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Air



# Guideline Series

DRY CLEANING  
AP-42 Section 4.1  
Reference Number  
4

## Control of Volatile Organic Emissions from Petroleum Dry Cleaners

### Preliminary Draft

Bill  
Is there now any info or are there any  
factors here in that are not already  
reflected in AP-42?  
If not, is this report in background file? Should be.  
if so, what is NOT included?  
① Arc's comment  
let's discuss further JAS

CTG

NOTICE

This document has not been formally released by EPA and should not now be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

# **Control of Volatile Organic Emissions from Petroleum Dry Cleaners**

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY  
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Office of Air Quality Planning and Standards  
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## 1.0 INTRODUCTION AND SUMMARY

### 1.1 INTRODUCTION

The Clean Air Act Amendments of 1977 require each state having areas in which the national ambient air quality standards (NAAQS) are exceeded to adopt and submit revised State Implementation Plans (SIP) to EPA. Revised SIP's were required to be submitted to EPA by January 1, 1979. States that were unable to demonstrate attainment with the NAAQS for ozone by the statutory deadline of December 31, 1982 could request extensions for attainment of the standard, but the extensions could not go beyond December 31, 1987. States granted an extension are required to submit a further revised SIP by July 1, 1982.

Sections 172(a)(2) and (b)(3) of the Clean Air Act require non-attainment area SIP's to include reasonably available control technology (RACT) requirements for stationary sources. As discussed in the "General Preamble for Proposed Rulemaking on Approval of State Implementation Plan Revisions for Nonattainment Areas," for ozone SIP's (44 FR 20372, April 4, 1979), EPA permitted states to defer the adoption of RACT regulations on a category of stationary sources of volatile organic compounds (VOC) until after EPA publishes a control techniques guideline (CTG) for that VOC source category (see 44 FR 53761, September 17, 1979). This delay allows states to make more technically sound decisions regarding the application of RACT.

CTG documents provide state and local air pollution control agencies with an information base for proceeding with the development and adoption of regulations that reflect RACT for specific stationary sources. Consequently, CTG documents review existing information and data concerning the technology and cost of various control techniques to reduce emissions. CTG documents also identify control techniques and

suggest emission limitations that EPA considers the "presumptive norm," which is broadly representative of RACT for the entire stationary source category covered by a CTG document.

CTG documents are, of necessity, general in nature and do not fully account for variations within a stationary source category. Reasonably available control technology, however, is defined as the lowest emission limitation that a particular source is capable of meeting, by the application of emission control technology that is reasonably available considering technical and economic feasibility. Thus, reasons may exist for states to develop regulations that deviate from the "presumptive norm" included in a CTG document. The CTG document, however, is a part of the rulemaking record that EPA considers in reviewing revised SIP's, and the information and data contained in the document are highly relevant to EPA's decision to approve or disapprove a SIP revision. If a state adopts emission limitations that are consistent with the information in the CTG, it may be able to rely solely on the information in the CTG to support its determination of RACT. Where this is not the case, the state must include documentation with its SIP revision to support and justify its RACT determination.

The sole purpose of this model regulation is to assist state and local agencies in development and adoption of regulations for specific stationary sources. This model regulation is not to be construed as rulemaking by EPA. This draft CTG document includes a model regulation based upon the "presumptive norm" considered broadly representative of RACT for the stationary source category covered by this document.

The Petroleum Dry Cleaning CTG document is being released in a working draft form to achieve two objectives: First, to provide an opportunity for public review and comment on the information and regulatory guidance contained in the document, and second, to provide as much assistance and lead time as possible to state and local agencies preparing RACT regulations for specific stationary sources covered by this document.

## 1.2 SUMMARY

The model regulation based on RACT would apply to petroleum dry cleaning dryers, filters, stills, and miscellaneous sources of VOC emissions in facilities that consume at least 123,000 liters of petroleum solvent per year, based on annual solvent purchases for each plant.

Dryer VOC emissions can be reduced under the model regulation by requiring the installation and proper operation of solvent recovery dryers. Compliance with this requirement can be determined by monitoring the condenser vapor outlet temperature (not to exceed 34°C) and the recovered solvent flow rate at the termination of the recovery phase (not in excess of 0.02 liters per minute). Other dryer VOC emission control techniques may be used in place of the recovery dryer, provided that VOC emissions from these alternative systems do not exceed 2.4 kg per 100 kg dry weight of articles dry cleaned.

