Of the remaining 10 percent, about 8 percent evaporates at the applicator station and 2 percent at the quency station. The rate at which VOC emissions occur is determined by the operating parameters of the line, including: (1) the width of the metal strip, (2) the VOC and solids content of the coating, (3) the speed at which the strip is processed, (4) the thickness at which the coating is applied and (5) whether emission abatement equipment has been installed. Annual emission from a coil coating line may range from 30-2000 megagrams (35-2200 tons). More detailed information on emission rates is presented in Reference 1.

C. Control Techniques and Emission Reductions

An 80-90 percent emission reduction can be achieved by venting the VOC that evaporates in the oven (90 percent) and directing it to an incinerator. An overall VOC emission reduction of 90 percent or more may be achieved if emissions from the coating application stations are also vented to an incinerator.[1]

Low solvent and waterborne coatings are also available for many end uses. These coatings may achieve emission reductions of up to 90 percent compared to conventional solvent-borne materials. In 1980, approximately 15 percent of the coatings used were waterborne.

D. Regulatory Status

The EPA issued a guideline (CTG) in 1977 and set NSPS standards (40 CFR 60 Subpart TT) in 1982 to control emissions from metal coil surface coating operations. The CTG recommends a VOC emission limit of 0.31 kilograms per liter of coating minus water (2.6 pounds per gallon minus water).[2] The NSPS has the following emission limits:

(1) 0.28 kilograms of VOC per liter (2.3 pounds per gallon) of coating solids applied for each calendar month for each affected facility that does not use an emission control device; or

(2) 0.14 kilograms of VOC per liter (1.2 pounds per gallon) of coating solids applied for each calendar month for each affected facility that continuously uses an emission control device; or

(3) a 90 percent emission reduction for each calendar month for each affected facility that continuously uses an emission control device, or

(4) a value between 0.14 (or a 90 percent emission reduction) and 0.28 kilograms of VOC per liter (1.2 and 2.3 pounds per gallon) of coating solids applied for each calendar month for each affected facility that intermittently uses an emission control device.

E. National Emission Estimate

It has been estimated that metal coil surface coating operations emitted approximately 33,000 megagrams (36,000 tons) in 1984.[3]

F. Capital and Annual Control Costs[1]

For a metal coil coating facility with a coating capacity of 14×10^6 square meters (15×10^7 square feet) per year, the capital and annual control cost for an incineration system capable of achieving 90 percent overall emission reduction is estimated to be $1,650,000 and $230,000, respectively (2nd quarter 1984 dollars). The annual emission

reduction at such a plant would be 750 megagrams (820 tons).

Control costs vary with the factors described in Section B above. More detailed information on control costs is provided in Chapter 8 of Reference 1.

G. References

1. Metal Coil Surface Coating Industry - Background Information for Proposed Standards, EPA-450/3-80-035a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1980.

2. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles,l and Light-Duty Trucks, EPA-450/2-77-008, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1977.

3. Based on information provided by the National Paint and Coatings Association, Inc.

4.5.1.6 Paper, Film and Foil*

A. Process and Facility Description

Paper is coated for a variety of decorative and functional purposes with a variety of coatings which may be waterborne, organic solvent-borne, or solventless extrusion type materials. A coating operation is defined as the application of a uniform layer across a substrate. This definition of coating also includes saturation processes. In paper-coating operations, the coating mixture is usually applied by means of a reverse roller, a knife, or a rotogravure roller to a web of paper. The major components of a paper-coating line are, in sequence: the unwind roll (from which the paper is fed to the process), the coating applicator, the oven, tension and chill rolls, and the rewind roll. Ovens may be divided into from two to five different temperature zones. The first is usually maintained at about 43°C. The other zones have progressively higher temperatures up to 200°C to cure the coating after most of the solvent has evaporated. The large volume organic solvents used in paper coating mixtures are toluene, xylene, methyl ethyl ketone, isopropyl alcohol, methanol, acetone and ethanol.[1] There are approximately 800 plants nationwide where paper-coating operations are employed.[2]

B. Emission Sources and Factors[3]

The main emission points from a paper-coating lines are the coating applicator and the oven. In a typical paper-coating plant, about 70 percent of all emissions are from the coating lines, The other 30 percent are emitted from solvent transfer, storage and mixing operations. Most of the VOC emitted by the line are from the first zone of the oven.

* Throughout this section, the term "paper coating" refers to coating of paper, plastic film and metallic foil. Products with plastic substrates such as magnetic tape and photographic film are included as are all types of pressure sensitive tapes and labels, regardless of substrate.

C. Control Techniques and Emission Reductions[1]

Almost all emissions from a coating line can be contained and sent to a control device. Thermal incinerators and carbon adsorbers can operate at 98 and 95 percent efficiencies, respectively. Use of low-solvent coatings can achieve significant reductions in VOC emissions when substituted for conventional organic solvent-borne coatings. One type, waterborne, can effect an 80 to 99 percent reduction.

Fugitive emissions from solvent transfer, storage and mixing operations can be reduced through good housekeeping practices, such as maintaining lids on mixing vessels, and good maintenance, such as repairing leaks promptly.

D. Regulatory Status[1]

The EPA issued a guideline in 1977 which recommends VOC emissions from paper-coating lines be limited to 0.35 kilograms of VOC per liter of coating minus water.

E. National Emission Estimates[4]

It has been estimated that 175,000 megagrams of VOC were emitted in 1984 by paper-coating operations (excluding those from coating pressure sensitive tapes and labels). Emission estimates for pollution from coating pressure sensitive tape and labels are given in Section 4.5.6.1.

F. Capital and Annual Control Costs[5]

The cost of carbon adsorption for a line coating adhesive onto 39 million square meters (10^6 m^2) year of paper have been estimated as $1,343,000 total installed capital costs and an annual operating credit of $648,000 due to the value of recovered solvent. Control costs will, of course, vary with the size of a line. Generally, the smaller the line, the greater the cost of control per ton of solvent removed. Costs for a range of line sizes are discussed in reference 5.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks, EPA-450/2-77-008, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1977.

2. Census of Manufacturers, 1982. Bureau of Census, U. S. Department of Commerce.

3. Paper Coating. In: Compilation of Air Pollutant Emission Factors, Third Editor, Supplement No. 15, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, January 1984.

4. Organic Solvent Use in Web-coating Operations, EPA-450/3-81-012, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1981.

5. Pressure Sensitive Tape and Label Surface Coating Industry - Background Information for Proposed Standards, EPA-450/3-80-003a, U. S. Environmental Protection Agency, September 1980.

4.5.1.6.1 Pressure Sensitive Tapes and Labels

A. Process and Facility Description[1,2]

The coating of pressure sensitive tapes and labels (PSTL) is an operation in which a backing material such as paper, cloth, or cellophane is coated one or more times to create a tape or label that sticks on contact. Adhesives and release agents are the two primary types of coatings applied in this industry. Essentially all of the VOC emissions from the PSTL industry come from solvent-based coatings which are used to produce 80 to 85 percent of all PSTL products.

In the solvent-based coating process, a roll of backing material is unrolled, coated, dried, and rolled up. The coating may be applied to the web by knife coater, blade coater, metering rod coater, gravure coater, reverse roll coater, or a dip and squeeze coater.

After the coating has been applied, the web moves into a drying oven where the web coating is dried by solvent evaporation and/or cured to a final finish. Direct-fired ovens are the most common type used. Drying ovens are typically multizoned with a separate hot air supply and exhaust for each zone. The temperature increases from zone to zone in the direction in which the web is moving, thus the zone maintained at the highest temperature is the final zone that the web traverses before exiting the oven. A large drying/curing oven may have up to six zones ranging in temperature from 43°C to 204°C.

A tandem coating line is one in which the web undergoes a sequence of coating and drying steps without rewidening between steps. Tandem coating lines are usually employed by plants that manufacture large volumes of the same product.

Over 100 plants with a total of about 300 coating lines produce pressure sensitive tapes and labels in the United States.

B. Emission Sources and Factors[2]

By definition, all PSTL products have an adhesive coating. It is generally the thickest coating applied and the source of 85 to 95 percent of the total emissions from a line.

In an uncontrolled facility, essentially all of the solvent used in the coating formulation is emitted to the atmosphere. Of these uncontrolled emissions, 80 to 95 percent are emitted from the drying oven. A small fraction of the coating solvent may remain in the web after drying. The remaining 5 to 20 percent of applied solvent is lost as fugitive emissions by evaporation from a number of small sources such as the applicator system and the coated web upstream of the drying oven. Some fugitive losses also occur from storage and handling of solvent, spills, and mixing tanks, and during cleaning of equipment, such as a gravure roll.

The emission factor for uncontrolled emissions from a drying oven ranges from 0.80 to 0.95 kg VOC per kg of total solvent used. The emission factors for fugitive losses in the plant and from the product due to retention are estimated at 0.01 - 0.15 and 0.01 - 0.05 kg VOC per kg total solvent used, respectively.

C. Control Techniques and Emission Reductions[1,2]

Carbon adsorption and thermal incineration control systems are suitable for the PSTL industry. Both systems can reduce the VOC emissions directed to them by 95 percent. The overall control efficiency for both devices is dependent upon the efficiency of the emission capture system.

Drying ovens capture 80 to 95 percent of VOC emissions from the coating process. Floor sweeps and/or hooding systems around the coating head and exposed coated web will increase the overall capture efficiency. Total enclosure of the entire coating line or lines theoretically can contain 100 percent of the emissions. By venting the exhausts from a total enclosure to a carbon adsorber or incinerator, overall emission control efficiencies of over 90 percent are possible.

An alternate emission control technique is the use of low-VOC coatings such as waterborne, hot-melt, and radiation cured coatings. Emissions of VOC from such coatings are negligible. There may not be a low-VOC coating available for every product in the PSTL industry.

D. Regulatory Status

The EPA issued a control techniques guideline in 1977 for paper coating, including the PSTL industry, which recommends emissions from coating lines be limited to 0.35 kilograms of VOC per liter of coating minus water.[3] In 1983, the EPA promulgated NSPS standards (40 CFR 60 Subpart RR) which requires emissions from coating lines to be limited to 0.20 kilograms of VOC per kilogram of coating solids applied. A 90 percent overall VOC emissions reduction is considered equivalent to this limit.

E. Current National Emission Estimate[1]

The estimated total national VOC emissions potential from the PSTL industry is from 300,000 to 600,000 megagrams per year.

F. Capital and Annual Control Costs[1]

The control costs of carbon adsorption for a 39 million square meters (10^6 m^2)/yr production PSTL plant have been estimated as $1,343,000 total installed capital costs and $648,000 total annual operating savings in operating costs due to the value of recovered savings. These costs are for a fairly large line which is typical of a manufacturing plant, but line size for pressure sensitive tape lines can vary greatly. Reference 1 gives costs for a range of line sizes.

G. References

1. Pressure Sensitive Tape and Label Surface Coating Industry - Background Information for Proposed Standards - and Promulgated Standards, EPA-450/3-80-003a and b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1980 and September 1983.

2. Pressure Sensitive Tapes and Labels. In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No. 13, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1982.

3. Control of Volatile Organic Emissions form Existing Stationary Soruces - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks, EPA 450/2-77-008, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1977.

4.5.1.6.2 Magnetic Tape

A. Process and Facility Description

Organic solvent, metal-oxide particles and suitable resins are combined to form the coatings used by magnetic tape coating operations. The coating equipment consists of an unwind roll for the plastic film substrate, a coating applicator, a drying oven and a windup roll for the coated tape. The coating mixture is supplied to the plastic film substrate by the coating applicator (often via some sort of roll or rotogravure coater). The plastic film is carried through the drying oven where organic solvent evaporates. The plastic substrate with the dried magnetic coating is then rewound at the end of the line. Slitting operations to produce the consumer product are almost always performed later as an off-line operation.

B. Emission Sources and Factors

Roughly ten percent of the solvent used by a plant evaporates from mix and storage tanks. Another ten percent evaporates from the coating applicator and the flash-off area between the coater and the oven. The remainder evaporates in the drying oven and is exhausted through the oven exhaust stack.

A typical coating operation with one coating line would process about 700 Mg of solvent annually. Of this, about 70 Mg will evaporate from the mix room and storage areas. The remainder, about 630 Mg, will evaporate from the coating line.

C. Control Techniques and Emission Reductions[1]

The oven exhaust, which typically contains 80 percent or more of the solvent used in the plant can be ducted to a control device operated at more than 95% efficiency to remove organic solvents from the gas stream. Carbon adsorption is the most commonly used control device since the recovered solvent can be reused. Other control devices used by the industry are incinerators and condensation systems.

Some plants have an enclosure around the coating applicator and flashoff area. Emissions from the enclosure are ducted to the control device. Vessels in the mix room can also be vented to a control device.

D. Regulatory Status

The EPA issued a guideline (CTG) in 1977 for "paper coating" which included magnetic tape and other plastic film coating.[2] This CTG recommends that emissions from the coating operation be no more than if a coating containing 0.35 kg of VOC per liter of coating (minus water) is used. This is equivalent to about an 81 percent reduction in emissions from a typical operation. An NSPS currently being written for this industry was proposed on January 22, 1986.[3]

E. Current National Emission Estimates

It is estimated that 38,000 Mg of VOC was used in the production of magnetic tapes in the U.S. in 1984.[4] Due to abatement devices already in use only about 20 percent of this solvent was actually emitted. Therefore, emissions were about 7,600 Mg/year of VOC from all domestic magnetic tape plants in 1984.

F. Capital and Annual Control Costs

For a typical line (0.66 meter wide, 2.5 m/second line speed), the capital cost for installing a carbon adsorber is $1,695,000.[1] The annual operating cost and capital charges for the absorber are estimated to be $43,200. This fairly low operating cost results from the large credit for recovered solvent which offsets part of the annualized capital cost. These costs are for a large line which is typical of manufacturing plants. Smaller lines are becoming increasingly popular. Their control equipment costs are lower, but recovered solvent credit is less. See reference 1 for a full cost analysis of various size lines.

G. References

1. "Magnetic Tape Manufacturing Industry - Background Information for Proposed Standards," Preliminary Draft, U.S. Environmental Protection Agency, November 1984.

2. "Control of Volatile Organic Emissions from Existing Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles and Light-Duty Trucks," U.S. Environmental Protection Agency, EPA-450/2-77-008, May 1977.

3. January 22, 1986, Federal Register, page 2996.

4. "Organic Solvent Use in Web Coating Operations," U.S. Environmental Protection Agency, EPA-450/3-81-012, September 1981.

4.5.1.7 Fabric Coating And Printing

A. Process and Facility Description

Fabric coating involves the application of decorative or protective coatings to a textile substrate. A large segment of this industry is application of rubber coatings to fabrics.[1] More specifically, for purposes of the regulatory program, fabric coating is the uniform application of, 1) an elastomeric or thermoplastic polymer solution, or 2) a vinyl plastisol or organisol, across all of one (or both) side of a supporting fabric surface or substrate.[2] The coating imparts to the fabric substrate such properties as elasticity, strength, stability, appearance, and resistance to abrasion, water, chemicals, heat, fire or oil.[3] Coatings are usually applied by blade, roll coater, reverse roll coater, rotogravure coater, or dip coater.

The basic fabric coating process includes preparation of the coating, the application of the coating to the substrate, and the drying/curing of the applied coating. The web substrate is unwound from a continuous roll, passed through a coating applicator and drying/curing oven, and then rewound.

Fabric printing is application of a decorative design to a fabric by intaglio (etched) roller (another name for rotogravure), rotary screen, or flat screen printing operation. The fabric web passes through the print machine where a print paste is applied to the substrate. After leaving the print machine, the web passes over steam cans or through a drying oven to remove water and organic solvent from the printed product. After the drying process, the fabric is washed and dried again.[4]

There are at least 130 fabric coating plants[3] and approximately 200 fabric printing plants[4] located throughout the United States.

B. Emission Sources and Factors

The major sources of VOC emissions in a fabric coating plant are the mixer and coating storage vessels, the coating applicator, and the drying oven. The relative contribution of these three areas are estimated at 10

to 25 percent, 20 to 30 percent and 45 to 70 percent, respectively. The potential VOC emissions from a fabric coating plant are equal to the total solvent used at the plant.[2]

The most significant source of VOC emissions in a fabric printing plant is the drying process, either the steam cans or the ovens. Other emissions occur as fugitive VOC. These are as evaporation from wastewater streams, open print paste barrels, printing troughs, the printing rollers and screens, "strikethrough" onto the backing material, and from the printed fabric before it reaches the drying process. Average emission factors for printing fabric are 142 kg VOC per 1000 kg fabric for roller printing, 23 kg VOC per 1000 kg fabric for rotary screen printing, and 79 kg VOC per 1000 kg fabric for flat screen printing.[5]

C. Control Techniques and Emission Reductions

Incineration is the most common means for control of coating application and curing emissions on fabric coating lines which use a variety of coating formulations. Coaters which use a single solvent can be most economically controlled by carbon adsorption.[2] Either of these control devices can reduce the VOC emissions in the gases directed to the device by 95 percent or more. Inert gas condensation systems may be applicable to some fabric coating lines. Such systems are estimated to be about 99 percent efficient in the recovery of solvent which passes through the system.[3]

The overall emission reduction achievable by any of technology depends on the efficiency of the vapor collection or capture device. Total enclosure of the coating and flashoff area should allow the operator to achieve a 95 percent capture efficiency. Partial enclosures, more common in this industry, should achieve 90 percent capture or more, if well-designed. Fugitive losses from solvent storage tanks may be reduced through use of pressure vacuum relief valves or disposable-canister carbon adsorbers.[3]

Presently there is no fabric printing plant that has installed add-on emission control technology for organic emissions.[5]

The use of low-solvent coatings or inks is an effective technique to reduce VOC emissions from both the fabric coating and printing industries. Waterborne, higher-solids, plastisol, calendered and extruded coatings are presently used in a significant number of fabric coating plants.[3] Use of low-solvent print pastes by the fabric printing industry has increased in the past decade. Significant reductions in VOC emissions have been achieved by switching to rotary screen printing processes that utilize waterborne print paste, or to a lesser extent, replacing the mineral spirit based intaglio inks with waterborne, foamed intaglio inks. Substitution of low-solvent coatings in place of conventional solvent-borne coatings can reduce VOC emissions by 60 to 98 percent, depending upon the formulations of the before and after coatings.[6]

D. Regulatory Status

The EPA issued a guideline (CTG) in 1977 which recommended emissions from fabric coating lines be limited to 0.35 kilograms of VOC per liter of coating (minus water). This limit was derived from use of an add-on control that results in an 81 percent overall emission reduction.[7] The EPA is currently developing a NSPS standard to regulate the emissions from polymeric coatings of supporting webs. It will restrict emissions from new fabric coating but not fabric printing operations.

Emissions from fabric printing lines are currently limited only by individual State regulations.

E. Current National Emission Estimates

The potential nationwide uncontrolled VOC emissions were estimated to have been 29,000 to 35,000 megagrams (in 1984) from fabric coating[3] and approximately 38,000 megagrams (in 1982) from fabric printing.[8]

F. Capital and Annual Control Costs

Capital and annualized cost of pollution control for fabric coaters are influenced primarily by the choice of abatement equipment, the total amount of VOC generated by the process being controlled and the level of control that is required. The VOC that is generated is a function of process rates, solvent content of the coatings and the rate of coating

consumption. Presented below is a table of capital and annualized cost (May 1984) for two types of control equipment and three rates of solvent usage. The analysis used to produce these values assumes the level of VOC control is 81 percent.

Solvent Usage (Mgs/yr)	Capital Cost ($)		Annualized Cost ($)	
	Carbon Adsorption	Condensation	Carbon Adsorption	Condensation
95	286,000	168,000	62,000	23,000
154	261,000	147,000	43,000	15,000
308	352,000	223,000	37,000	savings

For more details on control cost for fabric coatings, refer to reference 3.

Capital and annualized cost of pollution control for fabric printers are influenced generally by the same factors. One additional key determinant of solvent use, however, is whether the printing machine is rotary screen, flat screen, or roller. The solvent content for each respective type of print paste is different. The different pieces of equipment result in rather divergent process emission profiles, i.e., relative amounts of fugitive, flash off and oven emissions. Below are three sets of capital and annualized cost (May 1984) based on printing machine type.

Printing Machine Type	Organic Solvent Consumption(Mgs/yr)	Capital Cost ($)		Annualized Cost ($)	
		Carbon Adsorption	Incineration	Carbon Adsorption	Incinerati
Rotary Screen	270	990	1,020,000	1,310,000	1,390,000
Flat Screen	30	790	840,000	600,000	620,00
Roller	290	650	620,000	1,270,000	1,400,00

For additional information on control costfor fabric printing, refer to reference 10.

G. References

1. Summary of Group I Control Technique Guideline Documents for

Control of Volatile Organic Emissions from Existing Stationary Sources. EPA-450/3-78-120 U. S. Environmental Protection Agency, Research Triangle Park, N.C., December 1978.

2. Fabric Coating In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No.15, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, N.C., January 1984.

3. Polymeric Coating of Supporting Substrates - Background Information for Development of New Source Performance Standards (Draft), EPA Contract No. 68-02-3817, October 1985.

4. Fabric Printing. In: Summary of Technical Information for Selected Volatile Organic Compound Source Categories, EPA-450/3-81-007, U. S. Environmental Protection Agency, Research Triangle Park, N.C., May 1981.

5. Textile Fabric Printing. In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No.13, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, N.C., August 1982.

6. General Industrial Surface Coating. In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No. 15, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, N.C., January 1984.

7. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks. EPA-450/2-77-008. U. S. Environmental Protection Agency, Research Triangle Park, N.C., May 1977.

8. Memorandum from Johnson, W., EPA to Berry, J., EPA. Emission Estimates for CAS Industries, December 16, 1982.

9. Memorandum from Banker, L., MRI; to Crumpler, D., EPA. Final Tabular Costs, Polymeric Coating of Supporting Substrates, November 29, 1984.

10. Economic Impact Analysis of Catalytic Incineration and Carbon Adsorption on the Fabric Printing Industry, EPA Contract No. 68-02-3535, November 1981.

4.5.1.8 Metal Furniture

A. Process and Facility Description[1,2]

Metal furniture coating consists of the application of prime and top coatings to any piece of metal furniture or metal part included in the categories of household furniture, office furniture, public building and related furniture, and partitions and fixtures. Typically, the metal substrate is first cleaned, rinsed in a phosphate bath and oven-dried to improve coating adhesion. If a prime coat is necessary, the part may be dipped, sprayed, or flow coated and then dried in a curing oven. Subsequent top coats, or in the event no prime is requied, the single topcoat is usually by spray. The freshly-coated parts are conveyed to the oven through a flashoff tunnel during which the coating "flows out" to a uniform thickness and some of the solvent evaporates. The parts are baked in single or multi-pass ovens at 150-230°C.

There are approximately 1400 known domestic metal furniture coating plants, including 445 for household and 253 for office furniture.[3] There are likely several hundred more that custom manufacture, finish or refinish metal furniture that have not yet been identified.

B. Emission Sources and Factors

Specific emission sources on the coating line are the coating application, the flash-off area and the bake oven. On the average conveyorized spray coating line, it is estimated that about 40 percent of the total VOC emissions come from the application station, 30 percent from the flash-off area, and 30 percent from the bake oven. In addition, fugitive emissions also occur during mixing and transfer of coatings. The uncontrolled VOC emission factor for a metal furniture coating is 0.66 kilograms of VOC per liter coating (minus water).

C. Control Techniques and Emission Reductions[1]

Control techniques used by this industry include converting to low-solvent coatings, improving transfer efficiency with state-of-the-art application equipment or incineration. Adoption of high-solids or waterborne

coatings can reduce VOC emissions from prime-coating operations by 70 and 92 percent, respectively. Conversion to an electrodeposition prime coat can reduce emissions by 94 percent. Emissions from topcoats can be reduced by conversion to waterborne, high-solids or powder coatings, giving reductions of up to 80 percent, 70 percent, and 99 percent, respectively.

Transfer efficiency (TE) is the ratio of the amount of coating solids deposited onto the surface of the coated part to the total amount of coating solids used. Improved TE decreases the volume of coating that must be used, thereby decreasing the total VOC emission rate.

Historically, the large volumes of air used to ventilate open-spray booths and flash-off areas made the expense of incinerating emissions from these sources prohibitive. Many industries are now applying a novel air management techniques to reduce the exhaust gas rates, thereby making VOC control feasible at more reasonable cost. Incineration of the curing oven exhaust can reduce overall emissions from the metal furniture surface coating line by up to 25 percent. Coupled with other technologies noted above, incineration can achieve even larger plant-wide emission reductions.

D. Regulatory Status

The EPA issued a guideline (CTG) in 1977 and set NSPS standards in 1982 (40 CFR 60, Subpart EE) to control emissions from surface coating of metal furniture. Based on emission reductions achievable by converting to low solvent coatings, the CTG recommends an emission limit of 0.36 kilograms of VOC per liter of coating minus water.[5] The NSPS requires emissions be limited to 0.90 kilograms of VOC per liter of coating solids applied. The limit is based on the use of a coating with 62 percent by volume solids and a 60 percent TE.

E. National Emission Estimates

It is conservatively estimated that surface coating of metal furniture results in emissions of about 95,000 megagrams of VOC per year.[6]

F. Capital and Annual Control Costs

The captial and annualized cost of control using low solvent coating technology depends upon the type coating that is selected, the size of the operation, the type of substrates that are coated, and the resulting

TE. Capital costs will generally reflect charges to the painting lines, and extra or new equipment necessary for applying the new coating technology. The annualized cost will primarily reflect changes in coating consumption which is a function of the transfer efficiency and the solids content of the new coating.

The table below presents a few capital and annualized costs (May 1984) for various types of low solvent coating technologies and three sizes of plants.

Facility Size ($\frac{M^2 \text{ coated}}{yr}$)	4,000,000		780,000		45,000	
Substrate Shape/TE	Flat/85%		Complex/65%		Flat/85%	
Application Method	Spray		Spray		Spray	
Coating Technology	Cost ($)		Cost ($)		Cost ($)	
	Capital	Annualized	Capital	Annualized	Capital	Annualized
Powder	356,000	163,000	124,000	-	42,000	-
Waterborne	1,000,000	287,000	308,000	85,000	46,000	8,000
70% Solids	-0-	-	-0-	-	-0-	-
65% Solids	-0-	-	-0-	-	-0-	-
60% Solids	-0-	-	-0-	-	-0-	-

Note that the costs for 60, 65, and 70 solids coatings are essentially the same as for conventional coatings. See reference 1 for more details on capital and annualized cost.

G. References

1. Surface Coating of Metal Furniture - Background Information for Proposed Standards, EPA-450/3-80-007a, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1980.

2. Summary of Group I Control Technique Guideline Documents for Control of Volatile Organic Emissions from Existing Stationary Sources, EPA-450/3-78-120, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1978.

3. Census of Manufacturers, 1982. Bureau of Census, U. S. Department of Commerce.

4. Metal Furniture Surface Coating. In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No. 14, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1983.

5. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume III: Surface Coating of Metal Furniture, EPA-450/2-77-032, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1977.

6. 1982 data provided by the National Paint and Coatings Association.

4.5.1.9 Wood Furniture

A. Process and Facility Description[1]

The wood furniture industry is one of the largest sources of VOC emissions among surface coating industries for three reasons: 1) it is a large industry, 2) the coatings traditionally used contain very little solids material, about 90 percent or greater is solvent and 3) because of the extremely low solids content of the coatings, very high volume of coatings are required to build the coating film on the manufactured product. Kitchen cabinet and household furniture plants account for almost 90 percent of all wood furniture facilities. Most wood furniture products are coated in a roughly similar way, although furniture will usually receive a much more elaborate series and greater number of finishes than kitchen cabinets.

The coating finish is applied in a series of steps. The number and complexity of coating steps may vary greatly, but the usual sequence is as follows: body stain, wash coat, filler, sealer, glaze and shading stains, and the final topcoat. The various layers of coating used in a particular case are referred to collectively as a coating system. Furniture finishing is still something of an art and the techniques, equipment, and procedures may vary considerably from plant to plant.

In larger furniture factories with conveyorized coating lines, coatings are usually applied by air spray at a separate spray booth for each coating operation. After the coating is applied at one spray booth, the conveyor carries it either to the next spray booth or to an oven. Ovens for wood furniture are set at relatively low temperatures since almost all wood finishes are lacquer solutions and the oven accelerates evaporation of the solvent. Wood furniture coatings generally are not of a type that require baking or curing. Coating lines without ovens rely on "air drying" or evaporation of the solvent at ambient temperature.

There are currently over 2,500 wood household furniture plants and approximately 3,000 wood kitchen cabinet plants in the United States.[2]

B. Emission Sources and Factors[1]

Individual furniture factories vary greatly in size, but a moderately large factory can emit around 1300 kilograms of VOC per day or over 300 megagrams per year. The amount of solvent emissions from a piece of furniture depends on the amount of each type of coating used as well as its solvent content. The source of essentially all VOC emissions in this industry is the evaporation of solvents from the applied coatings.

More VOC emissions come from application of the topcoat than from any other single step in the coating system. Usually the topcoat material is applied in two or three consecutive layers, each of which completely coat the part. An emission factor for each layer is approximately 14 kg of VOC per 100 square meters. Overall emission levels for a coating system range from 85 to 160 kilograms of VOC per 100 square meters of surface coated.

C. Control Techniques and Emission Reductions

Is is possible to reduce VOC emissions from wood furniture finishing operations by changes in coating materials or processes and/or by the use of add-on emission control devices. Material changes involve substituting coatings that have less VOC components, such as waterborne and higher solids coatings. Process changes can reduce the quantity of coating being wasted. A promising process change is the installation of electrostatic spray equipment to decrease paint waste. Manufacturers of air-assisted airless spray guns indicate that this type of spray equipment will improve transfer efficiency and reduce emissions. Add-on controls to reduce VOC emissions have not been used by this industry. Incineration would be the most practical abatement technique. Its cost, however, will be excessive until the industry explores innovative air management techniques such as enclosure of the spray booth and some scheme for recirculating the air which ventilates the booth.

Recent gains by foreign manufacturers in domestic sales of "flat line" furniture is awakening segments of the wood furniture industry to the need to investigate modern manufacturing techniques and improved coating systems. (Flat line furniture is a "modern" type furniture that is coated as

panels lying flat on a moving conveyer. The flat pieces are subsequently assembled into "boxy" shaped furniture.) Coatings used are opaque, catalyzed high solids materials that require oven curing. A typical flat line coating could emit 80 percent less emissions than conventional materials based on lower VOC content alone if high solids catalyzed coatings are used.

Conversion to systems that use waterborne coatings could reduce emissions from 26 to 94 percent. Electrostatic spray equipment can reduce VOC emissions by about 50 percent as a result of improved transfer efficiency. Where incinerators are used, control efficiencies of at least 90 percent can be attained on the VOC directed to the incinerator.

D. Regulatory Status

Emissions from coating of wood furniture are currently limited by a few State regulations. Illinois and California are two States that have drafted such rules. California's model rule, which has been adopted in the Los Angeles area, focuses on improved transfer efficiency of the spray operation.

E. Current National Emission Estimates

Total VOC emissions from coating wood furniture in 1984 have been estimated to be about 200,000 megagrams.[3]

F. Capital and Annual Control Costs[1]

The capital and total annualized costs of control by converting to waterborne coatings at a medium-sized wood furniture plant with 12 spray booths and 12 ovens are estimated at about $368,000 and $68,000, respectively. Since very little use has been made of waterborne coatings in the wood furniture industry, these costs are somewhat hypothetical.

G. References

1. Surface Coating of Wood Furniture. In: Summary of Technical Information for Selected Volatile Organic Compound Source Categories, EPA-450/3-81-007. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1981.

2. Census of Manufacturers, 1982. Bureau of Census, U.S. Department of Commerce.

3. Based on information provided by the National Paint and Coatings Association, Inc.

4.5.1.10 Flat Wood Paneling

A. Process and Facility Description[1]

A typical flat wood coating facility applies stains and varnishes to natural plywood panels used for wall coverings. Other plants print wood grain patterns on particle board panels that were first undercoated with an opaque coating to mask the original surface. Coatings applied to flat wood paneling include fillers, sealers, "groove" coats, primers, stains, basecoats, inks and topcoats. Most coatings are applied by direct roll coating. Filler is usually applied by reverse roll coating. The offset rotogravure process is used where the coating and printing operation requires precision printing techniques. Other coating methods include spray techniques, brush coating and curtain coating. A typical flat wood paneling coating line includes a succession of coating operations. Each individual operation consists of the application of one or more coatings followed by a heated oven to cure the coatings. A typical production line begins with mechanical alterations of the substrate (filling of holes, cutting of grooves, sanding, etc.), followed by the coating operations, and packaging/stacking for shipment. Approximately 60 domestic plants coat flat wood paneling.[2]

B. Emission Sources and Factors

Emission of VOC from a flat wood coating occurs primarily at the coating line, although some emissions also occur at paint mixing and storage areas. All solvent that is not recovered can be considered a potential emission. VOC emission factors for conventional solvent based coatings applied to interior printed panels are as follows (expressed as kilograms of VOC per 100 m^2 coated): 3.0 for filler, 0.5 for sealer, 2.4 for basecoat, 0.3 for inks, and 1.8 for topcoats.[1]

C. Control Techniques and Emission Reduction[1]

Control techniques for flat wood panels include add-on controls, materials changes and process changes. Incineration should give a minimum control efficiency in excess of 95 percent of the VOC captured. Overall plant control would be less because not all organic emissions could be captured. Conversion to waterborne coatings can lower VOC emissions by

at least 70 percent. Use of low solvent coatings that cure by ultraviolet light is gaining greater acceptance and, where applicable, effects a near 100 percent reduction of VOC emissions. Over 99 percent reduction can be achieved by using coatings that cure by exposure to an electron beam, but costs of both the cure system and coatings limit the applicability of this technique at this time.

D. Regulatory Status

The EPA issued a guideline[1] (CTG) in 1978 recommending emission limits for VOC from the surface coating of flat wood paneling. These limits are given in the table below and are based upon the partial use of waterborne or low solvent coatings.

FACTORY FINISHED PANELING

Product Category	Recommended Limitation kg of VOC per 100 sq meters of coated surface
Printed interior wall panels made of hardwood plywood and thin particle board	2.9
Natural finish hardwood plywood panels	5.8
Class II finishes for hardwood paneling	4.8

E. National Emission Estimate[3]

It has been estimated that surface coating of flat wood paneling emitted 24,000 metric tons of VOC in 1981.

F. Capital and Annual Control Costs[1]

For a plant producing about 61.5 million square feet of paneling per year, the capital cost of changing to waterborne coatings is estimated to be $77,000. This gives an annualized capital charge of $13,000. The main additional annual expense would be the slight difference in material cost between waterborne and solvent-borne coatings. Costs for add-on controls such as incinerators will change with line size. Reference 1 contains a thorough discussion of these costs for various size lines.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VIII: Factors Surface Coating of Flat Wood Paneling, EPA-450/2-78-032, U. S. Environmental Protection Agency, Reserch Triangle Park, North Carolina, June 1978.

2. Flatwood Paneling Surface Coating Plants. In: Directory of Volatile Organic Compound Sourcs Coverred by Reasonably Available Control Technology (RACT) Requirements, Volume II: Group II RACT Categories, EPA-450/4-81-0076, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1981.

3. Based on 1981 production data supplied by the National Paint and Coatings Association, Inc.

4.5.1.11 Other Metal Products

A. Process and Facility Description[1]

The original equipment manufacturers discussed here have been referred to by a variety of names, including coaters of miscellaneous metal parts. The category includes hundreds of small- and medium-sized industries and their companies which coat metal parts for which more specific regulatory guidance was not published as part of the guideline series, (i.e. can, coil, wire, automobile and light-duty truck, metal furniture, and large appliances covered in sections 4.5.1.1 - 4.5.1.8). Although many products are coated by manufacturers in this category, the coating processes have many features in common. Typically, the metal substrate is first cleaned, rinsed in a phosphate bath and oven-dried to minimize contamination and maximize coating adhesion. If a prime coat is used, it may be applied by dipping, spraying, or flow-coating. The part is then dried in a curing oven. Subsequent top coats, or if no prime is used, the single topcoat is usually applied by spray. The freshly-coated parts are often conveyed through a flash-off tunnel or room , permit the coating to flow out to a uniform thickness. Some of the solvent will evaporate during this time. The parts are then baked in single or multi-pass ovens at 150-230°C. Large products with high mass such as large industrial, construction, and transportation equipment are usually coated with materials that will cure by air- or forced air-drying, rather than baking, since the specific heat capacity of the large mass makes raising its temperature high enough to cure a coating in an oven prohibitively expensive.

B. Emission Sources and Factors[1,2,3]

Organic emissions from coating miscellaneous metal parts and products are emitted from the application, flash-off area and the bake oven (if used). The bulk of VOC emitted by lines which spray or flow coat, evaporates from the application and flash-off areas. For dip-coating operations, the bulk of the VOC is emitted from the flash-off area and bake oven. Fugitive emissions also occur during mixing and transfer of

coatings. The uncontrolled VOC emission factor for a coating containing 25-volume percent solids and 75-volume percent organic solvent is 0.66 kilograms of VOC per liter of coating (minus water) consumed.

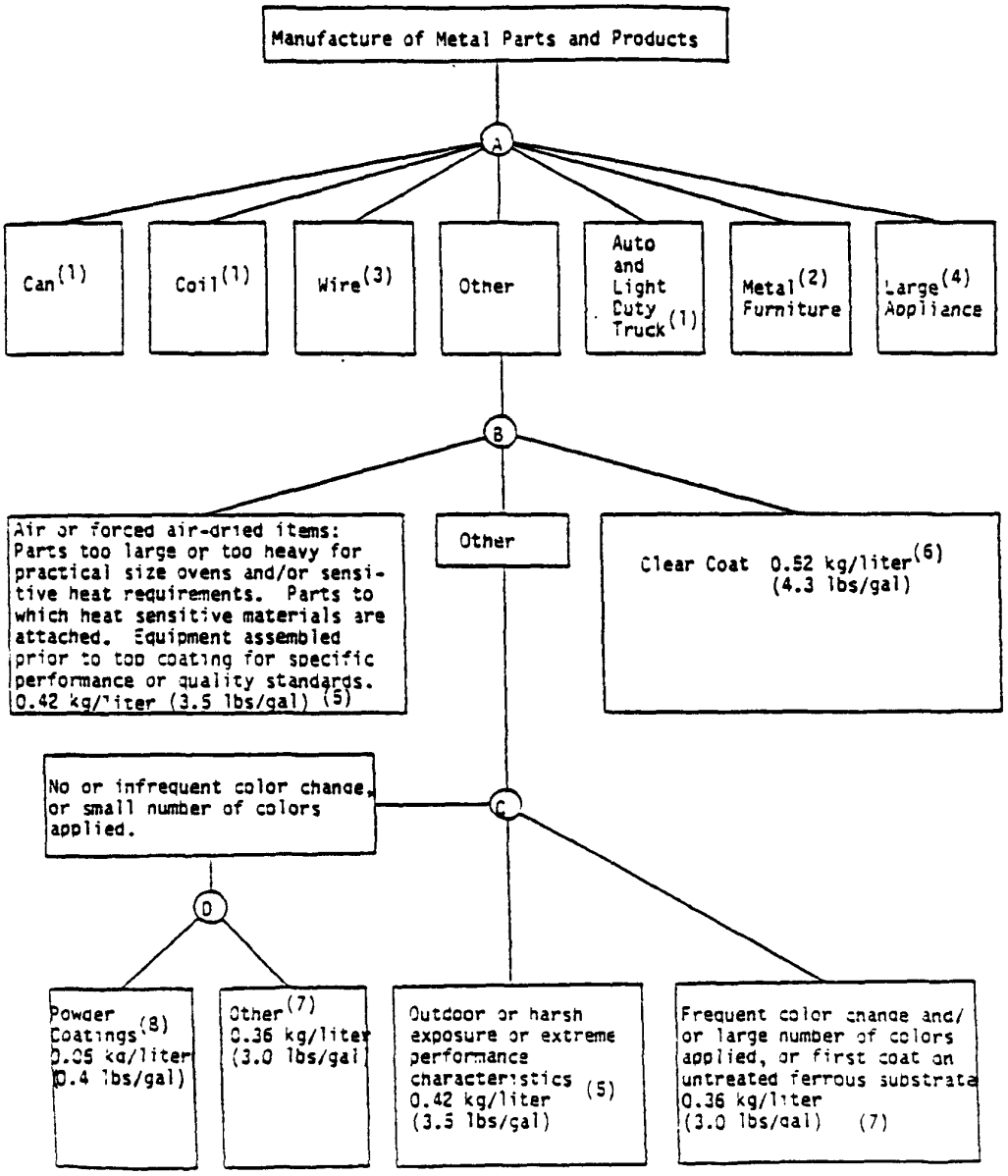
C. Control Techniques and Emission Reductions[1]

Control techniques available to the industries that coat miscellaneous metal parts and products include converting to low-solvent coatings, improving transfer efficiency with state-of-the-art application equipment, or incineration. Spray application of waterborne coatings can reduce emissions by 70 to 95 percent; use of higher solids coatings from 50 to 80 percent; and powder coatings, 95 to 98 percent. Use of electrodeposition (EDP) to apply prime coats can reduce emissions up to 94 percent over conventional coatings used for operations. Transfer efficiency is the ratio of the amount of coating solids deposited onto the surface of the coated part to the total amount of coating solids used. Improvements in transfer efficiency will decrease the volume of coating that must be sprayed to cover a specific part. Of course, the less paint used, the lower the total VOC emission rate.

Historically, the large volumes of air used to ventilate open spray booths and flash-off areas made the expense of incinerating emissions from these sources prohibitive. The VOC in the exhaust from a curing oven, however, can be concentrated (by reducing air throughput), to levels that makes incineration feasible. Incineration of the curing oven exhaust can reduce emissions from the surface coating line from 15 - 25 percent, depending on how much of the total emissions from the line are released from the oven.

D. Regulatory Status[1]

The EPA issued a control technique guideline (CTG) in 1978 to aid States in development of regulations for plants that surface coat miscellaneous metal parts and products. The recommended limits are given in Figure 4.5.11.1. To use the figure, start at the top of the diagram and at each decision node, choose the appropriate option.



Logic diagram for derivation of emission limits for coating of miscellaneous metal parts and products.

Figure 4.5.11.1

E. National Emission Estimate

It is estimated that emissions from surface coating of miscellaneous metal parts and products amounts to 330,000 megagrams of VOC yearly.[2]

F. Capital and Annual Control Costs[1]

A conveyorized single-coat spraying operation which coats 743,000 m^2/yr and uses incineration control is estimated to have capital and annual control costs of $1,400,000 and $460,000, respectively (May 1984 dollars). It is likely that most companies will plan to adapt low solvent coatings to comply with the regulations rather than attempt to abate.

The cost of complying with low solvent coatings will be dependent on the particular type of coating technology that is chosen and the shape of the substrate(s) being coated which affects the transfer efficiency of the application equipment. Cost of using higher solids paints would be comparable to the cost of applying conventional paints; therefore, the control cost would be negligible. The cost of using waterborne or powder coatings would be the same as or similar to cost for other coating industries that use those technologies. See section 4.5.1.8, Surface Coating of Metal Furniture, for additional cost information on waterborne and powder coatings.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VI: Surface Coating of Miscellaneous Metal Parts and Products, EPA-450/2-78-015, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1978.

2. 1982 data provided by the National Paint and Coatings Association.

3. Memorandum from Crumpler, D., U.S. Environmental Protection Agency/ OAQPS to File #84/21, VOC CTD, Emission Estimate for Miscellaneous Metal Parts and Products, May 31, 1985.

4.5.1.12 Surface Coating of Large Aircraft[1,2]

A. Process and Facility Description

The original equipment aircraft industry (not including refinishers of commercial and private aircraft) consists of about 175 establishments operated by 38 companies. They manufactured about 20,000 civilian and military aircraft in 1977 of which about 5,600 were exported. Aircraft are coated in facilities across the Nation but California, Texas, and Florida have particularly large numbers of plants.

The surface coating process for aircraft is relatively simple and straightforward, a "batch" type operation with one aircraft painted at a time. The first step is to prepare the skin of the aircraft to receive the coating. This could require sandblasting, or blasting with plastic beads followed by a solvent wipe.

The second step is application of a prime coating. It serves two main functions. It provides corrosion resistance in case the topcoat fails and it provides an intermediate surface to maximize bonding between the topcoat and substrate.

The final step, application of the topcoat provides color, corrosion protection, and, ideally, minimizes aerodynamic drag. Companies are very sensitive to the coating systems used on aircraft. Weight of the coating is kept to a minimum because excessive amounts increase fuel consumption and reduce the allowable payload. Two component polyurethanes are considered the best and most widely used topcoat for all types of aircraft.

To reduce exposure to contamination during painting, the aircraft is generally wheeled into an enclosed hangar, although some establishments have huge "spray booths" that can accommodate the plane.

The coatings are applied manually, often from mobile hydraulic scaffolding that permits the operator to move about and over all parts of the aircraft. The spray application methods presently used include air spray, air-assisted airless spray and electrostatic.

B. Emission Sources and Factors

The major VOC emissions are the solvent used to clean the substrate prior to coating (solvent wipe) and the VOC emitted during flash-off and cure of the prime and topcoats. It is estimated that large transport-type aircraft require about 60 gallons of primer and 80 gallons of topcoat each, whereas general aviation aircraft, those fixed wing aircraft that seat 2 to 20 people, require 10 and 7 gallons, respectively.

Additional emissions may result during thinning and from poor housekeeping practices such as spillage, waste disposal and clean-up procedures.

C. Control Techniques and Emission Reductions

There are three obvious approaches to reduce VOC emissions from coating aircraft: improve the method of application, convert to low-VOC coatings, and emphasize good housekeeping . Use of add-on control devices has been limited to-date (partially because of the large volumes of air required for ventillating the spray chamber with once-through air systems). Although the Air Force is known to operate a conventional carbon adsorber at one repaint facility. Abatement may gain greater favor as States place greater emphasis on control. If they do, present abatement costs can be ameloriated in several ways including: 1) recent commercialization of a unique new adsorbtion system which removes dilute organics from one stream and concentrates them into an air stream of much lower volume, thereby making recovery or combustion much less costly, 2) new air management schemes that permit much of the exhaust from a spray booth to be recycled, thereby reducing the cost of abatement and, 3) increasing use of personal air supplies that permit a reduction in the ventilation rate within a spray booth thereby decreasing abatement costs.

Since the quantity of VOC emissions from a surface-coating operation depends on the amount of coating applied, improvements in the efficiency of coating application or reductions in the VOC content of the coating will reduce emissions. Surface coating of aircraft is done by spray coating, and the transfer efficiency of the application method is a major factor

in the production of VOC (and also, amount of paint wasted). In general, transfer efficiencies vary with the configuration of the part being coated, the coating being applied, the equipment, and the skill and care of the operator.

Primers and topcoats can be applied by various spray techniques. These include air spray (both hot and cold), airless spray (both hot and cold), air-assisted airless spray (both hot and cold), electrostatic air spray, electrostatic-airless spray, and electrostatic air-assisted airless spray. An air spray produces a fine spray, but the air which aspirates the coating through the nozzle (at a rate of 8 to 30 scfm) also introduces turbulence. This air turbulence interferes with movement of the paint to the substrate and causes excessive "overspray," or waste. The ratio of the amount of material deposited on the surface being painted to the amount of material delivered from the spray gun is low. Airless spray which uses air only to pressurize the tank which delivers paint to the spray gun minimizes overspray; however, the particle size from an airless spray are larger and heavier and paint is wasted when these heavier particles drip to the floor before arriving at the substrate. Proponents of the air-assisted airless spray claim it to both eliminates drips or "tailings" and better focuses the spray pattern and consequently has a better transfer efficiency than either of the other two spray systems.

Changing to coatings which have less volatile organic compounds in the coating will also reduce emissions. A water-reducible epoxy primer has been approved for use on some military aircraft.[3] It has less than 2.9 lb VOC/gal coating (350 g/l) versus 5.4 lb VOC/gal coating (650 g/l) for typical solvent-based primers. Substitution of the water-reducible primer for solvent-based primer would reduce VOC emissions from priming operations by about 80 percent. There currently are no waterborne top coatings that meet military specifications. The most promising coating technology for topcoats appears to be two component, reaction type chemistries such as polyurethanes.

D. Regulatory Status

California limits emissions from coating aircraft coating. California Rule 67.9 Aerospace Coating Operations is applicable to coating, masking, surface cleaning and paint stripping. Effective in August, 1983, the rule originally restricted emissions from prime coat to 650 grams of VOC per liter and those from topcoat to 600 grams per liter. In July 1985, the standard automatically become more stringent, allowing prime-coats to release only 350 grams per liter and topcoats, 600 grams per liter. The regulation also limits several other smaller sources within the plant including emissions from pretreatment coatings, strippers, and maskants. It provides special consideration for coatings used for fuel tanks or to avoid electromagnetic radar detection.

E. National Emission Estimates

In 1976, an estimated 220,000 gallons of primer and 196,000 gallons of topcoat were used. Assuming 30 percent solids coatings, this represents approximately 1,400 tons of VOC emissions annually, or 4 tons daily. Of this, general aviation aircraft account for about 65 percent.

F. References

1. Surface Coating of Large Aircraft, Technical Information Document for Development of a Revised Ozone State Implementation Plan for Birmingham, Alabama, November 28, 1984.

2. Surface Coating in the Aircraft Industry; Booze, Allen and Hamilton, Inc., September 29, 1978.

3. Bud Levine, Development and Application of a Water-Reducible Primer for the Aerospace Industry, presented at the 77th Annual Meeting of the Air Pollution Control Association, June 1984.

of wash primer containing zinc chromate, phosphoric acid and polyvinyl butyral. The VOC content in this wash primer is estimated to be 60 to 70 percent. The primer coat is followed by an alkyd finish coat containing about 60 to 70 volume percent as applied. Acrylic base finish coats used by some manufacturers have about the same solvent content. Topcoats are applied in the 2 to 4 mil dry-film thickness range with conventional air-spray or airless spray equipment.

C. Control Technology and Emission Reduction

For those portions of the shipcoating operation that occur outdoors, economically acceptable use of abatement control technology seems remote at this time. As a result, emission reductions must be sought by changes in the solvent content of coatings and the efficiency with which the coatings are applied. Formulation of low solvent coatings for ships and boats may face problems not encountered by coatings for general metal products because of the corrosive nature of the marine environment.

Merely changing from use of air-spray equipment to another type will significantly reduce the paint wasted and accompanying air pollution. These improvements could reduce waste by as much as 20 to 40 percent.

Emissions from those portions of a ship painted indoors (plates and sub-units) can be controlled by abatement equipment. This has not been done to date, perhaps partially because these emissions constitute a small portion of the total from a ship building establishment.

Many of the coatings in present use are relatively high in VOC content; wash primers, 92 to 94 percent; preconstruction primers, 70 to 85 percent; and shop primers 65 to 75 percent. Antifouling paints are typically 70 percent solvent. Use of coatings with increased solids content (decreased solvent : solids ratios) could dramatically reduce the amount of VOC emitted to the atmosphere.

The only water-based coating in commercial use is the inorganic zinc primers used on ships. Such coatings are widely accepted for performance, however, during winter, their use is often practical only in warm regions because of the threat of freezing in colder parts of the Nation.

Based on the great strides in development of higher-solids coatings for industries such as the auto, appliance and furniture industries, coatings with solids contents of 35 to 40 volume percent for prime and 45 to 50 percent of topcoats is conceivable in the short term for most marine requirements. This would represent an emission reduction of 95 percent for wash primers and about 40 percent for preconstruction and shop primers.

E. Current National Emission Estimate

Information regarding sales of marine paints is not available from published sources. Based on industry interviews with suppliers of coating materials, it is estimated that roughly 50 to 100 tons of VOC might be emitted daily from surface coating of ships and boats.

In the mid-70's, the California Air Resources Board (CARB) estimated hydrocarbon emissions from marine-coating operations in California to be about 10 tons/day. Based on this estimate, industry sources consider 50 to 100 tons/day reasonable for the whole country.

Over 90 percent of these emissions may be attributed to coating of ships; the remaining emissions would result from coating of pleasure boats.

F. Capital and Annualized Control Costs

The cost of surface coating a new ship may be as much as 10 percent of the total cost of the ship. This, coupled with the high cost of repainting, or worse, the potentially higher cost of paint failure, makes selection of a coating system very critical.

Proper maintenance of antifouling coatings used under water on ocean-going vessels also significantly affect fuel costs. Hull roughness caused by corrosion will cause hydraulic turbulence or "drag" and increase power requirements. The magnitude of the costs is so high that in conducting an economic evaluation of a coating system, a life-cycle costing approach should be taken rather than the one-time cost.

For example:

- Dry-docking charges may be as high as $100,000 per day.

- Dry docks may not be available on short notice.
- A large tanker (VLCC) can consume more than $700,000 in extra fuel over a 30-month period because of drag caused by fouling.

Because of the large fixed cost associated with coating of ships, the cost of the coatings is near negligible. Consequently, a marine facility could pay a several fold greater price for a low solvent coating without significantly affecting the cost of the coating operation. On the other hand, the cost of using a new coating that requires more frequent repair can be huge.

G. References

[1] Surface coatings in the Ships and Boats Industry, Booze, Allen and Hamilton, Inc., September 29, 1978.

[2] County Business Patterns, 1975.

4.5.1.14 Plastic Parts for Business Machines

A. Process Description

Plastic parts for business machines are coated for several reasons. Exterior coatings are applied to improve appearance, colormatch, and provide chemical resistance. Metal-filled coatings are applied to interior surfaces to provide electromagnetic interference/ radio frequency interference (EMI/RFI) shielding. This limits both escape and intrusion of stray electronic signals, and in many cases is required by Federal Communications Commission (FCC) regulations. Coatings are generally spray applied in this industry, using air-atomized spray equipment. Many of the conventional and lower VOC content coatings used in this industry are two-component urethane coatings.[1]

B. Emission Sources and Factors

VOC emissions from plastic parts coating occur in the spray booth flash-off area and bake oven. Up to 90 percent of all VOC emissions come off in the spray booth. Annual VOC emissions from plastic parts coating facilities range from 10 to 200 megagrams. Annual emissions depend on the amount and VOC content of each coating used as described in Chapters 3 and 6 of Reference 1.

C. Control Techniques and Emission Reductions

Substitution of waterborne or higher-solids coatings for conventional coatings can reduce VOC emissions from exterior coating and EMI/RFI shielding by 60-80 percent. VOC emissions can also be reduced by improving transfer efficiency by switching to air-assisted-airless or electrostatic spray equipment. Since plastics are not electrically conductive, a conductive sensitizer must first be applied to the plastic when electrostatic spray equipment will be used. There are also several EMI/RFI shielding techniques (zinc-arc spray, electroless plating and conductive plastics) which may produce no VOC emissions. Incineration could be used to reduce emissions, but it has not been used in this industry because of the high cost associated with controlling what are typically high volume, low VOC concentration exhaust streams.[1]

D. Regulatory Status

The EPA has not issued a CTG for plastic parts coating. The Bay Area Air Quality Management District in California has adopted a regulation which limits emissions from exterior coating operations to 3.5 lb VOC/gallon of coating less water after January 1, 1985, and 2.8 lb VOC/gallon of coating less water after January 1, 1987.[2]

The EPA proposed a new source standard for surface coating of plastic parts for business machines in January 1986 (40 CFR 60 Subpart TTT). This standard limits emissions from exterior coating to 1.5 kilograms of VOC per liter of solids applied for prime coat, color coat and fog coat; and 2.3 kilograms of VOC per liter of solids applied for texture coat and touch-up. These limits are appoximately equal to 12.5 and 19.2 pounds of of VOC per gallon of solids deposited respectively. No standard was proposed for EMI/RFI shielding because the cost-effectiveness of each of the alternatives studied (higher solids solvent-borne nickel filled coatings, waterborne nickel filled coatings, and zinc-arc spray) was found to be too high compared to conventional nickel filled coatings. As waterborne nickel filled coatings see greater use, their cost should come down and they may become a cost-effective option. Similarly, electroless plating and vacuum deposition of aluminum may also become cost-effective control options in the future.

E. National Emission Estimate

Surface coating of plastic parts for business machines are estimated to have resulted in about 5,400 megagrams (6,000 tons) of VOC emissions in 1985 as described in Chapter 7 of Reference 1.

F. Capital and Annual Control Costs

Some additional capital expenditure may be required before low-VOC content coatings can be used. For example, automatic proportioning

equipment may be needed to mix the components of the highest solids (60 volume percent) two-component urethane exterior coatings at the spray gun immediately before spraying. The installed capital cost of this equipment is about $3500 per spray gun. On an annual basis, the productivity increases and labor savings associated with these coatings far outweigh the extra equipment costs.

G. References

1. Surface Coating of Plastic Parts for Business Machines - Background Information for Proposed Standards, EPA 450/3-85-019a. U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. December 1985.

2. Bay Area Air Quality Management District, Regulation 8, Rule 31, Surface Coating of Plastic Parts and Products, September 1983.

4.5.1.15 Flexible Vinyl And Urethane

A. Process and Facility Description [1,2]

Vinyl coating and printing refers to any printing or decorative or protective topcoat applied over a vinyl-coated fabric or a continuous vinyl sheet. Coating and printing of urethane substrates is essentially the same process as the coating and printing of vinyl. The vinyl or vinyl-coated fabric web is fed from a continuous roll through a series of rotogravure printing and coating stations (also see Section 4.5.2.1). A typical coating and printing line will successively apply a precoat, decorative print, and a wearcoat or topcoat. The precoat provides a background color for subsequent printing. The printing step consists of a series of print stations, each of which prints a different pattern or color. The topcoat provides protection against scuffing and wear. After each printing or coating station, the web travels through an oven where heated air evaporates the volatile solvent. At the end of the line, the finished product is rewound for shipment or further processing. There are approximately 100 plants in the U.S. which coat and print on flexible vinyl substrates.

B. Emission Sources and Factors[1]

The major source of VOC emissions from the line are the drying ovens. It is estimated that up to 79 percent of the solvent which enters a printing station is evaporated in the associated oven. The remaining 21 percent is emitted as fugitive vapors from the printing stations.

Other sources of fugitive emissions from a plant are the coating preparation and storage areas and from use of solvent to wash equipment and floors. The total VOC emissions from an average coating and printing operation are estimated to be 620 megagrams per year, equivalent to an emission factor of 0.075 kilograms of VOC per square meter of substrate processed.

C. Control Techniques and Emission Reductions[1]

The emission reduction achievable through the use of abatement devices is a function of the efficiencies of the vapor collection (or capture)

system and the control device. The best capture systems demonstrated in this and similar web-processing industries achieve 90 percent, or greater, capture efficiencies.[3] Abatement devices presently used are carbon adsorbers, incinerators, and wet scrubbers. Carbon adsorbers have demonstrated removal of 95 percent of the entering VOC. Similar efficiencies habe been demonstrated by incinerators, although more than 99 percent of the VOC entering an incinerator can be destroyed; the actual value is limited primarily by the operating temperature. The efficiency of VOC removal by wet caustic scrubbers used by this industry has been reported to be about 90 percent.

Significant reductions in VOC emissions may be possible in the near future through use of coatings and inks that contain less VOC. Several waterborne inks and topcoats are currently under development.

D. Regulatory Status

The EPA issued a control technique guideline (CTG) in 1977 which recommended an emission limit of 0.45 kilograms of VOC per liter of coating minus water which was based on an abatement system which achieves an 81 percent overall reduction of the VOC emitted by the vinyl surface coating line.[2]

The EPA also issued a CTG in 1978 recommending add-on control technology which would give a 65 percent overall VOC reduction for packaging rotogravure printing.[3] The rotogravure CTG also allows the use of waterborne inks, the volatile fraction of which must contain 25 percent or less by volume organic solvent and 75 percent or more of water to meet the specified level of control.

The EPA set NSPS standards in 1984 (40 CFR 60 subpart FFF) which requires an overall VOC emission reduction of 85 percent for new flexible vinyl and urethane coating and printing operations. This limit may also be met through the use of waterborne inks with an average VOC content of less than 1.0 kilogram of VOC per kilogram of ink solids.

E. Current National Emission Estimate[1]

It is estimated that the flexible vinyl and urethane coating and printing industry emitted about 23,000 megagrams of VOC (controlled) in 1984, with total potential (uncontrolled) emissions of about 64,000 megagrams of VOC.

F. Capital and Annual Control Costs[1]

The capital and annualized cost of controlling VOC from flexible vinyl or urethane is primarily a function of the rate at which VOC is generated by the printing press and in the ovens. This rate is affected by line speed, the number of printing stations served by the control device, coverage of the web, web width, and, the VOC content of the ink. Below is a table of capital and annualized cost (May 1984) for control by carbon adsorption of several different "model" plants.

Number of Print Stations	Production $m^2/yrx10^7$	Solvent Use Mg/yr	Capital Cost $	Annualized Cost $
3	1.8	280	1,240,000	13,320,000
6	1.8	1,300	2,240,000	14,600,000
6	0.9	650	1,240,000	7,560,000
18	11.0	1,700	7,470,000	79,840,000
36	11.0	8,000	13,450,000	87,040,000

For more detailed information on capital and annualized cost, see reference 1.

G. References

1. Flexible Vinyl Coating and Printing Operations - Background Information for Proposed Standards, EPA-450/3-81-016a, U. S. Environmental Protection Agency, Research Triangle Park, N.C., January 1983.

2. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles and Light-Duty Trucks, EPA-450/2-77-008, U. S. Environmental Protection Agency, Research Triangle Park, N.C. May 1977.

3. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume VIII - Graphic Arts - Rotogravure and Flexography, EPA-450/2-78-033, U. S. Environmental Protection Agency, Research Triangle Park, N.C., December 1978.

4.5.1.16 Architectural Coatings

A. Process and Facility Description

Architectural surface coatings (ASC) are defined as stock type or shelf coatings which are formulated for decorative and/or protective service for general application on new and existing residential, commercial, institutional, and industrial structures. These are distributed through wholesale-retail channels and purchased by the general public, painters, building contractors, and others.[1] ASC are applied in situ to a wide variety of interior and exterior architectural surfaces. ASC air dry to their final finish.

B. Emission Sources and Factors

VOC emissions from architectural surface coating result primarily from the evaporation of organic solvents. The total potential emissions are equal to the total organic solvent content of the coatings as applied plus any solvent used for cleanup.

C. Control Techniques and Emission Reductions

The only feasible technique for reducing VOC emissions from ASC is substitution of coatings that contain less organic solvent. Recent consumption trends indicate waterborne coatings are replacing solvent-based ASC in many cases.[2] Currently, waterborne coatings constitute about 80 percent of the interior ASC market and over 60 percent of the exterior ASC market.[3] It has been estimated that the substitution of waterborne coatings only in those cases where acceptable performance will be realized would still result in an emission reduction of about 35 percent compared to actual emissions (1975 data).[4]

D. Regulatory Status

VOC emissions from ASC are currently limited by only a few State and local regulations, most notably in California.

E. Current National Emission Estimates

Current emissions from ASC are estimated at 360,000 megagrams per year based on coating consumption in 1981.[3]

F. Capital and Annual Control Costs[2]

The use of waterborne coatings which perform as well as traditional solvent-borne coatings is not expected to increase coating costs per unit area coated for the consumer.

G. References

1. Glossary for Air Pollution Control of Industrial Coating Operations, Second Edition, EPA-450/3-83-013R, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1983.

2. Nonindustrial Surface Coating, in: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No. 12, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1981.

3. Information provided by the National Paint and Coatings Association, Inc.

4. "Consideration of Model Organic Solvent Rule Applicable to Architectural Coatings," June 1977, State of California Air Resources Board, Sacramento, California.

4.6.1.17 Auto Refinishing

A. Process and Facility Description[1,2,3]

Most automobile refinishing is done in conjunction with body repair work. Many times the entire vehicle is refinished. The refinishing process begins with washing or steam cleaning of the automobile surface, followed by sanding and a solvent wipe to remove contaminants. Primer and color coats are manually applied, usually with air-atomized spray guns. Refinishing paints may be acrylic lacquer, acrylic enamel, alkyd enamel, or polyurethane enamel. Although the number of shops with spray booths is increasing, most shops still do not have spray booths and do their painting in the general work area.

The coatings are generally allowed to air dry. Some shops use low-temperature bake ovens or portable heaters to speed up the drying process.

There is a very large number of automobile refinishing shops nationwide, as indicated by an estimate of 2,000 of these sources in the Philadelphia area alone.

B. Emission Sources and Factors[1,2,3]

VOC emissions from automobile refinishing result from the evaporation of organic solvent during the surface preparation and painting processes. Lacquer coatings contain about 0.78 kg of VOC per liter (6.5 lbs of VOC per gallon). Enamel coatings contain about 0.66-0.72 kg of VOC per liter (5.5 - 6.0 lbs of VOC per gallon). Additional VOC emissions occur from solvent wipe and clean-up operations.

C. Control Techniques and Emission Reductions

The most feasible approach to reduction of emissions from automobile refinishing involves lower VOC content coatings. Enamels contain less VOC than lacquers, but also dry slower. This is of concern because the wet coating is susceptible to contamination with dirt or dust. Bake ovens or portable heaters may be needed to speed the drying process and minimize contamination. Some low VOC content waterborne primers are also available.

Another way to reduce emissions is to improve transfer efficiency. Some shops use modified airspray guns that use less atomizing air and more shaping air to reduce bounce-back and overspray.[4] Some shops in Europe use hand-held electrostatic spray guns to reduce coating use and emissions.

Emission reduction by means of add-on controls (incineration or carbon adsorption) is technically feasible, but generally economically prohibitive due to the intermittent nature of the process, the low concentration of VOC in the spray booth exhaust stream and the fact that most repair shops are very small, low capital, businesses. Perhaps some large shops that paint many cars each day could afford some control equipment.

D. Regulatory Status

There are no regulations specifically for the control of VOC emissions from automobile refinishing.

E. Current National Emission Estimates[5]

The annual nationwide emissions of VOC from automobile refinishing are estimated at 200,000 megagrams (220,000 tons), based on 1981 coating use.

F. Capital and Annual Control Costs

The capital and net annual costs of incineration control of automobile refinishing emissions are estimated at $92,000 and $170,000, respectively (in 2nd quarter 1984 dollars updated from 1982 dollars in reference 3).

G. References

1. A Discusson of Alternatives to Reduce Emissions of Volatile Organic Compounds from the Automotive Refinishing Industry, California Air Resources Board, Sacramento, California, draft, April 1982.

2. Surface Coating in the Automotive Refinishing Industry, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1977.

3. Volatile Organic Compound Emission Controls for the Automobile Refinishing Industry, U.S. Environmental Protection Agency, Region III, Philadelphia, Pennsylvania, May 1983.

4. Industrial Finishing, October 1985, page 17.

5. National Paint and Coatings Association.

4.5.1.18 Other Surface Coating

There are a plethora of major coating operations for which detailed investigations have not been conducted by the Agency. These include, but are not limited to, large trucks ("18-wheelers"), their trailers, railroad rolling stock, heavy off-road equipment (cranes, earth-moving equipment) and farm machinery. These are now all considered under the general category of "miscellaneous metal products." Close scrutiny of their coating practices in light of the advances in technology since 1977 would likely reveal new lower-solvent coating options that would support a move to more stringent regulations for many industrial products. This is especially true of products that either use sufficiently high volumes of coatings to warrant the cost of the requisite research by coating manufacturers or are able to use coatings that have been developed for other large volume users.

Appendix A and Table 2-5 provides the Agency's best estimate of emissions from a variety of coating operations for which the Agency has data. There are a number of smaller sources of VOC emissions from miscellaneous coating operations for which the Agency does not have detailed emission estimates. However, an overall estimate for other surface coatings is given in Table 2-5 based on solvent usage data provided by the National Paint and Coating Association.[1]

Reference

1. NPCA Data Bank Program 1982, by SRI International and Chemical Marketing Services, Inc., prepared for the National Paint and Coatings Association.

4.5.2. Graphic Arts

The graphic arts or printing industry is characterized by both a large number of small plants and a small number of large plants. Historically, the bulk of commercial printing has been done in the large metropolitan areas of the country.

Printing operations of any sizeable volume utilize presses in which the image carrier is curved and mounted on a cylinder which rotates, or the image is engraved or etched directly on the cylinder. This type of arrangement is referred to as a rotary press. When the substrate to be printed is fed to the rotary press from a continuous roll, it is referred to as the "web."

In direct printing, the image is transferred directly from the image carrier to the substrate. In offset printing the image is transferred first to an intermediate roll (blanket roll) and then to the substrate.

There are four basic printing processes in the graphic arts industry which are potentially significant sources of VOC emissions: rotogravure, flexography, lithography, and letterpress.

4.5.2.1 Rotogravure

A. Process Description

In the rotogravure printing process, image areas are recessed relative to nonimage areas. The rotating cylinder picks up ink from an ink trough or fountain. Excess ink is scraped from the blank area by a steel doctor blade. The ink is then transferred directly as the roll contacts the web. The web is then dried in a low temperature dryer. Typical ink solvents include alcohols, aliphatic napthas, aromatic hydrocarbons, esters, glycol ethers, ketones and nitroparaffins.[1] It is estimated that there were approximately 1,600 rotogravure presses in the United States in 1984.[2]

B. Emission Sources and Factors

The major emission points from a rotogravure press are the ink fountains, wet printing cylinders, wet printed web and drier exhaust. The total amount of organic solvent consumed by the printing plant is the

maximum potential VOC emission (if no reaction by-products are formed during the drying operation). This consists of solvent in the raw ink, solvent contained in any extenders used, solvent added at the press, and solvent used for cleanup[3]. Estimated emission factors for rotogravure printing are 1.6 kilograms of VOC per kilogram of solvent base ink and 0.25 kilograms of VOC per kilogram of waterborne ink used at the press[2].

C. Control Techniques and Emission Reductions

Emission reductions from rotogravure press operations can be achieved by containing fugitive emissions from the print stations and directing them to a carbon adsorber or incinerator. A reduction efficiency of 95 percent of the VOC delivered to either of these devices is reasonable. Publication rotogravure plants with carbon adsorption systems have demonstrated overall recovery efficiencies of 75 percent. Packaging rotogravure presses can achieve an overall VOC recovery/control efficiency of 65 percent for either adsorption or incineration systems.[1] New publication rotogravure presses with good capture or containment devices can achieve better than 84 percent overall control.[3] For some printing operations, equivalent emission reductions may be possible through use of waterborne and/or high solids inks.

D. Regulatory Status

The EPA issued a guideline in 1978 which recommends a 65 percent overall VOC emission reduction for packaging rotogravure operations and a 75 percent reduction for publication rotogravure when add on control technology such as an incinerator or a carbon adsorber is used.[1] Use of waterborne coatings 1) where 75 percent by volume of the volatile portion is water or 2) where higher solids coating contain 60 percent solids will also comply with EPA guidelines. The EPA in 1982 set NSPS standards (40 CFR 60 Subpart QQ) which require an 84 percent emission reduction for publication rotogravure plants which are constructed on or after October 28, 1980.[3]

E. National Emission Estimates

It has been estimated that rotogravure package printing processes emitted 87,000 megagrams of VOC in 1984.[2] Solvent use for publication rotogravure is about 150,000 Mg/yr. Since carbon adsorption is widely used in the publication segment of the industry, only about 38,000 Mg are actually emitted from publication rotogravure each year.

F. Capital and Annual Control Costs[3]

For a typical four-press publication rotogravure facility, the capital cost for installing a carbon adsorber and associated solvent recovery equipment is estimated to be about $1,674,000 while total annual operating costs are estimated to return about $116,000 per year due to value of the recovered solvent. Line sizes vary and control costs vary with line size. Reference 3 gives a more complete discussion of costs.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume VIII: Graphic Arts - Rotogravure and Flexography. EPA-450/2-78-033, OAQPS No. 1.1-109, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1978.

2. Memo from Howle, R., Radian, to Johnson, W., EPA: CPB. July 20, 1984. Estimated Industry Emissions and Growth for the Paper, Film, and Foil Converting Source Category.

3. Publication Rotogravure Printing - Background Information for Proposed Standards - and Promulgated Standards, EPA-450/3-80-031a and b. U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1980 and October 1982.

4.5.2.2 Flexography

A. Process Description[1]

The image areas on the image cylinder of a flexographic press are raised above the nonimage areas. A distinguishing feature is that the image carrier is made of rubber which is attached to the cylinder. A feed cylinder which rotates in an ink fountain delivers ink to a distribution

roll, which in turn transfers ink to the image cylinder. Following transfer from the image cylinder to substrate, the ink dries by evaporation in a high velocity, low temperature (<120°F) air dryer. Some solvent is absorbed into the web. Typical ink solvents are alcohols, glycols, esters, hydrocarbons and ethers. An estimated 21,400 flexographic presses were in operation in the United States in 1984.

B. Emission Sources and Factors

The major emission points from a flexographic press are the ink fountains, feed cylinder, distribution roll, image cylinder, printed web and dryer exhaust. The potential amount of VOC emissions is equal to the total amount of solvent consumed by the printing plant if none of the ink reacts to form an organic by-product. This includes the solvent in the raw inks, solvent in any extenders used, the solvent added at the press, and clean-up solvent.[1] Typical emission factors for flexographic printing operations are 2.0 kilograms of VOC per kilogram of solvent-based ink and 0.25 kilograms of VOC per kilogram of waterborne ink.

C. Control Techniques and Emission Reductions[1]

Emissions from flexographic printing operations can be reduced by improvements in the equipment for containment of the emissions from the print station and installation of an incineration system. Overall, a capture efficiency of 65 to 70 percent and a combustion efficiency of 90 percent (for an overall reduction of 60 percent) appears reasonable. Some flexographic packaging operations can now use waterborne inks. Emission reductions equal to or better than those achieved by incineration can be attained when the solvent portion of the ink consists of 75 volume percent water and 25 volume percent organic solvent (solids to liquid ratio remaining the same). Higher-solids inks with 60 percent solids are becoming available.

D. Regulatory Status[1]

The EPA issued a control technique guideline (CTG) in 1978 which recommends States adopt limitations for flexographic printing. When add-on controls such as carbon adsorbers or incinerators are used, an

overall 60 percent control efficiency is reasonable. Use of waterborne inks whose volatile portion contains 75 volume percent water is an acceptable control techniques as is the use of higher-solids inks which contain 60 percent or more solids.

E. National Emission Estimates

It has been estimated that the flexographic package printing industry emitted 67,000 megagrams of VOC in 1984.

F. Capital and Annual Control Costs

For a flexographic printing plant using 400 megagrams of ink per year, the capital and total annualized costs of VOC control by thermal incineration with 40 percent heat recovery are estimated to be about $455,000 and $282,800, respectively. The costs vary widely with ink usage. See reference 1 which discusses costs for a variety of situations.

G. References

1. Control of Volatile Organic Emissions from Existing Stationary Sources--Volume VIII: Graphic Arts--Rotogravure and Flexography. EPA-450/2-78-033, OAQPS No. 1.2-109, U. S. Environmental Protection Agency. Research Triangle Park, North Carolina 27711. December 1978.

4.5.2.3 Lithography

A. Process and Facility Description

Lithography is a printing process characterized by a planographic image carrier (i.e., the image and nonimage areas are on the same plane) which is mounted on a plate cylinder. The image area is made water repellent while the nonimage area is water receptive. Rotation of the plate cylinder causes the image plate to first contact an aqueous fountain solution which typically contains up to 25 weight percent isopropyl alcohol. This solution wets only the nonimage area of the plate. The image plate then contacts the ink which adhered only to the image area. In offset lithographic printing, the ink is transferred from the image plate to a rubber-covered blanket cylinder. The blanket cylinder then transfers the image to the web. Lithographic heatset inks, containing approximately

40 volume percent solvent, require a heated dryer to solidify the printed ink. Other lithographic inks, containing about 5 volume percent solvent, dry by oxidation or by absorption into the substrate.

There are approximately 400 printing plants in the United States operating over 1000 heatset web offset lithographic printing presses.

B. Emission Sources and Factors

Emission points on a web-offset lithographic printing line include the ink fountains and associated inking rollers, the water fountains and associated dampening rollers, the plate and blanket cylinders, the dryer, and the final printed product. Alcohol is emitted from the dampening system and the plate and blanket cylinders at a rate of about 0.5 kilograms per kilogram of ink consumed.[1] Wash-up solvents are a small source of emissions from the inking system and the plate and blanket cylinders. When heat-set inks are printed, the drying oven is the major source of VOC emissions with 40 to 60 percent of the ink solvent evaporating from the oven.[2]

C. Control Techniques and Emission Reductions[1]

Two approaches for controlling VOC emissions from heat-set web offset lithographic printing presses are 1) material reformulation and 2) add-on control. Substitution of polyols, such as ethylene glycol, for the alcohol in the aqueous fountain solution can result in a reduction of VOC emissions from fountain solutions. Ink reformulation to reduce the solvent content will reduce VOC emissions from the dryer somewhat.

The two major add-on control systems that have been used successfully on lithographic printing presses are cooler/electrostatic precipitators (cooler/ESP) and incinerators. A cooler/ESP system has demonstrated an overall VOC control efficiency of about 80 percent when applied to heat-set web offset lithographic printing dryer exhausts. Thermal (direct flame) or catalytic incineration can effectively reduce dryer exhaust VOC emissions by 90 percent.

D. Regulatory Status

VOC emissions from lithographic printing are currently not limited by Federal regulations.

E. Current National Emission Estimate

Total annual emissions from all heatset web offset printing is about 70,000 megagrams per year.[1] This includes VOC emissions from lithographic package printing which have been estimated to be about 6,500 megagrams.[3]

F. Capital and Annual Control Costs[1]

Total installed capital costs for a catalytic incinerator with primary heat exchange is estimated at $134,000 for a printing press equipped with a high-velocity hot air dryer. The total annualized cost of this system, based on 2,000 hours per year operation, is estimated to be $42,000. Of course, these control costs will vary with line size. Reference 1 gives costs for a variety of line sizes.

G. References

1. Control of Volatile Organic Compound Emissions from Full-Web Process-Color Heatset Web Offset Lithographic Printing (Draft), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1981.

2. Graphic Arts. In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No.12, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1981.

3. Memo from Howle, R., Radian to Johnson, W., EPA. Estimated Industry Emissions and Growth for the Paper, Film, and Foil Converting Source Category. July 20, 1984.

4.5.2.4 Letterpress

A. Process and Facility Description[1,2]

Letterpress is the oldest form of moveable type printing, with the image areas raised relative to the blank or nonimage areas. The image carrier may be made of metal or plastic. Viscous ink is applied to the image carrier and transferred directly to paper or other substrate.

Letterpress is the dominate printing process for periodical and newspaper publishing. Newspaper ink is composed of petroleum oils and carbon black, but no volatile solvent. The ink "dries" by adsorption

into the substrate. Web presses printing on nonporous substrates employ solvent-borne inks which dry by evaporation. Sheet-fed presses employ solventless inks which dry by air oxidation.

There are over 10,000 commercial letterpress printing plants in the United States.[3]

B. Emission Sources and Factors[1]

The major VOC emission points on web letterpress printing lines are the image carrier and inking mechanism of the press, the dryer, the chill rolls and the printed product. About 60 percent of the solvent in the ink is lost in the drying process. Use of washup solvents contribute to overall VOC emissions.

C. Control Techniques and Emission Reductions[2]

Incinerators installed on print dryers have been reported to reduce overall VOC emissions by 90 percent. Use of ultraviolet curing inks in place of solvent-borne inks can essentially eliminate emissions. Use of heat reactive inks which contain only 15 percent of the organic solvent content of conventional inks will reduce overall emissions by 80 percent. A similar reduction is achievable with waterborne inks.

D. Regulatory Status

No Federal guidance has been published for limiting VOC emissions from letterpress printing operations. As a result, few, if any, States regulate letterpress operations.

E. Current National Emission Estimate

The total national use of VOC on web letterpress operations is estimated to be about 43,000 megagrams per year. All of this VOC may not be emitted since part of it may be adsorbed into the substrate on which the printing occurs.

F. Capital and Annual Control Costs

The installed cost of incinerators without heat recovery range from $148,000 to $480,000, while annual costs range from $148,000 to $1,480,000, depending on the plant size.[2] Use of heat recovery would increase capital costs, but lessen fuel usage. See reference 2 for a more detailed cost analysis.

G. References

1. Graphic Arts. In: Compilation of Air Pollutant Emission Factors, Third Edition, Supplement No. 12, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1981.

2. Graphic Arts, Web Letterpress Printing Operations. In: Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1977.

3. Census of Manufacturers, 1982. Bureau of Census, U. S. Department of Commerce.

4.5.2.5 Flexible Packaging

A. Processes and Facility Description

The flexible packaging industry prints, coats, and laminates bread wrappers, frozen food cartons, cigarette packages, pharmaceutical packages, and many other packages.[1,2] Printing is done mainly by rotogravure or flexography. [The emission sources in this industry are the same as discussed in sections 4.5.2.1 and 4.5.2.2 on rotogravure and flexographic printing since flexible packaging is a subcategory of rotogravure and flexographic printing. These processes are discussed again below, since flexible packaging is frequently considered a distinct industry.] Lamination is often used to build multilayer composites of paper, plastic film and foil. Sometimes coating is done on the last print station of a print line to give a clear protective topcoat to the film. Occasionally coating lines are operated separately from printing lines.

B. Emission Sources and Factors

Flexographic ink is purchased in a concentrated form and cut before use to acceptable press viscosity by adding solvent. As the ink sits in the ink pan on the print line, solvent continually evaporates and more solvent must periodically be added to keep the ink within an acceptable viscosity range. For an ink purchasd at 50 percent solids, the solvent entering the press would typically be from these sources:

1.	VOC in purchased ink	25%
2.	VOC added to reduce ink to printing viscosity (initial cut)	30%
3.	VOC added on line to maintain acceptable printing viscosity (make-up)	45%
	TOTAL	100%

The make-up solvent will evaporate from the ink pans and coating rolls as fugitive emissions. Most of the other 50 percent will evaporate either in the drying ovens associated with the print stations or from the final dryer. A typical flexographic converter will emit 2.0 kilograms of solvent for each kilogram of ink purchased. Emissions from rotogravure printing are also approximately 1.6 Kg VOC/Kg ink purchased. Average annual emissions per press from a package printing press and coater are:

Process	Average Uncontrolled Emissions[3] (Kg/yr) (per press)	Reported Range of Emissions (Kg/yr)
Flexographic Press	37,400	4.5 - 280,813
Rotogravure Press	77,000	7.7 - 324,327
Top Coater	150,000	81 - 1,070,391
Adhesive Coater	59,000	120 - 287,347
Primer Coater	52,000	1563 - 213,600

C. Control Techniques and Emission Reductions

Add-on controls such as carbon adsorption, incineration, or catalytic incineration can be used on the dryer exhausts. Because fugitive emissions on many printing lines may constitute 50% of all the solvent used, steps must be taken to reduce fugitive emissions from the ink trays and print rolls. This may be done by enclosing these areas, using doctor blades to replace some of the ink transfer rolls, using solvents which evaporate more slowly, or designing new lines so that more of the fugitive emissions are drawn into the dryers.

Waterborne inks have been developed for porous substrates such as paper, and some non-porous plastic substrates. Progress has een reported recently with using waterborne inks to print on certain plastic films with very slick surfaces such as high slip polyethylene. High solid inks with 60 volume percent solids have been developed in white which is the "color" of highest volume usage. A number of low solvent adhesives and coatings are available for laminating and topcoating operations.

D. Regulatory Status

The EPA issued a CTG in May 1977 which recommended that coating operations emit no more than 2.9 lb. VOC per gallon of coating (less water).[4] This is about an 81 percent reduction compared to the VOC content of conventional coatings. This paper coating CTG applied to many coating and laminating operations in the flexible packaging industry.

In December 1978, EPA issued a CTG for rotogravure and flexography operations.[5] This document recommended that add-on controls could be used to reduce overall VOC emissions from packaging rotogravure lines by 65 percent and from flexography lines by 60 percent. Also allowed as acceptable control techniques are a waterborne coating where 75 percent of the volatile portion is water or a high solids coatings with 60 percent solids.

E. National Emission Estimates[6,7,8]

Estimated 1984 solvent emissions (Mg/year) are:

Flexographic Package Printing	67,000
Rotogravure Package Printing	87,000
Flexible Package Coating	50,000
TOTAL	204,000 Mg/year

These flexographic and rotogravure printing estimates are included in the emission estimates made in Sections 4.5.2.1 and 4.5.2.2 for all products printed by rotogravure and flexography.

F. Capital and Annual Control Costs[5]

A flexible package printing line using 40 Mg of VOC per year could be controlled by a thermal incinerator with a capital cost of $132,000 and an annualized operating cost (including capital charges) of $40,500. Of course, control costs vary with line size. See Reference 5 for more detailed discussion of costs.

G. References

1. Strauss, Victor, The Printing Industry, Printing Industries of America, Inc., Washington, D.C., 1967.

2. Flexography Principles and Practice, Third Edition, Flexographic Technical Association, Inc., 1980.

3. Boies, D. et al (WAPORA, Inc.), Assessment of Organic Emissions in the Flexible Packaging Industry. (Prepared for Industrial Environmental Research Laboratory), Cincinnati, Ohio, Publication No. EPA-600/2-81-009, January 1981, pp. 50-72.

4. Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles and Light-Duty Trucks," U.S. Environmental Protection Agency, EPA-450/2-77-008, May 1977.

5. Control of Volatile Organic Emissions from Stationary Sources - Volume VIII: Graphic Arts - Rotogravure and Flexography," U.S. Environmental Protection Agency, EPA-450/2-78-033, December 1978.

6. 1982 Census of Manufacturers, Preliminary Report, Industrial Series SIC 2893, U.S. Department of Commerce, Washington, D.C., 1982, p. 4.

7. "Organic Solvent Use in Web Coating Operations," U.S. Environmental Protection Agency, EPA-450/3-81-012, September, 1981.

8. Memoramdum from Howle, R., Radian, to Johnson, W., U.S. EPA/ESED/CPB, July 20, 1984. Estimated Industry Emissions and Growth for the Paper, Film, and Foil Coating Source Category.

4.5.3 Adhesives

A. Process and Facility Description[1,2]

Adhesives are used for joining surfaces in assembly and construction of a large variety of products. Adhesives allow faster assembly speeds, less labor input, and more ability for joining dissimilar materials than other fastening methods. By far the largest use of adhesives is for the manufacture of pressure sensitive tapes and labels. Other large industrial users are automobile manufacturing (including especially attachment of vinyl roofs) packaging laminating, and construction of shoes. Adhesives may be waterborne, organic solvent-borne, or hot-melt. Only organic solvent-borne adhesives have the potential for significant VOC emissions.

Approximately 75 percent or more of all rubber-based adhesives are organic solvent-borne cements. Methods of application commonly used are brush application, spraying, dipping, felt pad application, and roller coating. Solvents used in solvent-borne adhesives include aliphatic and aromatic hydrocarbons, alcohols, and ketones.

B. Emission Sources and Factors[2]

The VOC emissions from solvent-based adhesives are a result of the evaporation of the solvents in the adhesive. Emissions arise mainly at the point of application and in many cases are swept from the area with local ventilation systems. Essentially all of the organic solvent in an adhesive is emitted to the atmosphere as the adhesive dries. Adhesives vary widely in composition but a typical solvent-borne adhesive might contain 80 weight percent solvent so that approximately 0.8 kg of VOC evaporates for every kg of adhesive used.

C. Control Techniques and Emission Reductions

The trend in control technology for solvent adhesives is not to control emissions from a solvent-borne adhesive, but rather to replace them with a low solvent type which can perform as well as the solvent-borne adhesive. Various types of low solvent adhesive include waterborne, hot-melt, solventless two-component, and radiation-cured. VOC reductions of 80 to 99 percent can be achieved by such replacement.[1]

Hot-melt adhesives are the most widely used of these alternative processes. Use of waterborne adhesives is expected to increase significantly in the future.[2]

D. Regulatory Status

The EPA has provided regulatory guidance only for the pressure sensitive tapes and labels industry; consequently, emissions from other adhesive applications are limited only by individual State and local emission control regulations if there are any. The EPA set NSPS standards only for the pressure sensitive tapes and labels industry. Emissions from that industry are discussed in more detail in Section 4.5.1.6.1.

E. Current National Emission Estimate

Annual VOC emissions from adhesive applications, excluding the pressure sensitive tapes and labels industry, are estimated at approximately 305,000 megagrams. Below are listed the largest uses of adhesives:

Application Sector	Estimated Solvent Emissions (1,000 Mg/yr)
1. Pressure Sensitive Tapes & Labels	263
2. Miscellaneous Household & Industrial	67
3. Rubber Products	21
4. Auto Assembly (excluding tires)	19
5. Packaging Laminates	18
6. Construction (excluding floor tile and wall covering)	14
7. Converted Paper Products	14
8. Floor Tile and Wall Covering	11
9. Footwear	7

F. Capital and Annual Control Costs[1]

Low-solvent adhesives may be lower or higher in cost, depending on the product. In any case, the adhesive is only a small component of the cost of the manufactured product and its price does not substantially affect the cost of the consumer product.

G. References:

1. Adhesives. In: Air Pollution Control Technology Applicable to 26 Sources of Volatile Organic Compounds. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 27, 1977.

2. Adhesives Application. In: Summary of Technical Information for Selected Volatile Organic Compound Source Categories, EPA-450/3-81-007, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1981.

4.6 OTHER SOLVENT USE

4.6.1 Solvent Metal Cleaning

A. Process and Facility Description

Solvent metal cleaning (degreasing) uses organic solvents to remove soluble impurities from metal surfaces. Organic solvents include petroleum distillates, chlorinated hydrocarbons, ketones, and alcohols. Industries frequently using solvent metal cleaning include automobiles, electronics, appliances, furniture, jewelry, plumbing, aircraft, refrigeration, business machinery, and fasteners.

Methods of solvent metal cleaning include cold cleaning, open top vapor degreasing, and conveyorized degreasing. Cold cleaning uses all types of solvents with the solvent maintained below its boiling point. Open top vapor degreasers use halogenated solvents heated to their boiling points. Both cold cleaners and open top vapor degreasers are batch operations. Converyorized degreasers are loaded continuously and may operate as vapor degreasers or as cold cleaners.

B. Emission Sources and Factors

For cold cleaners, emission sources are as follows: (1) bath evaporation, (2) solvent carry-out, (3) agitation, (4) waste solvent evaporation, and (5) spray evaporation. Emission rates vary widely with the average emission rate estimated to be about 0.3 megagrams (.33 tons) per year per unit.[2]

Unlike cold cleaners, open top vapor degreasers lose a relatively small proportion of their solvent in the waste material and as liquid carry-out. Most of the emissions are vapors that diffuse out of the degreaser into the work place. These fugitive emissions escape to the atmosphere through doors, windows, and exhausts. An average open top vapor degreaser with an open top area of 1.67m^2 (18 ft^2) has an emission rate of 4.2 kilograms (9.3 pounds) per hour or 9,500 kilograms (21,000 pounds) per year.[3]

Emission sources for converyorized degreasers include bath evaporation, carry-out emissions, exhaust emissions, and waste solvent emissions. Carry-out emissions are the largest single source. An average emission rate for a converyorized degreaser is about 25 megagrams (28 tons) per year while that for a nonboiling converyorized degreaser is almost 50 megagrams (55 tons) per year.

C. Control Techniques and Emission Reductions

Controls to reduce emissions from the solvent bath include the following: (1) improved cover, (2) high freeboard, (3) chilled water and refrigerated chillers, (4) carbon adsorption, and (5) safety switches. Carry-out emissions from cold cleaners can be reduced by using drainage racks and by controlling the velocity at which parts are introduced and withdrawn. Carry-out emissions from conveyorized degreasers are reduced by using a drying tunnel and rotating baskets.

Emission reductions are dependent upon both control devices and operating techniques. For example, by recycling waste solvent, closing the cover, and draining cleaned parts, emissions from a cold cleaning system can be reduced 50 percent. For an open top degreaser, imnplementing 10 main operating practices and installing a cover, safety switches and a major control device (high freeboard, refrigerated chiller, enclosed design, or carbon adsorption) may reduce emissions by 60 percent. For conveyorized degreasers combining five operating procedures, a control device (carbon adsorption or refrigerated chiller), a drying tunnel, safety switches, minimized openings, and down-time covers may reduce emissions by 60 percent.

D. Regulatory Status

A CTG was issued in November 1977. An NSPS was proposed in June, 1980. Both the NSPS and the CTG recommend regulations based on equipment specifications and operating requirements. Control equipment includes covers, drainage racks, specified freeboard ratios, safety switches, refrigerated freeboard devices, carbon adsorption systems, and drying tunnels. Requirements vary depending upon size and type of degreaser.

E. National Emission Estimates

The VOC emissions from organic solvent cleaners have been estimated at 920,000 megagrams (1 million tons) per year in 1984 (see Table 4.6.1-1). Emissions estimates are based on solvent consumption and test data. Appendices A and B in Reference 1 present the emissions information.

Table 4.6.1-1 1984 Emissions from Solvent Metal Cleaning[a]

Solvent Used	Emissions Mg/Year	Emissions Tons/Year
Halogenated		
Trichloroethylene	340,000	370,000
1,1,1-Trichloroethane[b]	350,000	390,000
Perchloroethylene[b]	120,000	130,000
Methylene Chloride[b]	60,000	70,000
Trichlorotrifluoroethane[b]	70,000	80,000
Aliphatic	430,000	470,000
Aromatic	90,000	100,000
Oxygenated	60,000	70,000
TOTAL EMISSIONS	1,520,000	1,680,000
TOTAL VOC EMISSIONS	920,000	1,010,000

[a] Projected from 1974 Consumption Figures.[6]

[b] Non-VOC (See Section 2.1 of Chapter 2.)

F. Current Captial and Annual Control Costs

For a large size model cold cleaner with $1.2m^2$ ($13\ ft^2$) working area, capital cost of controls for a cover and a drainage rack is $150 (in 1984 dollars). Total annualized costs with solvent recovery are a credit of $340.

For a typical open top vapor degreaser with $1.86m^2$ ($20\ ft^2$) working area and controlling with a cover and a refrigerated freeboard device, capital cost is $9,600 (in 1984 dollars). Total annualized costs with solvent recovery are a credit of $1,000.

For a conveyorized vapor degreaser with $4.65m^2$ ($50\ ft^2$) working area and using a refrigerated freeboard device, capital control cost is $17,100 (in 1984 dollars). Total annualized costs are a credit of $3,700.[7]

Costs are based on vendor quotations.

G. References

1. U.S. Environmental Protection Agency. Control of Volatile Organic Emissions for Solvent Metal Cleaning - OAQPS Guidelines. Research Triangle Park, North Carolina. Publication No. EPA-450/2-77-022. November, 1977.

2. Reference 1.

3. Reference 1.

4. Reference 1.

5. U.S. Environmental Protection Agency. Organic Solvent Cleaners - Background Information for Proposed Standards. Research Triangle Park, North Carolina. Publication No. EPA-450/2-78-045a. October, 1979.