VOC emissions from petroleum solvent filters and filter wastes can be reduced under the model regulation by requiring all petroleum dry cleaning facilities using filtration to install and properly operate a cartridge filtration system. Filtration cartridges should be drained in their sealed housing for no less than 8 hours. Alternative techniques for the control of filtration system VOC emissions may be used, provided that their controlled emission rate does not exceed 1.0 kg VOC per 100 kg dry weight of articles dry cleaned.

Vacuum still VOC emissions can be reduced under the terms of the model regulation by requiring that all vacuum still wastes be stored in containers that prevent VOC emissions. Compliance with this requirement should be determined by weekly visual inspections of the waste storage equipment for vapor and liquid leaks.

Fugitive VOC emissions from miscellaneous sources can be reduced in the model regulation by requiring that all petroleum solvent vapor and liquid leaks be repaired within 3 working days. If necessary repair parts are not on hand, a purchase order for these parts should be issued within 3 working days, and repairs should be completed within 3 working days of the parts arrival. Compliance with this requirement should be

based on weekly visual inspections of areas and devices that are frequent sources of VOC liquid and vapor leaks.

The owner or operator of a petroleum solvent dry cleaning facility, under the terms of the model regulation, can be required to achieve final compliance with the regulation no later than 19 months after implementation of the regulation. If, however, the control equipment is promptly ordered and delivery delays ensue, the deadline for final compliance should be 3 months following the delivery date of the equipment.

## 2. PETROLEUM DRY CLEANING INDUSTRY

The objective of this section is to describe the domestic petroleum dry cleaning industry. The dry cleaning process is discussed, as are solvent characteristics, emissions and the major petroleum dry cleaning equipment. Model plants also are presented that will be used in later chapters to evaluate the environmental and cost impacts of reasonably available control technology (RACT).

### 2.1 INDUSTRY DESCRIPTION

The dry cleaning industry is a service industry involved in the cleaning and/or renting of apparel. The total industry is subdivided according to the type of solvent used and the type of services offered. The solvents used are categorized into three broad groups: petroleum solvents, perchloroethylene (perc), and trichlorotrifluoroethane (F113, a registered trademark). The industry also is composed of three sectors which are delineated by the type of services offered. These are: (1) the self-service or coin-operated sector, (2) the commercial dry cleaning sector, and (3) the industrial dry cleaning sector. This report is concerned only with the sectors that use petroleum dry cleaning solvents.

Petroleum dry cleaning represents about 30 percent of the total quantity of clothes cleaned by the dry cleaning industry. Petroleum dry cleaning services are offered only by the commercial and industrial sectors of the industry, and represent about 25 and 50 percent, respectively, of the total clothes throughput for each of these industry sectors (Fisher, 1980b; Sluizer, 1980). Coin-operated or self-service petroleum dry cleaning plants are prohibited by National Fire Protection codes due to the highly volatile and flammable nature of petroleum solvents (NFPA, 1974). Consequently, most commercial and industrial petroleum dry cleaning plants are located away from densely populated residential areas and shopping centers.

Commercial petroleum dry cleaning establishments offer dry cleaning services to the general public, and include both independently owned ("Mom and Pop") dry cleaners and franchised ("One Hour Dry Cleaning") companies. Typically, these facilities clean personal items such as suits, coats, and dresses in a central cleaning plant that supports one or more pickup and distribution outlets. Of the 25,000 domestic commercial cleaners (representing 25 percent of the dry cleaning industry throughput as of 1979), approximately 6,000 use petroleum solvents. The average throughput in a typical commercial cleaner is 25 megagrams of cleaned articles per year (Fisher, 1980b).

Industrial dry cleaning establishments are much larger than their commercial counterparts and cater to industrial, professional, and institutional customers. Articles such as hospital uniforms, maintenance uniforms, shop towels, and rugs generally are cleaned by industrial dry cleaners. There are approximately 920 industrial cleaning establishments nationwide. In 1979, approximately 230 of these industrial plants used primarily petroleum dry cleaning solvents. A typical industrial petroleum dry cleaning plant processes roughly 390 megagrams of articles each year (Sluizer, 1980). The combined industrial and commercial petroleum dry cleaning sectors process approximately 250,000 megagrams of articles each year.