6. Reference 5.

7. Reference 5.

4.6.2 PETROLEUM DRY CLEANING

A. Process and Facility Description

Dry cleaning is a service industry, involved in the cleaning of apparel or renting apparel. Basically, the industry is segregated into three areas based on customers and types of services offered. These areas are: (1) coin-operated, (2) commercial, and (3) industrial. The industry is also subdivided according to the type of solvent used, they are: petroleum solvents, perchloroethylene (perc), and trichlorotrifluorethane (Freon-113, a registered trade mark). Freon-113 and perc will not be discussed further since they are considered negligibly reactive (See Section 2.1 of Chapter 2 for further discussion). Dry cleaning operations are similar to detergent and water wash operations. However, dry cleaners reclaim solvent used in washers and in many plants--from the article dryers. Soiled-solvent is cleaned by use of either filters, stills, settling tanks or combinations of these. There are approximately 6,000 facilities in the U. S. with petroleum dry cleaning equipment.[1]

B. Emission Sources and Factors

VOC's are emitted from dryers, washers, solvent filtration systems, settling tanks, stills, and piping and ductwork associated with the installation and operation of these devices. Because of the large number of variations in the types of equipment and operating practices, in dry cleaning plants there is a large variation in emission rates. For that reason, details on emission factors or typical plant emission rates will not be discussed here, but are discussed and documented in the references used in this section. The emission sources in dry cleaning plants can be characterized in two broad groups - vented and fugitive emissions. Solvent is vented from article dryers, solvent stills, and filter and article drying cabinets. The largest source of vented emissions is from article dryers. Fugitive emissions occur from all equipment in dry cleaning facilities, however, these emissions vary greatly since they are dependent on equipment operating and good housekeeping practices. The major fugitive emission sources are solvent or liquid leaks from pipes or

ductwork, and wet or not completely dried articles, used-wet filters, and solvent and still waste which are all left in open containers in or outside dry cleaning facilities.

C. Control Techniques and Emission Reductions

New petroleum article dryers using water cooled condensers have only recently been available and have been demonstrated to achieve emission reductions of approximately 80 percent (or reduced outlet emissions to 3.5 kilograms per 100 kilograms of articles cleaned).[1] Fugitive emission sources are controlled by improved operating and maintenance practices.

D. Regulatory Status

The EPA issued a CTG in 1982 and set NSPS standards in 1984 (40 CFR 60 Subpart JJJ) for dry cleaners using petroleum based solvents.[1,2] The CTG recommends that for facilities using 123,000 liters (about 32,500 gallons) of solvent per year or more: (1) limit dryer emissions to 3.5 kg petroleum solvent per 100 kg of articles cleaned or install and properly operate a petroleum recovery dryer (a dryer with a water cooled condser), (2) reduce the VOC content in filter wastes to 1.0 kg or less per 100 kg of articles cleaned, or use cartridge filters and drain them in their sealed housings for 8 hours or more before their removal, and (3) repair all leaks within 3 working days. The NSPS requires for all new, modified, or reconstructed equipment in a petroleum dry cleaning facility with more than 38 kg (about 84 pounds) dryer capacity to (1) install recovery dryers when installing new dryers and perform an initial test to verify proper operation of recovery dryers installed, (2) install cartridge filters when installing any filter system, and drain the filter in their sealed housing for 8 hours prior to removal, and (3) place a label on new dryers informing operators to preform periodic inspections for leaks and repair of leaks.

E. National Emission Estimates[2]

Annual VOC emissions from dry cleaning facilities using petroleum solvent is estimated to be 83,000 megagrams (91,000 tons). This estimate does not include the reductions from either the CTG or the NSPS.

F. Capital and Annual Control[2]

For a typical plant cleaning 82,000 kg (about 180,000 pounds) of articles per year with petroleum solvent the difference in capital costs for installing a recovery dryer (with a refrigerated water chiller) instead of a normal (non-recovery) dryer is estimated to be $21,400. The difference in annual operating costs and capital charges is estimated to be $2,950. A net savings of $2,350 for solvent recovery would be realized; this reducing the annual costs to $600.

G. References

1. Guideline Series: Control of Volatile Organic Compound Emissions from Large Petroleum Dry Cleaners, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/3-82-009, September 1982.

2. Petroleum Dry Cleaners - Background Information for Proposed Standards--and Promulgated Standards, EPA-450/3-82-012a and b, November 1982 and September 1984.

4.6.3. Cutback Asphalt

A. Process and Facility Description

Liquefied asphalts are generally prepared by cutting back or blending asphalt cement with petroleum distillate or by emulsifying asphalt cement with water and an emulsifying agent. Heated asphalt cement is generally used to make asphalt pavements such as asphalt concrete. Cutback and emulsified asphalt are used in nearly all paving applications. In most applications cutback and emulsified asphalt are sprayed directly on the road surface; the principal other mode is in cold mix applications normally used for winter time patching.

B. Emission Sources and Factors

Emissions from cutback asphalt occur as the petroleum distillate (diluent) evaporates; the average diluent content in the cutback is 35 percent by volume. The percentage of diluent to evaporate is dependent on the cure type. The emission factors are: Slow cure (SC) - 20 to 30 percent of diluent content, average 25 percent; Medium cure (MC) - 60 to 80 percent, average 70 percent; Rapid cure (RC) - 70 to 90 percent, average 80 percent. These factors are independent of the percent of diluent in the mix within the normal range of diluent usage for cutback asphalts.[1]

C. Control Techniques and Emission Reductions

The technology to control hydrocarbon emissions from these paving operations consists of substituting emulsified asphalts in place of cutback asphalts. Emulsified asphalts use water and non-volatile emulsifying agents for liquefaction; virtually no pollutants are emitted during the curing of emulsions. Emulsified asphalts are used widely in the construction and maintenance of pavements ranging from high traffic volume highways and airports to low-volume rural roads and city streets.

D. Regulatory Status

The EPA issued a CTG in 1977 to control emissions from the use of cutback asphalt.[2] The CTG recommends the substitution of an emulsified asphalt for cutback asphalt. The use of cutback asphalt has decreasd 41 percent from 3.7 million metric tons (4.1 million tons) in 1977[3] to 1.1 million metric tons (1.2 million tons) in 1983[4].

E. National Emission Estimates

National emissions in 1983 are estimated at 195,000 metric tons (214,000 tons) of VOC from the use of 1.1 million metric tons (1.2 million tons) of cutback asphalt. This estimate is based on a weighted average of the diluent in and diluent that evaporates from slow, medium, and rapid cure cutback asphalt, i.e., approximately 17.5 percent (by weight) of the cutback asphalt evaporates to the atmosphere[5].

F. Capital and Annual Control Costs

A cost comparison of asphalt cutbacks with emulsions is best stated in terms of price per gallon for the total asphalt mix. A review of the December 1984 price quotations shows that emulsified asphalts were cheaper than cutback asphalts[6]. Therefore, the replacement of cutbacks with emulsions will generally result in a savings.

G. References

1. Guideline Series: Control of Volatile Organic Compounds from Use of Cutback Asphalt, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-77-037, December 1977. p.2.3.

2. Ibid.

3. Ibid. p.3.2.

4. Asphalt Usage 1983 United States and Canada, the Asphalt Institute, June 1984, p.4.

5. Guideline Series: Control of Volatile Organic Compounds from Use of Cutback Asphalt, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/2-77-037, December 1977. p.4-1.

6. Engineering News Record, A McGraw-Hill weekly publication, December 6, 1984.

4.7 OTHER MISCELLANEOUS SOURCES

4.7.1 Stationary Fuel Combustion

Stationary fuel combustion sources may utilize external or internal combustion. External combustion sources include boilers for steam generation, heaters for the heating of process streams, and driers and kilns for the curing of products. Internal combustion sources include gas turbines and reciprocating internal combustion engines.

4.7.1.1 Stationary External Combustion Sources

A. Process and Facility Description

External combustion sources are categorized according to the type of fuel burned in the unit. Coal, fuel oil, and natural gas are the primary fuels used in stationary external combustion units. LPG, wood and other cellulose materials are also used to a lesser degree in external combustion sources. The largest market for liquified petroleum gas, LPG, is the domestic-commercial market, followed by the chemical industry and the internal combustion engine.

Bituminous coal is the most abundant fossil fuel in the United States. Capacities of coal-fired furnaces range from 4.5 Kg (10 lb) to 360 Mg (400 tons) of coal per hour.

Anthracite coal is used in some industrial and institutional boilers and also in hand-fired furnaces. It has a low volatile content and a relatively high ignition temperature.

Lignite is a geologically young coal with properties that are intemediate to those of bituminous coal and peat. Lignite has a high moisture content of 35 to 40 percent by weight, and the heating value of 1.5 to 1.8 J/Kg (6000-7500) Btu/lb) is low on a wet basis. It is generally burned in the vicinity of where it is mined. Although a small amount is used in industrial and domestic applications, it is mainly used for steam production in electric power plants.

The two major types of fuel oil are residual and distillate. Distillate oil is primarily a domestic fuel, but it is used in commercial and industrial applications where high-quality oil is required. Residual oils are produced from the residue remaining after the lighter fractions (gasoline, kerosene and distillate oils) have been removed from the crude oil. More viscous and less volatile than distillate oil, residual oils must be heated for easier handling and for proper combustion. Residual oils also have higher ash and sulfur contents.

Natural gas is used mainly for industrial process steam and heat production and for space heating. It consists primarily of methane with varying amounts of ethane and smaller amounts of naitrogen, helium, and carbon dioxide.

The major oil price increases and embargos of the 1970's forced companies to consider wood as an energy source for industrial heat or power generation. High transportation costs result in localized markets. Prime candidates for wood combustion are companies which generate considerable quantities of wood/bark wastes. Residential wood combustion has increased dramatically during the past decade.

Liquified petroleum gas consists mainly of butane, propane, or a mixture of the two, and trace amounts of propylene and butylene. It is sold as a liquid in metal cylinders under pressure and also form tank truck and tank cars. The heating value ranges from 26.3 KJ/m^3 (97,400 Btu/gal) to 24.5 KJ/m^2 (90,000 Btu/gal).

B. Emission Sources and Factors

Volatile organic emissins from stationary external combustion sources are dependent on type and size of equipment, method of firing, maintenance practices, and on the grade and composition of the fuel. Considerable variation in organic emissions can occur, depending on the efficiency of operation of the individual unit. Incomplete combustion leads to more emissions. Emission factors are given in Table 4.7.1-1.

Table 4.7.1-1 Emission Factors for Stationary External Combustion Sources

	Unit Type			
	Utility	Industrial	Commercial	Residential
Coal - All types				
Nonmethane VOC				
lb/ton	0.07	0.07	0.07	10
Kg/Mg	0.04	0.04	0.65	5
Rating	A	A	A	D
Methane VOC				
lb/ton	0.03	0.03	0.8	8
Kg/Mg	0.015	0.015	0.4	4
Rating	A	A	A	B
Wood				
Nonmethane VOC				
lb/ton	-	1.4	-	100
Kg/Mg	-	0.7	-	51
Rating		D		D
Methane VOC				
lb/ton	-	0.3	-	1.0
Kg/Mg	-	0.15	-	0.5
Rating		E		D
Fuel Oil - Residual				
Nonmethane				
$lb/10^3$ gal	0.09	0.034	0.14	-
$Kg/10^3$ l	0.76	0.28	1.13	-
Rating	A			
Methane VOC				
$lb/10^3$ gal	0.03	0.12	0.057	-
$Kg/10^3$ l	0.28	1.0	0.475	-
Rating	A	A	A	
Fuel Oil - Distillate				
Nonmethane				
$Kg/10^3$ gal	-	0.024	0.04	0.085
$Kg/10^3$ l	-	0.2	0.34	0.713
Rating	-	A	A	A
Methane				
$lb/10^3$ gal	-	0.006	0.026	0.214
$Kg/10^3$ l	-	0.052	0.216	1.78
Rating		A	A	A
Natural Gas				
Nonmethane				
$lb/10^6$ ft^3	1.4	2.8	5.3	5.3
$Kg/10^6$ m^3	2.3	44	84	84
Rating	C	C	D	D
Methane				
$lb/10^6$ ft^3	.3	3	2.7	2.7
$Kg/10^6$ m^3	4.8	48	43	43
Rating	C	C	D	D

C. Control Techniques and Emission Reduction

Volatile organic emissions from stationary external combustion sources can be most effectively reduced by improved operating practice and equipment designs which improve combustion efficiency. Organic emissions are directly related to residence time, temperature, and turbulence in the combustion zone. A high degree of fuel and air turbulence greatly increases combustion efficiency. The trend toward better steam utilization in steam-electric generating plants results in improved efficiency in the conversion of thermal energy from fossil fuels into electrical energy. Continued research in the areas of magnetohydrodynamics, electrogas dynamics, fuel cells, and solar energy may result in improved fuel usage and consequently reduced organic emissions.

Flue gas monitoring systems such as oxygen and smoke recorders are helpful in indicating the efficiency of furnace operation. The substitution of gas or oil for coal in any type of furnace reduces emissions when good combustion techniques are used. This reduction is largely effected by the better mixing and firing characteristics of a liquid or gaseous fuel compared to those of a solid.

D. Regulatory Status

The New Source Performance Standards promulgated for stationary external combustion sources (fossil fuel fired steam generators and electric uility steam generators) do not set limits on VOC emissions.

The EPA is presently developing New Source Performance Standards for wood stoves.

E. National Emission Estimates

Table 4.7.1-2 presents VOC emissions from all types of stationary external combustion sources. Emission estimates are based on emission factors with ratings varying from A to D.

F. Capital and Annual Control Costs

Costs associated with increasing combustion efficiency will be site specific. Increased efficiency reduces fuel consumption, the largest part of annual costs.

TABLE 4.7.1-2 VOC Emissions from Stationary Source Fuel Combustion

Source	1983 Emissions Tg/yr (10^6 Mg)
Utility	0.0
Industrial	0.1
Commercial	0.2
Residential	2.0
Total	2.1

Reference 2.

Note: A value of zero indicates emissions of less than 50,000 Mg.

G. References

1. External Combustion Sources. Compilation of Air Pollution Emission Factors, U.S. Environmental Protection Agency, Research Triangle Park, N.C. AP-42, August 1982.

2. National Air Pollutant Emission Estimates, 1940-1983, U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/4-84-028, December 1984, p.14.

4.7.1.2 Stationary Internal Combustion Sources

A. Process and Facility Description

Internal combustion engines include gas turbines or large heavy-duty, general utility reciprocating engines. Most stationary internal combustion engines are used to generate electric power, to pump gas or other liquids, or to compress air for pneumatic machinery.

Stationary gas turbines are used primarily in electrical generation for continuous, peaking or stand-by power. The primary fuels are natural gas and No. 2 (distillate) fuel oil, although residual oil is sometimes used. Emissions from gas turbines are considerably lower than emissions from reciprocating engines; however, reciprocating engines are generally more efficient. The rated power of reciprocating engines ranges from less than 15 kW to 10,044 kW (20 to 13,500 hp). There are substantial variations in both annual usage and engine duty cycles.

B. Emission Sources and Factors

The organic emissions from stationary internal combustion sources result from incomplete combustion of the fuel. The emissions contain unburned fuel components as well as organics formed from the partial combustion and thermal cracking of the fuel. Combustion and cracking products include aldehydes and low molecular weight saturated and unsaturated hydrocarbons. Emissions from compression engines, particularly reciprocating engines, are significantly greater than those from external boilers. Table 4.7.1-3 presents emission factors for stationary internal combustion sources.

C. Control Techniques and Emission Reductions

Emissions from internal combustion sources can be minimized by proper operating practices and good maintenance. Emissions can be reduced greatly with the application of catalytic converters, thermal reactors or exhaust manifold air injections to the engine exhaust.

The catalytic converter has been proven effective on mobile gasoline engines. It contains a catalyst which causes the oxidation of HC and CO to water and CO_2 at reduced temperatures. Unleaded low-sulfur fuel should be used to protect the catalyst and prevent the formation of H_2SO_4.

Table 4.7.1-3 Emission Factors for Stationary Internal Combustion Sources

	Methane	Nonmethane
Diesel Engines		
lb/10^3 hph	0.07	0.63
g/kWh	0.04	0.04
Rating	C	C
Gas Engines		
lb/10^3 hph	4.7	1.5
g/kWh	2.9	0.9
Rating	C	C
Oil-fired Turbines		
lb/MWh	.79	-
kg/MWh	.36	-
Rating	B	-
Gas-fired Turbines		
lb/MWh	.79	-
kg/MWh	.36	-
Rating	B	-

A thermal reactor provides a site for oxidation at elevated temperatures maintained by the heat released from the oxidation of CO and HC. Air is added to the exhaust stream in a container specially designed to maximize both the residence time and turbulence of the charge.

Air injection into the exhaust system is similar to the thermal reactor. However, since the existing shape of the exhaust system is not changed and the volume is not optimized for maximum residence time, heat retention or mixing, air injection may not be as effective as the thermal reactor.

D. Regulatory Status

New Source Performance Standards have been promulgated for stationary gas turbines and proposed for stationary reciprocating internal combustion. Neither standard sets limits on VOC emissions.

E. National Emission Estimates

Table 4.7.1-2 presents VOC emissions from all types of stationary combustion sources. Emissions estimates are based on emissions for factors with ratings varying from A to D.

F. Capital and Annual Control Costs

No cost data are available.

G. References

1. Stationary Large Base Diesel and Dual Fuel Engines. Compilation of Air Pollution Emission Factors, U.S. Environmental Protection Agency, Research Triangle Park, N.C., AP-42, August 1982.

4.7.2 Forest, Agricultural, and Open Burning

A. Source Description

Forest burning refers to forest wildfires, an uncontrolled burning of forest fuel which can occur over hundreds of acres. Agricultural burning refers to the combustion of field crop refuse. Agricultural burning is a type of open burning. Open burning is used for disposal of muncipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, bulky industrial refuse, and leaves. Open burning can be done in open drums or baskets, in fields and yards, and in large open dumps or pits.

B. Emission Sources and Factors

Wildfire combustion is dependent upon the size and quantity of forest fuels, the meteorological conditions, and the topographic features. Fuel type and fuel quantity have been incorporated into a U. S. Forest Service model which estimates fuel loading per acre for all regions of the country. Using fuel loadings, acreage, and pollutant yields (12 Kg VOC/Mg of forest fuel consumed), emissions can be calculated.[1]

Emissions from agricultural refuse burning are dependent upon moisture content, wind direction relative to fire direction, fuel loading, and how the refuse is arranged. Emission factors for open agricultural burning are presented in Table 4.7.2-1. These factors, along with fuel loadings and acreage, can be used to calculate VOC emissions.

Table 4.7.2-2 presents emission factors for open burning of nonagricultural material.

C. Control Techniques and Emission Reductions

Emissions from open burning are prevented by regulations which prevent refuse burning. Wildfire frequencies are reduced by prescribed burning, a preventive burning of forest litter and underbrush.

D. Regulatory Status

Federal air regulations have not been set for forest, agricultural, or open burning.

E. National Emission Estimates

VOC emissions due to wildfires during 1983 were estimated to be 800,000 megagrams.[3] VOC emissions due to other burning during 1983 were estimated to be 100,000 megagrams.[4] All emissions estimates are based upon emission factors.

TABLE 4.7.2-1 VOC EMISSION FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS
EMISSION FACTOR RATING: B

Source	VOC	
	Methane	Nonmethane
Field Crops--Unspecified		
kg/Mg	2.7	9
lb/ton	5.4	18
Vine Crops		
kg/Mg	.8	3
lb/ton	1.7	5
Weeds		
kg/Mg	1.5	4.5
lb/ton	3	9
Orchard Crops--Unspecified		
kg/Mg	1.2	4
lb/ton	2.5	8
Forest Residues		
kg/Mg	2.8	9
lb/ton	5.7	19

TABLE 4.7.2-2 VOC Emission Factors for Open Burning at Nonagricultural Material
Emission Factor Rating: B

Source	VOC	
	Methane	Nonmethane
Municipal Refuse		
kg/mg	6.5	15
lb/ton	13	30
Automobile Components		
kg/mg	5	16
lb/ton	10	32

F. Capital and Annual Control Costs

No cost data are available.

G. References

1. Forest Wildfires. In - Compilation of Air Pollution Emission Factors, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, January 1975.

2. Open Burning. In - Compilation of Air Pollution Emission Factors, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP42, May 1983.

3. National Air Pollutant Emission Estimates, 1940-1983, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-450/4-84-028, December 1984.

4. Reference 3.

4.7.3 Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF)

A. Process and Facility Description

Hazardous waste is primarily managed through treatment, storage, and or disposal in surface impoundments, landfills, tanks, waste piles, land treatment areas, and containers. Landfills are disposal facilities in which hazardous wastes (excluding free liquids) are placed in containers or in bulk form, covered over with soils and left indefinitely. In land treatment, wastes are deposited on or worked into the soil so that natural processes can degrade and demobilize the hazardous constituents in the wastes. Surface impoundments are large basins that are used to either treat or store primarily aqueous wastes. Approximately 96 percent of all generated hazardous wastes are managed on site with only 4 percent being shipped off site either as bulk wastes via tank trucks, rail cars, or pipelines or as containerized wastes. It is estimated that approximately 5,000 sites in the United States manage hazardous waste. Based on a 1981 survey, approximately 71 billion gallons of RCRA-regulated hazardous waste were generated.[1]

B. Emission Sources and Factors

These operations are primarily fugitive (non-point source) emission sources. The potential for emissions begins at the point of generation and continues through the ultimate treatment/disposal stage. Emissions may occur during waste transfer as tank trucks are bottom-filled and displaced vapors are vented to the atmosphere. During landfilling, emissions can arise from liquids spilled on the ground or from solids, sludges, and bulk liquids which are exposed to the atmosphere. Once the landfill is covered, emissions can occur from compounds diffusing toward the surface and escaping to the atmosphere. In surface impoundments and open tanks, atmospheric emissions are produced by the volatilization of compounds at the surface followed by their diffusion into the atmosphere. At land treatment facilities emissions can occur from pools of liquid waste that may form prior to seepage, from the evaporation of volatile constituents in the soil pore-spaces that diffuse to the soil surface, and from tilling the soil. In fixed roof tanks volatile materials diffuse into the head space and are vented to the atmosphere. Leakage at the seal of floating roof tanks can contribute to emissions.[3] Emission factors for these sources are under development.

C. Control Techniques and Emission Reduction[2]

Control of emissions from the TSDF can be accomplished through several means: pretreatment techniques, design and operating practices, physical barriers, and capture and control techniques. Distillation, stripping, carbon adsorption, and solvent extraction may be appropriate pretreatment control techniques to reduce the volatiles content of wastes to be placed in surface impoundments, tanks, and landfills. Design considerations such as increased freeboard depth may be a control option for surface impoundments. Submerging the influent pipes into the bulk liquid in surface impoundments and tanks is an option. Temporary covers may be used during the active life of a landfill. Overloading of wastes onto land treatment areas should be avoided. Floating rafts and synthetic covers are examples of physical barriers to reduce emissions from surface impoundments. Installation of floating roofs on storage tanks can decrease emissions. Capture and control would include venting emissions from covered surface impoundments, tanks, and landfills, and from exhaust gas streams and condenser vents on pretreatment devices to an adsorber or incinerator. The emission reduction benefits are in the process of being quantified (See next subsection).

D. Regulatory Status

With its enactment of the Resource Conservation and Recovery Act of 1976 (RCRA) and its subsequent amendments thereto in 1978 and 1980, Congress required the EPA to promulgate a regulatory program ensuring adequate protection to human health and the environment in the generation, transportation, and management of hazardous wastes. On November 9, 1984, President Reagan signed amendments to RCRA requiring development of air regulations for TSDF within 30 months. Sources to be regulated under Section 3004 of RCRA that are to be considered for air emissions regulations include surface impoundments, landfills, tanks, waste piles, land treatment facilities, containers, and waste transfer operations. Work in the area of TSDF air emissions is in the very preliminary stages, and standards are still to be developed.

E. National Emission Estimates

A preliminary 1983 nationwide VOC emissions estimate based on 54 RCRA regulated chemicals from TSDF estimated emissions to be about 1600 gigagrams (1.7 million tons) per year. Upon extrapolating this estimate to

reflect emissions from all RCRA regulated chemicals, total nationwide VOC emissions from TSDF were estimated to be between 1600 and 5400 gigagrams (1.7 and 5.9 million tons) per year.[3]

F. Capital and Annual Control Costs

Currently, there are no available cost estimates for potential TSDF control techniques. Cost estimates will be developed as the program progresses.

G. References

1. National Survey of Hazardous Waste Generators and Treatment, Storage and Disposal Facilities regulated under RCRA in 1981, Westat, Inc., U.S. EPA Contract No. 68-01-6861, April 20, 1984.

2. Evaluation of Emission Controls for Hazardous Waste Treatment, Storage and Disposal Facilities, Arthur D. Little, Inc., U.S. EPA Contract No. 68-01-6160, November 16, 1984.

3. Assessment of Air Emissions from Hazardous Waste Treatment, Storage and Disposal Facilities (TSDF) Preliminary National Emissions Estimate, Draft Final Report by GCA Corporation, U.S. EPA Contract No. 68-02-3168, August 1983.

4.7.4 Publicly Owned Treatment Works (POTWs)

A. Process and Facility Description

Approximately 15,000 publicly owned treatment works (POTWs) in the United States treat domestic, nonresidential and industrial wastewaters. Approximately 1,500 of these POTWs treat 82 percent of all industrial wastewater discharged to POTWs.

POTWs use a combination of biological and physical/chemical treatment methods and are primarily designed to reduce discharges of biochemical oxygen demand (BOD) and total suspended solids (TSS) to be receiving stream. In addition, plants typically chlorinate the final effluent to reduce bacterial counts. Biological treatment includes activated sludge, aerated lagoons, stabilization ponds, trickling filters, oxidation ditches, and rotating biological contactors (RBC). Physical/chemical treatment includes clarification, filtration, coagulation, flocculation, flow equalization, chlorination, and carbon adsorption. Additonal biological and physical/chemical treatment methods are used to treat wastewater sludges.

B. Emission Sources and Factors

Air emissions from POTWs are due to volatilization of the organic compounds contained in the influent. Organic compounds can volatilize en route to the POTW and at the POTW itself. Volatilization can occur wherever air-liquid contact is provided. Important locations within a POTW where this stripping can occur include aerated lagoons, activated sludge, trickling filters, RBC, equalization basins, and aerated grit chambers. Additional stripping can occur in other areas which provide air-wastewater contact such as hydraulic jumps, overflow weirs, clarifier surfaces and open channels. Incineration of sewage sludge also results in emissions associated with the oraganic constituents that have adsorbed to the sludge.

C. Control Techniques and Emission Reduction

Control of emissions from POTWs can be accomplished through the following methods: pretreatment, in-plant, and post-treatment. Pretreatment methods include steam stripping, distillation, carbon adsorption, solvent

extraction, and industrial process changes. All these methods can reduce the volatiles content of the industrial wastewater prior to discharge to the collection system. In-plant controls can include carbon adsorption, covered tanks, and steam stripping. Post-treatment would include use of a carbon adsorber or flare to control emissions from covered treatment units. Emission reduction data are not presently available.

D. Reulatory Status

Regulations for air emissions from POTWs have not yet been developed. Several different program offices within EPA are currently investigating air emissions from wastewater treatment. A task force was formed in February 1986 to develop the Agency approach for regulation of these air emissions.

E. National Emission Estimates

Total nationwide volatile organic compound (VOC) emissions from POTWs were estimated to be 21,000 Mg/yr (23,000 tons/yr) in 1985.[1]

F. Capital and Annual Control Costs

Cost estimates for POTW control techniques are not presently available.

G. References

1. Domestic Sewage Study, Draft Final Report by Science Applications International Corporation, U.S. EPA Contract No. 68-01-6912, WA No. 17, October 24, 1985.

APPENDIX A

Appendix A gives a listing of volatile organic compound (VOC) emissions in the United States for various miscellaneous organic solvent uses. This list concentrates on industries that emit VOC when applying paints and coatings to manufactured products or when applying printing inks. The list also covers VOC emitted from the use of common household products and from some other miscellaneous manufacturing industries.

Industry	Baseline VOC Emissions Before Control (Metric Tons per Year)	Status (NR means no regulations)
Pressure Sensitive Tapes and Labels	450,000	Paper Coating CTG, 5/77; NSPS proposed 12/30/80
Architectural Coating	360,000	NR
Aerosol Products	292,000	NR
Wood Furniture	200,000	NR
Metal Manufacture (metal rolling)	200,000	NR
Autobody Refinishing	200,000	NR
Miscellaneous Web Coating	175,000	Paper Coating CTG, 5/77
Polymers and Resins	172,000	Draft CTG, 1982; NSPS being written
Use of Household Products Containing VOC	160,000	NR
Synthetic Fibers	151,000	NSPS promulgated 4/5/84
Publication Rotogravure	150,000	Graphic Arts CTG, 12/78; NSPS promulgated 11/8/82

Industry	Baseline VOC Emission Before Control (Metric Tons Per Year)	Status (NR means no regulations)
Pesticides	140,000	NR
Toiletries	113,000	NR
Industrial Maintenance Paints	106,000	NR
Metal Furniture	95,000	Metal Furniture CTG 10/77; NSPS promulgated 10/29/82
Rotogravure Package Printing	87,000	Graphic Arts CTG 5/77
Fabricated Metal Products	84,000	Misc. Metal CTG, 6/78
Paint Removing	75,000	NR
Heat-set, Web Offset Printing	70,000	NR
Cans	68,000	Can CTG 5/77; NSPS promulgated 8/25/83
Flexible Vinyl Coating	68,000	Fabric coating CTG 5/77; NSPS promulgated 6/29/84
Flexographic Package Printing	67,000	Graphic Arts CTG 5/77
Rubber Tire Manufacture	65,000	Tire CTG 12/78; NSPS proposed 1/20/83
Automobile Painting OEM	64,000	CTG, 5/77; NSPS promulgated 10/24/80

Industry	Baseline VOC Emission Before Control (Metric Tons Per Year)	Status (NR means no regulations)
Windshield Washing	52,000	NR
Flexible Packaging Coating	50,000	Paper-coating and Graphic Arts CTG, 5/77 and 12/78
Ferrous Foundaries	49,000	NR
Rubber (Elastomeric-Coated Fabric)	43,000	Fabric Coating CTG, 5/77
Letter-Press Printing	43,000	CTG, 5/77
Truck and Bus Bodies	41,000	Misc. Metal CTG, 6/78
Polishes and Waxes	41,000	NR
Textile Dyeing	39,000	NR
Photographic Products	38,000	Paper-Coating CTG, 5/77
Fabric Printing	38,000	NR
Whiskey Distilleries (and Warehousing)	38,000	NR
Machinery (Industrial and Commercial)	35,000	Misc. Metal CTG, 6/78

Industry	Baseline VOC Emissions Before Control (Metric Tons per Year)	Status (NR means no regulations)
Magnetic Tape	33,000	Paper-coating CTG, 5/77 NSPS proposed 1/22/86
Traffic Paint	33,000	NR
Coil-coating	33,000	Coil-coating CTG, 5/77; NSPS promulgated 11/1/82
Recreational Vehicles Farm Machinery and Construction Equipment	30,000	Misc. Metal CTG, 6/78
Magnet Wire Coating	30,000	Magnet Wire CTG, 12/77
Construction adhesives (including use for floor tile and wall coverings)	27,000	NR
(Non-Tire) Rubber Product Adhesives	24,000	NR
Large Appliances	24,000	Appliance CTG, 12/77; NSPS promulgated 10/27/82
Flat Wood Coating	24,000	Wood Paneling CTG 6/78
Vinyl Floor Coverings	23,000	Fabric-coating CTG, 5/77
Textile-finishing	21,000	NR
Gift Wrap	21,000	Paper-coating CTG, 5/77
Auto Assembly Adhesives	21,000	NR

Industry	Baseline VOC Emissions Before Control (Metric Tons per Year)	Status (NR means no regulations)
Marine coatings (Ships and Boats)	20,000	NR
Rubber Footware Manufacture	20,000	NR
Non-Ferrous Foundaries	18,000	NR
Paint Manufacture	17,000	NR
Small Appliances	17,000	Miscellaneous Metal CTG, 6/78
Office Copier Paper	16,000	Paper-coating CTG 5/77
Extraction Hardwood Pulping	15,000	NR
Inked Ribbons for Business Machines	15,000	Paper-coating CTG 5/77
Space Deodorant	15,000	NR
Foam-blowing	13,000	NR
Plywood	12,000	Plywood CTD 5/83
Moth Control	12,000	NR
Fabricated Rubber Goods	12,000	NR
Fiberglass Reinforced Plastics	11,000	NR

Industry	Baseline VOC Emissions Before Control (Metric Tons per Year)	Status (NR means no regulations)
Solvent Extraction	11,000	NR
SBR Rubber Production	11,000	NR
Electronics (includes Integrated Circuits)	10,000	NR
Textile Heat-setting	9,000	NR
Non-Petroleum Lube Oil Manufacturing	9,000	NR
Nitrocellulose-coated Products	9,000	Paper-coating CTG 5/77
Aluminum Extrusions	9,000	Misc. Metal CTG, 6/78
Shoe Adhesive	8,000	NR
Railroad Equipment Coating	8,000	Misc. Metal CTG, 6/78
Wall Covering Coatings	7,000	Paper-coating CTG, 5/77
Plastic Parts Coating for Business Machines	5,000	NSPS proposed 1/8/86
Petroleum Lube Oil Manufacturing	5,000	NR
Adhesive Manufacture	5,000	NR
Extraction, Rare Metals	5,000	NR
Sandpaper Manufacture	3,000	Paper-coating CTG, 5/77
Carbon Paper Manufacture	3,000	Paper-coating CTG, 5/77
Textile Texturizing	3,000	NR
Tanneries	2,800	NR

Industry	Baseline VOC Emissions Before Control (Metric Tons per Year)	Status (NR means no regulations)
Aircraft Coating OEM	2,000	NR
Tire Retreading	2,000	NR
Rubber Reclaiming	1,300	NR
Light Bulbs and CRT's	500	NR
Pails and Drums	Unknown	Misc. Metal CTG 6/78
Cosmetic Manufacture	Unknown	NR
Pressure-treating of Wood	Unknown	NR
Food Processing (including Coffee Roasting)	Unknown	NR

APPENDIX B

Appendix B - Cost Indexes

Costs presented in Chapter 4 have been updated to 1984 (second quarter or May 1984) costs using the indexes presented in this appendix. The cost indexes shown on Tables B-1 and B-2 are based on national or industry average increases in product, fabrication or labor costs. Using these indexes to update actual cost estimates will not provide the reader with the actual cost that can be expected in 1984, but provide a rough cost estimate for comparing control costs on an equal year basis with control costs from other industries.

Capital costs and installation costs are updated by using the CE Plant or Fabrication Equipment Cost Indexes. The Fabrication Equipment Cost index is used in cases where control costs are for add-on equipment or minor modifications to process lines or units. The CE plant index is used in cases where control costs are for major changes or conversions in the process lines or units. Annual costs are either recalculated using the updated capital costs or updated by using the fixed weighted price indexes for gross national product. Cost estimates are updated by using the following formula:

$$\text{Updated Cost Estimate} = \text{Cost Estimate in X year(month or quarter) \$} \times \frac{\text{index for second quarter or May 1984}}{\text{index for X year(month or quarter)}}$$

Table B-1. Chemical Engineering Plant (CEP) Index and Fabricated Equipment (FE) Component Values*

Date	CEP	FE	Date	CEP	FE	Date	CEP	FE
Dec. 1977	210.3	226.2	Jun. 1979	237.2	259.9	Dec. 1980	272.5	304.0
Jan. 1978	210.6	226.6	Jul. 1979	239.3	262.6	Jan. 1981	276.6	305.9
Feb. 1978	213.1	233.0	Aug. 1979	240.7	264.2	Feb. 1981	280.5	307.1
Mar. 1978	214.1	233.6	Sep. 1979	243.4	266.6	Mar. 1981	286.3	314.7
Apr. 1978	215.7	237.1	Oct. 1979	245.8	271.6	Apr. 1981	290.3	321.9
May 1978	216.9	237.3	Nov. 1979	246.8	272.6	May 1981	295.2	321.6
Jun. 1978	217.7	237.4	Dec. 1979	247.6	273.7	Jun. 1981	298.2	322.9
Jul. 1978	219.2	238.6	Jan. 1980	248.5	273.8	Jul. 1981	303.1	325.6
Aug. 1978	221.6	243.3	Feb. 1980	250.8	276.9	Aug. 1981	305.2	325.7
Sep. 1978	222.8	243.2	Mar. 1980	253.5	277.7	Sep. 1981	307.8	326.7
Oct. 1978	223.5	243.8	Apr. 1980	257.3	289.3	Oct. 1981	308.4	330.8
Nov. 1978	224.7	244.1	May 1980	258.5	290.9	Nov. 1981	306.6	329.4
Dec. 1978	225.9	245.2	Jun. 1980	259.2	291.3	Dec. 1982	305.6	328.9
Jan. 1979	225.9	245.2	Jul. 1980	263.6	296.7	Jan 1982	311.8	324.5
Feb. 1979	231.0	252.5	Aug. 1980	264.9	297.3	Feb. 1982	310.7	323.4
Mar. 1979	232.5	253.1	Sep. 1980	266.2	298.1	Mar. 1982	311.4	324.1
Apr. 1979	234.0	253.7	Oct. 1980	268.6	301.2	Apr. 1982	313.2	327.8
May 1979	236.6	258.3	Nov. 1980	269.7	302.5	May 1982	314.5	329.1

Table B-1. Chemical Engineering Plant (CEP) Index and Fabricated Equipment (FE) Component Values* (Con't)

Date	CEP	FE	Date	CEP	FE	Date	CEP	FE
Jun. 1982	313.3	327.5						
Jul. 1982	314.2	327.1						
Aug. 1982	315.0	326.2						
Sep. 1982	315.6	326.7						
Oct. 1982	316.3	325.8						
Nov. 1982	315.3	324.8						
Dec. 1982	316.1	325.1						
Jan. 1983	315.5	324.4						
Feb. 1983	316.9	327.6						
Mar. 1983	315.9	326.8						
Apr. 1983	315.5	326.6						
May 1983	315.9	327.1						
Jun. 1983	315.7	327.3						
Jul. 1983	316.5	327.0						
Aug. 1983	316.7	327.1						
Sep. 1983	318.3	328.0						
Oct. 1983	318.2	327.8						
Nov. 1983	318.0	328.9						
Dec. 1983	319.3	330.1						
Jan. 1984	320.3	331.5						
Feb. 1984	320.4	333.0						
Mar. 1984	321.3	332.9						
Apr. 1984	321.9	333.8						
May 1984	322.7	334.6						
Jun. 1984	322.5	333.8						
July 1984	323.5	335.4						
Aug. 1984	323.6	335.1						
Sep. 1984								
Oct. 1984								
Nov. 1984								
Dec. 1984								
Jan. 1985								

* Source: Chemical Engineering, McGraw-Hill Publications

Table B-2. Implicit Price Deflators for Gross National Product (GNP) and Fixed-Weighted Price Indexes for Gross National Product (WGNP) (1972 = 100)

	1st Q	2nd Q	3rd Q	4th Q
1977				
GNP	138.13	140.52	142.19	144.23
WGNP	139.9	142.3	144.0	146.1
1978				
GNP	145.8	148.8	151.3	153.8
WGNP	149.1	152.6	155.7	159.0
1979				
GNP	160.22	163.81	167.20	170.58
WGNP	162.8	166.6	170.6	174.4
1980				
GNP	171.23	175.28	170.18	183.81
WGNP	177.1	181.1	185.1	189.7
1981				
GNP	190.01	193.17	197.36	201.55
WGNP	195.9	199.9	204.20	208.40
1982				
GNP	203.36	206.15	208.03	210.00
WGNP	210.7	213.1	216.2	218.70
1983				
GNP	212.87	214.25	215.89	218.21
WGNP	220.7	222.9	225.5	227.6
1984				
GNP	220.58	222.4	NA	NA
WGNP	230.4	232.8	NA	NA

Source: Survey of Current Business, U. S. Department of Commerce, Bureau of Economic Analysis

APPENDIX C
ADDITIONAL INFORMATION CONTROL TECHNOLOGIES

1. "Summary of Control Technologies For Dilute VOC Emission Streams", EPA, OAQPS, ESD, CPB, CAS, October 5, 1989

2. "Carbon Adsorption for Control of VOC Emissions: Theory and Full Scale System Performance", EPA, OAQPS, June 1988, EPA-450/3-88-012.

October 5, 1989

Summary of Control Technologies for
Dilute VOC Emission Streams

Due to lack of compliance with the ozone standard in many parts of the nation, it is becoming increasingly necessary to control sources of volatile organic compounds (VOCs) which in the past have frequently been considered too difficult or costly to control. The control of VOC from dilute, large volume sources, for example, the exhaust from paint spray booths, has been a challenging and often costly problem. If controlling a dilute (i.e. low VOC concentration) gas stream with incineration, costly supplemental fuels must be used. Steam regeneration of a carbon adsorption system can also be very costly especially if the recovered material is not reusable or marketable.

In recent years, technology has been developed which should make the control of low VOC concentration emissions considerably more cost effective. Information on three relatively new systems has been presented to this office. They are the Calgon CADRE system, the Met Pro KPR system and the Weatherly/Nobel Chematuer Polyad FB system. CADRE and KPR utilize granular activated carbon and activated carbon fiber respectively to concentrate the VOC prior to sending it to a final control device, i.e., an incinerator or a solvent recovery unit. The Polyad FB system is a fluidized bed solvent recovery unit which utilizes an adsorbent made of a propriatory polymer. Each of these systems has proven efficient and cost effective in trial applications and, for Polyad FB and KPR, plant applications. Each system will be discussed including available cost and operating data. The information presented was provided by the manufacturers.

The Calgon CADRE System

Calgon Carbon Corporation in Pittsburgh, Pennsylvania, has been a major domestic supplier of activated carbon for several years. It did not market hardware, but rather sold carbon to the several carbon adsorber hardware

manufacturers. In 1987, it began marketing a combined carbon adsorption/incineration system they refer to as CADRE. CADRE was conceived as an alternative to direct incineration of low concentration (< 500 ppm), high volume streams or as an alternative in applications where steam regenerated carbon adsorber designs were not economical due to high steam costs.

CADRE is a two-vessel system designed for up to 10,000 SCFM; for higher flows, multiple vessels are used. The adsorption part of the system behaves as a normal carbon adsorber with one bed adsorbing while the other is regenerated and held off line. Regeneration, however, is done with 300 to 350° F flue gas from the incinerator rather than steam which is typically used to regenerate carbon adsorbers. Figure 1 presents a schematic of CADRE. This system is most economical for low concentration, high flow rate streams where 15-20 pounds of steam per pound adsorbate would be required as compared to a typical range of 6-8 pounds steam/pound adsorbate. Because of low mass flow rate of solvent a bed can remain in the adsorption cycle for a much longer period of time before breaking through than if it were operating on a much richer stream.

The incinerator is operated at 1650° F if the exhaust contains halogenated compounds and 1500° F for organic compounds. The hot gas regeneration flow to the incinerator is limited to 5 to 10 percent of the contaminated air stream flow rate to the adsorber. The hot regeneration gas desorbs the organic in a concentrated stream and the low air flow rate allows use of a much smaller incinerator than would be required for the entire process exhaust air flow. Additionally, because of the low concentration of VOC in the process exhaust, a bed will remain in the adsorbtion mode for an extended period of time compared to the length of the regeneration cycle. As a result, the incinerator must be operated only intermittently.

EPA has in the past received comments that certain industries have a concern with the use of incinerators for the control of coating solvents from nitrocellulose base coatings. They report that the nitrocellulose in the overspray plates out on the duct work, thereby providing a flammable burn path

from a incinerator back into the plant (spraybooth). As a result, a fire may start in the incinerator and "flashback" through the ventilation duct thus endangering employees. While the Agency has not reviewed this issue in depth (the wide availability of flame arrestors for similar purposes would be examined), the use of a high efficiency filtration system and a control system such as CADRE would appear to eliminate such concerns. Since the incinerator is only operational during regeneration of a carbon bed (i.e., the carbon bed is disconnected from the VOC source), the incinerator is effectively isolated from the coating process. Therefore, there can be no danger to workers due to "flashback" caused by the incinerator.

Calgon guarantees that their system will achieve an average efficiency of 95 percent. In pilot testing the carbon system obtained greater than 99 percent removal efficiency and the incinerator efficiency exceeded 99.9 percent for an overall control of 98.9 percent.

Limited information is available on operations and costs of the CADRE system. Calgon has been contracted to install systems for:

- Superfund site, Long Island, NY, 9000 CFM
- Defense contractor - aircraft, Texas, 3500 CFM
- Metal furniture spray booth, Michigan.

One CADRE system is operational at a superfund site in Washington with a flow rate of 3500 CFM. They are achieving approximately 90 - 95 percent control, however, levels of VOC in the gas stream are so low that the exact level of control cannot be determined. Installation costs were unavailable, however, as other systems are being installed, and data becomes available it will be appended to this report.

The Met-Pro KPR System

Met-Pro Corporation, Harleysville, Pennsylvania, has licensed a VOC control called the KPR Solvent system for dilute, large volume sources. The system has been primarily marketed towards paint spray booths, due to the fact that they are almost always dilute large volume sources. Thirty KPR systems had been installed as of June 1988 in a variety of facilities utilizing paint spray systems including automobile painting and aircraft parts painting.

The KPR system consists of a cylindrical rotor containing activated carbon fiber formed into a "honeycomb". Solvent laden air enters the cylinder and flows radially through a segment of the cylinder. The cylinder rotates, continuously exposing a different portion of the rotor to the contaminated air. As the rotor turns, a second, smaller, hot, air stream passes through removing the VOC carrying it from the rotor. See Figure 2. The concentrated exhaust from the KPR rotor is then routed to an incinerator or carbon adsorber and is typically concentrated to 5 to 20 times that of the inlet to the adsorption rotor.

The control efficiency of the KPR rotor for most solvents is reportedly 95-98 percent. Incineration can obtain up to 99 percent control efficiency as well. Therefore, the control efficiency for the system can range 90 - 97 percent.

Met-Pro has reported achieving a control efficiency of > 95 percent using the KPR system at an auto parts coating facility. At one aerospace facility, the KPR system has been reported to achieve 90 percent control efficiency on an inlet stream with a concentration of only 7 ppm.

The concentrating effect of the KPR system permits the incinerator to be significantly smaller thereby reducing operating costs (fuel) over that of a conventional incinerator. The KPR system is most cost effective when the concentrated flow from the rotor is directed to an incinerator. Heat from the incinerator can be used to heat the desorption air and to preheat the

incinerator inlet stream, often requiring no additional fuel. Catalytic incinerators are less expensive to operate than conventional thermal incinerators.

One advantage of the KPR system that Met-Pro reports is that there is no risk of bedfires with the KPR rotor, even for ketones which require carefully controlled regeneration conditions to preclude bedfires in conventional fixed bed systems. This is due to the quick and continuous adsorb/desorb cycle of the KPR system, approximately 7 minutes, which does not allow the carbon to get hot enough to ignite.

The system, sold as modular units, is small and light weight, readily suitable for roof mounting. A diagram of KPR installation is found at Figure 3.

Met Pro provided cost information for two operations: a 25,000 CFM auto parts paint spray booth with a VOC control cost of $1571/ton and a 250,000 CFM auto topcoat paint spray booth with a VOC control cost of $2546/ton.

The cost breakdown for the KPR system on the auto parts paint spray booth is as follows:

Installed capital cost	$1,000,000
Annual operating cost	$75,000 *
Tons/year removed	175

* Electricity	$27,000 assuming 3840 operating hours at $0.05/KWH
Fuel gas	$8,500 assuming $4.00/MMBTU
Manpower	$11,000 assuming $20/hr.
Spare parts	$27,000

Control efficiency is reported to be 94 percent.

If it were assumed that $200,000 of the $1,000,000 capital costs plus interest were paid

per year, the cost of control per ton VOC removed would be:

$$\frac{\$200,000 + \$75,000}{175 \text{ tons}} = \$1571/\text{ton}$$

The Nobel-Chemateur Polyad FB System

The Polyad FB Air Purification and Solvent Recovery System is a continuous fluidized bed process. It was developed by Nobel Chemateur, the chemical engineering company of Nobel Industries Sweden, and marketed in the U.S. by Weatherly Inc., Atlanta, Georgia.

The adsorbent for the Polyad FB system, called Bonopore, consists of macro-porous polymer particles with a very high specific surface (approximately 800 m^2/g) and a particle diameter of about 0.5 mm. Bonopore is easy to desorb, requiring a low regeneration temperature (typically 100°C) and less air or N_2 than typical of other adsorbents. It can also be modified physically and chemically to suit various applications. Additionally, it does not degrade or initiate polymerization of solvents, or other VOC which can occur with carbon.

The recommended solvent concentration for the Polyad FB system is 0.1 - 10g solvent per m^3 air (approximately 20 - 3000 ppm). The system is usually designed for 90 - 95 percent control, but reportedly can achieve almost 100 percent if required. System can be designed for flows from as little as a few hundred m^3 per hour up to several hundred thousand m^3 per hour.

The Polyad FB system consists of two main parts: the adsorption section comprising the main fan and one or more beds where incoming air is purified and the desorption section comprising a polymer container, stripper column, condenser for cooling the solvent, fan for pneumatic transport, and tank and pump for the recovered solvent. Figure 4 is a diagram of the Polyad FB process.

The solvent is adsorbed by the polymer particles as the air passes upward through the adsorption beds. The flow of air also causes the adsorbent to fluidize so that the polymer particles behave as a liquid and flow from the adsorption to the desorption section. A continuous flow of adsorbent through the beds is maintained as the saturated adsorbent is removed from the bottom and regenerated adsorbent is fed in at the top of the adsorption section.

The saturated adsorbent is transported to the top of the desorption section for regeneration. As it descends through the desorber; it is heated to a temperature at which the solvent is released. The vacuum created in the top of the desorber by the pneumatic transport fan draws air and the released solvent, where it is directed to a condenser for recovery.

Weatherly provided cost information for an installation at a 6000 cfm wood furniture spray coating operation in Sweden:

Installed capital cost (in US dollars)	$600,000
Annual operating cost	$6360*
Tons/year removed	45 **

Bonopore Adsorbent $3240 assuming replacement of 120 kg/year at $27/kg

Does not include labor or other maintenance costs.

---

*Electricity $3120 assuming 2496 operating hours at $0.05/KWH

**Weatherly reported that the solvent concentration was a maximum of 2.7g/m^3 (approximately 700 ppm). As this was the only concentration reported, it was used to determine the tons/year removed.

If it were assumed that $120,000 of the $600,000 capital costs plus interest were paid per year, the cost of control per ton VOC removed would be:

$$\frac{(\$120,000 + \$6360)}{45 \text{ tons}} = \$2808/\text{ton}$$

As the Polyad FB system is a solvent recovery device, the value of the recovered solvent would reduce the control cost.

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United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

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Carbon Adsorption for Control of VOC Emissions: Theory and Full Scale System Performance

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Emission Standards Division

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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1. INTRODUCTION

This report presents the results of an investigation into the performance and operation of vapor phase carbon adsorption systems. This investigation was initiated as a result of comments received by the U. S. Environmental Protection Agency (EPA). These comments were in reference to the draft new source performance standards (NSPS) for control of VOC emissions from the manufacture of magnetic tape. The commenter challenged EPA's supporting data for the proposed performance requirements for carbon adsorption systems and the costs for operating and maintaining carbon adsorption systems at the required performance level. Specifically, the commenter contended that the 95 percent efficiency requirement is not achievable on a continuous basis due to the inherent variability of carbon adsorption systems. They also stated that ketones, which are commonly used solvents in magnetic tape manufacture, reduce the performance of carbon adsorbers and increase system variability and shorten bed life which increases the cost of using carbon adsorption.

In order to respond to these comments, the EPA requested additional information from manufacturers and users of carbon adsorber systems to further investigate system performance and costs. The EPA also again reviewed information obtained from previous studies by the Agency. This report summarizes the results of this study.

This report is organized as follows. Section 2 presents the conclusions of this study. Section 3 presents a description of the vapor phase adsorption process, discusses impacts of changes in inlet vent stream characteristics on adsorber performance, and presents supporting test data. Section 4 presents a description of the carbon adsorber system which the commenter used as a basis for developing their comments, and a discussion of the design and operation of that system.

2. SUMMARY AND CONCLUSIONS

This report was specifically designed to address comments submitted concerning the proposed new source performance standards for magnetic tape manufacture. These comments may be summarized as follows:

- One commenter questioned whether any supporting data exist for the Agency's position that 95 percent VOC removal efficiency can be achieved continuously by carbon adsorption systems over all averaging periods, including short-term periods. The commenter submitted information indicating that 24-hour averages of efficiency of his adsorption system vary dramatically from day to day. Days when the average efficiency was above 95 percent were followed quickly by days with an average efficiency of less than 90 percent. It was this information that caused the commenter to question the Agency's decision to determine compliance and assess adsorber operation and maintenance based on short-term measurements of adsorber performance.

- The same commenter also stated that the evaluation of carbon adsorption to control VOC emissions has not adequately addressed the problems associated with the use of ketones by the magnetic tape industry. The commenter submitted data that, in the commenter's opinion, demonstrated reduced adsorber efficiency caused by the use of ketones. The commenter also implied that the variability in carbon adsorber performance is greater when ketones are present in the solvent laden air stream and that ketones shorten the useful life of the carbon in adsorption systems, resulting in greater cost impacts attributable to the NSPS than indicated by the cost analysis carried out by EPA prior to proposal.

In order to address these comments, information was requested from a number of sources. These included both magnetic tape manufacturers and other types of coating operations using carbon adsorbers to control VOC emissions. A meeting was also held with representatives of a major supplier of activated carbon to obtain their perspective on proper adsorber system design and operation based on their long term experience in this field. In addition, two sites were visited to obtain first hand information on the operation of carbon adsorber systems. Emission test data from 15 tests performed for the Emission Standards Division of EPA and the Office of Research and Development were also reviewed to provide additional substantiation of adsorber performance and to attempt to compare long- and short-term removal efficiency.

Based on the data collected for this study, the following conclusions have been made.

- When the carbon adsorber system is properly designed and operated, the adsorption/desorption process is predictable and reproducible from cycle to cycle.

- For well designed and operated carbon adsorber systems, continuous VOC removal efficiencies of over 95 percent are achievable over long- and short-term periods for a variety of solvents, including mixtures that contain ketones such as methyl ethyl ketone (MEK) and cyclohexanone. Several plants have been shown to continuously achieve removal efficiencies of 97-99 percent.

- All facilities identified by this study which had removal efficiencies below 95 percent had identifiable operational problems which contributed to their poor performance. All of the operational problems identified were correctable.

- A carbon adsorption system must be designed based on the following process parameters: 1) particular solvent or solvent blend being recovered, 2) solvent load, 3) vent stream flowrate, and 4) vent stream temperature. Assuming the initial design provides sufficient capacity to account for normal daily process variations and the adsorber is properly operated, the performance of a carbon adsorber system will be essentially constant from cycle to cycle, and long-term and short-term efficiency will be the same.

- If a carbon adsorber bed is left on-line after breakthrough, adsorber efficiency will be significantly reduced and may also become much more variable. A key to maintaining high continuous removal efficiencies is to detect breakthrough and bring a fresh bed on-line. There should always be a fresh bed available if the system is properly designed and operated.

- Because continuous high removal efficiency can be achieved by a properly designed and operated carbon adsorber system, short-term performance testing and monitoring requirements are appropriate as long as the complete system cycle is included in the test or monitoring period.

- A consensus of carbon suppliers, carbon adsorption system vendors, and carbon adsorption system operators indicates that when cyclohexanone is adsorbed, it exothermally reacts on the carbon surface to form higher molecular weight products which cannot be removed by normal steam desorption. The subsequent build up of these compounds results in a steady decrease in the adsorptive capacity of the carbon. This loss in adsorptive capacity decreases the time which a carbon bed can remain on-line before breakthrough occurs. When the adsorption cycle time approaches the time require

for off-line bed regeneration and proper cool down, the carbon must be replaced. If the carbon is not replaced the point will be reached where the operator will be forced to either: 1) leave the bed on-line past breakthrough in order to properly regenerate the off-line bed or 2) switch to the regenerating bed before it has been adequately steamed and cooled. The result in either case will be a dramatic drop in removal efficiency.

- The carbon adsorber system of which the commenter reported as having highly variable and frequently low removal efficiencies is significantly under-designed for the actual solvent loading it is required to control. This results in the system being operated a significant portion of the time after breakthrough has occurred. As a result, the efficiency of this system is extremely sensitive to variations in the process conditions and therefore exhibits significant variations in efficiency from day-to-day and cycle to cycle. The variations also result in significantly reduced long-term efficiency. If the system was operated within the design limits, then the reduced efficiency and efficiency variation should not occur.

- As a carbon bed ages and its total adsorptive capacity gradually decreases due to fouling, the working capacity can in some cases be maintained at the desired level by increasing the steam flow during desorption. This will increase steam costs. The decision of whether to use higher steam flow or replace the carbon is based on the cost of additional steam versus the cost of new carbon.

- A key parameter to maintaining continuously high removal efficiency is replacing the carbon well before fouling reduces the adsorptive capcity. More frequent carbon replacement results in higher annualized carbon costs, but also prevents reaching the point where the adsorber performance falls below the design value.

3. THEORY AND PERFORMANCE OF CONVENTIONAL FIXED BED CARBON ADSORBERS

This section presents a general description of carbon adsorbers used to remove volatile organic compounds (VOC) from a gaseous process stream. The purpose of this presentation is to provide information necessary to draw conclusions concerning the following:

- The ability of carbon adsorbers to remove 95 percent or more of the VOC in a process stream on both a short-term and long-term basis;
- the effect of various operating parameters such as solvent type, bed age, inlet stream temperature, concentration, flowrate, and regeneration steam flow on adsorber performance.

The information presented here was obtained from industry and vendor responses to information requests from EPA, evaluation of carbon adsorber emission test data gathered for this and previous EPA studies, and a meeting with a major vendor of activated carbon and carbon adsorption/incineration systems.

The first part of this section is a discussion of the basic theory of carbon adsorption (Section 3.1). Section 3.2 describes the design considerations for full scale systems, Section 3.3 presents a discussion of how adsorber efficiency is calculated, and Section 3.4 presents the impact of operating variables on system performance. Section 3.5 presents emission test data to substantiate the performance of carbon adsorbers. Finally Section 3.6 presents conclusions concerning carbon adsorber performance.

3.1 MECHANISM OF ADSORPTION AND DESORPTION

This section presents a detailed description of the mechanisms of carbon adsorption and desorption. To describe the mechanisms involved, a simplified approach using a single bed of activated carbon is developed. The principles involved in the single bed system are then applied to describe the operation of a typical carbon adsorber system.

For gas phase carbon adsorption applications, the adsorber system does not actually recover the VOC. It is used to transfer the VOC from a medium where it is difficult to recover (the vent stream gas), to a more concentrated form in a different medium (usually steam) where the VOC can be more easily recovered. This transfer occurs in two steps. The first is the

adsorption step where the VOC (adsorbate) is adsorbed onto the surface of activated carbon (adsorbent). The second step is where the adsorbate is removed from the carbon (desorption) and recovered for reuse. Both of these steps are equally important in the overall process.

The adsorption process can be either physical or chemical. In physical adsorption the organic molecule is held to the surface by weak van der Waal type forces or intermolecular cohesion.[1] The chemical nature of the adsorbed gas remains unchanged, thus the process is readily reversible. Regenerative pollution control equipment requires the adsorption process be physical. In chemical adsorption, electrons are exchanged thus chemically bonding the molecule to the surface of the carbon particle.[2] Chemical adsorption is not readily reversible and, therefore, is not suitable for the regenerative adsorber systems used in air pollution control applications.[3]

Figure 3-1 presents a series of exploded views which describe the subsystems which make up a carbon adsorber bed. A carbon bed is comprised of carbon pellets. The pellets are made up of carbon particles which have been sintered together. The carbon used in adsorption is made by a two step process. In the first, material from various sources such as coconut shells, petroleum products, wood and coal is carbonized by heating it in the absence of air until all organic compounds except the carbon are volatilized. Then using high temperature steam, air, or carbon dioxide, the carbon is made porous or activated.[4] Depending upon the extent of this process and the original source, the carbon can be made to fit the use for which it is desired.

The pore structure within a carbon particle is illustrated in Figure 3-2. The external surface area of a carbon particle is a few square meters per gram; however, within the pores the available surface area is hundreds of square meters per gram.[5]

The pores within the carbon are classified according to their size. Large pores (greater than 2,000 nanometers in diameter) are called macropores and smaller pores (less than 200 nanometers) are called micropores.[6] Pores with diameters between these ranges are called transitional pores.[7] Micropores are where the majority of the adsorption occurs so it is desirable to have a large amount of the pore space in this form.[8]

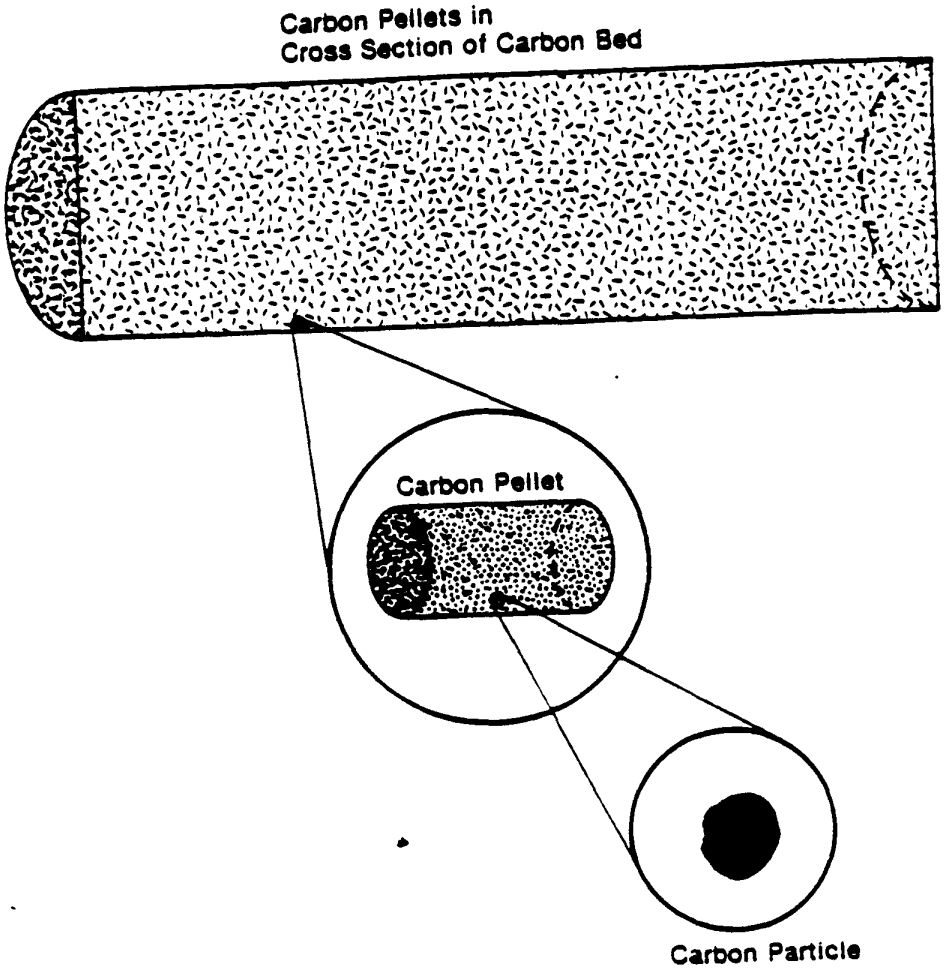

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Figure 3-1. Representation of Carbon Pellets/Particles in Carbon Bed

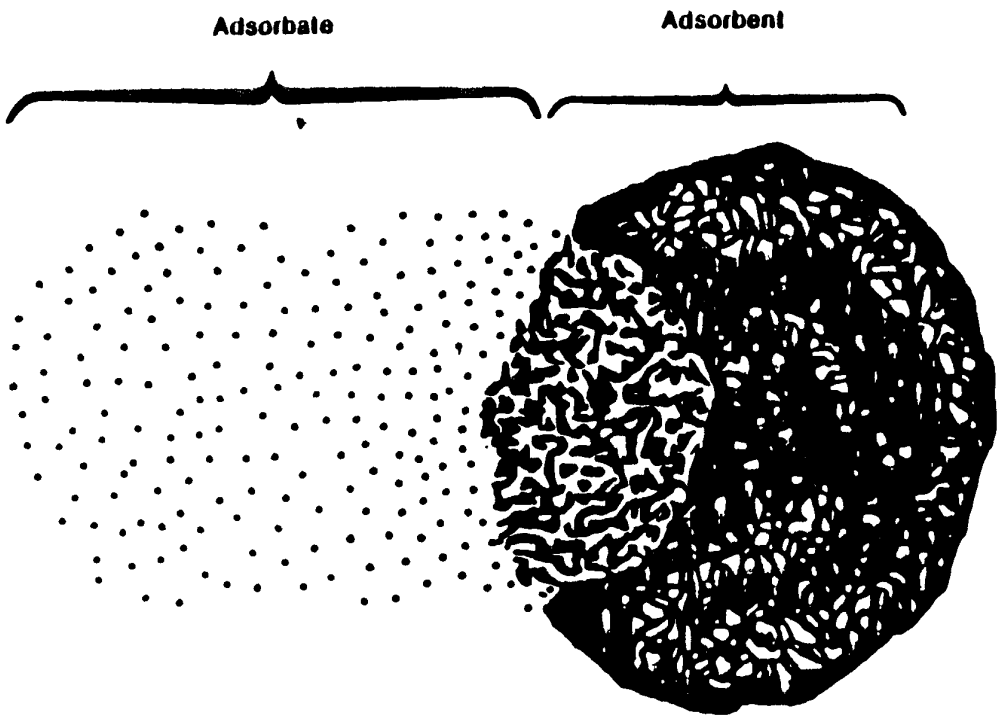

Figure 3-2. Representation of Pores in Activated Carbon Particle

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The adsorption process begins with the mechanical movement of the vent stream through the carbon bed, which brings the organic molecules into contact with the carbon pellets. The remainder of the adsorption process consists of three steps as illustrated in Figure 3-3. The adsorbate must first diffuse into the carbon pellet to the surface of the carbon particle. Next, the adsorbate molecule must diffuse from the surface into the pores within the carbon particle. The extent of the diffusion within the pores is dependent on the size of the molecules and the pore structure of the carbon. Diffusion into the larger pores occurs fairly rapidly, but as the pore diameters become smaller the diffusing molecule strikes the walls and sticks for short periods of time.[9] This diffusion process continues until the molecule reaches a location where it no longer has sufficient energy to escape the forces which hold it to the pore wall. This usually occurs where the pore diameter is not more than approximately twice the diameter of the adsorbate molecule.[10]

The adsorption process continues until the amount of adsorbate on the carbon reaches a thermodynamic equilibrium with the adsorbate in the gas phase. The thermodynamic equilibrium is a function of the carbon type, temperature of the carbon and adsorbate, and the adsorbate partial pressure (concentration) in the vent stream. The amount of adsorbate a particular carbon can hold is called the equilibrium capacity.

As previously mentioned, the purpose of the carbon adsorber is to actually transfer the adsorbate from the gas stream to a medium where it can more easily be recovered or disposed of. Therefore, at some point the adsorbate must be removed from the carbon. This process is called desorption or regeneration. Desorption is accomplished by shifting the thermodynamic equilibrium established during the adsorption step. There are three ways to shift the equilibrium: 1) increase the temperature, which is usually brought about by the addition of steam, 2) reduce the pressure of the atmosphere surrounding the carbon, and 3) reduce the concentration in the gas stream outside the carbon to a value less than the concentration inside the carbon. In most air pollution control applications, increasing the temperature is used for desorption.

During desorption some adsorbed molecules are not removed. The reason is that to remove all the adsorbate requires sufficient time for the adsorbate

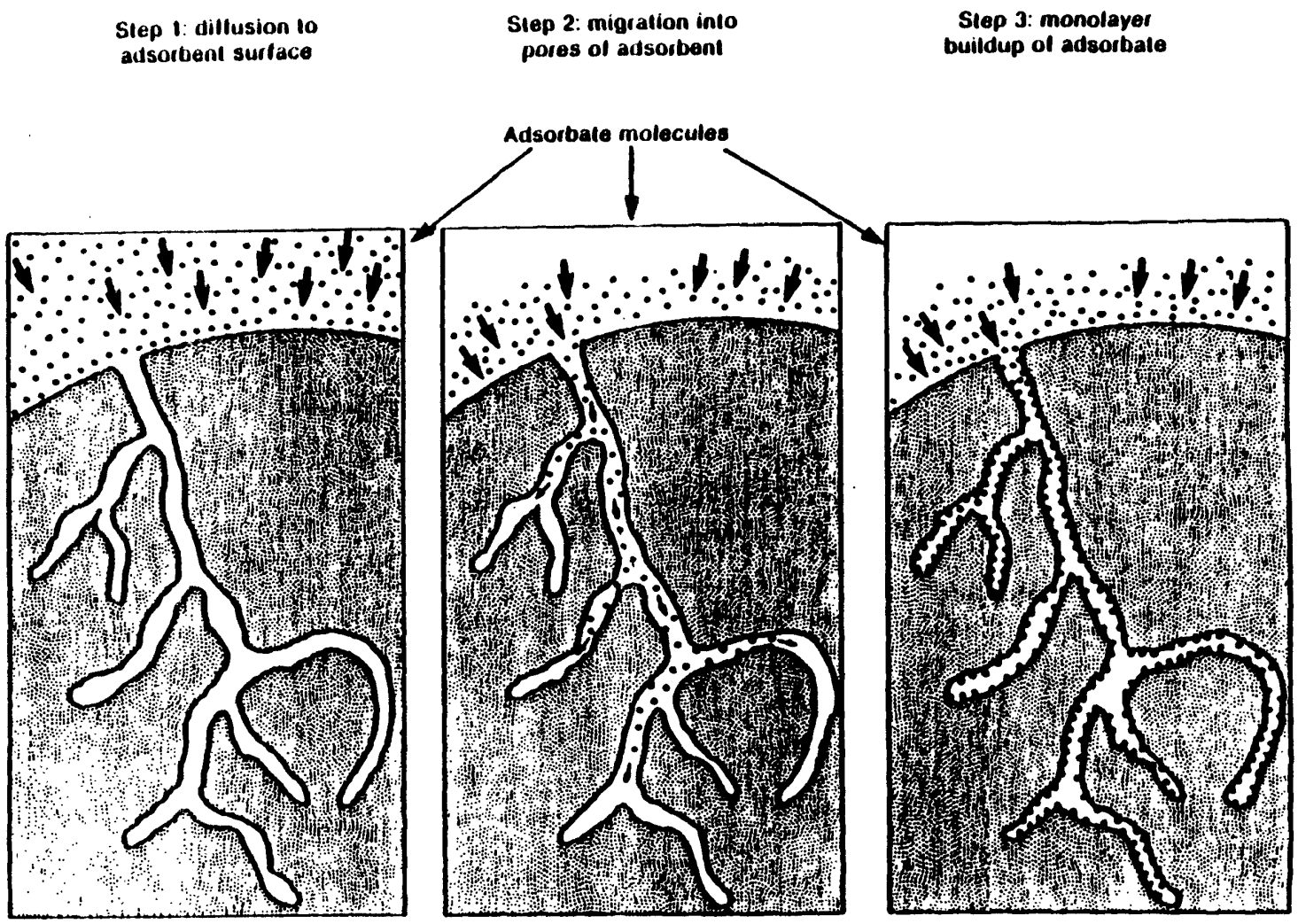

Figure 3-3. Mechanism of Adsorption

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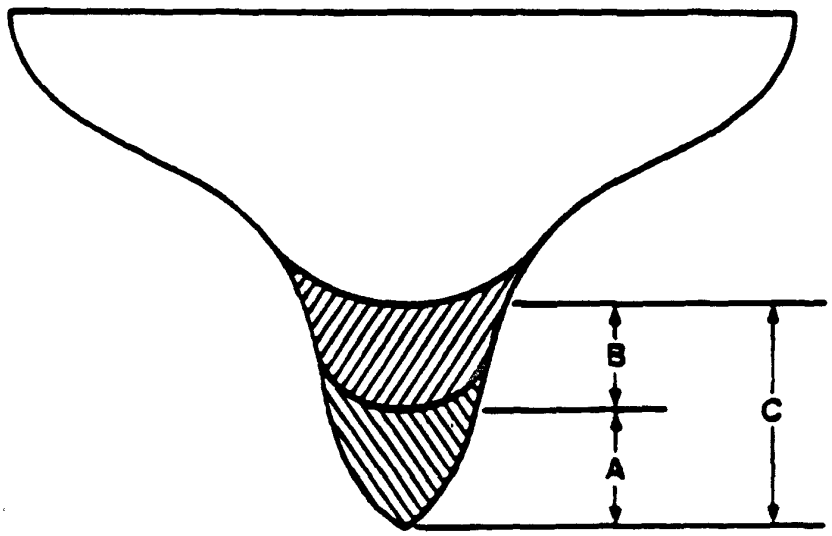
molecules to diffuse out of the carbon particle, and that the temperature be high enough to cause all the adsorbate to desorb. However, the energy cost to accomplish this is higher than the cost to leave some adsorbate in the carbon and use a larger amount of carbon to achieve the desired system performance.

Adsorbate remaining in the carbon after desorption is called the heel. The amount of heel is a function of the desorption time and temperature. Increasing adsorption time and/or temperature will reduce the heel. In virgin carbon, a stable heel is established after two to three adsorption/ desorption cycles.[11]

The process discussed above is summarized by the simplified representation of a carbon pore shown in Figure 3-4. As shown, the pore has three different volumes: the equilibrium capacity, working capacity, and the heel.[12] As previously discussed, the equilibrium capacity is a function of the carbon type, bed temperature, and the partial pressure of the adsorbate in the vent stream. It represents the maximum amount of adsorbate which can be adsorbed by the carbon when it is at equilibrium with the surrounding conditions. The heel represents the adsorbate which remains in the pore after desorption. It is a function of the particular carbon, the adsorbates in the vent stream, and the steaming conditions.

The practical application of the adsorption process to a full size carbon bed is illustrated in Figure 3-5. In this figure, the solvent laden air (SLA) flows from left to right. As shown, there are three zones in the bed labeled saturated, mass transfer, and fresh. The saturated zone is located at the entrance to the bed and represents the carbon which has already adsorbed its working capacity of adsorbate. The saturated carbon is at thermodynamic equilibrium with the incoming vent stream. Therefore, no net mass transfer occurs in this zone. The mass transfer zone (MTZ) is the section of the carbon bed where the adsorbate is removed from the carrier stream. The carbon in this zone is at various degrees of saturation, but is still able to adsorb some adsorbate. For a typical system, the mass transfer occurs within a section approximately three inches in depth.[13] The fresh zone is downstream of the mass transfer zone and represents the region of the bed where no new adsorbate has passed since the last regeneration. This zone still has all its working capacity (i.e., equilibrium capacity minus the heel) available.



A = Residual or Heel (located deep in the pore and difficult to dislodge)
B = Working Capacity (bounded by the heel remaining from previous cycles and portion of pore too large in diameter to retain organic)
C = Equilibrium Capacity

Figure 3-4. Simplified Representation of Carbon Capacity[12]

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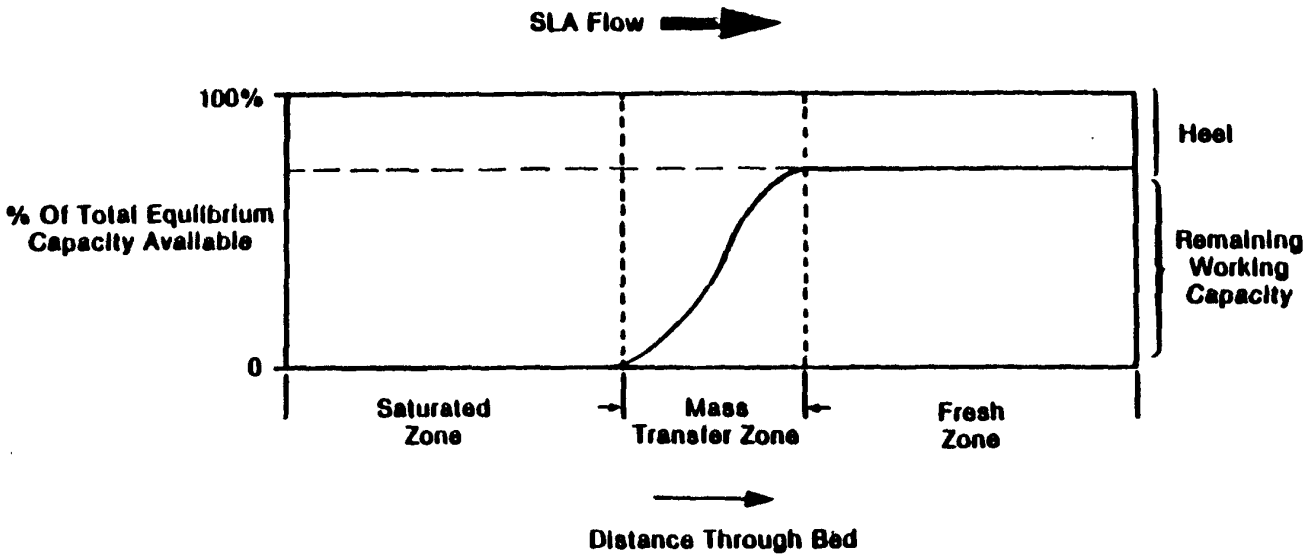

Figure 3-5. Available Working Capacity as a Function of Distance Through Bed for an Operating Bed

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During operation the mass transfer zone moves down the bed in the direction of flow. Breakthrough occurs when the mass transfer zone first reaches the bed outlet. The breakthrough point is characterized by the beginning of a sharp increase in the outlet concentration. The available adsorption time for a specific bed before breakthrough occurs is a function of the amount of carbon present, its working capacity, and the concentration and mass flowrate of adsorbate.

Figure 3-6 shows a simplified representation of the carbon pores in each of the three zones. Pores A through E represent typical pores at different locations in the bed. Pore A, which is at the front of the bed, is already completely saturated while Pore E, which has not been exposed to adsorbate during this cycle, still retains its entire working capacity. Pores B, C, and D which are located in the MTZ, depict various degrees of saturation. A cross section of the bed perpendicular to the air flow will reveal pores at similar levels of saturation. In the MTZ, pore B has been exposed to the adsorbate for the longest period of time and is nearly saturated while the MTZ has just reached pore D which still retains most of its adsorptive capacity. As the adsorption cycle continues and more adsorbate enters the bed, the mass transfer zone will continue to move through the bed.

Figure 3-7 depicts the VOC concentration within the carrier gas as a function of axial distance down the bed. Since equilibrium has been reached with the incoming adsorbate in the region prior to the mass transfer zone, the vapor stream concentration is equal to the inlet concentration. Within the mass transfer zone, the concentration of the vapor stream drops off because the organic is being adsorbed into the pores.

Theoretically, the concentration in the third zone should be zero.[14] However, a small amount of adsorbate is typically present. This is a result of two factors:

1. A small amount of SLA may pass through the adsorber without actually contacting the carbon.

2. Due to the low concentration of adsorbate in the vent stream in the last few inches of the bed, the heel remaining from the previous cycle will slowly desorb.

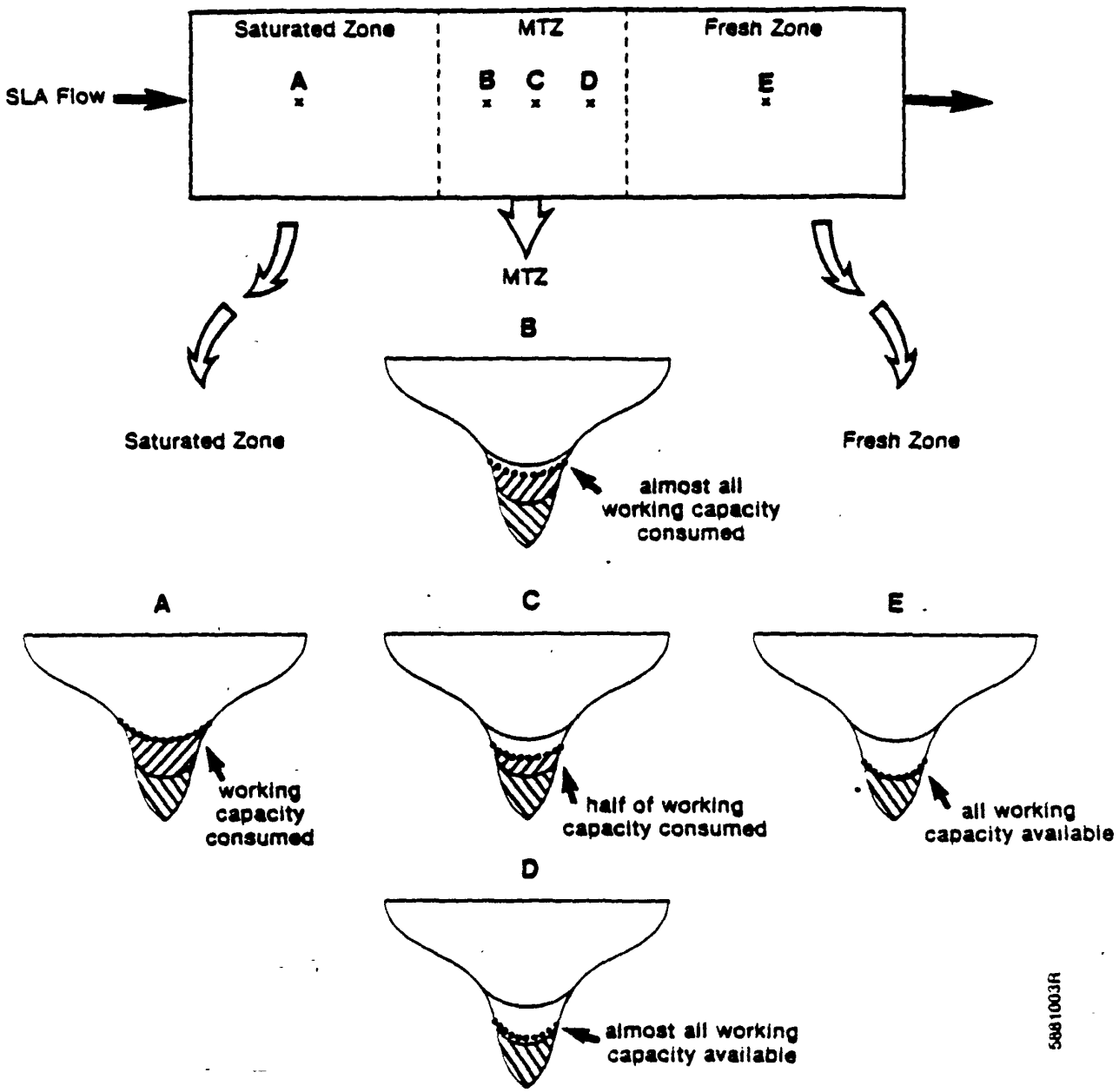

Figure 3-6. Simplified Pore Representation of Capacity as a Function of Distance Through Bed

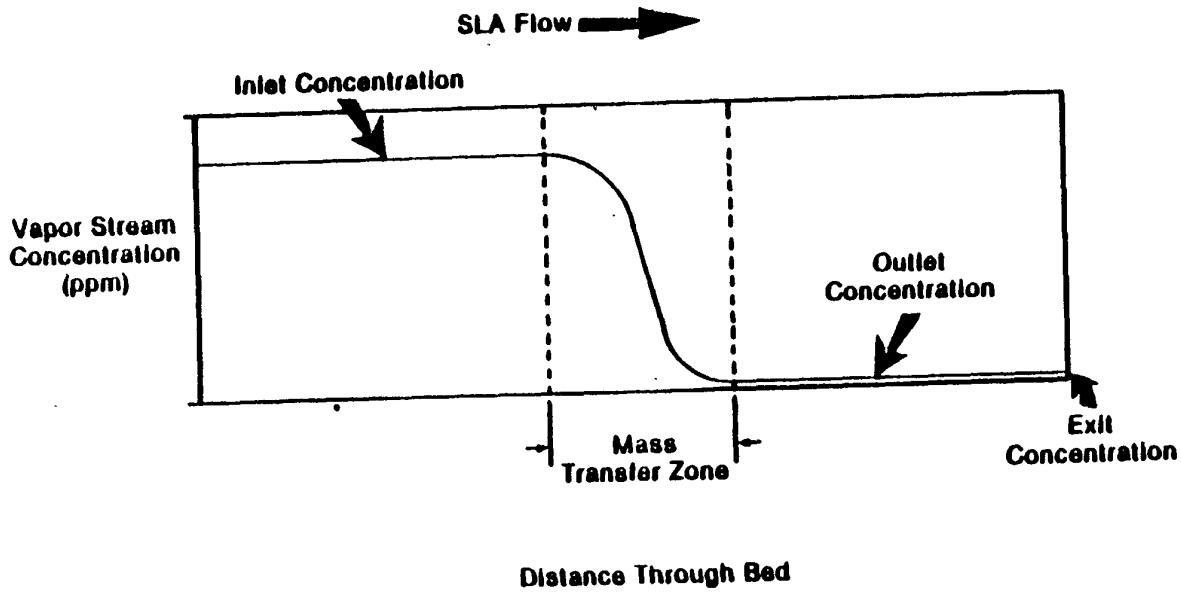

Figure 3-7. Vapor Stream Concentration as a Function of Distance Through Bed

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Test results on full scale systems have shown outlet concentrations as low as 0.5 ppm.[15] This outlet concentration can be minimized by proper system design, as discussed in the next section.

The breakthrough curve, which is the outlet concentration as a function of time, is a mirror image of the concentration profile in the mass transfer zone. As the mass transfer zone reaches the end of the bed, the outlet concentration rises. This will continue until the outlet equals the inlet concentration.

3.2 FULL SCALE ADSORPTION SYSTEMS

This section describes full scale adsorption system design and operation. The basic mechanisms were previously described in Section 3.1. Section 3.2.1 presents an overview of the adsorber system. Section 3.2.2 discusses specific design considerations for a full scale system.

3.2.1 System Overview

The process flow diagram for a typical two bed carbon adsorber system is shown in Figure 3-8. The adsorber system can be broken down into three separate sections; pretreatment, carbon adsorber, and recovery/waste treatment. The vent stream containing the adsorbate enters the adsorption system via the pretreatment section. If the vent stream is above the maximum design temperature it is reduced within the pretreatment section, usually with a heat exchanger. In addition, a filter is included in the pretreatment section to remove any particulate present in the vent stream.

From the pretreatment section, the vent stream enters the adsorber. Figure 3-8 depicts a two bed adsorber system. In order to provide continuous emission control, at least two adsorber beds are needed so that one is on-line while the other is regenerated. Adsorber systems with three or more beds are operated similarly. During operation, the organic-laden vent stream passes through the on-line bed for a predetermined time period or until breakthrough occurs. The on-line bed is then taken off-line for regeneration (desorption) and the other bed is brought on-line.

Regeneration of the off-line bed is usually accomplished by passing steam through the bed countercurrent to the direction of vent stream flow. The steam which is injected into the bed serves several purposes; 1) it

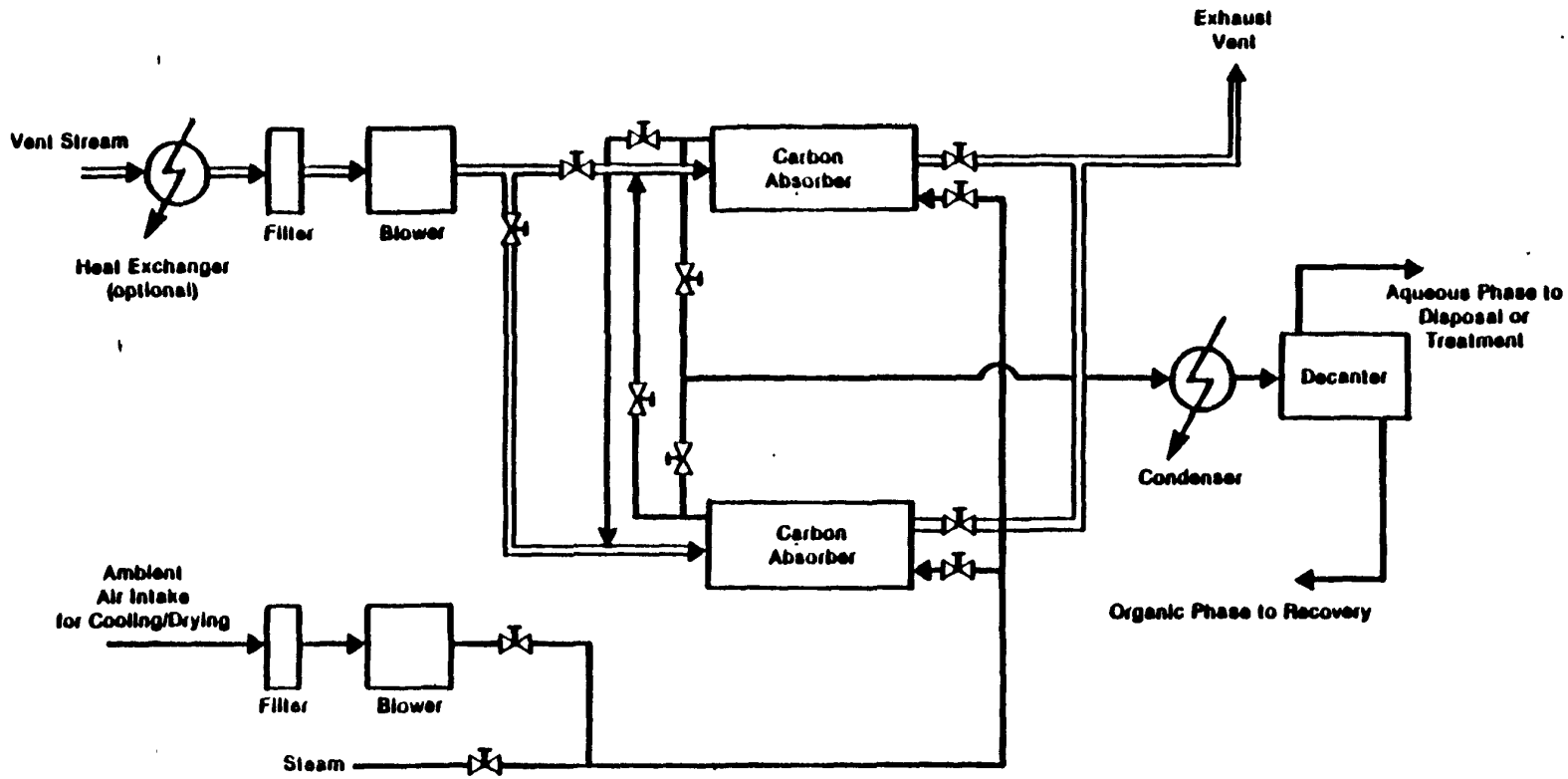

Figure 3-8. Carbon Adsorber System Process Flow Diagram

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provides the energy to raise and hold the bed at an elevated temperature, 2) it provides the energy required to desorb the adsorbate from the carbon, and 3) it carries the desorbed adsorbate from the bed. The steam is condensed and then decanted. There are two liquid phases present in the decanter, the aqueous and organic. The organic phase is generally recovered for reuse. The aqueous phase is either disposed of or, if the level of organics is high, treated prior to disposal. After the desorption step, the bed is sometimes dried using heated air. However, this is not required in most cases because removing water from the carbon usually has little effect on the adsorption process. In fact, the moisture left on the bed can be beneficial because it acts as a heat sink during the adsorption process.[16]

Finally, the regenerated bed is then cooled by passing ambient air through it. In a well designed system both cooling and drying are performed with the air flow countercurrent to the direction of flow when the adsorber is on-line. The air exiting the regenerating bed is directed through the on-line bed to remove any trace adsorbate.

3.2.2 Full Scale System Design Considerations

Section 3.2.1 discussed the overall adsorption system. This section focuses on the design of the adsorber section itself. Both the physical system design and the system control and operation during adsorption and desorption are important in order to achieve high removal efficiencies on a continuous basis.

The design of full scale carbon adsorption systems begins with a determination of the inlet stream characteristics. The characteristics which may be important are:

- Specific compound(s) present;
- flowrate and temperature (range and average);
- adsorbate concentration (range and average; and
- relative humidity.

Any commercial activated carbon should be capable of providing acceptable performance if the system is designed based on that particular carbon. However, selecting a carbon which has a majority of micropores which are

smaller than approximately twice the diameter of the adsorbate molecules, will result in the greatest adsorptive forces.[17]

Once the carbon has been selected, the required bed area is calculated based on the desired superficial velocity. For a specified flowrate, the bed area determines the superficial velocity of the vent stream through the bed. The lower limit of superficial velocity is 20 ft/min to insure proper air distribution. The upper limit is usually 100 ft/min.[18] This upper limit is to keep bed pressure drops within the discharge head capacities of the types of fans used in these applications, and to avoid excessively high system power costs. Typical superficial velocities are based on vendor experience and the results of pilot scale testing and will usually be between 50 and 100 ft/min.

Generally, carbon adsorber bed depths range from 1.5 to 3.0 feet.[19] A bed depth of at least 1.5 feet is used to insure that the bed is substantially deeper than the MTZ, which is normally three inches deep.[20] If the MTZ is longer than the bed, breakthrough will occur almost immediately. The maximum bed depth of three feet is based on keeping system pressure drop within reasonable limits.

Within the constraints discussed above determination of the bed depth becomes a function of the volume of carbon required for one adsorption cycle. The minimum volume of carbon is determined by the solvent mass loading, the carbon's working capacity, carbon density, and the desired available adsorption time. The solvent mass loading and carbon density are fixed by the stream being treated and the choices of carbon, respectively. The working capacity and available adsorption time are interrelated and are determined by the particular carbon, design temperature, adsorbate concentration, specific compounds present, superficial velocity, and regeneration parameters. The available adsorption time as a minimum must be greater than the time required to regenerate (steam and cool) the off-line bed(s).

If the adsorbate contains multiple organic compounds, interactions between those compounds must also be considered in the estimation of working capacity. More strongly adsorbed compounds displace the less strongly adsorbed and push them through the bed.[21] This creates a wave front of the lower molecular weight compounds (which tend to be the compounds less strongly

adsorbed) at the front of the MTZ. The phenomenon must be accounted for in estimating the system design working capacity to insure that breakthrough of any of the compounds does not occur.

At this point it is necessary to determine the working capacity and specify an adsorption time to determine the carbon volume. Empirical data from pilot scale testing are usually required to accurately determine working capacity for a specified set of inlet conditions, superficial velocity, and desorption steam flow. However, the desorption steam flow selected, in turn, affects the working capacity and the minimum required adsorption time. The economic trade-offs of system capital costs versus steam costs will determine what set of regeneration conditions will result in the lowest annual costs.