## 2.2 PROCESS DESCRIPTION

Petroleum dry cleaning operations are similar to detergent and water wash operations. Unlike perchloroethylene dry cleaning, which can have both washing and drying operations in the same machine (dry-to-dry), petroleum dry cleaning is a batch operation where articles are washed and dried in separate machines. Figure 2-1 depicts a typical petroleum dry cleaning operation. Articles to be dry cleaned are sorted into lots according to color, fabric, degree of soiling, etc., and are placed in their appropriate washers. For example, one lot might consist of light colored, light weave, casual clothing which can be placed in one washer, while another lot might be made up of heavy weave, heavily soiled industrial uniforms placed in another washer. Articles are then agitated in the solvent. The more heavily soiled articles go through

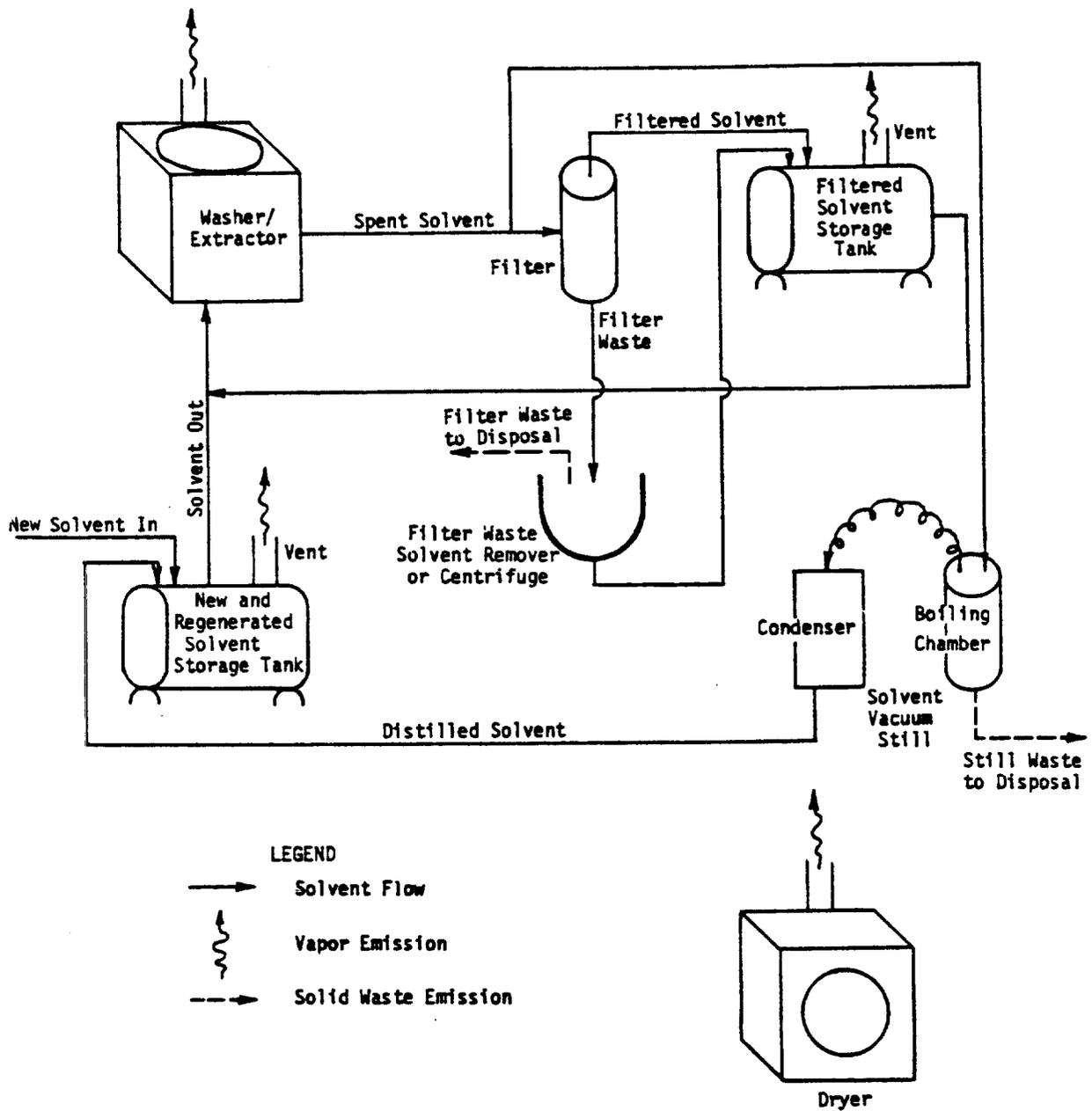


Figure 2-1. Petroleum Dry Cleaning Plant Flow Diagram.