Steaming requirements are set as part of the initial system design. The longer the bed steaming time the greater the amount of adsorbate removed, and therefore the smaller the amount of removable heel remaining. As previously discussed, the working capacity of a carbon bed, which is the amount of adsorbate the bed can remove during an adsorption cycle, is the difference between the heel and the equilibrium capacity. Therefore, the longer the bed is steamed, the greater the available working capacity. An example of the relationship of working capacity versus steam consumption for three compounds is shown in Figure 3-9.[22] The shape of this curve is similar for most compounds. However, specific values of working capacity versus steam flow vary from compound to compound. The curve usually begins to flatten out at some steam consumption. Increasing steam use beyond the point where the curve begins to flatten out will result in only a small increase in working capacity.

In well designed systems the bed is steamed countercurrent to the direction of flow during adsorption.[23] This will help minimize the adsorbate emitted at the adsorber outlet prior to breakthrough. Figure 3-10, which is a plot of the adsorbate concentration left on the bed after steaming as a function of axial distance through the bed, illustrates why this is true. After steaming, the concentration of adsorbate (i.e., the amount of heel which remains) is lower at the end of the bed where the steam enters. When the adsorber is brought on-line, the lower amount of heel where the SLA exits the bed means less adsorbate is available to desorb. Also, having more working

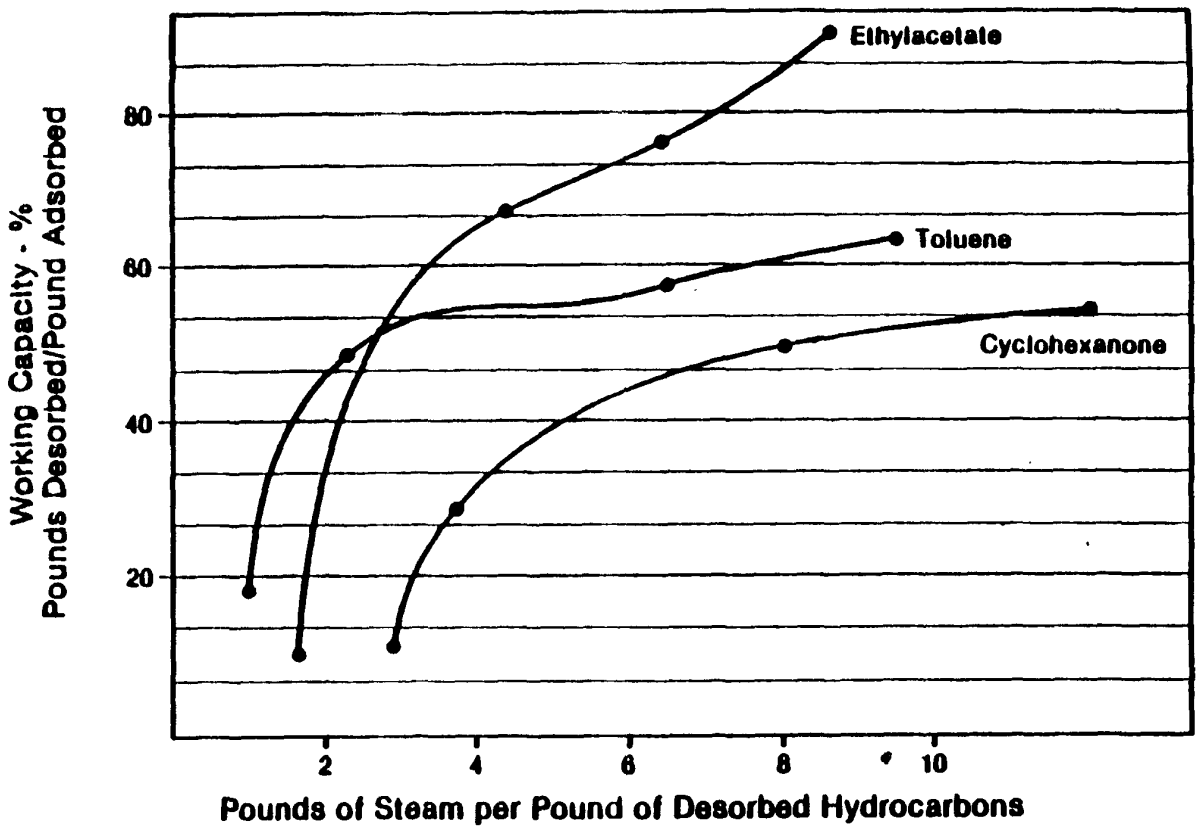

Figure 3-9. Steam Consumption versus Working Capacities

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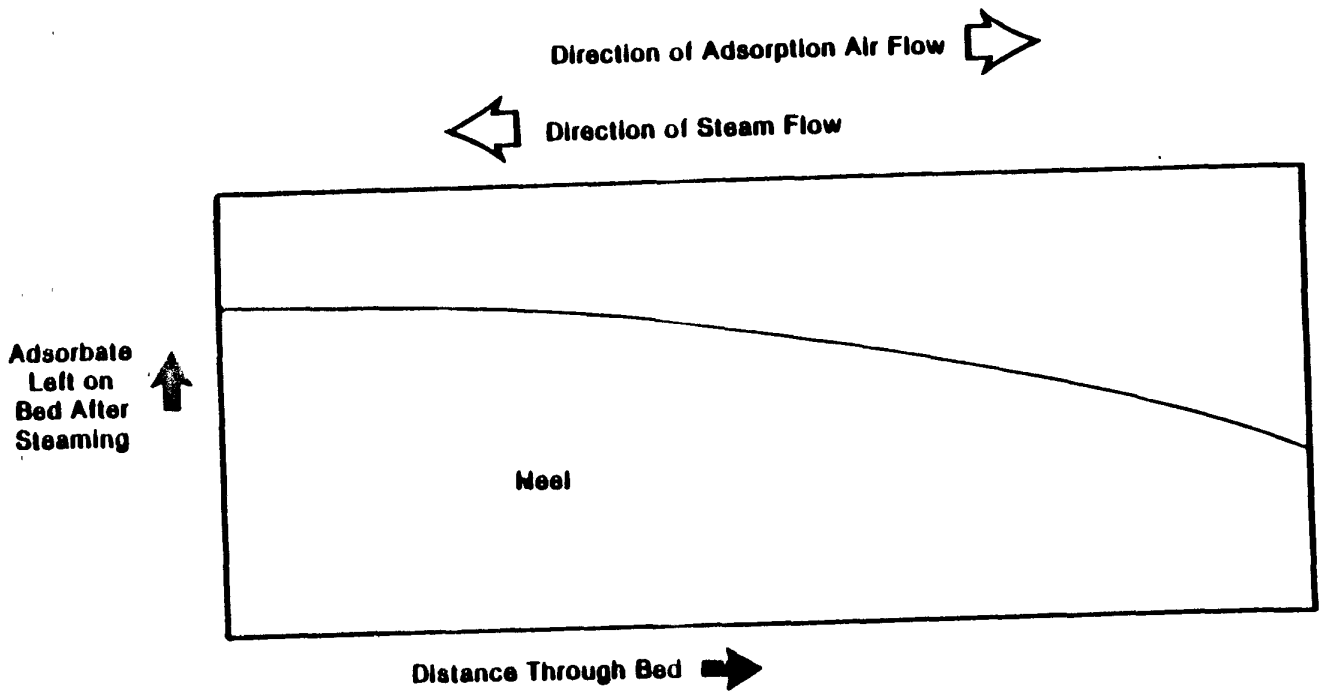

Figure 3-10. Adsorbate Concentration in Bed After Steaming Countercurrently as a Function of Distance Through Bed

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capacity available at the bed exit helps prevent momentary increases in outlet concentration as a result of changes in inlet conditions caused by process upsets. If the bed is steamed cocurrent to the direction of flow during adsorption, the reverse heel profile exists and a higher outlet concentrations will result.

Another consideration in adsorber design is fouling. Fouling occurs when compounds are present in the vent stream which will not desorb from the bed. These compounds can be solid particles, high molecular weight compounds, or compounds which chemically react on the surface of the carbon (such as some ketones). Regardless of the source, bed fouling gradually reduces the carbon adsorption capacity.

There are two methods to compensate for fouling. One is to increase volume of carbon beyond the minimum required to achieve the desired adsorption time. The second is to gradually increase the amount of steam used to regenerate the bed. Increasing the steam used in regeneration reduces the heel, which helps maintain sufficient working capacity. A combination of these methods can also be used.

A typical adsorption/desorption cycling arrangement for a two bed adsorber system is shown in Figure 3-11. For the purpose of discussion, illustrative times are shown on the figure corresponding to operational aspects of the system. The sequence begins with bed 1 coming on-line as bed 2 goes off-line at t_0. For the example shown, adsorption lasts 90 minutes, the steaming time is fixed at 30 minutes, and the cooling/drying time is also 30 minutes. The off-line bed has 30 minutes during which it is on standby. In this example, the 30 minutes of standby time allows the operator to compensate any daily variations in vent stream conditions and bed fouling without having to leave a bed on-line after breakthrough. It is important that a bed not be left on-line after breakthrough because that will significantly reduce the overall removal efficiency for that cycle.

Two types of trigger mechanisms are used for controlling the adsorption/desorption cycles: continuous monitors and timers. Continuous monitors take a bed off-line when a specified outlet concentration is reached. Timers cycle the bed at a specified time. A combination may also be used. One advantage to using continuous monitors is that they allow the beds to remain on-line

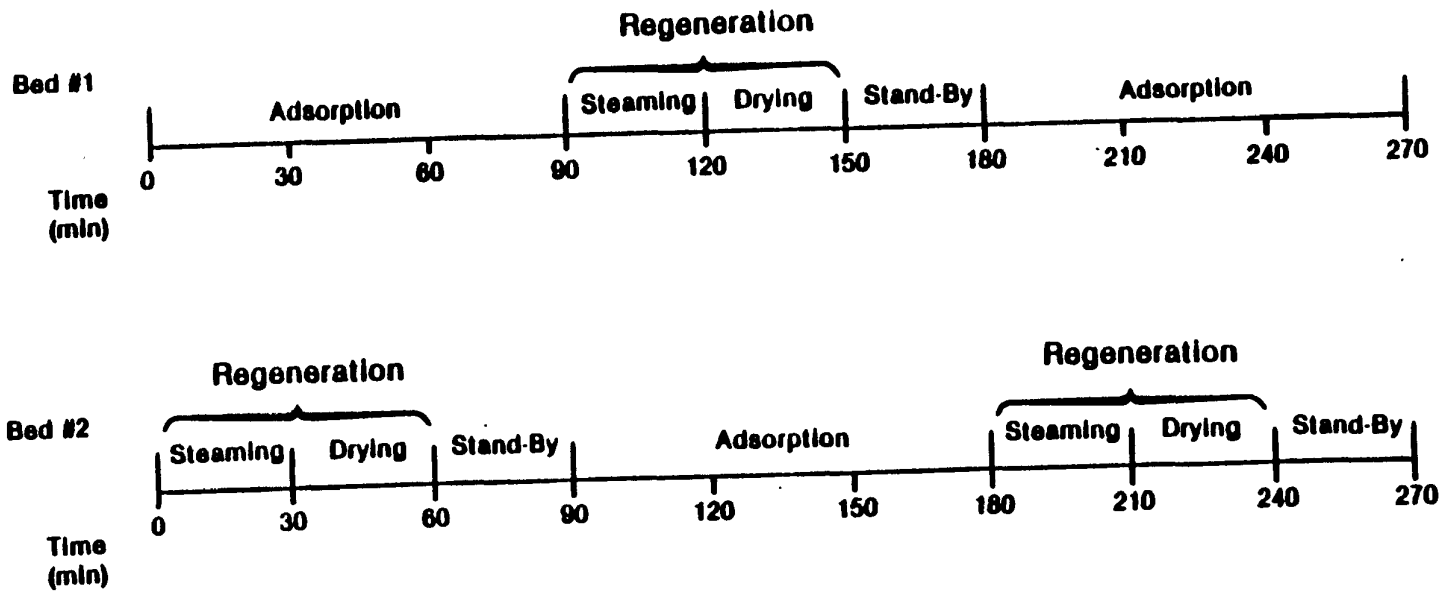

Figure 3-11. Adsorption/Desorption Cycles in a 2 Bed System

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until breakthrough, thus fully utilizing their capacity during each cycle. This is not the case for a timer based system, because to properly guard against breakthrough allowances must be made for variations in the breakthrough time due to changes in the inlet stream characteristics.

Although continuous monitors allow for the use of more of the available adsorption capacity than timers, do, timers can be used in many situations as the trigger mechanism. They are especially appropriate for adsorbates which do not foul the bed or where inlet stream characteristics are very stable. If a timer is used, continuous monitors or a periodic sampling program should be used to adjust the adsorption times as necessary. Deviations in operating conditions do not affect properly designed systems which use timers unless the conditions exceed the range of the design specifications. If this is allowed to occur, a bed may be kept on-line after breakthrough has occurred, This would result in a significantly reduced removal efficiency.

A final, and important, consideration in system design is prevention of channeling. Channeling occurs when a portion of the SLA bypasses the bed, or a certain section of the bed receives a greater portion of the flow than other sections. The inlet of the vessel must be designed to achieve proper distribution of the SLA so that it does not impinge on a portion of the bed at high velocity. The potential for channeling can be minimized by the use of distribution baffles. It is also important to achieve proper distribution of the regeneration steam. If steam is not well distributed the steam flow can also cause channels to form in the bed. Also, poor steam distribution will result in some portion of the bed not being properly regenerated.

Proper design can minimize the potential for channeling. However, maintenance of the distribution baffles and steam distribution system should be performed during scheduled system shutdowns or whenever an increase is detected in the adsorber outlet VOC concentration which is significant enough to result in a removal efficiency below the minimum design level.

3.3 CARBON ADSORBER LONG- AND SHORT-TERM EFFICIENCY

This section discusses the relationship of long and short-term carbon adsorber efficiency. Section 3.3.1 discusses the calculation of instantaneous

versus cycle efficiency. Section 3.3.2 discusses the variability of short-term efficiency. Section 3.3.3 discusses the relationship of outlet concentration and efficiency.

3.3.1 Calculation of Carbon Adsorber Efficiency

In order to discuss carbon adsorber long- and short-term efficiency, a short discussion of the relationship of efficiency to the inlet and outlet concentrations over time is necessary.

The inlet and outlet concentration as a function of time for a single adsorption cycle of a typical carbon adsorber is shown in Figure 3-12. The outlet concentration curve is also called the breakthrough curve. For the example shown, the inlet concentration is C_i and the outlet concentration is C_o. The adsorber was brought on-line at t_0 and taken off-line at t_2 when the outlet concentration reached some predetermined set point concentration level.

At any point in time the instantaneous removal efficiency (IRE) for this adsorber is determined as the difference between the inlet and outlet concentration divided by the inlet concentration. At time t_1 the instantaneous removal efficiency is:

$$IRE_1 = \frac{C_i - C_o}{C_i}$$

The overall removal efficiency (ORE) at any given time during the cycle is determined by the difference between the areas under the inlet and outlet curves divided by the area under the outlet curve. For the adsorber shown in Figures 3-12 at time t_1 the overall removal efficiency is:

$$ORE_1 = \frac{\text{Area (ADEF)} - \text{Area (BCEF)}}{\text{Area (ADEF)}}$$

As an example, in the magnetic tape manufacturing industry a typical inlet concentration might be 3000 ppmv and a typical outlet concentration might be 30 ppmv or less prior to breakthrough.[24] To achieve a 95 percent removal efficiency over the period of an adsorption cycle a system with an inlet concentration of 3,000 ppm must have a time weighted average outlet concentration of 150 ppm or less. At an outlet concentration of 30 ppmv the removal efficiency is 99 percent for most of the cycle. Therefore, when breakthrough occurs the outlet concentration can rise above the 150 ppm point

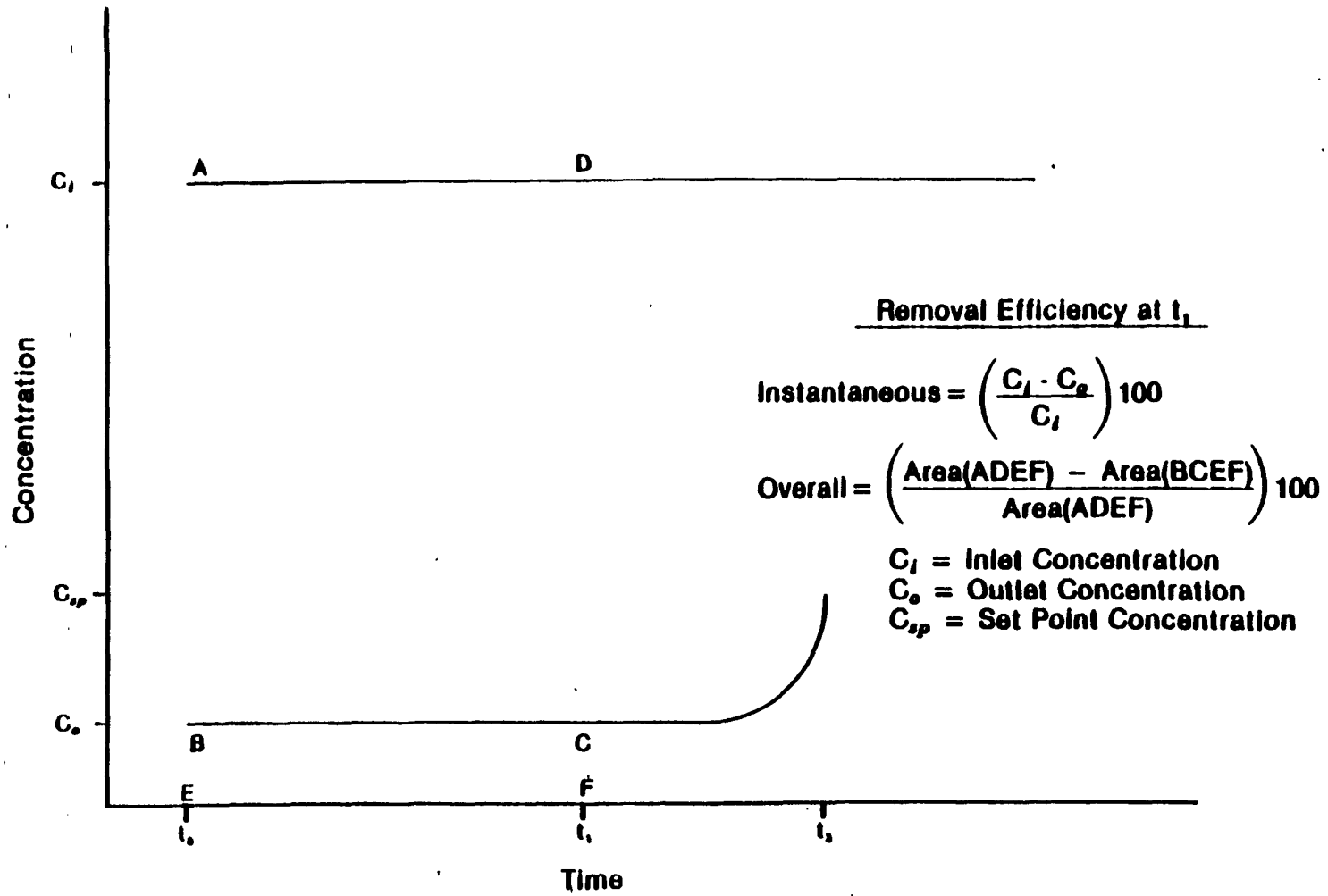

Figure 3-12. Determination of Carbon Adsorber Removal Efficiency

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without the overall removal efficiency going below of the required 95 percent. Therefore, for a system designed and operated to maintain a certain minimum instantaneous removal efficiency, the cycle efficiency will be higher than the instantaneous efficiency. At one site the cycling set point for their system is 2 hours or whenever the instantaneous removal efficiency reaches 95 percent. The result is an overall removal efficiency greater than 99 percent.[25]

3.3.2 Variability of Short-Term Removal Efficiency

A significant issue raised is the variability of short-term carbon adsorber removal efficiency. Assuming that inlet stream characteristics never vary, and the adsorber is always operated the same way, cycle efficiencies should be almost identical.[26] The only change expected would be a gradual decrease in carbon working capacity due to bed aging. However, the change in performance from one cycle to the next due to bed aging will be insignificant.

However, in actual applications, inlet stream characteristics such as concentration, temperature, and flowrate may vary. Also, the operator may make deliberate changes in the solvent being adsorbed, or in system operation. If for a well designed and operated system it can be shown that changes in inlet stream characteristics or operation do not significantly affect cycle-to-cycle efficiency, then the short-term removal efficiency can be expected to be essentially constant for industrial applications. These evaluations are shown in Section 3-4.

3.3.3 Relationship of Outlet Concentration and Efficiency

A typical plot of inlet and outlet concentrations versus time for a carbon adsorber was previously presented in Figure 3-12. Figure 3-13 presents a similar curve for the outlet concentration only. In this example Y represents the outlet concentration at the beginning of the cycle. At the breakthrough time the outlet concentration begins a sharp increase. At this time a fresh bed should be put on-line, and the other bed which has just broken through regenerated.

The dashed line represents what happens if the operator does not remove the bed which has broken through from service. The outlet concentration will increase until it equals the adsorber inlet concentration, which in this example is X.

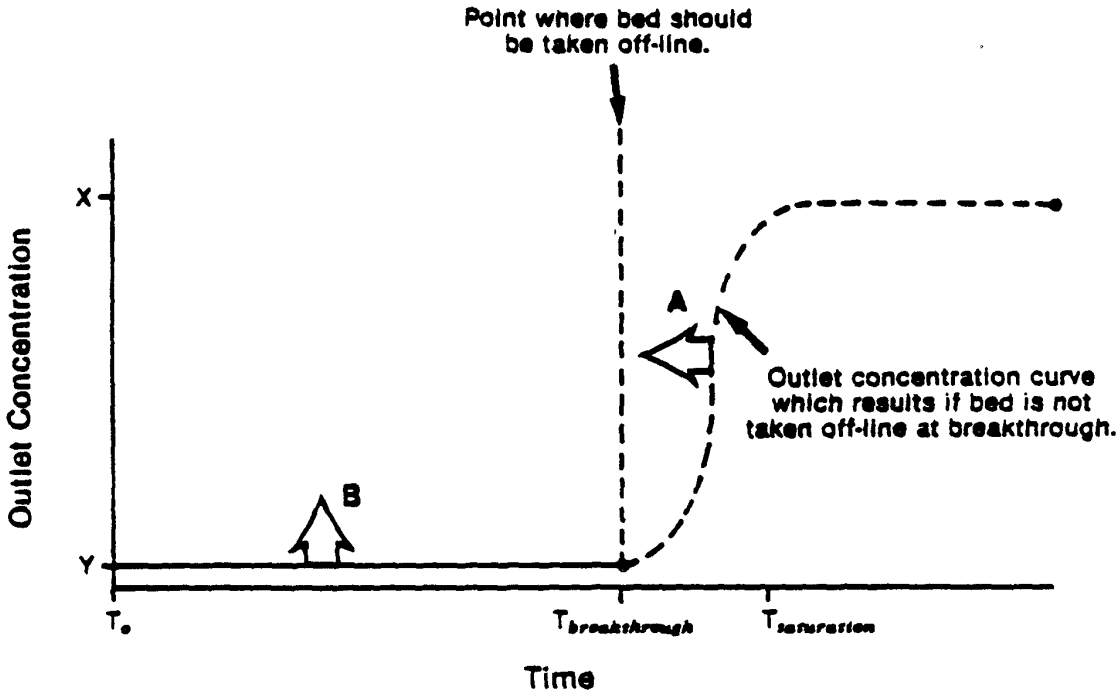

Figure 3-13. Typical Carbon Adsorption Breakthrough Curve

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Also shown in this figure are arrows labeled "A" and "B". These arrows represent the two possible shifts in the breakthrough curve which could occur. The shift labeled "A" indicates a decrease in the adsorption cycle time prior to breakthrough. A shift of this type normally should have little effect on the efficiency of the adsorber, because the bed can be taken off-line for regeneration prior to the release of any significant emissions. A slight efficiency reduction over multiple cycles will occur because breakthrough will occur more frequently. The magnitude of the efficiency change, however, will be very small.

A shift of the A type will significantly affect efficiency if a bed is left on-line after breakthrough. There are three possible reasons for a bed to be left on-line after breakthrough.

1. The operator may not be aware of how quickly the concentration rises after breakthrough and the resulting deleterious effect on the efficiency of his adsorption system.

2. The operator may have no way of knowing when breakthrough occurs (suitable analytical instruments have not been installed).

3. The operator may not have a replacement bed properly desorbed and cooled, ready for service.

The first two reasons are operational problems and easily overcome. The third should not occur if the system was designed properly and is being operated within the design specifications, and the carbon is replaced when necessary.

If beds are left on-line after breakthrough removal efficiencies will also become much more variable. As an example, assume that the adsorber system discussed in Section 3.3.1 has a three hour adsorption time at which point breakthrough occurs, a 3,000 ppmv inlet concentration, and a 30 ppmv outlet concentration. Due to a process change the inlet concentration of VOC now increases to 3,500 ppmv occasionally and this variability was not accounted for in the system design. In this case, breakthrough would now occur approximately 26 minutes earlier. If the operator does not take the bed off-line at this time, the outlet concentration increases very quickly to 3,500 ppm, and for that cycle the adsorber efficiency will be reduced to approximately 85 percent. If the inlet concentration varies from 3,000 to

3,500 ppm on a daily basis, then the adsorber removal efficiency will also vary from 99 to 85 percent on a daily basis. This example demonstrates that if the system is not designed to account for normal process variations, efficiency will both be reduced, and become much more variable than is normally the case with well designed and operated systems.

The shift "B" indicates an increase in the baseline outlet concentration prior to breakthrough. A shift of this type could result in a significant decrease in the removal efficiency achievable by the adsorber depending on the inlet concentration and the magnitude of the outlet concentration change.

For the purpose of this analysis, it is important to understand the two potential shifts in the breakthrough curve relative to the adsorption mechanism itself. Assuming a constant adsorbate loading rate, a shift of type "A" indicates a change in the working capacity of the carbon for a given adsorbate. The working capacity is a function of fouling and the equilibrium conditions (i.e., temperature, pressure, and partial pressure of the adsorbate) for a particular set of operating conditions (i.e., steaming time, temperature, and duration). Therefore, changes in the equilibrium conditions which effect the working capacity lead to type "A" shifts in the breakthrougn curve.

A shift of type "B" indicates one of two possibilities: 1) A portion of the inlet stream has bypassed the bed by either short circuiting or channeling (as previously discussed, channeling can be avoided with proper design and maintenance). 2) A greater amount of heel is present in the last few inches of the carbon bed. As stated previously, the amount of heel is a function of the conditions which are established at the end of the steaming cycle. The amount of heel related to the steaming time, temperature, and flow.

Each of the potential operational variables for a carbon adsorber is evaluated in the next section relative to its ability to shift the breakthrough curve of Figure 3-13 in either the "A" or "B" direction. Proper operation practices necessary to prevent degradation of the adsorber system are also discussed where appropriate. The results from this evaluation are then used to determine the effect on the removal efficiency which is

achievable by the system. In presenting this discussion, data and information available from industry, vendors and emission test reports are used where available.

3.4 EFFECT OF OPERATING VARIABLES ON ADSORBER PERFORMANCE

The objective of this section is to determine if the normal expected day-to-day process variations would be expected to necessarily cause daily variations in carbon adsorber performance. Also assessed are impacts of deliberate process changes, such as a change in solvent, on adsorber performance. Potential daily operating variables include the operating temperature, inlet adsorbate concentration, humidity, volumetric flowrate, and bed fouling. Changes from the initial design operating conditions include the adsorbate types(s), and steaming conditions. Channeling will also be discussed.

Each of the daily normal operational variables is evaluated relative to its effect on the breakthrough curve from a typical carbon adsorber bed. For the purpose of this discussion, the assumption is made that any affect on the performance of a single bed may be taken as representative of the effect on the overall adsorber system's performance.

3.4.1 Temperature

The operating temperature of an adsorber can be affected in three ways: changes in the inlet stream temperature, exothermic chemical reactions taking place inside the adsorber, or failure of the cooling step after regeneration. Changes in the inlet stream's temperature lead to changes in the adsorber operating temperature. Changes in the inlet solvent loading can change the rate of heat generation due to the heat of adsorption. Heat can also be generated within the system from chemical reactions taking place on the bed. Ketones in particular, have been identified by several studies as particularly reactive compounds.[27] The problem is usually not serious. however, unless the concentration of adsorbate is extremely high, the gas flowrate through the carbon is relatively low, and the carbon is dry and contains no heel.

Each of the possible scenarios given above results in a variation in the temperature at which the adsorption process takes place. Therefore, the effect of temperature on the breakthrough curve must be evaluated. As

previously discussed, the two possible shift directions "A" and "B" can be assessed by studying the effect of temperature on the working capacity and the heel, respectively. As shown in Figure 3-14, the relationship between carbon capacity and temperature indicates that as the temperature within the bed increases, the adsorptive capacity of the carbon decreases. Thus, as the temperature increases, the working capacity of the carbon also decreases. Therefore, a shift in the breakthrough curve is to the left or to shorter adsorption times. A shift in this direction has no effect on the achievable removal efficiency but does require a change in the cycle time to compensate for the shift.

Changes in operating temperature should not cause a B shift in the breakthrough curve. This is because the outlet concentration at the beginning of the cycle is primarily a function of the heel remaining in the last few inches of the bed. The amount of heel is established by the bed steaming conditions during desorption. Only if the temperature of the carbon in the adsorber rises to values close to those during steaming is there a chance the removable heel will desorb and subsequently decrease the achievable removal efficiency.

Temperature fluctuations in the inlet stream can be essentially eliminated with installation of a heat exchanger upstream of the carbon adsorber. A properly designed system will not permit the inlet temperature to exceed the maximum design temperature.

To illustrate the insensitivity of carbon adsorber efficiency to minor changes in the bed temperature, the bed temperature and the corresponding instantaneous removal efficiencies for an operating adsorber system are presented in Figure 3-15.[28] As shown, the carbon bed temperature varies from 60 to 90°F during the adsorption cycle while the corresponding removal efficiencies remain well above 99 percent. The outlet VOC concentration remained constant at approximately 20 ppm.[29]

As discussed in the section describing the effect of changes in the adsorbates, ketones are known to exothermically polymerize on the carbon bed. A system designed for ketones must assure the air flow through the bed is sufficient to remove the heat of reaction to insure the bed temperature is not be significantly affected.[30]

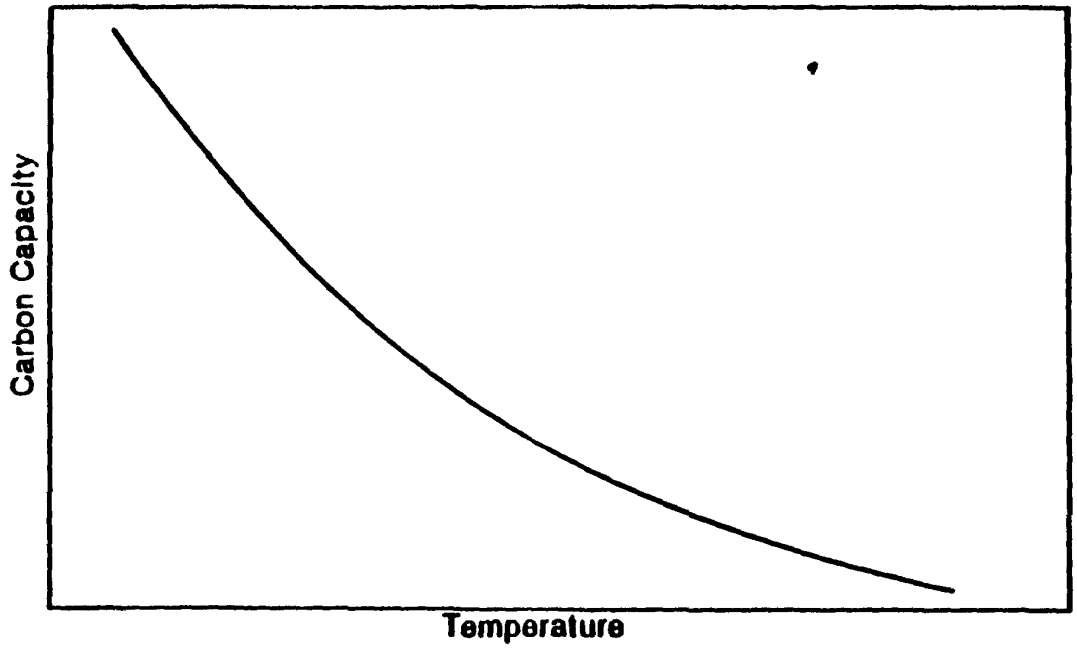

Figure 3-14. Carbon Capacity vs. Temperature at Constant Pressure

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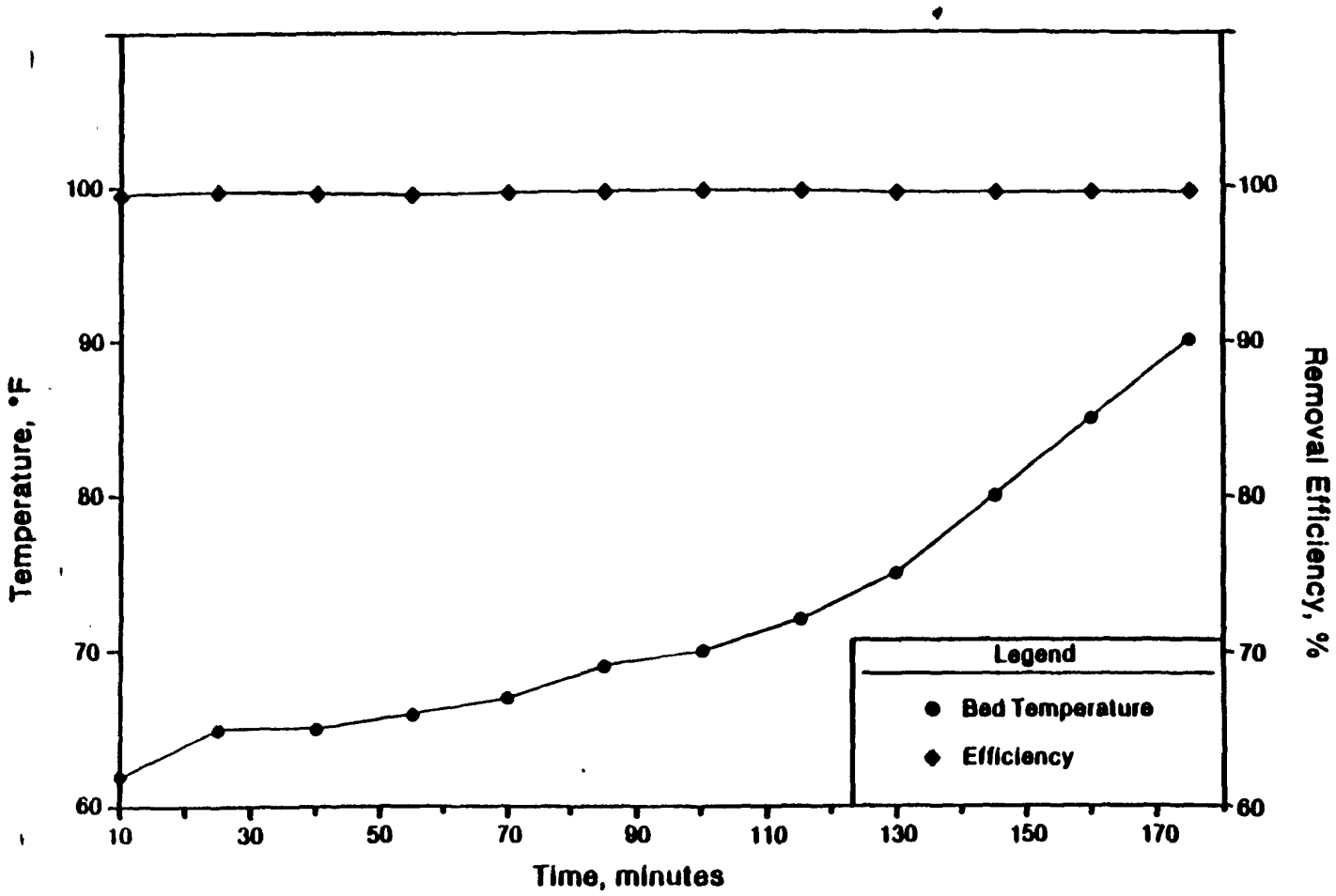

Figure 3-15. Carbon Adsorber Removal Efficiency with Varying Bed Temperature for a Complete Adsorption Cycle

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A properly designed and operated system will limit unacceptable heat buildup due to reactions in the in any of the following ways:

- Thorough steam desorption and cool down,
- use of the maximum superficial velocity to aid in heat removal,
- avoiding prolonged adsorption periods, and
- humidity control or even use of liquid water to act as a heat sink.

When a system is designed to handle a ketone-bearing stream, bed temperature is normally monitored to detect hot spots and initiate protective action for the carbon bed.

3.4.2 Concentration

The concentration of organics in the inlet stream may vary because of process changes. Short-term variations are those which occur within a given cycle while long term variations may last over several cycles. Changes can occur as equipment or product lines are either brought on or taken off-line.

For the purpose of this discussion, the flowrate through the bed is assumed to remain constant. Therefore, when the concentration increases, the loading rate to the adsorber increases.

Increasing the concentration will increase the working capacity of the carbon. However, the working capacity increase will not be large enough to completely offset the increase in mass loading. Therefore, the net effect will be a breakthrough curve shift in the A direction. The effect of variations in inlet concentration on the outlet concentration prior to breakthrough should be negligible. As stated previously, the outlet concentration is a function of the heel in the last few inches of the bed that remains after regeneration. Because the inlet stream reaches equilibrium with the carbon within the mass transfer zone, the amount of heel at the adsorber outlet is independent of inlet concentration. Therefore, short-term variations in the inlet concentration will not cause a B shift in the breakthrough curve.

To illustrate the independence of the outlet concentration on short-term variations in the inlet concentration, the inlet and outlet concentration and corresponding removal efficiency for an operating adsorber system are

presented in Figure 3-16. (GTR Test #6)[31] As shown in Figure 3-16 the inlet concentration varies continuously over the six hour period shown while the corresponding outlet concentrations and removal efficiencies show little variation. For inlet variations between 200 and 550 ppm the outlet concentration varies only from 5 to 15 ppm and the corresponding removal efficiency varies from 95 to 99 percent.

Figure 3-17 also presents inlet concentration, outlet concentration, and the corresponding removal efficiency for a similar performance test conducted on the same adsorber system discussed above.[32] As shown in Figure 3-17, the outlet concentration (0 to 5 ppm) remains relatively constant for the entire test period, although the inlet concentration varies from 40 ppm to 880 ppm. Figure 3-17 also shows the removal efficiency over the test period. During the majority of the test period the removal efficiency was well above 95 percent. However, when the inlet concentration dropped below 50 ppm, the removal efficiency was also significantly reduced. This is as expected because carbon adsorbers are essentially constant outlet devices, so a large decrease in inlet concentration will reduce short-term removal efficiency.

Because the outlet concentration remains constant throughout an adsorption cycle, large variations in the inlet concentration will result in corresponding variations in removal efficiency. However, if the bed is properly regenerated, the outlet concentration can be set at a level where greater than 95 percent removal is achieved for the entire range of inlet concentrations. In addition, in many applications of carbon adsorption, a reduction in inlet concentration is the result of equipment (such as coating lines) being shut down. By diverting or shutting off the air flow from idle equipment, inlet concentrations can be maintained at higher levels required to ensure the desired removal efficiency.

3.4.3 Humidity

Working capacity as a function of steam consumption is shown for relative humidities of 50 and 100 percent, in Figure 3-18.[33] As shown, relative humidity does not significantly affect working capacity. This is generally the case for adsorbate concentrations greater than 1,000 ppm.[34] Therefore, there should be only a slight change in the breakthrough time associated with variations in relative humidity in this case.

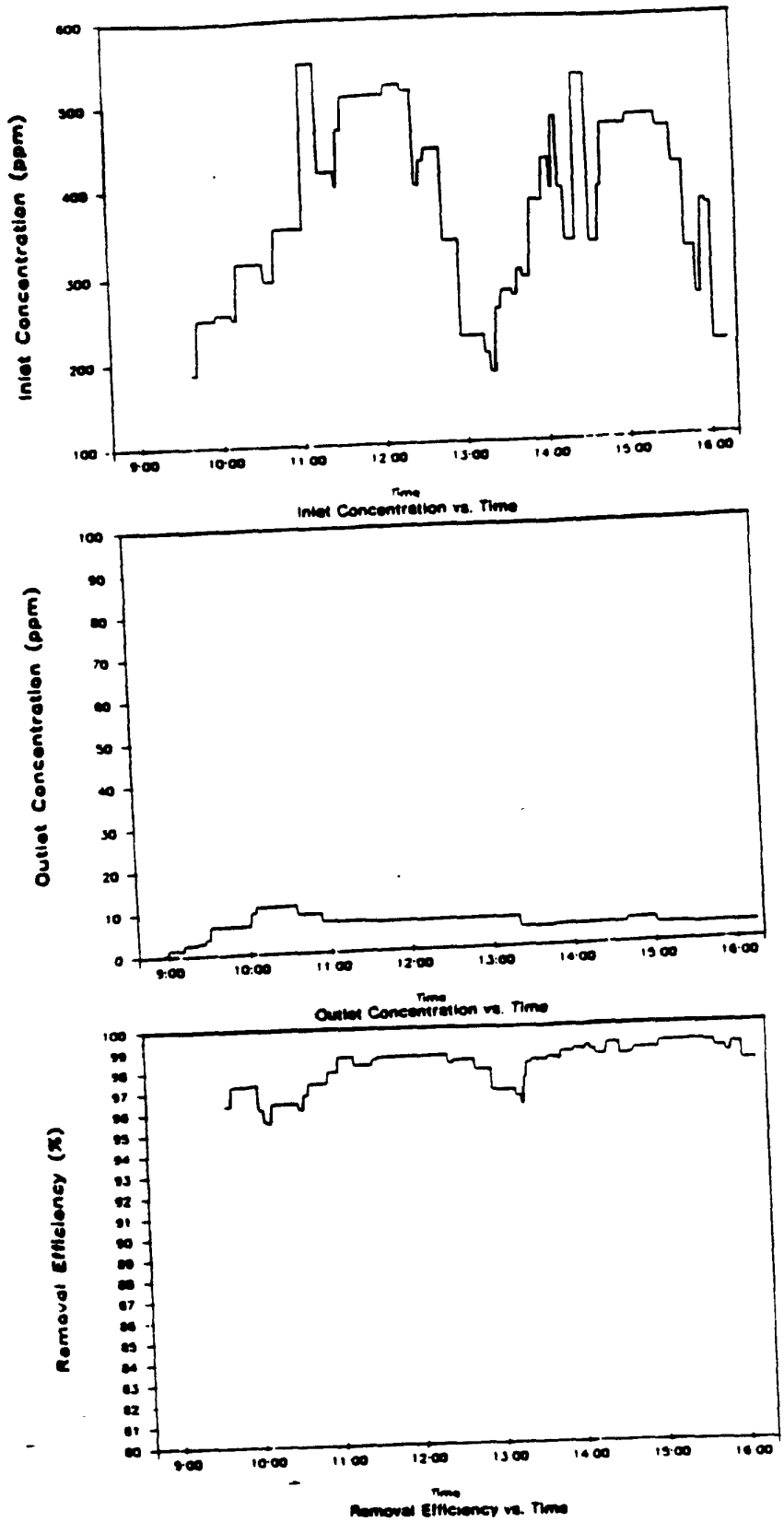

Figure 3-16. GTR Test Number 6 Continuous inlet/outlet VOC concentration data and removal efficiency.

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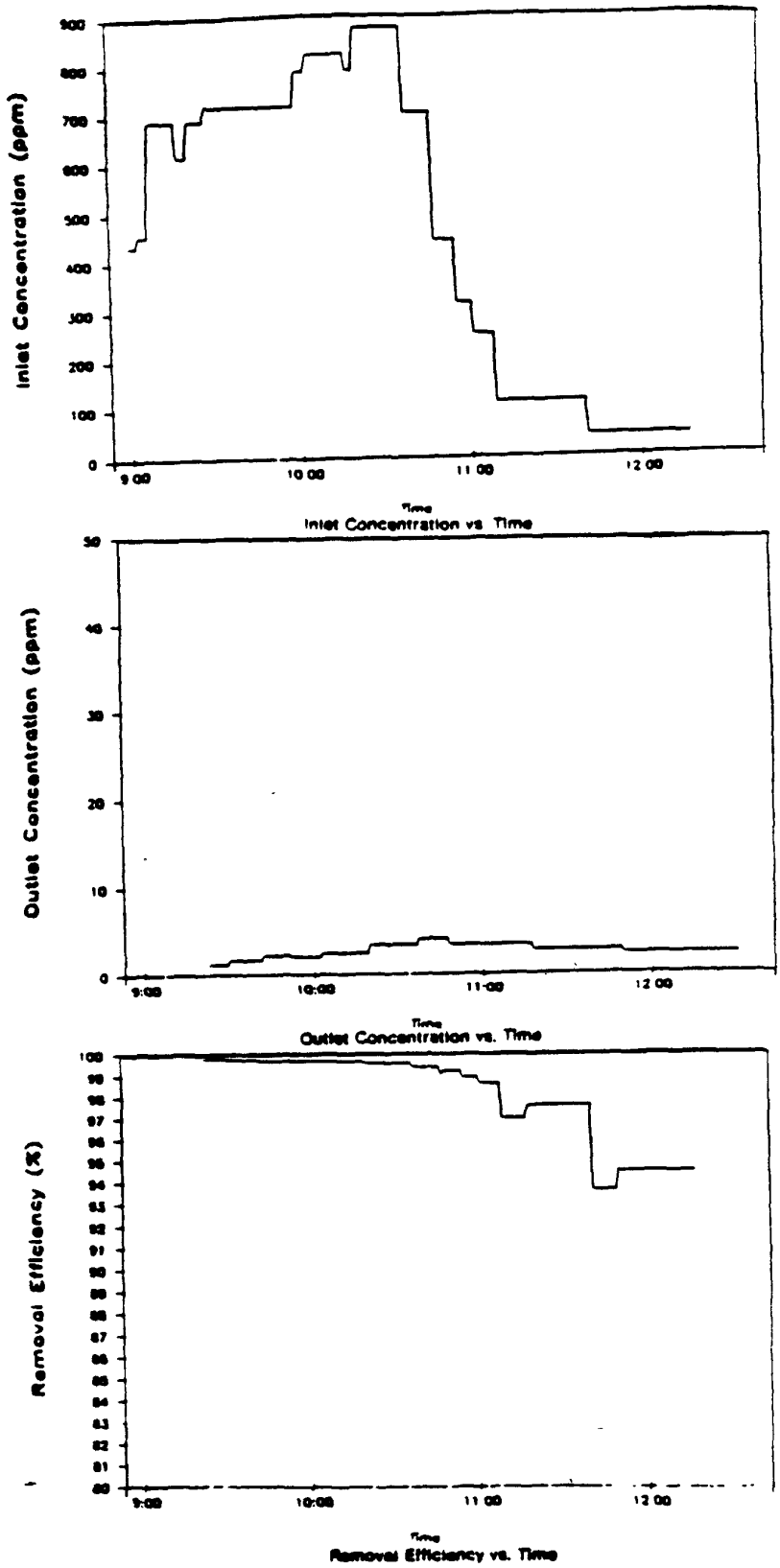

Figure 3-17. GTR Test Number 5 Continuous inlet/outlet VOC concentration data and removal efficiency.

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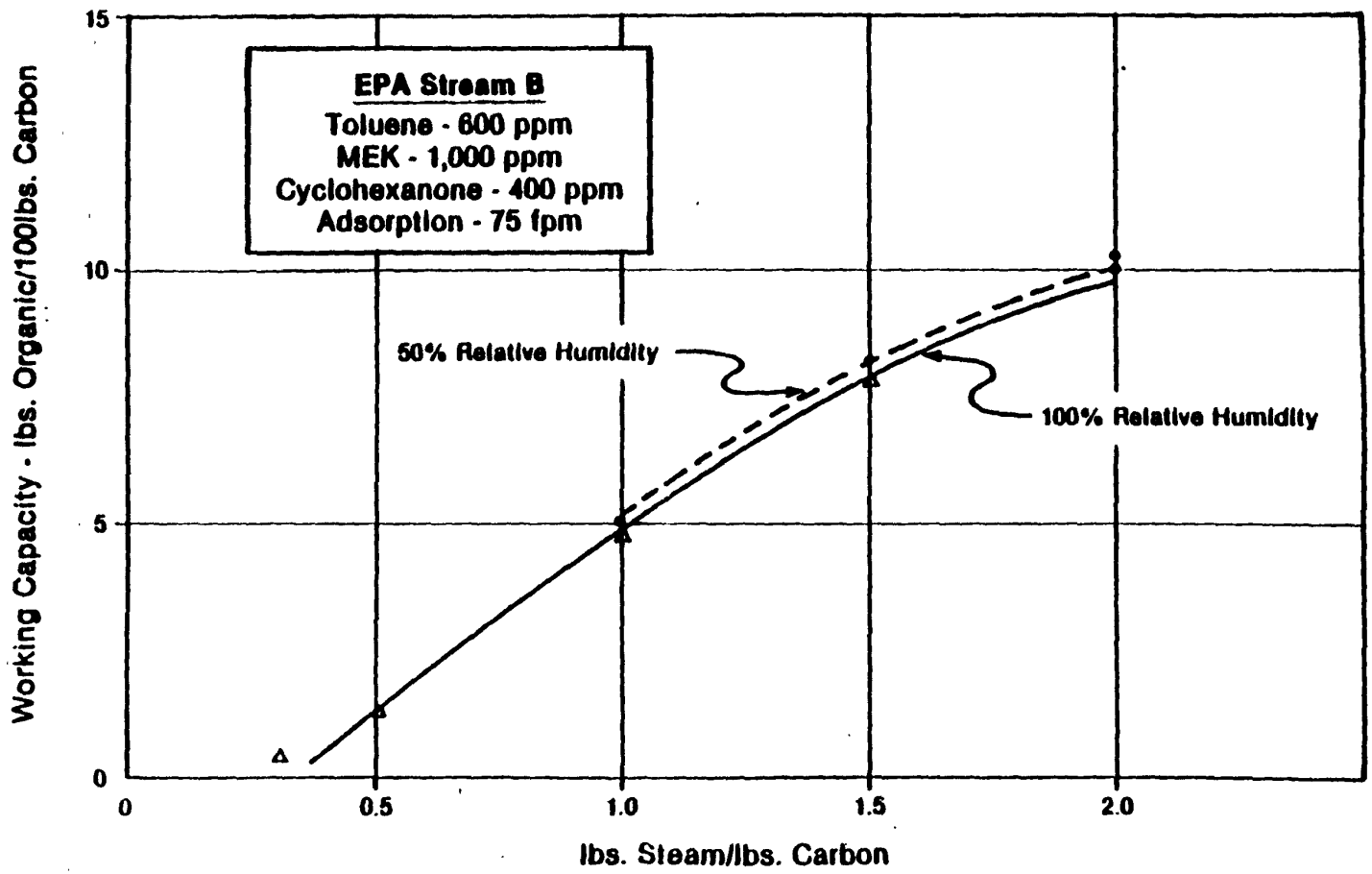


Figure 3-18. Effect of Relative Humidity on Working Capacity

Below adsorbate concentrations of 1,000 ppm water begins to compete with adsorbate for the available adsorption sites and the bed working capacity for that adsorbate is then affected. In this case, some type of dehumidification system upstream of the bed or dilution with ambient air may be required.

Relative humidity has no effect on the amount of heel which is retained within the carbon pore. Therefore, there is no B shift in the breakthrough curve and no subsequent change in the achievable removal efficiency on a long- or short-term basis.

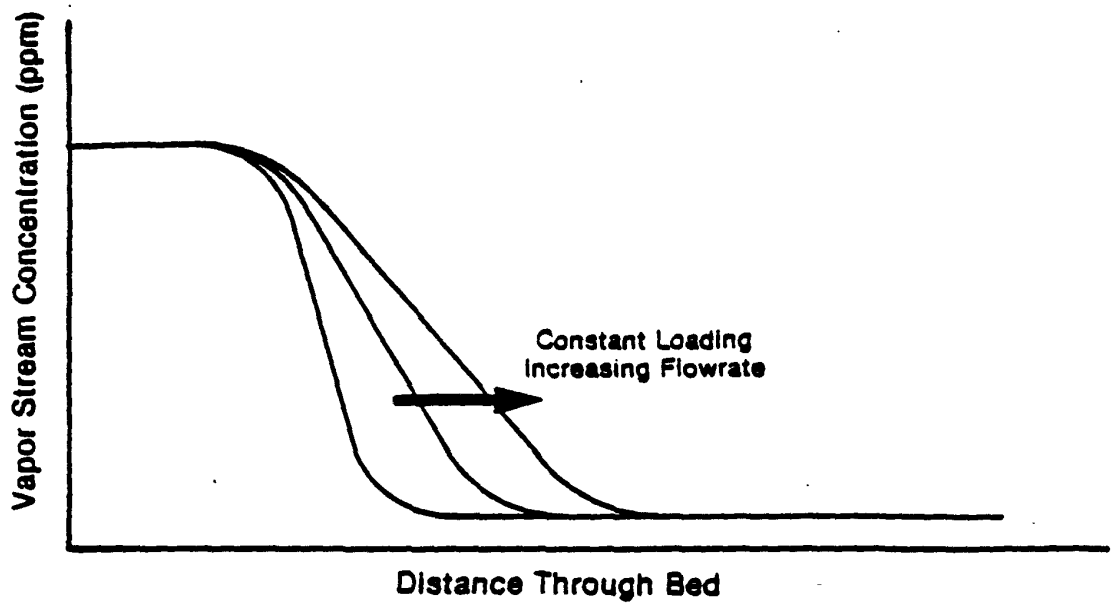
High relative humidities are present in most operating systems regardless of the vent stream conditions because of the water remaining on the bed after steaming. As shown in Figure 3-18, the working capacity gained by reducing the humidity is small. In this case, reducing steam humidity would probably not be cost-effective. In addition, the water content in the bed provides a heat sink valuable in controlling bed temperature.

3.4.4 Volumetric Flowrate

The superficial bed velocity for a system changes as the volumetric flow to the system changes. The primary effect is to change the width of the mass transfer zone within the bed. As the superficial velocity increases, the width of the mass transfer zone also increases because the individual carbon pellets are exposed to the adsorbate for a shorter period of time, thus the quantity removed at a given point decreases. The effect of a wider mass transfer zone on the shape of the breakthrough curve is shown in the top of Figure 3-19. As shown in the bottom figure, the time prior to breakthrough is shortened by increases in volumetric flowrate because of the wider MTZ.

To illustrate the independence of carbon adsorber removal efficiency to short-term variations in the volumetric flowrate, the flowrate and corresponding instantaneous removal efficiencies for an operating adsorber system are presented in Figure 3-20.[35] As shown, the flowrate varies randomly during the entire adsorption cycle while the corresponding removal efficiencies show little variation. For flowrate variations from 45,000 to 25,000 scfm the removal efficiency varies less than 0.5 percent with all efficiencies being well above 99 percent.

Since variations in the volumetric flowrate do not affect the amount of heel on the bed at a given time, there is no B shift in the outlet



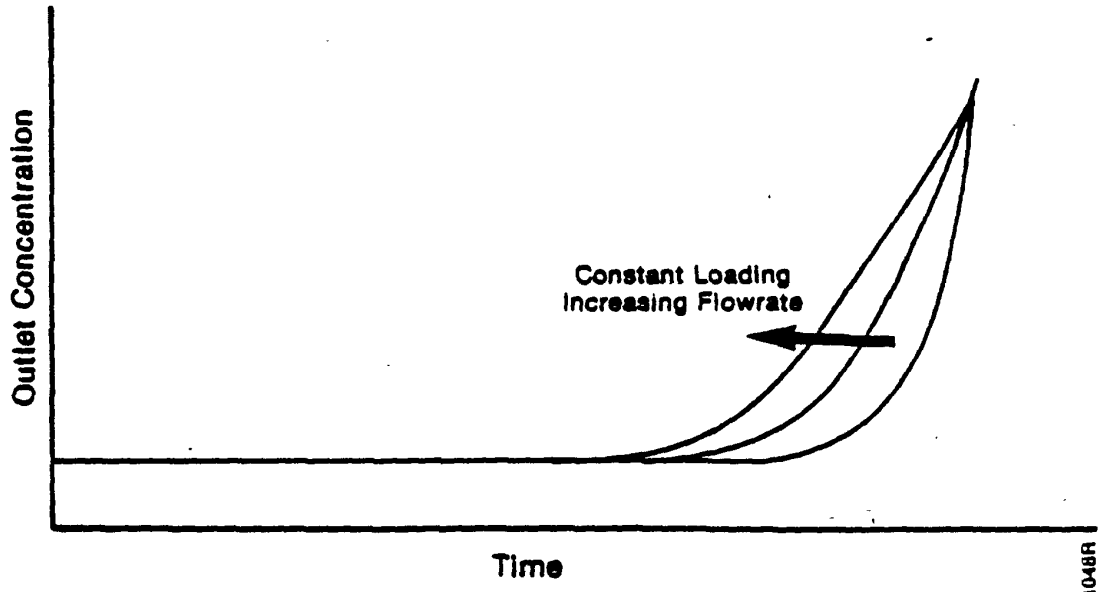


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Figure 3-19. Effect of Variation in Volumetric Flowrate on the Shape of the Breakthrough Curve

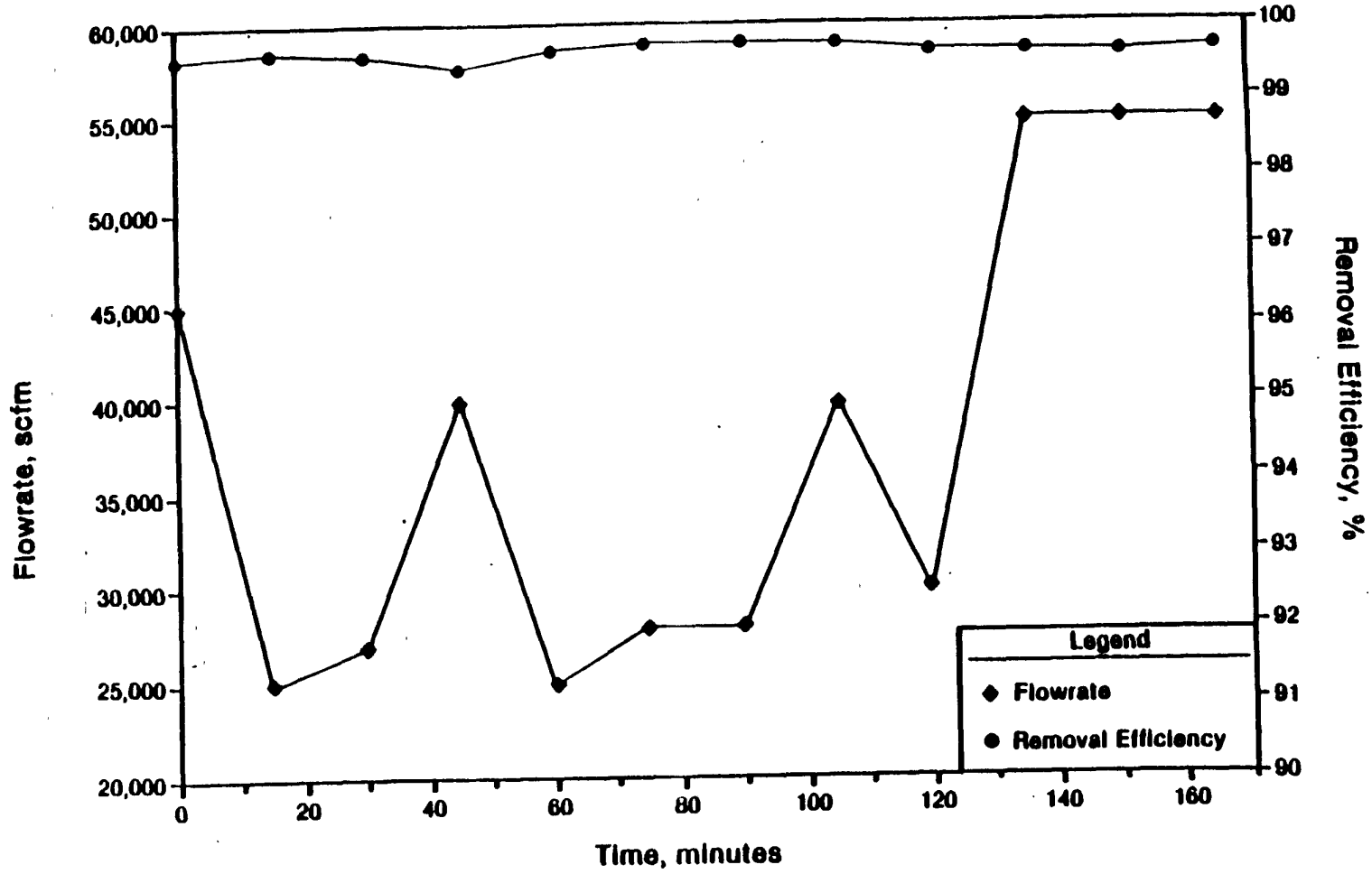

Figure 3-20. Carbon Adsorber Removal Efficiency with Varying Flowrate for a Complete Adsorption Cycle

concentration prior to breakthrough, due to either long- or short-term variations in the flowrate. Consequently, there is no effect on the long- or short-term removal efficiency achievable by the system.

3.4.5 Bed Fouling

This section discusses the effect of bed fouling an adsorber removal efficiency. The causes of bed fouling were previously discussed in Section 3.2.2. Bed fouling gradually decreases working capacity by tying up the active adsorption sites in the micropores or blocking the pores which prevent adsorbate molecules from entering. Because the capacity of the system is decreased, the time prior to breakthrough is shortened. As discussed previously, this has no effect on an adsorber's removal efficiency until the shortened length of the adsorption cycle begins to conflict with the regeneration time. At this point the carbon should be replaced.

Fouling will not affect the outlet concentration prior to breakthrough.[36] Therefore there will be no B shift in the breakthrough curve. The reason is that fouling will not affect the amount of heel left in the bed.

As previously discussed, fouling does gradually reduce bed working capacity. In some cases the steam flow and/or temperature can be increased to reduce the heel and therefore increase working capacity the bed ages. However, as previously shown in Figure 3-9, the point will be reached where increasing the steam flow will have little beneficial effect on working capacity. Therefore, even if the system is well designed and operated, a point will be approached where there is insufficient time to regenerate the off-line bed before the on-line bed reaches breakthrough. At this time, carbon will need to be replaced.

Figure 3-21 presents overall removal efficiency plotted as function of carbon bed age for a system on a vent stream containing cyclohexanone, tetrahydrofuran, methylethylketone (MEK), and toluene.[37] Both cyclohexanone and MEK are known to cause bed fouling. As shown, there is only a slight decline in the removal efficiency from 99.6 percent for the newest bed to 99.4 percent for the oldest bed.

Though fouling of the carbon bed has no affect on the efficiency of an adsorber system, it does reduce bed life, which in turn increases the annual operating cost of the system. The fouling rate is affected by numerous

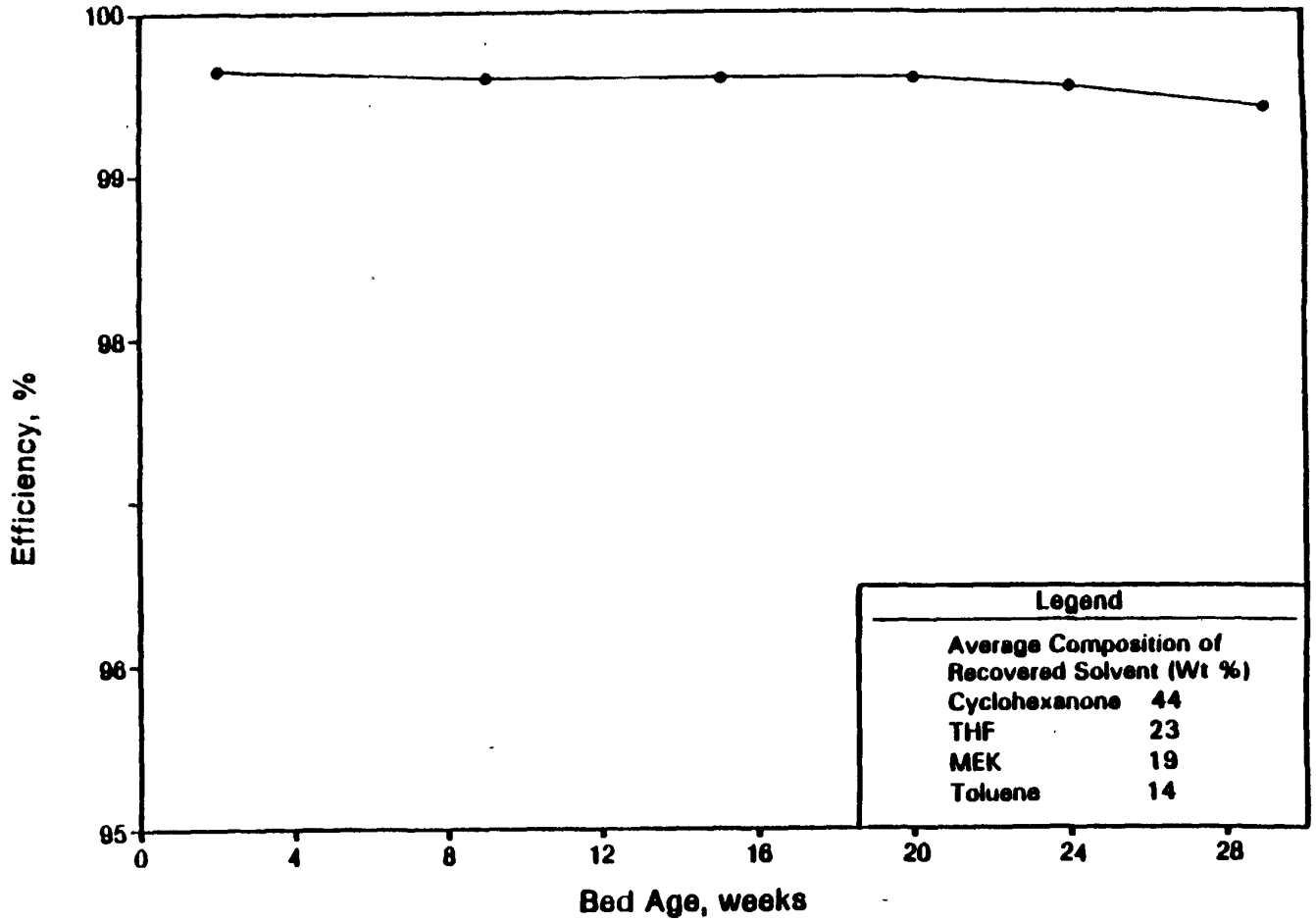

Figure 3-21. Carbon Adsorber Removal Efficiency as a Function of Bed Age for a Ketone Containing System

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factors, but the adsorbate characteristics can be considered the most dramatic. The effect of several solvent blends on bed life is shown in Table 3-1. For the toluene and isopropylacetate (IPA) application shown, the beds have not yet been changed after six years of operation and no shortening of the adsorption time prior to breakthrough has been detected. For the toluene and hexane application shown, the bed life is reported to be 10 years.

Lifetime removal efficiencies are also shown in Table 3-1. High removal efficiencies are shown even for streams containing high concentrations of cyclohexanone, a known fouling agent. Facility A has a 99.4 percent removal efficiency on a six bed adsorption system. The bed life for this facility is significantly less than the other facilities shown. The overall removal efficiency at Facility A reflects the aggregate for a system with beds at various stages of life. The solvent recovered at this facility includes approximately 44 percent by weight cyclohexanone and 19 percent methyl ethyl ketone. Based on the overall system removal efficiency for this system of 99.4 percent, it can be concluded that all the beds in the system are achieving well above 95 percent removal.

3.4.6 Channeling

As discussed in Section 3.3, a carbon adsorber system should be designed with adequate flow baffles and proper steam distribution to prevent channeling. If channeling does occur, it will cause elevation of the background outlet concentration over a cycle, or a gradual increase during the cycle. For systems with VOC monitors, these increases will be readily apparent. If the amount of channeling is small, the system may still be able to retain the required removal efficiency. If significant channeling occurs, then adsorber removal efficiency would be significantly degraded.

In a well designed system, channeling need not occur. From the perspective of the ability of a carbon adsorber to meet a specific regulatory removal requirement channeling is actually a malfunction of the system, rather than a factor causing inherent variability in short-term efficiency.

3.5 DELIBERATE CHANGES FROM INITIAL DESIGN OPERATING CONDITIONS

This section discusses the effect of changing the adsorbate type(s) and steaming conditions. To assess the impact of each change on the future

TABLE 3-1. REPORTED BED LIVES FOR VARIOUS SOLVENT BLENDS[38-41]

Facility	Solvent blend	Reported bed life	Reported removal efficiency (%)
A	44% Cyclohexanone[c] 14% Methyl Ethyl Ketone 23% Tetrahydrofuran 19% Toluene	-[d]	99.4
B	50% Toluene 50% Isopropyl Acetate	>6 Years	98[a]
C	95% Toluene 5% Hexane	10 Years	99.5[b]
D	Methyl Ethyl Ketone	5 Years	99.6

[a]Value reported by company. No data was provided to verify.

[b]Estimation: Assumed average inlet loading was mid range in design specification range, and outlet loading was the reported value.

[c]Actual solvent blends at this facility vary. The values are typical of the total solvent recovered daily.

[d]The specific bed life at this facility is confidential business information. However, it is significantly lower than the other values shown. This reduced bed life is believed to be at least partially due to the presence of cyclohexanone and methyl ethyl ketone.

operation and performance of the adsorber system, the logic associated with the initial specification of each design parameter is discussed.

3.5.1 Adsorbate

The concentration and type of organic are key factors in the design of a carbon adsorption system. The adsorption characteristics of each compound are assessed by using their physical properties data, such as: 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.[42] High vapor pressure/low boiling point adsorbates and low molecular weight compounds adsorb less readily.[43] Compounds with molecular weights greater than 142 adsorb readily but are difficult to desorb.[44]

If the adsorbate is water soluble, water left as condensate in the bed after steaming and cooling can contain adsorbate.[45] 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 until the concentration falls rapidly to a normal baseline value.

The properties and adsorption characteristics affect both the design and operating conditions. If the feed stream is changed, the adsorber system must be re-evaluated. If it can accommodate the new feed, there will be no effect on the achievable removal efficiency; although on-line adsorption time and steaming requirements may need to be changed. If timers are used as the trigger mechanisms, the new working capacity of the beds must be determined. Using this working capacity and a maximum inlet loading, the appropriate new adsorption time can be determined so that the timers can be reset for the new operating conditions.

Changing the adsorbate can also affect the desorption cycle. The relationship between steam usage and working capacity was previously shown for three different compounds in Figure 3-9. As can be seen, if the adsorbate blend is changed, the optimum steam requirements may also change.

3.5.2 Steaming Conditions

As previously discussed, steaming requirements are determined as part of the initial system design. Variables which must be considered are the

steaming temperature, duration, and rate. Generally, steam temperature is fixed with a given plant. For this reason, the effect of temperature is not discussed. The amount of steam required is determined by the required working capacity. Once the initial design is set, as long as the amount of steam used per desorption cycle remains constant, the available working capacity will remain constant assuming no fouling or other degradation of the carbon bed.

In actual application, however, the carbon's total absorption capacity gradually decreases over time due to fouling. If the operator desires to maintain the same breakthrough time, steam use per desorption cycle must be gradually increased. (Alternately, if sufficient standby time is available, the length of the adsorption cycle can be gradually decreased as previously discussed.) At some point the amount of steam required per desorption cycle becomes so great that either there is insufficient time to complete desorption before breakthrough of the on-line bed, or the cost of steam becomes too great. At this point the carbon must be replaced.

Although steaming amount is important in the desorption process, duration is also a consideration. In order to remove the adsorbate, sufficient time at the steaming temperature is required. This is to allow for diffusion of the adsorbate out of the pores and out of the carbon particle. Without sufficient time, increasing the flow of steam will not remove the adsorbate from deep within the pores of the carbon.

3.6 PERFORMANCE INFORMATION ON INDUSTRIAL ADSORBERS

Available data concerning the ability of carbon adsorber systems to achieve 95 percent removal efficiencies are summarized in this section. Data from performance tests sponsored by EPA's Office of Research and Development (ORD), three test programs sponsored by EPA's Emissions Standards Division (ESD), and industry are used to support the conclusions reached. For each of the tests, the design parameters, operating conditions during testing, and test information and results are given. A comparison between design and operating information is then used to evaluate if a given system was operated within design limits during testing.

Data sources along with the site codes and test numbering scheme used in the presentation are discussed in Section 3.6.1. In Section 3.6.2 the

adsorber system operation is discussed with respect to the removal efficiencies achieved at a given site. Specifically, poor system operating procedures which were identified are explained. Finally, in Section 3.6 the conclusions reached regarding adsorber performance are presented.

3.6.1 Data Sources

A summary of the available carbon adsorber emissions test results is given in Table 3-2. Average overall removal efficiencies, design and actual operating conditions, and testing information are given for each of 12 sites. Emissions test data were available for 11 of the 12 sites. The twelfth reported efficiencies, but provided no supporting data. For each of the tests 1-15, a unique test number is reported. Repeat tests were done at 4 of the twelve sites. Table 3-3 presents individual average bed removal efficiencies for several of these sites.

Tests 1-10 were performance tests performed as part of an EPA/ORD study of carbon adsorber performance in various industries.[46] The manufacturing processes included are rubberized fabric, magnetic tape, flexible packaging, and rotogravure printing. Test 6 of this study was not presented for reasons discussed in Section 3.6.2. Six of the 10 tests were conducted in early 1982. The four follow-up tests were performed one to two years after the initial test. Tests 11-13 were performed as part of EPA/ESD performance evaluations at three specific sites.[47-49] Results from Tests 14 and 15 were provided by industry.[50,51]

Tests 1-13 were conducted in accordance with approved EPA methods. Inlet and outlet concentrations were measured semicontinuously with flame ionization detector total hydrocarbon instrumentation as described in EPA Method 25A. Volumetric flow rates were measured according to EPA Methods 1 and 2. All tests were verified by EPA-specified quality assurance/quality control procedures.

Tests 14 and 15 were performed in accordance with EPA Methods 1,2, and 25. Method 25 differs from Method 25A in that integrated bag samples are taken and the concentration of the gas within the bag is used to determine the removal efficiency over the sampling period. Although this method does not give the semicontinuous data provided by Method 25A, it provides a means for accurately assessing the average removal efficiency over the sampling period.

TABLE 3-2. PERFORMANCE TEST DATA FOR CARBON ADSORPTION SYSTEMS

		Design Parameters					Conditions During Test						
Test No.	Site	Flowrate (SCFM)	Components[a] in inlet stream	Adsorbate Loading (lb/hr)	Temperature (F)	Steam Flow (lb/hr)	Flowrate (SCFM)	Components in Inlet Stream[a]	Adsorbate Loading (lb/hr)	Temperature (F)	Steam Flow (lb/hr)	Bed Age (years)	Average[n] Removal Efficiency (%)
1	A	11,200	MEK - 60% Toluene - 40	575	95	2,375	11,400	MEK - 100%	284	94	2,410	0.4	84.9[b]
2	B	12,700	THF - 50% Toluene - 50%	140	90	900[m]	9,800	THF - 50% Toluene - 50%	195[c]	74	600	2	99.7
3	B	12,700	THF - 50% Toluene - 50%	140	90	900	9,500	THF - 75% Toluene - 25%	140	90	860	3.8	95.3[d]
4	C	23,000	THF, Toluene, MEK, MIBK, Cyclohexanone	600	85	2,400	19,800	THF, Toluene, MEK, MIBK, Cyclohexanone	1,260[c]	81	2,900	0.4	94.8[e]
5	D	22,000	Hexane - 100%	1,300	95	4,130	17,700	Hexane - 100%	355	89	3,200	3	99.1
7	E	11,100	Toluene - 100%	204	100	1,170	9,100	Toluene - 100%	249[c]	104	3,000	5	97.6
8	E	11,100	Toluene - 100%	204	100	1,170	7,800	Toluene - 100%	101	132[f]	2,800	6.5	94.6[g,h]
9	F	80,000	Toluene - 60% IPAC - 40%	810	120	1,180	33,400	Toluene - 60% IPAC - 40%	929[c]	91	3,400	0.2	97.5
10	F	80,000	Toluene - 60% IPAC - 40%	810	120	1,180	33,900	Toluene - 60% IPAC - 40%	892[c]	67	3,300	1.6	97.8
11	G	NR[i]	NR	NR	NR	NR	8,400	MEK - 95% MIBK, Toluene - 5%	3,550	NR	NR	NR	98.9
12	H	NR	NR	NR	NR	NR	48,800	Toluene - 100%	980	94	11,000	NR	98[j]
13	I	75,000	NR	NR	NR	NR	61,200	Toluene - 30% Xylene - 4% Lactol Spirits - 66%	1,279	100	NR	NR	95.8
14	J	10,000 -	MEK - 20-50%	180 -	<200	12,000	60,000-	THF - 5,410 (lb per day)	NR	120	12,000	Variable	99.4
		83,700	Cyclohexanone - 20-50% THF - 5-25% Toluene - 5-25%	2,800			70,000	Toluene - 3,210 MEK - 4,480 Cyclohexanone - 10,500					
15	K	24,000	MEK - 100%	1,200	NR	1,750	24,000	MEK - 100%	402[k]	83	1,750	2	99.6
	L	28,000	Toluene - 95% Hexane - 5%	860 1,070	120	3,000	28,000	NR	NR	120	3,000	N/A[l]	99.5

TABLE 3-2. PERFORMANCE TEST DATA FOR CARBON ADSORPTION SYSTEMS (*Continued*)

[a]MEK = Methyl ethyl ketone; THF = Tetrahydrofuran; MIBK = Methyl isobutyl ketone; IPAC = Isopropyl acetate.

[b]The low removal efficiency was a result of adsorbate blend being different from system design specifications, cocurrent steaming, cooling with adsorbate laden air, and malfunction in condenser system.

[c]Solvent loading was above design specification during test.

[d]Removal efficiency was reduced due to reduction in desorption steam temperature, change in solvents, and elevated adsorber inlet temperature.

[e]Removal efficiency was likely reduced due to high adsorbate loading causing premature system breakthrough.

[f]Inlet stream temperature was above design specifications during test.

[g]Data from bed 2 were not included in average because a steam valve leak caused a severe reduction in bed capacity.

[h]Overall system removal efficiency was reduced due to the inlet stream temperature being above design.

[i]NR = Data not reported.

[j]Removal efficiency is time weighted according to length of time individual lines were operating.

[k]Inlet adsorbate loading expressed as 67 lb C_1/hr. To convert to loading in terms of lb MEK/hr need to multiply by 6 (MW MEK = 72/MW C_1 =12).

[l]Not applicable. These data are not from a specific performance test. Removal efficiency was calculated from inlet and outlet concentrations reported by the facility.

[m]Continuous average, including distillation steam.

[n]The average of the removal efficiency of the individual beds.

TABLE 3-3. PERFORMANCE TEST DATA FOR CARBON ADSORPTION SYSTEMS[53-56] ON A PER BED BASIS

Test number	Bed designation	Data collection time period	Removal efficiency, %
1	A	NA[b]	87.2[a]
	B	NA	78.9[a]
2	1	NA	99.6
	2	NA	99.8
	3	NA	99.8
3	1	NA	97.3
	2	NA	92.7
	3	NA	95.9
4	1A	705 min.	94.0
	1B	826 min.	94.0
	1B	382 min.	94.3
	1B	280 min.	89.2[c,d]
	2A	247 min.	92.9
	2A	279 min.	91.3
	2B	105 min.	88.9[d,e]
	2B	247 min.	95.5
	3A	128 min.	96.2
	3A	271 min.	97.7
	3A	647 min.	96.6
	3B	898 min.	98.0
	3B	781 min.	96.2
5	1	451 min.	99.4
	2	388 min.	99.3
	2	507 min.	99.0
	2	228 min.	99.4[e]
	3	295 min.	98.9[f]
7	A	NA	97.0
	B	NA	97.6
	C	NA	98.3

(continued)

TABLE 3-3. (Continued)

Test number	Bed designation	Data collection time period	Removal efficiency, %
8	A	NA	91.4
	B	NA	91.4
	C	NA	97.8
9	1-1	7.6 hrs.	98.0
	1-1	9.1 hrs.	97.4
	1-1	8.6 hrs.	97.8
	1-1	8.1 hrs.	96.6
	1-1	5.5 hrs.	97.3
	1-1	6.8 hrs.	97.6
	1-2	8.5	97.9
	1-2	9.4	96.8
	1-2	8.2	97.0
	1-2	6.0	97.6
	1-3	8.1	97.8
	1-3	6.4	97.5
	1-3	7.4	98.1
10	1-1	NA	97.9
	1-2	NA	98.1
	1-3	NA	97.5
11	1	NA	99.8
	1	NA	95.5
	1	NA	97.7
	1	NA	97.8
	1	NA	98.9
	3	NA	99.4
	3	NA	96.4
	3	NA	98.5
	3	NA	98.8
	3	NA	98.7

[a]Data are from one cycle; overall system efficiency was 84.9 percent.

[b]NA = Not available.

[c]Only one coating line in operation.

[d]Collected during startup of one of the lines.

[e]Coating process unsteady during this period.

[f]Not representative of normal operation; system returning to steady-state after all beds on adsorption.

Site L supplied no detailed information so only the reported removal efficiency is presented.[52]

3.6.2 Removal Efficiency Data for Performance Tests

The overall removal efficiencies presented in Table 3-2 range from 84.9 to 99.7 percent for a variety of adsorbates including MEK, toluene, THF, MIBK, cyclohexanone, hexane, and IPAC. On a per bed basis, the range of removal efficiencies is 52.3 to 99.8 percent. As shown, the bed ages associated with the adsorbers tested range from 3 to 78 months.

The overall removal efficiency of 84.9 percent reported for Test 1 is the result of both operating outside of the original design range and poor operation during the test. The system was designed to recover an adsorbate blend consisting of 60 percent methyl ethyl ketone and 40 percent toluene. At the time of the test, the organic feed was 100 percent methyl ethyl ketone. As discussed in Section 3.5.1, switching adsorbate blends can have a detrimental effect on removal efficiency. In addition, several operating practices at this site may have contributed to the reduced control efficiency. These include cocurrent steaming of the bed, cocurrent cooling of the bed with the adsorbate laden stream, and operating with a malfunctioning steam condenser.

Cocurrent steaming leaves more residual solvent at the bed outlet than countercurrent steaming, thus increasing the outlet concentration when the bed is brought on-line. Cooling the bed with the adsorbate laden vent stream further aggravates this problem because it allows adsorbate laden air to enter the bed when the system working capacity is at its lowest. This allows adsorbate to spread down the bed much further than if the system is operated correctly. For reasons which have been discussed in Section 3.4.1 this caused the system to be more sensitive to variations in the operating temperature.

The final problem associated with this system was a malfunction in the condenser system. The system was not cooling the desorbate stream sufficiently. Since the steam from the condenser was recycled to the on-line bed, unusually high amounts of solvent were allowed to enter the bed from the recycle stream. This additional solvent loading led to premature breakthrough.

In summary, these problems would indicate that this system was not well designed and was poorly operated. Its removal efficiency is not representative of a well designed and operated system. It should be noted that several of the problems would have been discovered as part of normal operation if the system had used continuous outlet monitors.

The average overall removal efficiency presented for Test 2 is 99.7 percent.
The individual bed efficiencies range from 99.6 to 99.8 percent. The solvent blend for this system was 50 percent toluene and 50 percent tetrahydrofuran, and all of the operating conditions were within design specifications with the exception of the loading rate. The design specification was 140 lb/hr, but the actual loading rate was 195 lb/hr.

Test 3 is a follow-up test at site B. For this test, the average system overall removal efficiency was 95.3 percent with the individual bed efficiencies ranging from 92.7 to 97.3 percent. All of the beds had lower removal efficiencies than in the initial test, Test 2. The reduced removal efficiency during the second test was attributed to the following in the test report:[57]

- Increased carbon age;
- lower regeneration steam temperature;
- higher SLA inlet temperature; and
- change in solvent formulation to 75 tetrahydrofuran and 25 percent toluene.

Figure 3-22 presents a typical outlet concentration curve for this test.[58] During the initial test (Test 2), the typical outlet concentration had an initial spike and then decreased to approximately 1 ppm for the remainder adsorption cycle. However, during Test 3, the outlet concentration was much higher and an upward trend indicating the beginning of breakthrough can be seen at the end of the cycle.[59] This result would be expected due to the factors shown above. If the desorption and adsorption cycles had been adjusted to account for the changes in SLA inlet temperature, solvent

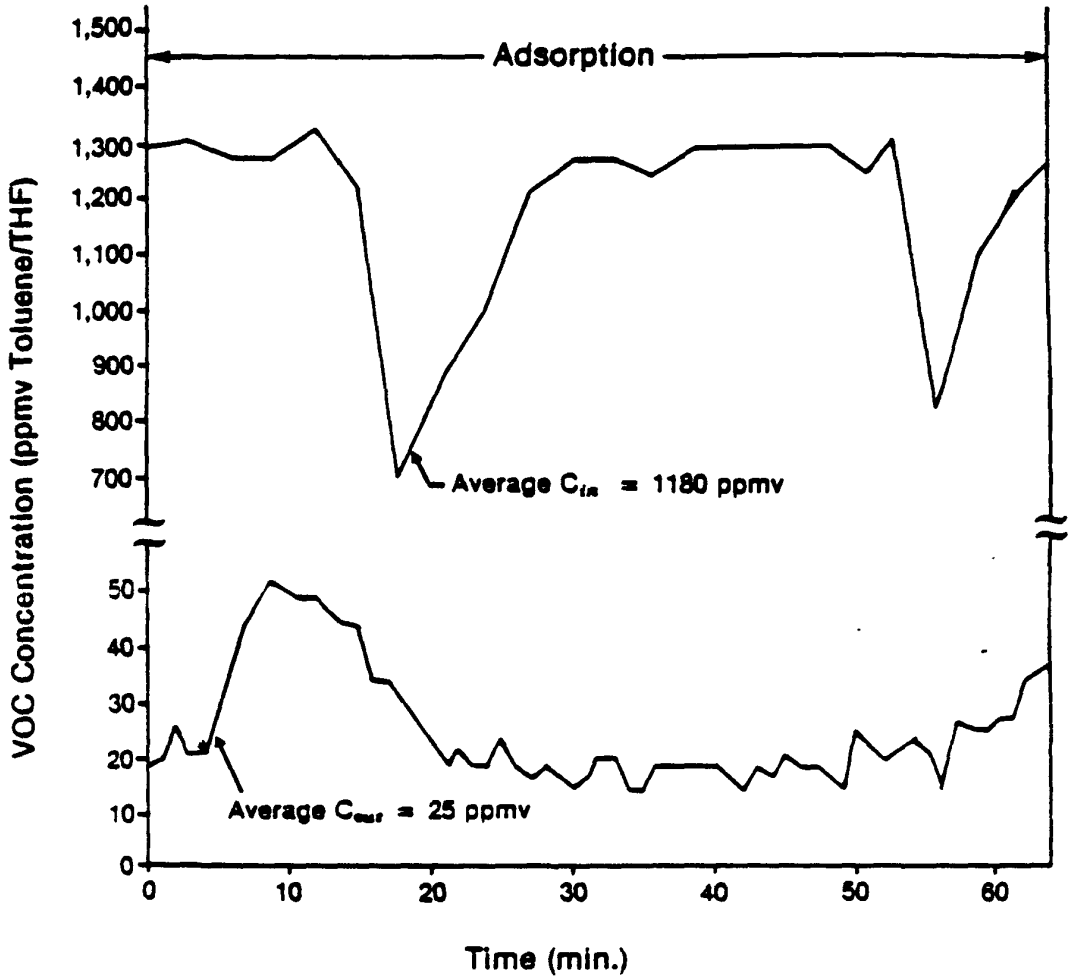

Figure 3-22. Inlet/Outlet Concentration Curve for Test 3

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composition, and regeneration steam temperature, and carbon age then the performance during Test 3 should have been similar to the Test 2 performance.

However, even though this system did show reduced efficiency in Test 3 the average system efficiency was over 95 percent, which would be sufficient to meet the 95 percent removal efficiency requirement in the proposed magnetic tapes regulation.

The adsorbate blend concentrations for Test 4 are not specified, but the blend included tetrahydrofuran, toluene, methyl ethyl ketone, methyl isobutyl ketone, and cyclohexanone. The average overall removal efficiency for Test 4 is 94.8 percent. Individual bed removal efficiencies ranged between 89.2 and 98.0 percent. The average loading for the test period was 1,260 lb/hr which is over twice the design level of 600 lb/hr. If the adsorption time had been shortened to account for the increased loading (as discussed in Section 3.4), removal efficiencies for all beds would have been higher and as discussed in Section 3.3.3, the variability would be less.

Hexane is the only adsorbate at Test 5. The overall removal efficiency shown for this test period is 99.1 percent with individual bed efficiencies ranging between 98.9 and 99.4 percent. All of the operating conditions were within design specifications.

The follow up test at this site was Test 6. In this test, an extremely low removal efficiency was achieved due to a leaking steam valve. Excursions in the outlet concentration were shown to coincide with the steaming cycle for the off-line bed. In this system, the steam flow is cocurrent, in the same direction as the air flow during adsorption. Consequently, the steam leak allowed the solvent laden steam from the off-line bed to enter the outlet stream of the on line beds. This resulted in false readings at the adsorber outlet. For this reason no data from this test were included in this report.

The results shown for Test 7 are for a single component system in which toluene is recovered. The overall removal efficiency for this test is 97.6 percent even through both the inlet temperature and loading rate were slightly above design specifications. The individual bed removal efficiencies were between 97.0 and 98.3 percent.

The follow up to Test 7 is Test 8. Toluene was also the only adsorbate for this test. The removal efficiency for bed 2 is not included in the

average removal efficiency of 94.6 percent which is shown for this test. (Table 3-2) A steam valve leak allowed steam to leak into bed 2 raising the temperature significantly, and severely reducing the working capacity. As in Test 6, the outlet concentration peaks were shown to coincide with the desorption period of the off-line bed. Since the data for this bed are not representative, they were not included. The lower removal efficiency for the other two beds is the result of two related problems. A malfunctioning inlet air cooler allowed the inlet temperature to rise 32°F above the design maximum and also a timer occasionally malfunctioned. Once again, the use of continuous outlet monitors in the operation of this system would have helped to uncover the malfunction in operation.

Tests 9 and 10 were both conducted at site F with an adsorbate blend of 60 percent toluene and 40 percent isopropyl acetate. The overall removal efficiencies for these two tests were 97.5 percent and 97.8 percent, respectively. The individual bed removal efficiencies were 96.8 to 98.1 percent. These removal efficiencies agree well with what would be expected for the two sets of operating conditions. In both tests, the inlet adsorbate loading was above the design specifications of 810 lb/hr. All of the other operating conditions were within design specifications during both tests.

No design parameters or individual bed removal efficiencies were available for Tests 11, 12, and 13. Therefore, it was not possible to assess the system operation in terms of design. The adsorbates for Test 11 were methyl ethyl ketone, methyl isobutyl ketone, and toluene. The overall removal efficiency shown for Test 11 is 98.9 percent. For Test 12 the overall removal efficiency was 98 percent for a adsorbate of 100 percent toluene. The adsorbate mixture for Test 13 was 30 percent toluene, 4 percent xylene, and 66 percent lactol spirits, and the overall removal efficiency is 95.8 percent.

The overall removal efficiency shown for Test 14 is 99.4 percent. The average composition of the recovered VOC at this site is as follows: 44 percent cyclohexanone, 23 percent tetrahydrofuran, 19 percent methyl ethyl ketone, and 14 percent toluene. All of the operating conditions shown for this test are within the design limits. In Test 15, the adsorbate is

100 percent methyl ethyl ketone and the overall removal efficiency is 99.6 percent. None of the operating conditions at this site were outside of the design conditions reported.

No actual test data are available for site L, but the overall removal efficiency was reported by the company 99.5 percent. The adsorbate blend at this site was 95 percent toluene and 5 percent hexane.

The performance test data shown in this section generally show removal efficiencies above 95 percent. For cases where the removal efficiency was below 95 percent, correctable problems were identified which were the cause of the lower removal efficiencies. It should be noted that these performance test data are fairly short duration ranging from less than 2 hours up to 15 hours. If the time periods of startup and system malfunctions are not considered, the removal efficiencies are fairly consistent with little variability from bed to bed.

3.6.3 Continuous Removal Efficiency Data

Continuous efficiency data are available from two sites. These data are presented to show a short-term efficiency variability. The data encompass a relatively broad range of solvent blends, adsorbate loadings, flowrates, and inlet temperatures.

Figures 3-23 and 3-24 present continuous inlet and outlet concentration and removal efficiency data versus time for two test runs from site G in Table 3-2. As shown in the figures, the inlet concentrations vary significantly throughout the respective testing periods. However, the outlet concentrations remain fairly consistent regardless of the inlet concentrations, and are almost always less than 10 ppm. The removal efficiencies are also fairly consistent and are generally above 95 percent. The only time the removal efficiency is below 95 percent is when the inlet concentration falls below about 50 ppm. This is expected since as previously discussed, the outlet concentration is independent of the inlet concentration. Therefore, if the inlet concentration is allowed to fall below the design value, the instantaneous removal efficiency can also decrease below design levels.

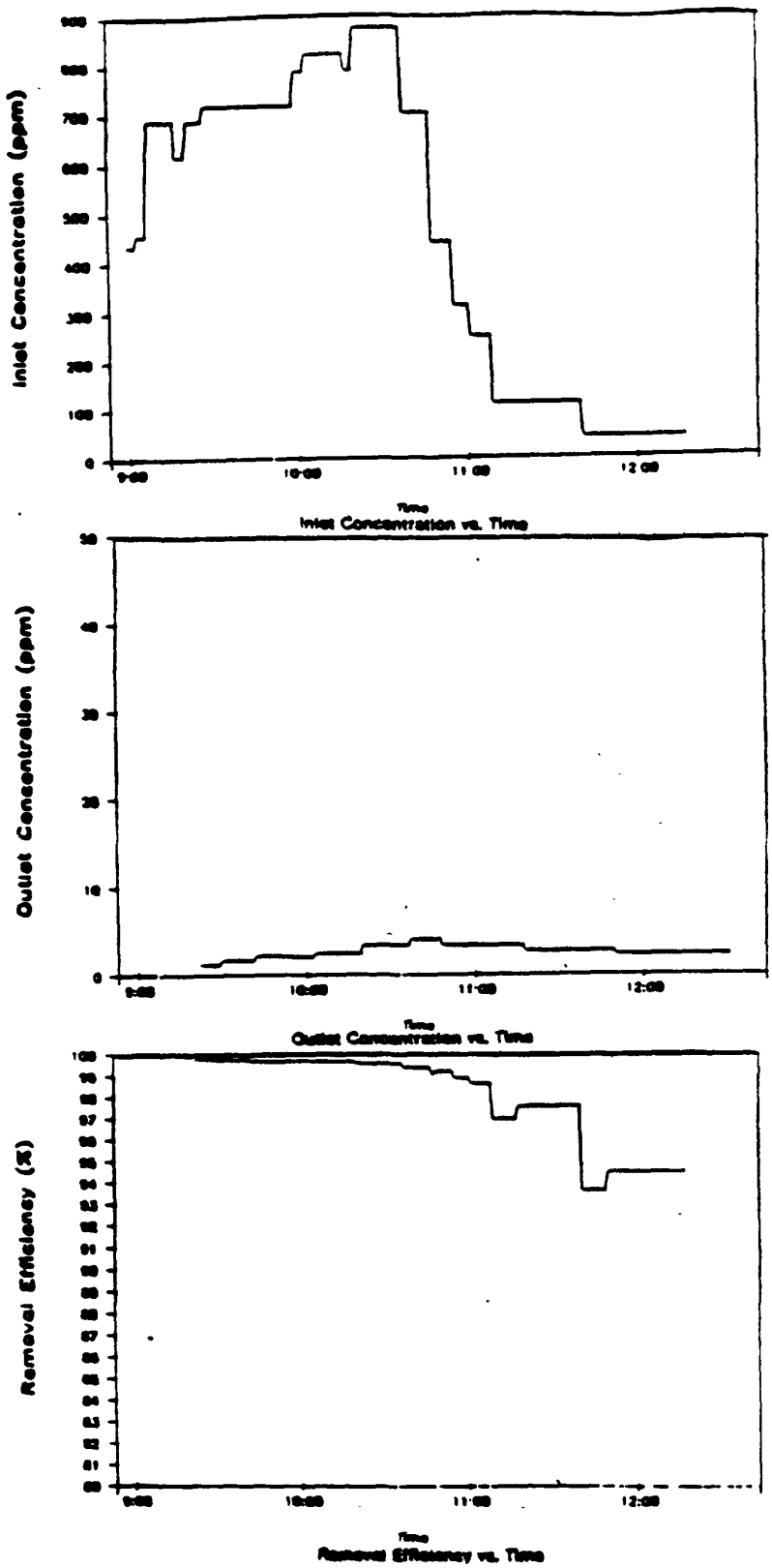

Figure 3-23. GTR Test Number 5 Continuous Inlet/Outlet VOC Concentration Data and Removal Efficiency

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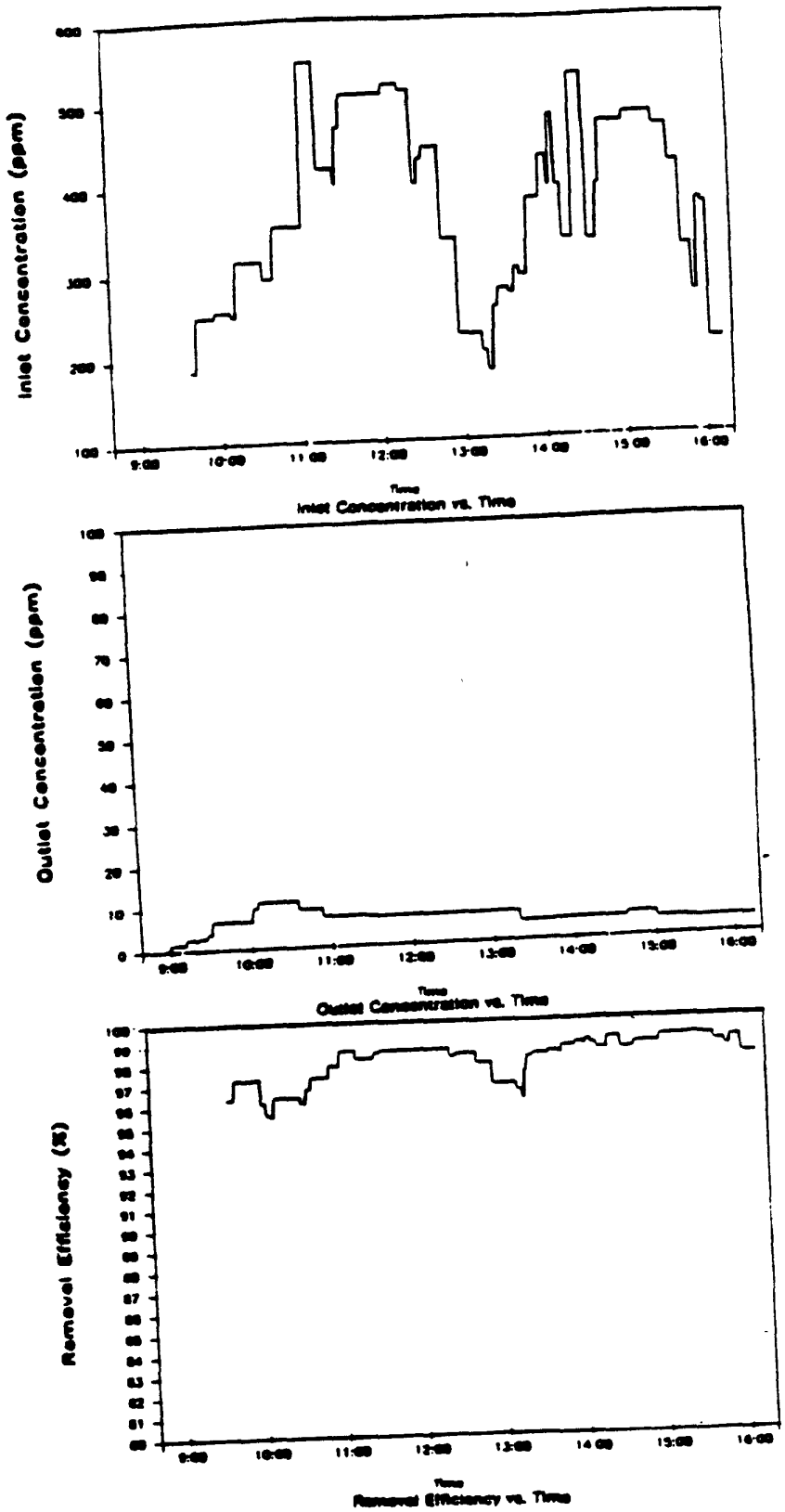

Figure 3-24. GTR Test Number 6 Continuous Inlet/Outlet VOC Concentration Data and Removal Efficiency

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Inlet and outlet concentrations and instantaneous and cumulative removal efficiencies for six adsorber beds at site J are presented in Figures 3-25a through 3-25j. The continuous data shown were obtained at the request of EPA and are typical of normal facility operation.[60] As previously discussed, the solvent blend at this facility ranges from 20-25 weight percent cyclohexanone and 20-50 weight percent methyl ethyl ketone (MEK). Both cyclohexanone and MEK have been identified as chemicals which react on carbon to cause fouling. The data are continuous monitor readouts for each of the six carbon beds which comprise the complete system. The inlet concentrations vary between about 2,000 ppm and 3,000 ppm, with adsorbers #1 and #2 having the highest inlet concentrations. The continuous outlet concentrations from all 6 adsorbers are below 50 ppm. Of particular note is the fact that both the instantaneous removal efficiency and the cumulative efficiency over the entire monitoring period for all adsorbers are above 98.5 percent.

The instantaneous removal efficiencies of the newest bed ranged from 99.3 to 99.8 percent. The efficiency of the oldest bed ranged from 99.9 to 98.5 percent. One reason the removal efficiencies of the beds stay well above 95 percent is that the beds are changed frequently. This facility could operate the beds until their removal efficiency has reached 95 percent, but has chosen not be do so to avoid operation problems which could cause overall removal efficiency to fall below the desired value.

The data from these two sites indicate that the 95 percent removal efficiency can be maintained continuously if the carbon absorber is properly designed, operated within its design specifications, and well maintained.

3.7 CONCLUSIONS REGARDING CARBON ADSORBER PERFORMANCE

The data presented in Section 3.6 demonstrate that properly designed and operated carbon adsorption systems can achieve 95 percent removal on a continuous basis. This removal efficiency is shown for numerous solvent blends and bed ages. Greater than 95 percent removal efficiency is shown for streams that contain mixtures of ketones that include cyclohexanone, and for which claims have been made that 95 percent is not achievable using carbon

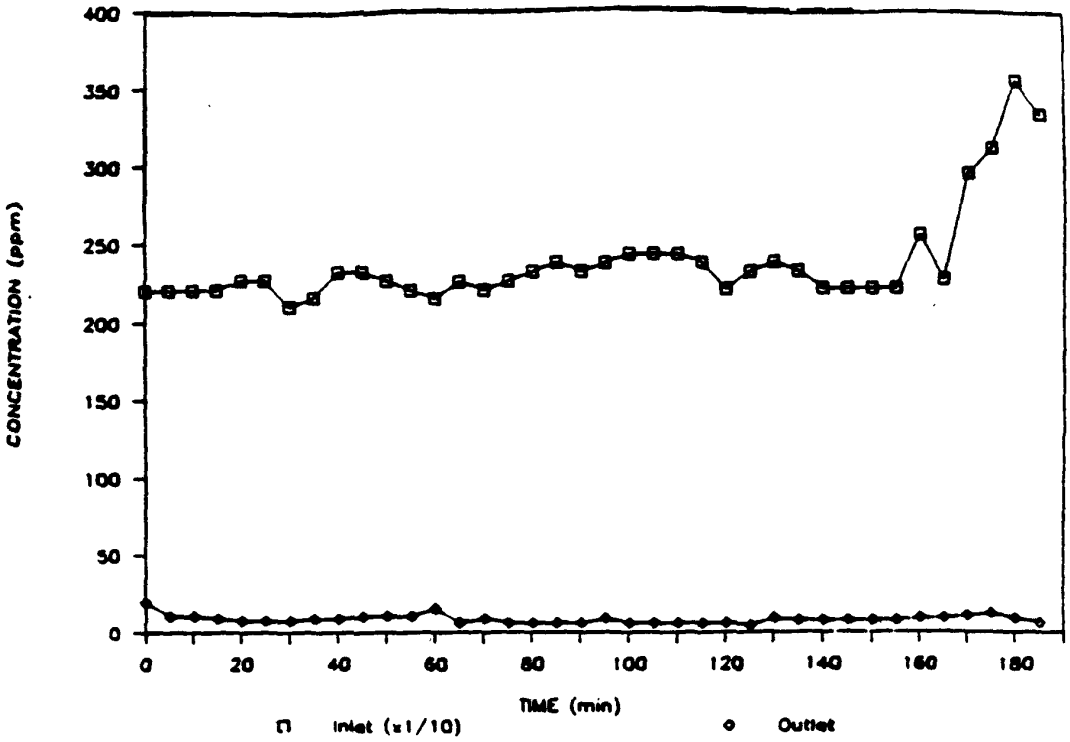


Figure 3-25a. Inlet and Outlet Concentration Versus Cycle Time for Adsorber #1

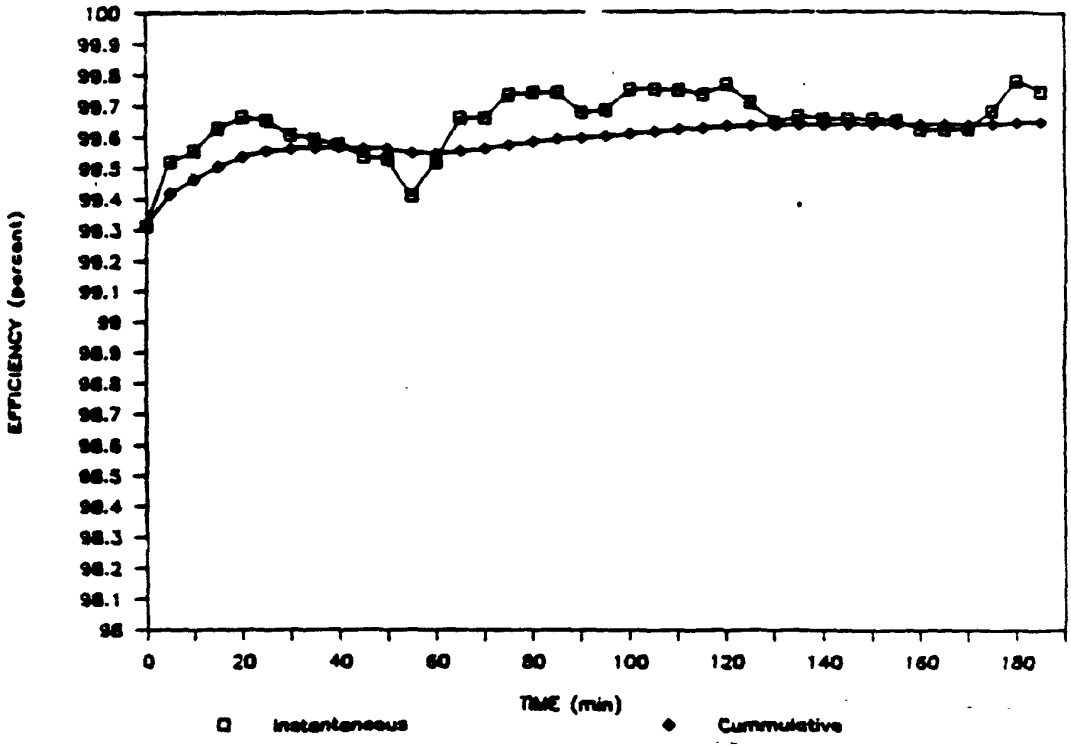


Figure 3-25b. Instantaneous and Cumulative Efficiency Versus Cycle Time for Adsorber #1

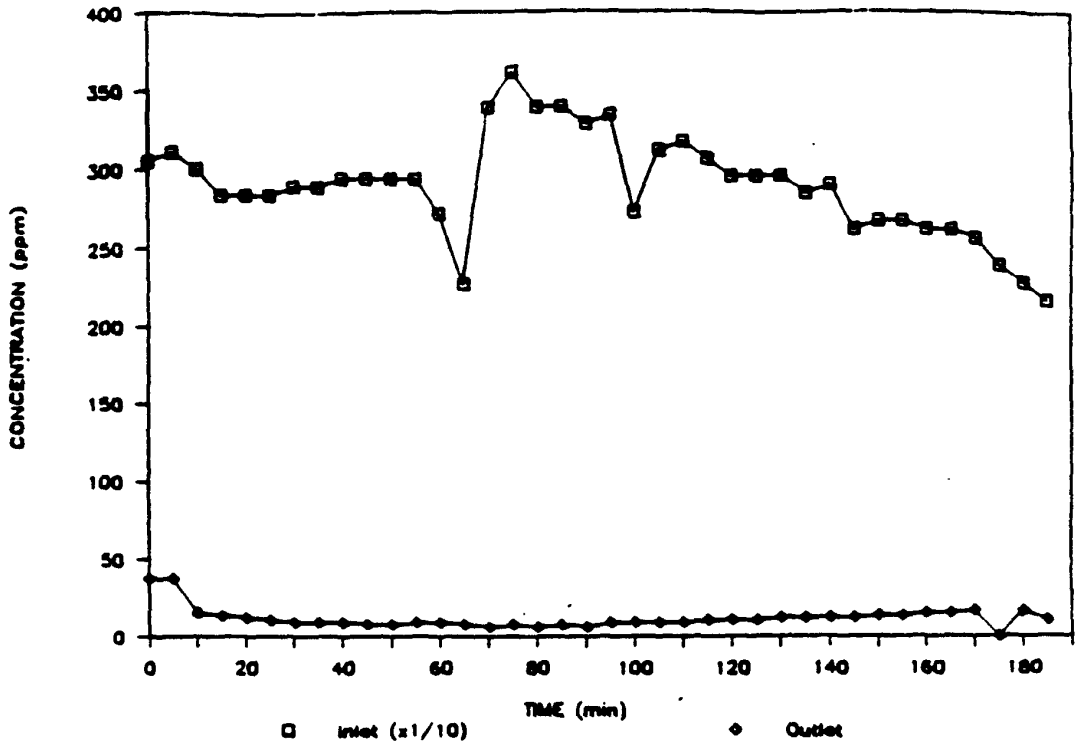


Figure 3-25c. Inlet and Outlet Concentration Versus Cycle Time for Adsorber #2

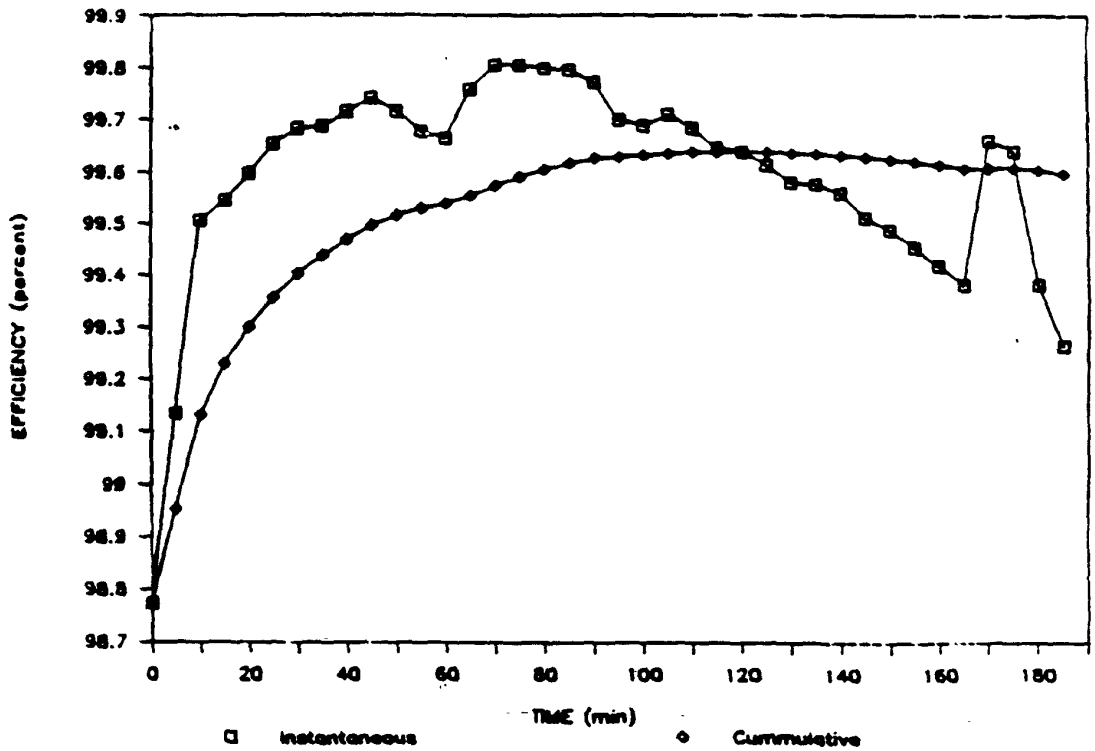


Figure 3-25d. Instantaneous and Cumulative Efficiency Versus Cycle Time for Adsorber #2

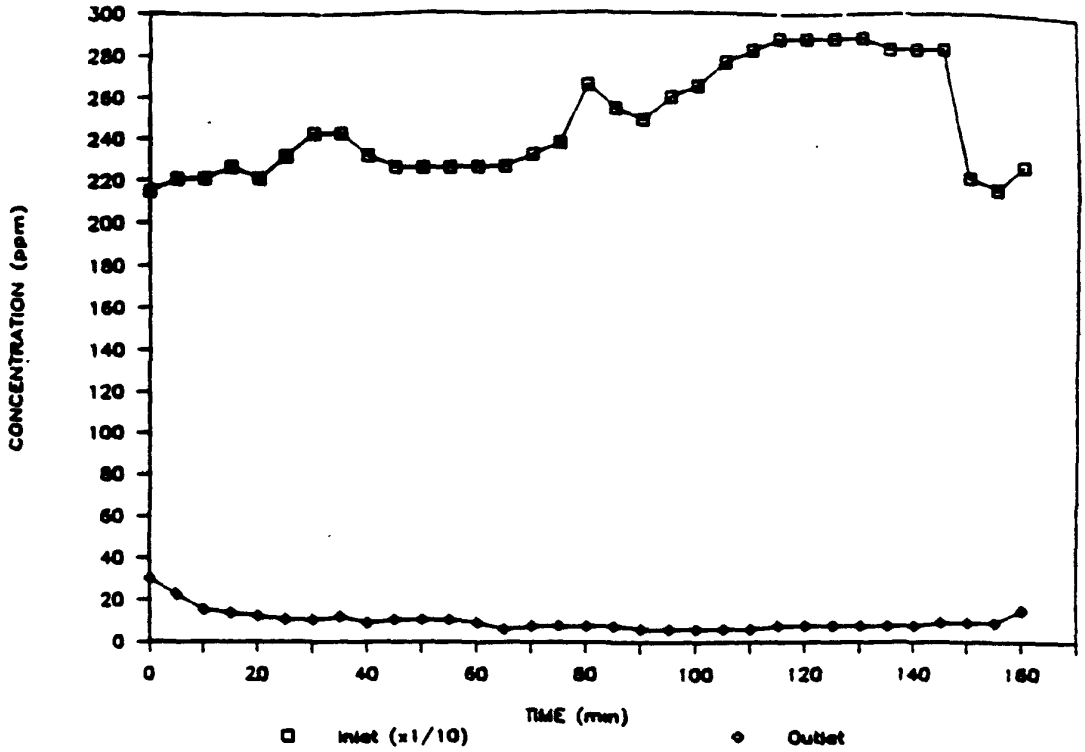


Figure 3-25e. Inlet and Outlet Concentration Versus Cycle Time for Adsorber #3

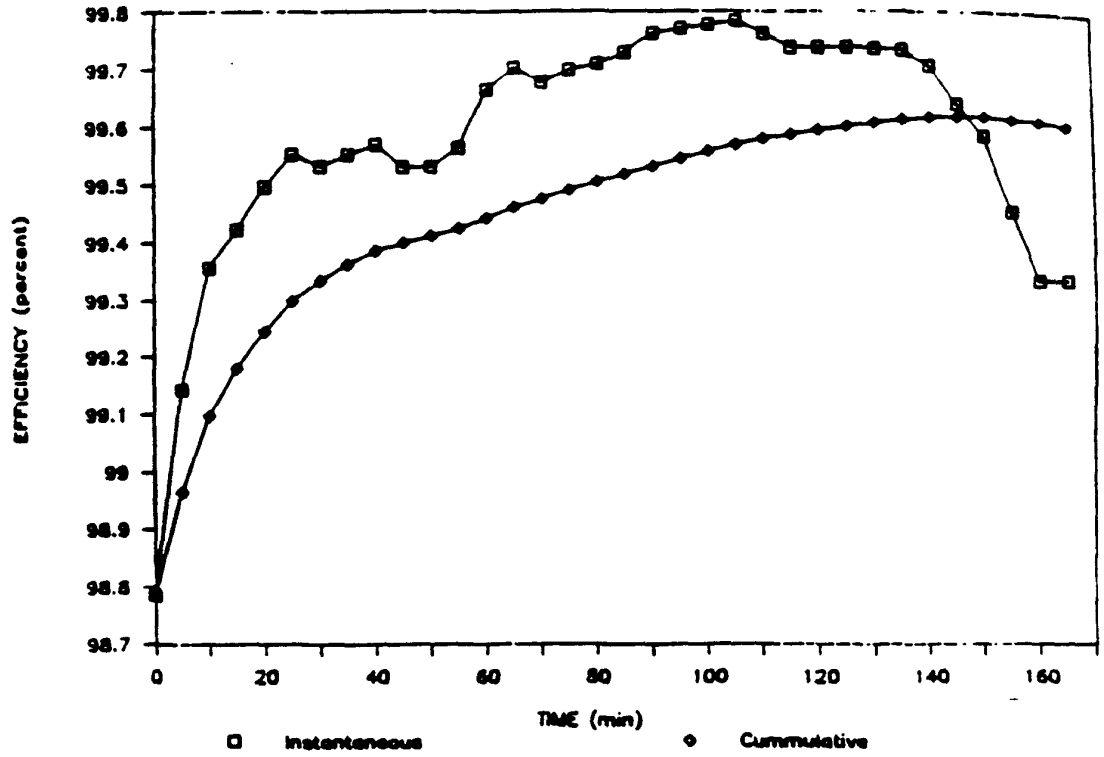


Figure 3-25f. Instantaneous and Cumulative Efficiency Versus Cycle Time for Adsorber #3

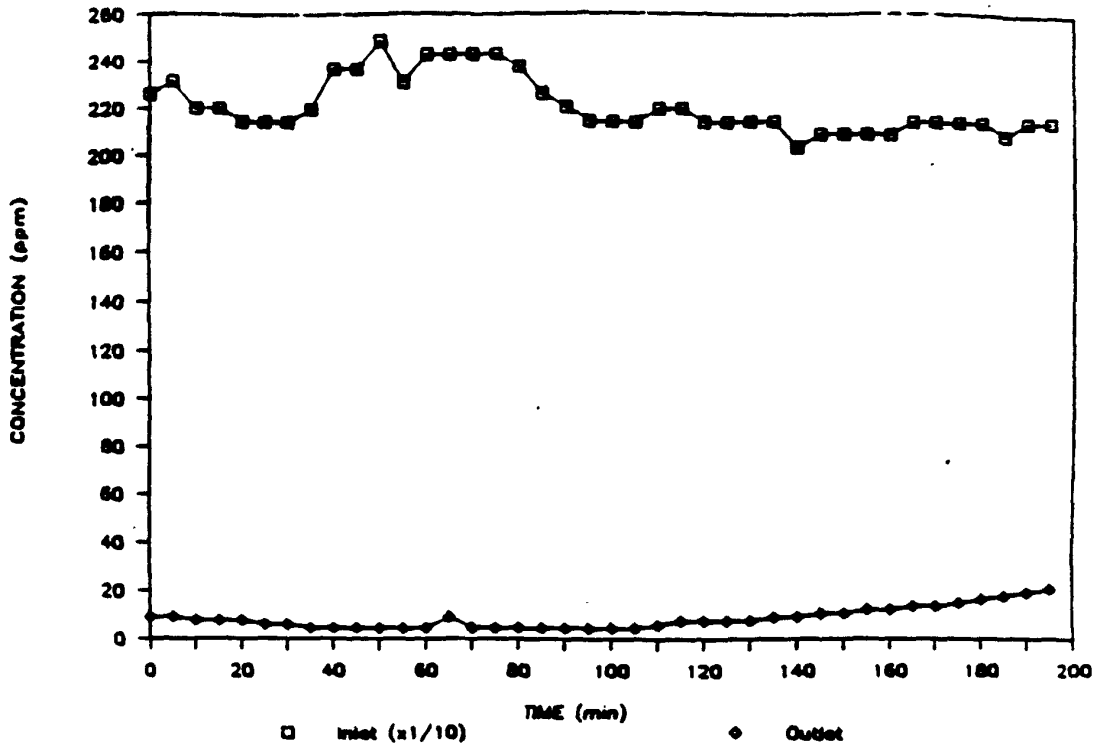


Figure 3-25g. Inlet and Outlet Concentration Versus Cycle Time for Adsorber # 4

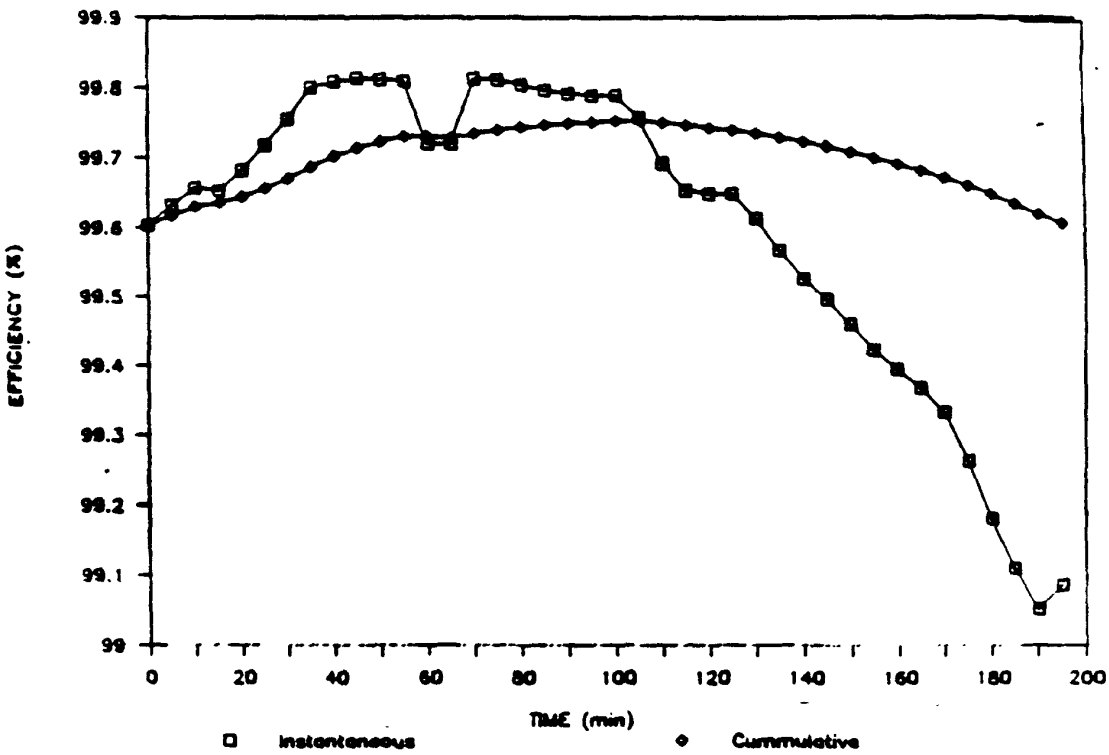


Figure 3-25h. Instantaneous and Cumulative Efficiency Versus Cycle Time or Adsorber #4

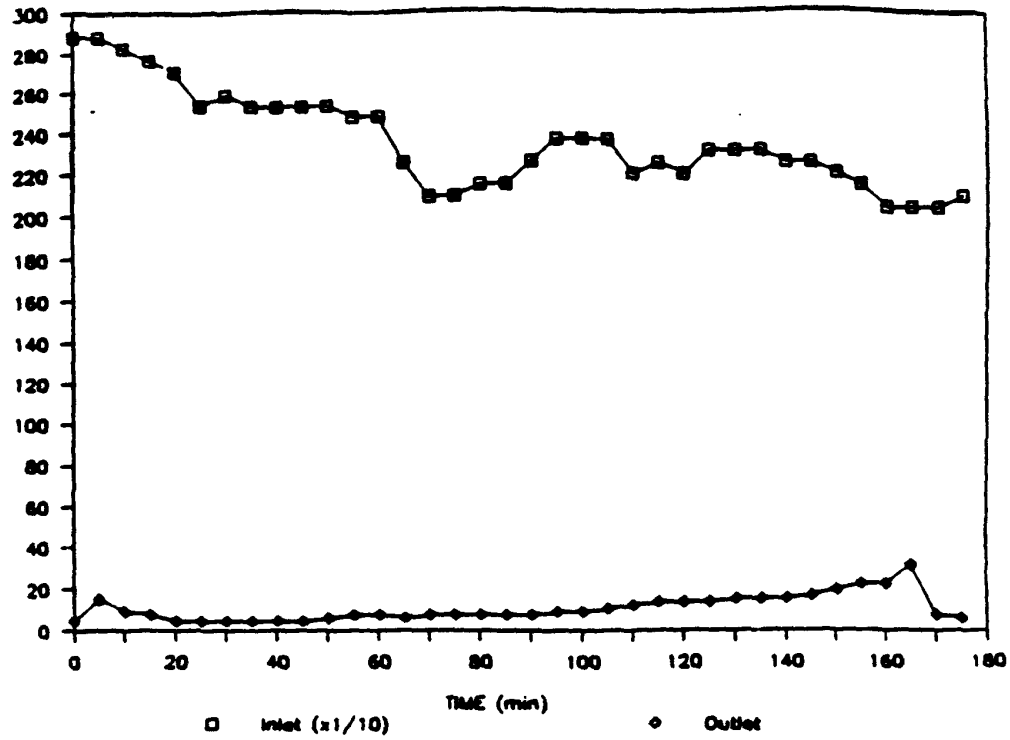


Figure 3-25i. Inlet and Outlet Concentration Versus Cycle Time for Adsorber #5

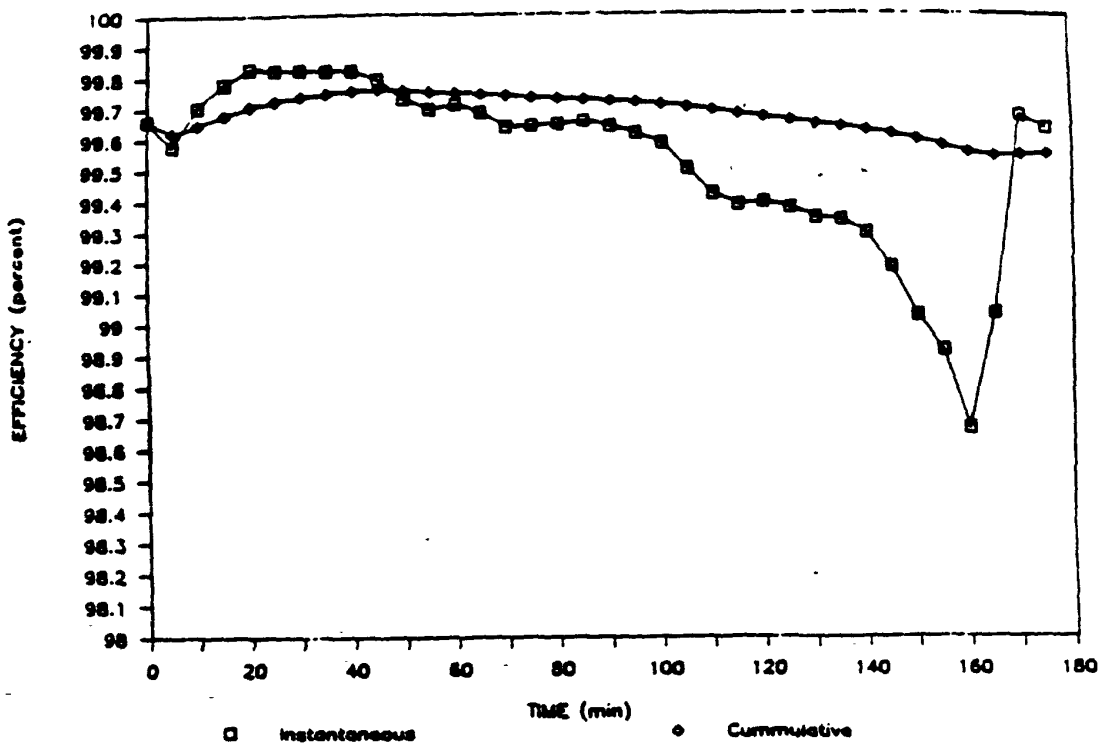


Figure 3-25j. Instantaneous and Cumulative Efficiency Versus Cycle Time for Adsorber #5

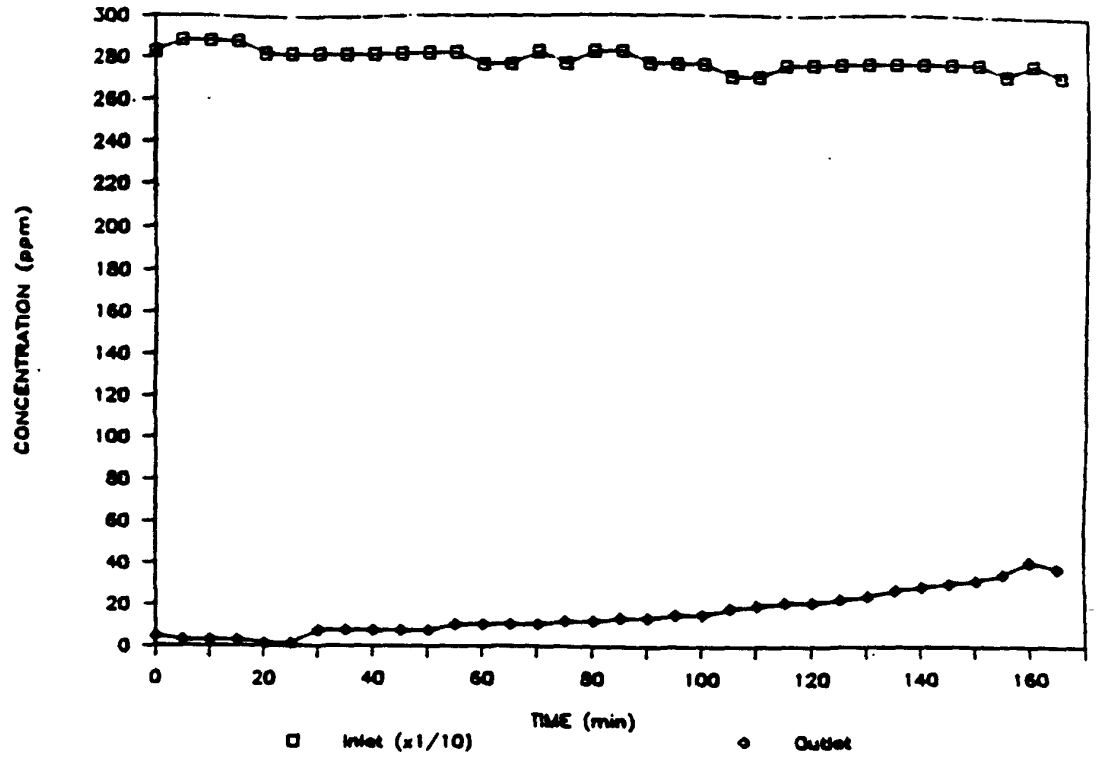
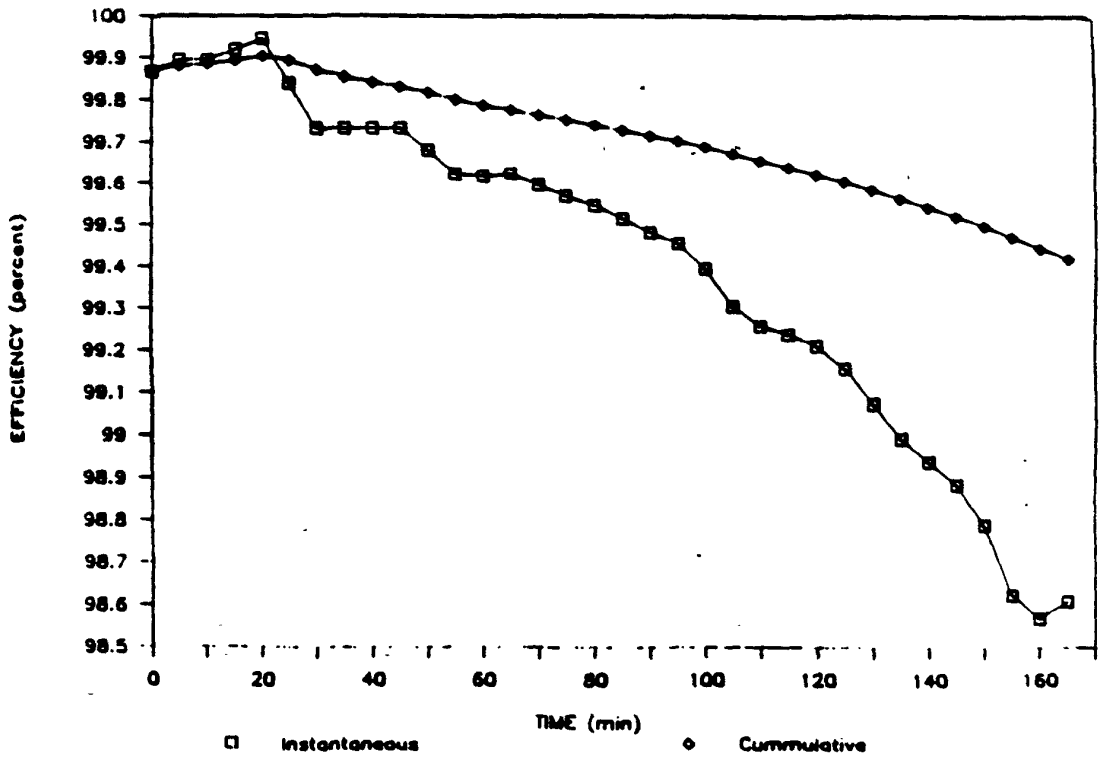


Figure 3-25k. Inlet and Outlet Concentration Versus Cycle Time for Adsorber #6.



C-94 Figure 3-25l. Instantaneous and Cumulative Efficiency Versus Cycle Time for Adsorber #6.

adsorption. In every case where the removal efficiency was less than 95 percent, correctable and easily identifiable operational problems were responsible for lower removal efficiencies.

The key to achieving 95 percent removal is proper design and operation of the adsorption system. If this is done, maintaining a removal efficiency of 95 percent becomes only a matter of cost where the economic trade-offs come in the form of steam cost versus carbon replacement costs. The carbon must be steamed sufficiently to desorb the adsorbate, but excessive steam use raises the operating costs. The adsorption time must be sufficiently long to allow regeneration of the other bed(s). This will require replacement of the carbon when its working capacity gets too low.

In Section 3.4 it was shown that if a system is designed for a full range of operating conditions, operated correctly, and the carbon is replaced before its working capacity has been reduced to the point where beds are operated after breakthrough, the short-term removal efficiency should not vary significantly. Based on the information and data presented here, it can be concluded that a removal efficiency of 95 percent or greater is continuously achievable.

4. CARBON ADSORPTION SYSTEM AT COMMENTER'S FACILITY

This section presents an analysis of the carbon adsorption system located at the commenter's facility. The information presented contains data for which the commenter has made a claim of confidentiality. This information is located in the confidential files of the Director, Emission Standards Division, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. This information is confidential, pending final determination by the Administrator, and is not available for public inspection.

5. REFERENCES

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2. Reference 1.

3. Reference 1, p. 5-6.

4. Reference 1, p. 5-13.

5. Reference 1, p. 5-2.

6. Reference 1, p. 5-14.

7. Reference 1, p. 5-14.

8. Reference 1, p. 5-14.

9. Reference 1, p. 5-3.

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11. Memorandum from Barnett, K. W., Radian Corporation to Carbon Adsorber/ Condensation Project File. February 29, 1988. Meeting Minutes EPA/Calgon Carbon Corporation. p. 8.

12. Reference 11, p. 7.

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14. Reference 11, p. 18.

15. Crane, G., Carbon Adsorption for VOC Control. U. S. Environmental Protection Agency. January 1982. p. 18.

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27. Miller, K. J., C. R. Noddings, and R. C. Nattkemper. 3M Company. St. Paul, Minnesota. (Presented at Air Pollution Control Association Meeting. New York, New York. June 21-26, 1987.) p. 4.

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34. Letter from Shuliger, W., Calgon Carbon Corporation to Wyatt, S. R., EPA. November 11, 1987. Response to information request.

35. Reference 28, p. 5.

36. Reference 11, p. 19.

37. Reference 28, p. 14.

38. Reference 28, p. 13.

39. Letter and attachments from Sapovich, M., Diversitech General, to Farmer, J., U. S. Environmental Protection Agency. January 12, 1988. Response to Section 114 information request.

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50. Letter and attachments from Gilbert, R., Ampex to Farmer, J. R., U. S. Environmental Protection Agency. December 16, 1987. Response to Section 114 questionnaire.

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53. Reference 46.

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57. Reference 46, p. 108.

58. Reference 46, p. 109.

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APPENDIX D

LISTING OF AIR EMISSION CONTROL STANDARDS AND DOCUMENTS[1]

	Page
A. STATUS OF STANDARDS AND BIDS	
- New Source Performance Standards (NSPS)	D- 2
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B. CONTROL DOCUMENTS	
- Control Techniques Guidance Documents (CTG)	D-21
- Control Technology Documents	D-24
- CTGs to be Developed	D-25
- Control Technology Center (CTC) Reports	D-26

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[1] Copies of the documents listed in this appendix and report that are more than one year old are normally only available through: National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, Virginia 22161
(703) 487-4650.

STATUS OF STANDARDS OF PERFORMANCE
New Source Performance Standards
40 CFR 60

Updated: 02/18/92

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review	BID NO.
Priority List		Categories of Stationary Sources		08/31/78 (43FR38872)	08/21/79 (44FR49222)		EPA-450/3-78-019
				05/13/81-R (46FR25601)	01/08/82 (47FR950)		EPA-450/3-79-023
General Provisions	A	Opacity Recordkeeping and Reporting	Opacity	07/31/84 (49FR30676)			
				09/17/84-C (49FR36410)	12/27/85 (50FR53108)		EPA-450/3-85-013
	A	Continuous Opacity Monitors		12/27/85 (50FR53115)	03/26/87 (52FR9778)		EPA-450/3-85-013
					05/11/87-C (52FR17555)		
	A	Flares Revision		04/16/85 (50FR14941)	01/21/86 (51FR2699)		EPA-450/3-80-033a&b
	A	Quality Assurance Requirements for Gaseous CEMS		03/14/84 (49FR9676)	06/04/87 (52FR21003)		EPA-450/3-82-010
State Plans for Desig. Facilities	B	Revised emission guideline publication date		04/20/88 (53FR12962)	02/20/89 (54FR52188)		
Fossil-Fuel Fired Steam Generators for Which Construction is Commenced After 8/17/71 and Before 9/19/78	D	Utility and Industrial (coal, oil, and gas)	PM, SO2, NOx	08/17/71	12/23/71	06/14/74 clarification	EPA-450/3-79-021 APTD-0711 EPA-450/2-76-030a&b
		Wood Residue Amendment	PM, SOx, NOx	01/17/79	11/22/76 (41FR51397)		
		Amendment & final rule			11/25/86-A (51FR42796)		
		Lignite fired steam generators (Amendment)	NOx	12/22/76 (41FR55792)	03/07/78 (43FR9276)		
		Revision for 30-day Averaging	SO2	10/21/83 (48FR48960)			
				01/17/84-P (49FR1997)	11-08-85-R (50FR46464)		EPA-450/3-82-013a EPA-450/3-82-013b
				03/23/84-P (49FR10950)	08-17-89 (54FR34008)		
				06/01/84-P (49FR22835)			

U.S. EPA/Office of Air Quality Planning and Standards
Emission Standards Division (MD-13)
Research Triangle Park, NC 27711

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STATUS OF STANDARDS OF PERFORMANCE
New Source Performance Standards
40 CFR 60

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
		Method 5B & 5F revision to Appendix A (sulfuric acid exclusion)		05/29/85 (50FR21863)	11/26/86 (51FR42839)		EPA-450/3-86-008
		Central Illinois Pub. Service Co.; Newton, IL Power Station - Bubble Revision	SO2	01/25/85-A (50FR3688) 03/29/85-P (50FR12574)	08/04/87 (52FR28946)		
	D,Da, E,I, BB	Method 3 & 3B		03/01/89 (54FR8564)			
Elect. Utility Steam Generating Units for Which Construction is Commenced After 9/18/78		Utility boilers (solid, liquid, & gaseous fuels)	PM, SO2, NOx	09/19/78 (43FR42154)	06/11/79 (44FR33581)		EPA-450/2-78-005a EPA-450/2-78-006a EPA-450/2-78-007a EPA-450/2-78-007a-1 EPA-450/3-79-021 EPA-450/3-86-008
		Method 5B & 5F revision to Appendix A (sulfuric acid exclusion)		05/29/85 (50FR21863)	11/26/86 (51FR42839)		
	D,Da, E,I, BB	Method 3 & 3B		03/01/89 (54FR8564)			
Industrial Boilers	Db	Industrial boilers (coal, oil, gas, solid waste, wood and bagasse)	NOx, PM	06/19/84 (49FR25102)	11/25/86 (51FR42768)		EPA-450/3-82-006a&b
		Correction to proposed rule		07/30/84-P (49FR30337) 12/02/85-C (50FR49422)			EPA-450/3-82-007
		Method 5B & 5F revision to Appendix A (sulfuric acid exclusion)		05/29/85 (50FR21863)	11/26/86 (50FR42839)		EPA-450/3-86-008
		Oil-fired boilers	PM	06/19/86 (51FR22384)	12/16/87 (52FR47826) 12/18/89 (54FR51820)-A		EPA-450/3-87-024
		Industrial boilers	SO2	06/19/86 (51FR22384)	12/16/87 (52FR47826) 12/18/89 (54FR51818)-A		

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STATUS OF STANDARDS OF PERFORMANCE
New Source Performance Standards
40 CFR 60

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Small Industrial Commercial-Institutional Generating Units	Dc	Steam generating units	PM, SO_2	06/09/89 (54FR24792)	09/12/90 (55FR37674)		EPA-450/3-89-11 EPA-450/3-89-12 EPA-450/3-89-13 EPA-450/3-89-14 EPA-450/3/89-15 EPA-450/3/89-16 EPA-450/3/89-17 EPA-450/3/89-18
Municipal Incinerators (>50 tons/day)	E	Incinerators	PM	08/17/71 06/19/84 (49FR25102)	12/23/71	11/27/79 (44FR7939)	APTD-0711 EPA-450/3-79-009 EPA-450/3-82-006a&b
							EPA-450/3-83-021
Municipal Waste Combustor Emissions	Ca,Ea	Response to Petition and ANPR			07-07-87 (52FR25399)		
		Methods 23&24		12/20/89 (54FR52190)			
			MWC Emissions	12/20/89 (54FR5225) 10/05/90 (55FR40870)	02-11-91 (55FR5488)		EPA-450/3-89-27b EPA-450/3/89-27c EPA-600/3/89-057 EPA-600/3/89-063 EPA-600/3/89-279 EPA-600/3/89-008 EPA-450/3-89-27d EPA-450/3-91-003 EPA-450/3-91-004 EPA-450/3-90-021
Portland Cement Plants	F	Kiln, clinker cooler	PM	08/17/71	12/23/71	10/22/79 (44FR60761)	APTD-0711 EPA-450/3-79-012
		Notice of review & proposed amendments		09/10/85 (50FR36956)	12/14/88 (53FR50354	09/10/85 (50FR36956)	EPA-450/3-85-003a EPA-450/3-85-003b
Nitric Acid Plants	G	Process equipment	NOx	08/17/71	12/23/71	06/19/79 04/05/84	APTD-0711 EPA-450/3-79-013a
Sulfuric Acid Plants	H	Process equipment	SOx, acid mist	08/17/71	12/23/71	03/15/79 (44FR15742) 08/26/85 (50FR34461)	APTD-0711 EPA-450/3-79-003 EPA-450/3-85-012
Sulfuric Acid Plants 111(d)		Process equipment	Acid mist		10/18/77		EPA-450/2-77-019

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STATUS OF STANDARDS OF PERFORMANCE
New Source Performance Standards
40 CFR 60

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Asphalt Concrete Plants	I	Process equipment	PM	06/11/73	03/08/74	08/31/79 (44FR51225)	EPA-450/2-74-003 APTD-1352a-b EPA-450/3-79/014
		Review and amendment of stds.			01/24/86-A (51FR3298)	01/24/86 (51FR3298) 04/10/86-C (51FR12324)	EPA-450/3-85-024
Petroleum Refineries	J	Fuel gas combustion devices	SO2	06/11/73 (38FR15406)	03/8/74 (39FR9308) 03/12/79-A (44FR13480)	10/22/79 (44FR60761)	EPA-450/2-74-003 APTD-1352a-b EPA-450/3-79-008
				03/03/80-A (45FR13991)	12/01/80-A (45FR79452)	12/02/86 (51FR43572)	EPA-450/3-86-011
		Claus sulfur recovery	SO2, reduced sulfur compounds, H2S	10/04/76 (41FR43866)	03/15/78 (43FR10866)	12/28/83 (48FR57238)	EPA-450/2-76-016a&
				03/20/79-A (44FR17120)	10/25/79 (44FR61542)		EPA-450/3-83-014
		FCCU Catalyst Regenerators	SOx	01/17/84 (49FR2058)		10/22/79 (44FR60761)	EPA-450/3-82-013
				11/08/85-R (50FR46464)			
			Part., CO	06/11/73 (38FR15406)	03/08/74 (39FR9308)		EPA-450/2-74-003 APTD-1352a-b
				08/30/76 (41FR36600)	06/24/77-A (42FR32426)		EPA-450/3-79-008
		Method 5F & 5B revision to Appendix A (sulfuric acid exclusion)		05/29/85 (50FR21863)	11/26/86 (51FR42839)		EPA-450/3-86-008
		Method 15A (alternative TRS method)		07/11/86 (51FR25212)	06/01/87 (52FR20391)		
		Method 10A			07/02/86	08/18/87 (51FR24164)	(52FR30674)
		Method 16 A and 16B		12/08/86 (51FR44075)	09/29/87 (52FR36408) 02/02/88 (53FR2914)-C		
Storage Vessels for Petroleum Liquids Construction after 6/11/73 & Prior to 5/19/78	K	Gasoline, crude oil, & distillate storage tanks >40,000 gallons capacity	VOC	06/11/73	03/08/74		APTD-1352a-b EPA-450/2-74-003
				07/23/84 (49FR29713)	04/08/87 (52FR11420) 06/16/87-C (52FR22779)		

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STATUS OF STANDARDS OF PERFORMANCE
New Source Performance Standards
40 CFR 60

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BTD No.
Storage Vessels for Petroleum Liquids Contruction after 5/18/78	Ka	Gasoline, crude oil, & distillate storage tanks >40,000 gallons capacity, vapor pressure > 1.5	VOC	05/18/78	04/04/80 12/18/80-C (45FR83228)		
				07/23/84 (49FR29713)	04/08/87 (52FR11420)		
		Equivalency determination/amendment		04/29/81 (46FR23984)	12/01/82 (47FR54258)		
Storage Vessels (including Petroleum Liquid Storage Vessels) for which Construction, Reconstruction, or Modification commenced after 7/23/84	Kb	Volatile organic liquid storage tanks > 20,000 gallons & 4 psi or > 40,000 gallons & 0.5 psi	VOC	07/23/84 (49FR29713)	04/08/87 (52FR11420)		EPA-450/3-81-003a
		Flare revision		04/16/85 (50FR14941)			EPA-450/3-80-003a&b EPA-450/3-82-010
Secondary Lead Smelters and Refineries	L	Blast & reverberatory furnaces, pot furnaces	PM	06/11/73 (38FR15406)	03/08/74 (39FR9308)	04/17/80 (45FR26304)	APTD-1352a-b EPA-450/2-74-003
Secondary Brass & Bronze Ingot Production Plants	M	Reverberatory and electric furnaces & blast furnaces	PM	06/11/73 (38FR15406)	03/08/74 (39FR9308)	06/19/79 (44FR35953)	APTD-1352a-b EPA-450/2-74-003
				05/23/84 (49FR21864)	10/30/84 (49FR43616)	05/23/84 (49FR21864)	EPA-450/3-84-009
Iron and Steel Mills	N	Basic oxygen process furnaces (BOPF)	PM	06/11/73 (38FR15406)	03/08/74 (39FR9318)		APTD-1352a-b EPA-450/2-74-003
		Primary emission sources	Opacity std.	03/02/77 (39FR9308)	04/13/78 (43FR15602)	03/21/79 (44FR17460)	EPA-450/3-78-116
Iron & Steel Mills (cont'd)				01/20/83 (48FR2658)	01/02/86 (51FR150)		
Iron and Steel Mills (Revised)	Na	BOPF, hot metal and skimming stations	Fugitive PM	01/20/83 (46FR2058)	01/02/86 (51FR150)		EPA-450/3-82-005a EPA-45-/3-82-005b
Sewage Treatment Plants	O	Sludge incinerators	PM	06/11/73	03/08/74 11/10/77-A (42FR58520)	11/27/79 (44FR67934)	APTD-1352a-c EPA-450/3-79-010
				04/18/86 (51FR13424)	10/06/88 (53FR39412)	04/18/86 (51FR13424)	EPA-450/3-84-010a EPA-450/3-84-010b
Primary Copper Smelters	P	Roaster, smelting furnace, converter Dryers	SOx PM	10/16/74	01/15/76 11/01/77-A	03/07/84 (49FR8572)	EPA-450/2-74-002a EPA-450/3-83-018a&b

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STATUS OF STANDARDS OF PERFORMANCE
New Source Performance Standards
40 CFR 60

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Primary Zinc Smelters	Q	Roaster Sintering machine	SOx PM	10/16/74	01/15/76	10/08/82 (47FR44587)	EPA-450/2-74-002a
Primary Lead Smelters	R	Sintering machine, electric smelting furnace, converter	SOx	10/16/74	01/15/76	10/08/82 (47FR44587)	EPA-450/2-74-002a
		Blast or reverberatory furnace, sintering machine discharge end	PM				
Primary Aluminum Reduction Plants	S	Pot lines & anode bake plants	Fluorides	10/23/74 (39FR37730) 09/19/78-A (43FR42186)	01/26/76 (41FR3826) 06/30/80 (45FR44202)	12/11/86 (51FR44643)	EPA-450/2-74-020a-c EPA-450/2-78-025a EPA-450/3-79-026 EPA-450/3-86-010
Primary Aluminum Reduction Plants 111(d)		Pot lines & anode bake plants	Fluorides	04/11/79 Draft CTG	04/17/80 Final CTG		EPA-450/2-78-049a&b
Phosphate Fertilizer Industry	T U V W X	Wet process phosphoric Superphosphoric acid Diammonium phosphate Triple superphos. prod. Granular trp. superphos. prod.	Fluorides Fluorides Fluorides Fluorides Fluorides	10/22/74	08/06/75	11/21/80	EPA-450/2-74-019a&b EPA-450/3-79-038R
		Small facility exclusion for Subparts T, U, V, W		06/21/82 (47FR26750)	02/17/83 (48FR7128)		
Phosphate Fertilizer Plants (111(d)		Wet process phos. acid Superphosphoric acid Diammonium phosphate Triple superphos. prod. Trpl. superphos. stor.	Fluorides Fluorides Fluorides Fluorides Fluorides	05/12/76	03/01/77		
Coal Preparation Plants	Y	Air tables and thermal dryers	PM	10/24/74	01/15/76	04/14/81 (46FR21769) 04/03/89 (54FR13384)	EPA-450/2-74-021a-c EPA-450/3-80-022 EPA-450/3-88-001
Ferroalloy Production Facilities	Z	Specific furnaces	PM, CO	10/21/74	05/04/76	01/26/81 (46FR8033)	EPA-450/2-74-018a-c EPA-450/3-80-041
Steel Plants: Electric Arc Furnaces	AA	Electric arc furnaces	PM	10/21/74 08/17/83 (48FR37338)	09/23/75 10/31/84 (49FR43838)	04/21/80 (45FR26910)	EPA-450/2-74-017a&b EPA-450/3-79-033 EPA-450/3-82-020a

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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Kraft Pulp Mills	BB	Digesters, lime kiln, recovery furnace, washer, evaporator, strippers, smelt & BLO tanks	Total reduced sulfur (TRS)	09/24/76 (41FR42012)	02/23/78 (43FR7568)		EPA-450/2-76-014a&b
				01/19/84-R (49FR2448)	05/20/86 (51FR18538)	01/19/84-R (49FR2448)	EPA-450/3-83-017
		Recovery furnace, lime, kiln, smelt tank	PM	09/24/76 (41FR42012)	02/23/78 (43FR7568)		
					08/07/78-A		
		Alternat. monitoring procedure		08/17/84-A (49FR32987)	06/17/85-W (50FR25095)		
		Innovative technology waiver		09/06/84 (49FR35156)	02/14/85-A (50FR6316)		
					02/25/85-C (50FR7595)		
Kraft Pulp Mills 111(d)		Digesters, lime kiln, recovery furnace, washer, evaporator, strippers, smelt & BLO tank	Total reduced sulfur (TRS)	02/23/78	05/22/79		EPA-450/2-78-003a&b
		Recovery furnace, lime, kiln, smelt tank	PM	02/23/78	05/22/79		
	D,Da, E,I, BB	Method 3 & 3B		(54FR8564)		03/01/89	
Glass Manufacturing Plants	CC	Glass melting furnace	PM	06/15/79 (44FR34840)	10/07/80 (45FR66742)		EPA-450/3-79-005a&b
				11/02/83-R (48FR50671)	10/19/84 (49FR41030)		
Grain Elevators	DD	Truck loading & unloading stations, barge or ship loading & unloading stations, railcar loading & unloading stations, & grain handling operations	PM	01/13/77	08/03/78	03/27/84	EPA-450/2-77-001a&
					11/05/87-C (52FR42434)	(49FR11750)	EPA-450/3-84-001

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STATUS OF STANDARDS OF PERFORMANCE

New Source Performance Standards

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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Surface Coating Metal Furniture	EE	Each metal furniture surface coating operation	VOC	11/28/80 (45FR79390)	10/29/82 (47FR49278)		EPA-450/3-80-007a&b
		Exemption of small metal furniture surface coating facilities using < 1,000 gallons of coating/year		10/16/84-R (49FR40542)	04/30/85-R (50FR18247)		
Stationary Internal Combustion Engines	FF	Each IC engine	NOx	07/23/79 (44FR43152)			EPA-450/3-78-125
Stationary Gas Turbines	GG	Each gas turbine	NOx, SOx	10/03/77 (42FR53782)	09/10/79 (44FR52792)	10/06/83 (48FR45701)	EPA-450/2-77-017a&
		Large industrial turbines exempted from NOx std.		04/15/81-R (46FR22005)	01/27/82 (47FR3767) 07/31/84-R (49FR30672) 11/05/87-C (52FR42434)		
Lime Manufacturing Plants	HH	Rotary kiln, hydrator	PM	05/03/77 09/02/82-R (47FR38832)	03/07/78 04/26/84 (49FR18076) 02/17/87-R 52FR4773		EPA-450/2-77-007a&b EPA-450/3-84-008
Sodium Carbonate	II	Calciners, dryers, bleachers	PM	10/15/80 (45FR68616)	09/22/81-W (46FR46813)		EPA-450/3-80-029a
Degreasers (Organic Solvent Cleaners)	JJ	Cold cleaner, vapor degreaser, conveyorized degreaser	VOC, PCE, TCE, MCF, MC, FR 113	06/11/80 (45FR39766) 04/21/81 (46FR22768) 08/10/87-P (52FR29548)	Applicability date deferred		EPA-450/2-78-045a
Lead Acid Battery Manufacturing Plants	KK	Lead oxide production grid casting, paste mixing, three-process operation & lead reclamation	Lead	01/14/80 (45FR2790)	04/16/82 (47FR16564)		EPA-450/3-79-028a&b
Metallic Minerals	LL	Metallic mineral processing operations prior to metal reduction	PM	08/24/82 (47FR36859)	02/21/84 (49FR6458)		EPA-450/3-81-009a

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New Source Performance Standards
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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Automobile and Light-Duty Truck Surface Coating Operations	MM	Prime, guide coat, & top coat operations at assembly plants	VOC emissions	10/05/79 (44FR57792)	12/24/80 (45FR85410) 09/09/85 (50FR36830)		EPA-450/3-79-030a&b
		Prime coat revision		07/29/82-R (47FR32743)			
		Innovative technology waiver		08/06/82 (47FR34342)	02/04/83 (48FR5452)		
		Innovative technology waiver		09/24/84 (49FR37548)	09/09/85 (50FR36830)		
		Innovative technology waiver		09/30/86 (51FR34898)			
		Innovat. techn. waiver correction		11/04/86-C (51FR40043)			
Phosphate Rock Plants	NN	Grinding, drying & calcining facilities	PM	09/21/79 (44FR54970)	04/16/82 (47FR16582) 03/27/90-N (55FR11338)		EPA-450/3-79-017a&b
Perchloro-ethylene Dry Cleaning	OO	Dryer, washers, filters, stills, muck cookers	VOC	11/25/80 (45FR78174) 12/09/91 (56FR64382)-W			EPA-450/3-79-029a
Ammonium Sulfate Manufacture	PP	Ammonium sulfate dryer	PM	02/04/80 (45FR7758)	11/12/80 (45FR74846)	03/06/85 (50FR9055)	EPA-450/3-79-034a&b EPA-450/3-85-004
Graphic Arts Industry (Rotogravure)	QQ	Each publication roto-gravure printing press	VOC	10/28/80 (45FR71538)	11/08/82 (47FR50644) 01/10/83-C (48FR1056)		EPA-450/3-80-031a&b
Pressure Sensi-tive Tapes & Labels Coating	RR	Adhesive coating line, release coating line, precoat coating line	VOC	12/30/80 (45FR86278)	10/18/83 (48FR48368)		EPA-450/3-80-003a&b
Indus. Surface Coating: Large Appliances	SS	Each surface coating operation	VOC	12/24/80 (45FR85085)	10/27/82 (47FR47778)		EPA-450/3-80-037a&b
Metal Coil Surface Coating	TT	Each prime coating operation, each finish coat operation	VOC	01/05/81 (46FR1102)	11/01/82 (47FR49606) 01/10/83-C (48FR1056) 06/24/86-C (51FR22938)		EPA-450/3-80-035a&b

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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Asphalt Process & Asphalt Roofing Manufacture	UU	Blowing stills, saturator, asphalt storage tanks, minerals handling, & storage facilities	PM	11/18/80 (45FR76427) 05/26/81-A (46FR28180)	08/06/82 (47FR34137)		EPA-450/3-80-021a&b
SOCMI Equipment Leaks (Fugitive)	VV	Listed equipment (fugitive sources) grouped within a process unit	VOC	01/05/81 (46FR1136)	10/18/83 (48FR48328)		EPA-450/3-80-033a&b
		Notice of "AID" Availability		05/07/82 (47FR19724)	10/18/83 (48FR48328)		EPA-450/3-82-010
		Flare Revision		04/16/85 (50FR14941)	01/21/86 (51FR2699)		EPA-450/3-80-033a&b
Beverage Can Coatings	WW	Each exterior base coat operations, over-varnish coating operation & inside spray coating at 2 piece beverage can plants	VOC	11/26/80 (45FR78980)	08/25/83 (48FR38728)		EPA-450/3-80-036a&b
Bulk Gasoline Terminals	XX	Gasoline terminals-- total of all loading racks	VOC	12/17/80 (45FR83126)	08/18/83 (48FR37578) 12/22/83-C (48FR56580)		EPA-450/3-80-038a&b
[RESERVED]	YY	(FORMERLY ASSIGNED TO ELECTRIC ARC FURNACES IN A FERROUS FOUNDRY)					
Residential Wood Heaters	AAA	Freestanding woodstoves & fireplace inserts	PM	02/18/87 (52FR4994)	02/26/88 (53FR5860) 04/12/88-C (53FR12009) 04/26/88-C (53FR14888)		EPA-450/3-87-025
		Advance notice of proposed rulemaking			08/02/85 (50FR31504)		
		Notice of rulemaking negotiation			09/30/86 (51FR34672)		

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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Rubber Tires	BBB	Undertread cementing, tread end cementing, sidewall cementing, bead cementing, water-based green tire spraying, organic-based green tire spraying, Michelin-A, Michelin-B, & Michelin-C-automatic	VOC	01/20/83 (48FR2676)	09/15/87 (52FR34868) 09/19/89 (54FR38634)-R		EPA-450/3-81-008a
Polymers and Resins	DDD	Raw material preparation, polymerization, material recovery, product finishing, product storage process sections, fugitive emissions	VOC	09/30/87 (52FR36678) 01/10/89 (54FR890)-P	12/11/90 (55FR51010)		EPA-450/3-83-019a EPA-450/3-89-019b
By-Product Coke Oven Battery Stacks	EEE	Coke oven battery	PM	At present no NSPS to be developed			
Flexible Vinyl and Urethane Coating Printing Operation	FFF	Rotogravure printing & coating of flexible vinyl products	VOC	01/18/83 (48FR2276) Supplemt.-10/11/83 (48FR46224)	06/29/84 (49FR26885)		EPA-450/3-81-016a&b
Petroleum Refineries: Equipment Leaks	GGG	(1) Each compressor (2) Listed equipment (fugitive emission) sources grouped within a process unit	VOC	01/04/83 (48FR279)	05/30/84 (49FR22598)		EPA-450/3-80-033b EPA-450/3-81-015a
		Flare Revision		04/16/85 (50FR1494)			EPA-450/3-82-010 EPA-450/3-80-033a&b
Synthetic Fiber Production Facilities	HHH	Solvent-spun synthetic fiber manufacturing facilities	VOC	11/23/82 (47FR52932)	04/05/84 (49FR13646)		EPA-450/3-82-011a&b
SOCMI - Air Oxidation	III	Manufact. of synthetic organic chemicals via air oxidation processes	VOC	10/21/83 (48FR48932) 05/16/85-P (50FR20446)	06/29/90 (55FR26912)		EPA-450/3-82-001a EPA-450/3-82-001b
Petroleum Dry Cleaning	JJJ	Dry cleaning equipment in which petroleum solvent is used	VOC	12/14/82 (47FR56118)	09/21/84 (49FR37328)		EPA-450/3-82-012a&b
		Response to petition for reconsideration and final amendments to rule			11/27/85 (50FR49022)		

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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Onshore Natural Gas Processing	KKK	Natural gas production facilities--equipment leaks of VOC	VOC	01/20/84 (49FR2636)	06/24/85 (50FR26122)		EPA-450/3-82-024a EPA-450/3-82-024b
		Flare Revision			01/21/86 (51FR2699)		
Onshore Natural Gas Processing	LLL	Natural gas production	SO2	01/20/84 (49FR2656)	10/01/85 (50FR40158)		EPA-450/3-82-023a EPA-450/3-82-023b
Coke Oven Wet Quenching	MMM	Conventional wet quenching facilities	PM	No schedule - at present no NSPS to be developed			
Distillation Operations (SOCMI)	NNN	Each distillation column in petrol. refinery & synthetic organic chem. plant used in making one of 220 chemicals.	VOC	12/30/83 (48FR57538) 05/16/85-P (50FR20446)	06/29/90 (55FR26931)		EPA-450/3-83-005a EPA-450/3-83-005b
		Flare Revision		04/16/85 (50FR14941)			EPA-450/3-82-010 EPA-450/3-80-033a&b
Non-Metallic Minerals (includes light-weight aggregate, gypsum, & perlite)	OOO	Each crusher, grinding mill, screening operation, bucket conveyor, bagging operation, storage bin, enclosed truck or railcar loading station.	PM	08/31/83 (48FR39566)	08/01/85 (50FR31328)		EPA-450/3-83-001a EPA-450/3-83-001b
Wool Fiberglass Insulation Manufacturing	PPP	New, modified, & reconstructed wool fiberglass insulation manufacturing lines utilizing the rotary spin forming process	PM	02/07/84 (49FR4590)	02/25/85 (50FR7694)		EPA-450/3-83-022a
Pet. Refinery Wastewater Systems	QQQ	Individual drain systems, oil-water separators, drain systems with ancillary downstream wastewater components	VOC	05/04/87 (52FR6334)	11/23/88 (53FR47616)		EPA-450/3-85-001a EPA-450/3-85-001b
SOCMI Reactor Processes	RRR			06/29/90 (55FR26953)			EPA-450/3-85-005a
Magnetic Tape Industry	SSS	Industrial paper ctg. (foil & plastic film)	VOC	01/22/86 (51FR2996)	10/3/88 (53FR38892)		EPA-450/3-85-029a EPA-450/3-85-029b
		Withdrawal - solvent storage tanks		11/25/86-W (51FR42800)			

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Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Plastic Parts for Business Machines Coatings	TTT	New, modified, & reconstructed facilities that surface coat plastic parts for business machines.	VOC	01/08/86 (51FR854) 03/27/86-C (51FR10556)	01/29/88 (53FR2672) 05/27/88 (53FR19300)-C		EPA-450/3-85-019a&b
Calciners & Dryers in Mineral Indust.	UUU	Mineral calciners and dryers at mineral processing plants	PM	04/23/86 (51FR15438) 04/29/86-C (51FR15916)			EPA-450/3-85-025a
Polymeric Coatings	VVV	New, modified, & reconstructed facilities which perform polymeric coating of supporting substrates	VOC	04/30/87 (52FR15906)	09/11/89 (54FR37534)		EPA-450/3-85-022a
Municipal Solid Waste	WWW	New, modified (Landfill Gas) MSW Landfills		05/30/91 (56FR24468)			

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STATUS OF STANDARDS OF PERFORMANCE
National Emission Standards for Hazardous Air Pollutants
40 CFR 61

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
General Provisions	A	Amendments to General Provisions	all pollutants	06/06/84-R (49FR23568) 04/16/85 (50FR14941)	11/07/85-R (50FR46284)		EPA-450/3-80-033a&b EPA-450/3-82-010
Radionuclides Underground Uranium Mines	B	(HANDLED BY OFFICE OF RADIATION IN WASHINGTON, D.C.)					
Beryllium	C	Extraction plants, ceramic plants, foundries, incinerators, propellant plants, machining operations	Beryllium	12-07-71 (36FR23239)	03/31/71-L (36FR5931) 04/06/73 (38FR8826) 05/03/74-R (39FR15396)		APTD-1503 APTD-0753
Beryllium, Rocket Motor Firing	D	Rocket motor firing	Beryllium	12/07/71 (36FR23239)	04/06/73 (38FR8826) 05/03/74-R (39FR15396)		APTD-1503 APTD-0753
Mercury	E	Ore Processing, chlor-alkali manufacturing sludge incinerators	Mercury	12/07/71 (36FR23239) 10/25/74-A (39FR38064) 12/26/84-R (49FR50146) 10/14/75-A (40FR48292)	03/31/71-L 04/06/73 (38FR8826) 05/03/74-R (38FR15396) 03/19/87 (52FR8724)	12/26/84 (49FR50146)	APTD-1503 APTD-0753 EPA-450/2-74-009a EPA-450/3-84-014 EPA-450/3-84-0146)
Vinyl Chloride	F	Ethylene dichloride manufacture via O2 HCl, vinyl chloride manufacture, polyvinyl chloride manufacture	Vinyl Chloride	12/24/75 (40FR59532) 06/02/77-A (42FR28154) 01/09/85 (50FR1182) 09/21/89 (54FR38938)	12/24/75-L 10/21/76 (41FR46560) 01/09/85-W (50FR1182) 09/30/86 (51FR34904) 07/10/90 (55FR28346)		EPA-450/2-75-009a&b EPA-450/3-82-003 EPA-450/3-85-002 EPA-450/3-86-004
Emissions from Coke Oven Wet Coal Charging Topside Leaks, and Door Leaks	G	Wet-coal charged coke oven batteries	Coke oven emissions	04/23/87 (52FR13586) 09/20/87 (52FR36594)-P	09/18/84-L (49FR36560)		

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STATUS OF STANDARDS OF PERFORMANCE
National Emission Standards for Hazardous Air Pollutants
40 CFR 61

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
		*SUBPART NUMBER REASSIGNED TO RADIONUCLIDES AFTER WITHDRAWAL OF PROPOSED NESHAP. RADIONUCLIDES HANDLED BY OFFICE OF AIR AND RADIATION, WASHINGTON, D.C.					
		Denial of petition for reconsideration of withdrawal		08/23/85 (50FR34144) 07/28/88 (53FR28496)			
Benzene Emiss. from Ethyl-benzene/Styrene	I*	Alkylation reactor section, EB hydroperoxi-dation reactor, hydrogen separation system	Benzene	12/18/80 (45FR83448)			EPA-450/3-79-035a
				03/06/84 (49FR8386)	06/06/84-W (49FR23478) 10/02/84-C (49FR38945)		EPA-450/3-84-003
		Denial of petition for reconsideration of withdrawal		08/23/85 (50FR34144) 07/28/88 (53FR28496)			
Benzene Equipt. Leaks	J	Listed equipment	Benzene	01/05/81 (46FR1165)	06/06/84 (49FR23498)		EPA-450/3-80-032a&b
		Denial of petition for reconsideration of withdrawal		08/23/85 (50FR34144) 07/28/88 (53FR28496)			
Benzene Emiss. from Benzene Storage Tanks	K*	Each storage tank	Benzene	12/19/80 (45FR83952)			EPA-450/3-80-034a
		Notice of additional emission date		11/24/82 (47FR53058)			
				03/06/84 (49FR8386)	06/06/84-W (49FR23478)		EPA-450/3-84-004
		Denial of petition for reconsideration of withdrawal		08/23/85 (50FR34144) 07/28/88 (53FR28496)	09/14/89 (54FR38044)		
		*SUBPART NUMBER REASSIGNED TO RADIONUCLIDES AFTER WITHDRAWAL OF PROPOSED NESHAP. RADIONUCLIDES HANDLED BY OFFICE OF AIR AND RADIATION, WASHINGTON, D.C.					

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STATUS OF STANDARDS OF PERFORMANCE
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40 CFR 61

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Benzene Emiss. from Coke By-Product Recovery Plants	L	Process equipment, storage facilities, equipment leaks, and sumps	Benzene	06/06/84 (49FR23522) 08/27/84-P (49FR33904)	09/14/89 (54FR38044)		EPA-450/3-83-016a EPA-450/3-83-016b
		Flare revision		04/16/85 (50FR14941) 07/28/88 (53FR28496) 04/01/91 (56FR13368)	09/19/91 (56FR47404)		EPA-450/3-80-033a&b EPA-450/3-82-010
Benzene Emiss. from Chem. Mfg. Process Vents, Indust. Solvent Use, Benzene Waste Oper, Benzene Transf. Oper.& Gasoline Marketing	AA	Pharmaceutical Mfg. facilities	Benzene	09/14/89 (54FR38083)	03/07/90 (55FR8292) 05/02/90 (55FR18330) 10/31/90 (55FR45804)		EPA-450/3-78-031 EPA-600/1-78-61 EPA-450/5-84-001 EPA-600/X-85-022 EPA-450/3-80-028b EPA-450/3-87-001a
	BB	Benzene Transfer Operations	Benzene				EPA-450/3-81-008a EPA-450/3-87-026
	CC	Gasoline Storage Vessels at Service Stations	Benzene				EPA-450/3-80-038a EPA-450/3-88-038b EPA-450/3-84-012a
	DD	Bulk Gasoline Terminals	Benzene				EPA-450/3-84-012b EPA-450/3-84-001a
	EE	Bulk Gasoline Plants	Benzene				EPA-450/3-84-012c
	FF	Benzene Waste Operations	Benzene				(56FR6382)-N
	GG	Industrial Solv. Use at Benzene Rubber Tire Mfg. Facil.					
Asbestos	M	Asbestos mills; roadway surfacing (asbestos tailings); demolition; spraying, fabrication, waste disposal & insulating	Asbestos	12/07/71 (36FR23239)	03/31/71-L (36FR5931) 04/06/73 (38FR8826) 05/03/74-R (39FR15396)		APTD-150 APTD-0753
		Manufacture of shotgun shells, renovation, fabrication, asphalt concrete, products containing asbestos		10/25/74-A (39FR38064)	10/14/75-A (40FR48292) 03/02/77-A (42FR12127) 06/19/78 (43FR26372)		EPA-450/2-74-009a EPA-450/2-77-030
		Reaffirm work practice standards		07/13/83-A (48FR32126)	04/05/84 (49FR13658)		
		final rule, correction			03/10/86-C (51FR8199)		
		Enforcement & Compliance		01/10/89-R (54FR912)	11/20/90 (55FR48406)		EPA-450/3-90/017

A - amendment R - revision
C - correction W - withdrawal
P - reop. for publ. comnt. L - listing
N - notice

STATUS OF STANDARDS OF PERFORMANCE
National Emission Standards for Hazardous Air Pollutants
40 CFR 61

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Inorganic Arsenic Emiss. from Glass Manufacturing Plants	N	Melting furnaces	Inorganic arsenic		06/05/80-L (45FR37886)		
	N	Melting furnaces		07/20/83 (48FR33112) 12/16/83 (48FR55880) 03/20/84-P (49FR36877)	08/04/86 (51FR27956) 10/03/86-C (51FR353654) 08/04/86		EPA-450/5-82-005 EPA-450/3-83-011a EPA-450/3-83-011b EPA-450/5-85-001
Inorganic Arsenic Emiss. from Low Arsenic Feedstock Copper Smelter	O	Low arsenic smelters (smelting furnace & copper converter)	Inorganic arsenic	07/20/83 (48FR33112) 12/16/83-P (48FR55880) 09/20/84-P (49FR36877)	08/04/86 (51FR27956) 10/03/86-C (51FR35354)		EPA-450/3-83-010a EPA-450/3-83-010b EPA-450/5-85-001
Inorganic Arsenic Emiss. from High Arsenic Feedstock Copper Smelter	P	High arsenic smelters (copper converters)	Inorganic arsenic	07/20/83 (48FR33112) 12/16/83-P (48FR55880)	08/04/86 (51FR27956) 10/03/86-C (51FR35354)		EPA-450/3-83-009a EPA-450/3-83-010b EPA-450/5-85-001
		Test Methods 108B & 108C		01/26/89			
Radionuclides	Q-T	(HANDLED BY OFFICE OF RADIATION IN WASHINGTON, D.C.)					
[RESERVED]	U						
Equipment Leaks	V	Listed Equipment	Volatile hazardous pollutants	01/05/81 (46FR1136)	06/06/84 (49FR23498)		EPA-450/3-80-033a EPA-450/3-80-032b
		Flare Revision		04/16/85 (50FR14941)	01/21/86 (51FR2699)		EPA-450/3-80-033a&b
Uranium Mill Tailings	W	(HANDLED BY OFFICE OF RADIATION IN WASHINGTON, D.C.)					

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STATUS OF STANDARDS OF PERFORMANCE
National Emission Standards for Hazardous Air Pollutants
40 CFR 63

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Early Reductions	D		All HAPs	6/13/91 (56FR27338)			EPA-450/3-91-012a EPA-450/3-91-013
Perchloro-ethylene	M	Dry Cleaning	Perchloro-ethylene	12/09/91 (56FR64382)			EPA-450/3-91-020a EPA-450/3-91-021

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STATUS OF STANDARDS OF PERFORMANCE
RCRA* SECTION 3004(n) Air Emission Standards
40 CFR 264 and 265

Source	Subpart	Affected Facility	Pollutant	Proposal Date	Promulgation Date	Review Date	BID No.
Hazardous Waste Treatment, Storage, and Disposal Facilities;	C	Equipment leaks and certain process vents	Volatile organic emissions	02/05/87 (52FR3748)	06/21/90 (55FR25454) 04/26/91-A (56FR19290)		EPA-450/3-89-009
	AA	Process Vents	Volatile organic emissions	02/05/87 (52FR3748) 07/22/91 (56FR83490)	06/21/90 (55FR25454) 04/26/91-A (56FR19290)		
	BB	Equipment Leaks	Volatile organic emissions	02/05/87 (52FR3748) 07/22/91 (56FR83490)	06/21/90 (55FR25454) 04/26/91-A (56FR25454)		
	CC	Tanks, Surface Imp. & Containers		07/22/91 (56FR83490)			EPA-450/3-89-023a/b/c

*Resource Conservation and Recovery Act

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P - reop. for publ. comnt. L - listing

CONTROL TECHNIQUES GUIDELINES DOCUMENTS
(Groups, I, II, III)

1. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume I: Control Methods for Surface Coating Operations, EPA-450/2-76-028, November 1976. (Group I) Engineer: Bill Johnson. NTIS No. PB-260 386

2. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks, EPA-450/2-77-008, May 1977. (Group I) Engineer: Dave Salman (cans, coils: automobiles, and light-duty trucks); Bill Johnson (paper, fabric). NTIS No. PB-272 445

3. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume III: Surface Coating of Metal Furniture, EPA-450/2-77-032, December 1977. (Group I) Engineer: Dennis Crumpler. NTIS No. PB-278 257

4. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume IV: Surface Coating of Insulation of Magnet Wire, EPA-450/2-77-033, December 1977. (Group I) Engineer: Bill Johnson. NTIS No. PB-278 258

5. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume V: Surface Coating of Large Appliances, EPA-450/2-77-034, December 1977. (Group I) Engineer: Bill Johnson. NTIS No. PB-278 259

6. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VI: Surface Coating of Miscellaneous Metal Parts and Products, EPA-450/2-78-015, June 1978. (Group II) Engineer: Dennis Crumpler, Dave Salman or Bill Johnson (in that order). NTIS No. PB-286-157

7. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VII: Factory Surface Coating of Flat Wood Paneling, EPA-450/2-78-032, June 1978. (Group II) Engineer: See J. Berry. NTIS No. PB-292 490

8. Control of Volatile Organic Emissions from Existing Stationary Sources, Volume VIII: Graphic Arts - Rotogravure and Flexography, EPA-450/2-78-033, December 1978. (Group II) Engineer: Bill Johnson. NTIS No. PB-292 490

9. Control of Volatile Organic Emissions from Bulk Gasoline Plants, EPA-450/2-77-035, December 1977. (Group I) Engineer: Steve Shedd. NTIS No. PB-276 722

10. Control of Volatile Organic Emissions from Storage of Petroleum Liquids in Fixed Roof Tanks, EPA-450/2-77-036, December 1977. (Group I) Engineer: Randy McDonald. NTIS No. PB-276 749

11. Control of Refinery Vacuum Producing Systems, Wastewater Separators, and Process Unit Turnarounds, EPA-450/2-77-025, October 1977. (Group I) Engineer: K. C. Hustvedt. NTIS No. PB-275 662

12. Control of Volatile Organic Compounds from Use of Cutback Asphalt, EPA-450/2-77-037, December 1977. (Group I) Engineer: Dave Markwordt. NTIS No. PB-278 185

13. Control of Hydrocarbons from Tank Truck Gasoline Loading Terminals, EPA-450/2-77-026, December 1977. (Group I) Engineer: Steve Shedd. NTIS No. PB-275 060

14. Design Criteria for Stage I Vapor Control Systems - Gasoline Service Stations, November 1975. (Group I) Engineer: Steve Shedd.

15. Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment, EPA-450/2-78-036, June 1978. (Group II) Engineer: K. C. Hustvedt. NTIS No. PB-286 158

16. Control of Volatile Organic Emissions from Petroleum Liquid Storage in External Floating Roof Tanks, EPA-450/2-78-047, December 1978. (Group II) Engineer: Randy McDonald. NTIS No. PB-290 579

17. Control of Volatile Organic Emissions from Perchloroethylene Dry Cleaning Systems, EPA-450/2-78-050, December 1978. (Group II) Engineer: Steve Shedd. NTIS No. PB-290 613

18. Control of Volatile Organic Compound Leaks from Gasoline Tank Trucks and Vapor Collection Systems, EPA-450/2-78-051, December 1978. (Group II) Engineer: Steve Shedd. NTIS No. PB-290 568

19. Control of Volatile Organic Compound Emissions from Volatile Organic Liquid Storage in Floating and Fixed Roof Tanks, DRAFT, August 1981. (Group III) Engineer: Randy McDonald.

20. Control of Volatile Organic Compound Emissions from Large Petroleum Dry Cleaners, EPA-450/3-82-009, September 1982. (Group III) Engineer: Steve Shedd. NTIS No. PB-83-124 875

21. Control of Volatile Organic Compound Fugitive Emissions from Synthetic Organic Chemical Polymer and Resin Manufacturing Equipment, EPA-450/3-83-006, March 1984. (Group III) Engineer: K. C. Hustvedt. NTIS No. PB-84-161 520. Cost $17.50

22. Control of Volatile Organic Compound Equipment Leaks from Natural Gas/Gasoline Processing Plants, EPA-450/2-83-007, December 1983. Engineer: K. C. Hustvedt. NTIS No. PB-84-161 520. Cost $17.50

23. Control of Volatile Organic Emissions from Solvent Metal Cleaning, EPA-450/2-77-022, November 1977. (Group I) Engineer: Dave Beck. NTIS No. PB-274 557. Cost $19.00

24. Control of Volatile Organic Emissions from Manufacture of Synthesized Pharmaceutical Products, 450/2-78-029, December 1978. (Group II) Engineer: Dave Beck or Leslie Evans. NTIS No. PB-290 580. Cost $14.50

25. Control of Volatile Organic Emissions from Manufacture of Pneumatic Rubber Tires, EPA-450/2-78-030, December 1978. (Group II) Engineer: Dave Salman. NTIS No. PB-290 557. Cost $10.00

26. Control Techniques for Volatile Organic Emissions from Stationary Sources, EPA-450/2-78-022, May 1978. (Group II) Engineer: Dave Beck. NTIS No. PB-284 804. Cost $41.50

27. Control of Volatile Organic Compound Emissions from Air Oxidation Processes in Synthetic Organic Chemical Manufacturing Industry, EPA-450/3-84-015, December 1984. (Group III) Engineer: Leslie Evans. NTIS No. PB-85-164 275. Cost $22.00

28. Control of Volatile Organic Compound Emissions from Manufacture of High-Density Polyethylene, Polypropylene, and Polystyrene Resins, EPA-450/3-83-008, November 1983. (Group III) Engineer: William Johnson. NTIS No. PB-84-134 600

29. Fugitive Emission Sources of Organic Compounds - Additional Information on Emissions, Emission Reductions, and Costs, EPA-450/3-82-010, April 1982. Engineer: K. C. Hustvedt. NTIS No. PB-82-217 126. Cost $22.00

Address for NTIS

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(703)487-4650

Address for CPB/EPA

U. S. Environmental Protection Agency
Chemicals and Petroleum Branch/ESD (MD-13)
Research Triangle Park, North Carolina 27711

CONTROL TECHNOLOGY DOCUMENTS

[Documents Which Provide Background Information on Controls Only - Not RACT]

1. Alternative Control Technology Document - Halogenated Solvent Cleaners - EPA-450/3-89-030, August 1989.

2. Reduction of Volatile Organic Compound Emissions from the Application of Traffic Markings - EPA-450/3-88-007, August 1988

3. Alternative Control Technology Document - Ethylene Oxide Sterilization/Fumigation Operations - EPA-450/3-89-007, March 1989

4. Reduction of Volatile Organic Compound Emissions from Automobile Refinishing - EPA-450/3-88-009. NTIS No. PB-89-148 282

5. Alternative Control Technology Document - Organic Waste Process Vents, EPA-450/3-91-007, December 1990

6. Technical Guidance - Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, EPA-450/3-91-022a, November 1991. NTIS No. PB-92-132844

Address for NTIS

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U. S. Environmental Protection Agency
Chemicals and Petroleum Branch/ESD (MD-13)
Research Triangle Park, North Carolina 27711

(April 1992)

CONTROL TECHNIQUES GUIDELINE DOCUMENTS TO BE DEVELOPED
(IN ACCORDANCE WITH CLEAN AIR ACT AMENDMENTS OF 1990)

SOMCI[1] Distillation
SOCMI Reactor Vents
Batch Operations
Volatile Organic Liquid Storage
Wastewater[2]
Plastic Parts - Business Machines
Plastic Parts - Other
Wood Furniture
Offset Lithography
Autobody Refinishing
Cleanup Solvents
Aerospace
Shipbuilding and Repair

OTHER TITLE I ACTIVITIES
Marine Tank Vessel Loading Rule
Architectural and Industrial Coatings Rule
Consumer and Commercial Products Report to Congress

<u>Information Contact:</u>
U.S. Environmental Protection Agency
Chemicals and Petroleum Branch (MD-13)
Research Triangle Park, North Carolina 27711

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[1] SOCMI = Synthetic Organic Chemical Manufacturing Industry

[2] Wastewater includes: Organic Chemicals, Plastics, Synthetic Fibers, Pesticides, Pharmaceutical, and Hazardous Waste facilities

April 1992

Control Technology Center (CTC)
Reports Addressing VOC Emissions and Controls

"HAP-PRO," EPA-600/8-91-211a, PB92-135904 (manual); EPA-600/8-91-211b (software); PB92-501212 (manual and software)

"Handbook: Control Technologies for Hazardous Air Pollutants" (HAP Manual), EPA-625/6-91-014

"Emission Factors for Iron Foundries--Criteria and Toxic Pollutants," EPA-600/2-90-044, PB90-266743

"Evaluation of VOC Emissions from Heated Roofing Asphalt," EPA-600/2-91-061, PB92-115286

"Assessment of VOC Emissions and Their Control from Bakers Yeast Manufacturing Facilities, EPA-450/3-91-027, PB92-145408

"Powder Coating Technology Update," EPA-450/3-89-033, PB90-127341

"Radiation Curable Coatings," EPA-600/2-91-035, PB91-219550

"Best Demonstrated Control Technology for Graphic Arts," EPA-450/3-91-008, PB91-168427

"ASPEN Expert System for Steam Stripping Calculations: Users' Manual," EPA-450/3-90-003

"Industrial Wastewater VOC Emissions--Background for BACT/LAER," EPA-450/3-90-004, PB90-194754

"Evaluation of Emission Control Devices at Waferboard Plants," EPA-450/3-90-002, PB90-131442

"Evaluation of Air Toxic Emissions at Minnesota's Reconstituted Panelboard Plants," EPA-450/3-91-009

"Control of VOC Emissions from Polystyrene Foam Manufacturing," EPA-450/3-90-020, PB91-102111

"Landfill Air Emissions Estimation Model," EPA-600/8-90-085a, PB91-167718, manual; EPA-600/8-90-085b, PB91-507541, software and manual

"Air Emissions from the Treatment of Soil Contaminated with Petroleum Fuels"

"Ultrasonic Cleaning of Rotogravure Cylinder, "EPA-450/3-89-024, PB89-148282

"Reduction of Volatile Organic Emissions from Automobile Refinishing," EPA-450/3-88-009, PB89-148282

"Reduction of Volatile Organic Compound Emissions from Traffic Markings," EPA-450/3-88-007, PB89-148274

"Evaluation of Emission Controls at Leeds Architectural Products" (Spray Booth Controls), EPA-450/3-89-001, PB90-120106

"Air Stripping of Contaminated Water Sources--Air Emissions and Controls," EPA-450/3-87-017, PB88-106166

"Surface Impoundment Modeling Systems (SIMS) Version 2.0 Users' Manual," EPA-450/4-90-019a, PB91-156711 and "Background Document for Surface Impoundment Modeling System (SIMS) Version 2.0," EPA-450/4-90-019b, PB91-156729 PB91-506911 (Manual), PB 91-506998 (software, Manual and Background),

"Control Technology Assessment for Air Emissions from Wastewater Treatment," EPA-450/3-89-008, PB89-207922

"Evaluation of Emission Sources at a Waferboard Manufacturing Plant," EPA-450/3-87-021, PB88-107735

"Evaluation of Emission Factors for Formaldehyde from Certain Wood Processing Operations," EPA-450/3-87-023, PB88-118492

"Assessment of VOC Emissions from Fiberglass Boat Manufacturing," EPA-600/2-90-019, PB90-216532

Control Technology Center (MD-13)
US Environmental Protection Agency
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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

This document is a summary document containing general information on sources of volatile organic compound (VOC) emissions, applicable control techniques, and the impacts resulting from control applications. It references other documents which contain much more detailed information on individual sources and control techniques. This is the third edition of a report originally published by the Department of Health, Education, and Welfare (HEW) titled, "Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (AP-68)." The first edition was published in March 1970 by the National Air Pollution Control Administration, a part of HEW.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Air Pollution Volatile Organic Compounds	Air Pollution Control	13b

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