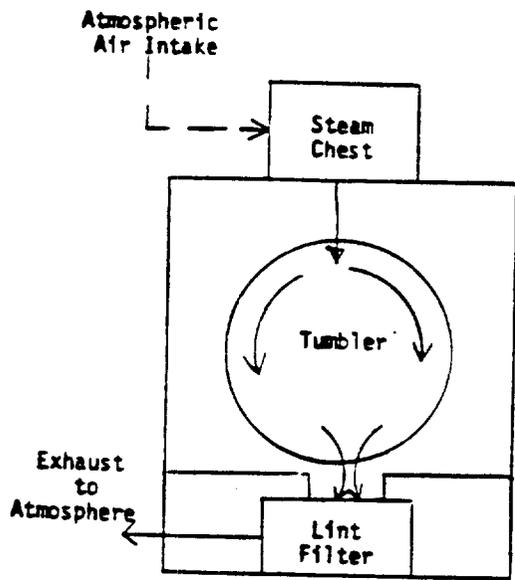
two or more wash cycles: the first with recycled, soiled solvent and the second with clean solvent.

Industrial dry cleaners often use a cleaning process where water-soluble materials are removed from articles in a water and detergent wash. This process, sometimes called a "dual" or "double phase" process, takes place in modern washers and is used by more than 90 percent of industrial dry cleaners (see Figure 2-2b) (Sluizer, 1980).

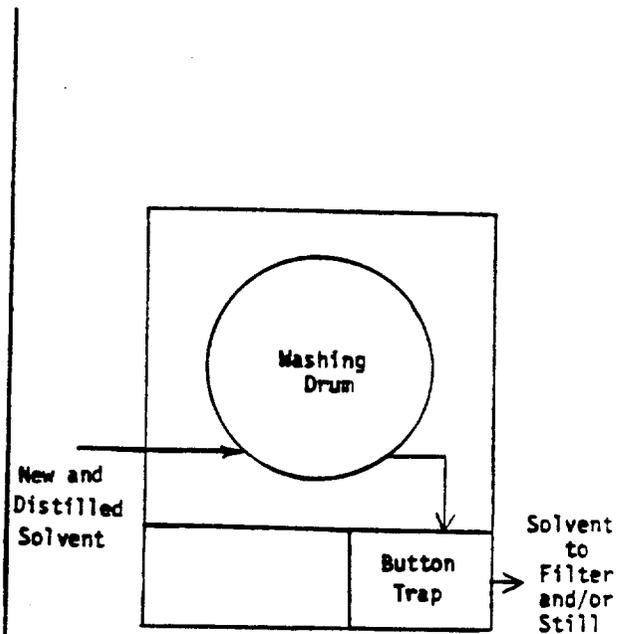
Commercial dry cleaners also use a dual phase process for cleaning articles. However, most (up to 90 percent) of the commercial dry cleaners use a "charged" system, a process where both soap, up to 4 percent by volume, and controlled amounts of water (0.1 to 0.3 percent by volume) are manually or automatically added to the solvent (Fisher, 1980b; Phillips, 1966). The volume of soap and water added to the solvent usually is controlled by either the load type, load weight, moisture present in the solvent, relative humidity of the air, or a combination thereof.

After completion of the wash cycle, articles are spun at high speeds to remove excess solvent. This spin cycle usually occurs in the same equipment used for washing; however, approximately 23 percent of existing plants (older petroleum plants) have separate, high speed centrifugal extractors (Watts and Fisher, 1975). When the spin cycle has terminated, articles are transferred from the washer/extractor to a dryer (tumbler). Inside the dryer, any remaining solvent is removed from the articles by evaporation in a heated air stream and vented to the atmosphere.

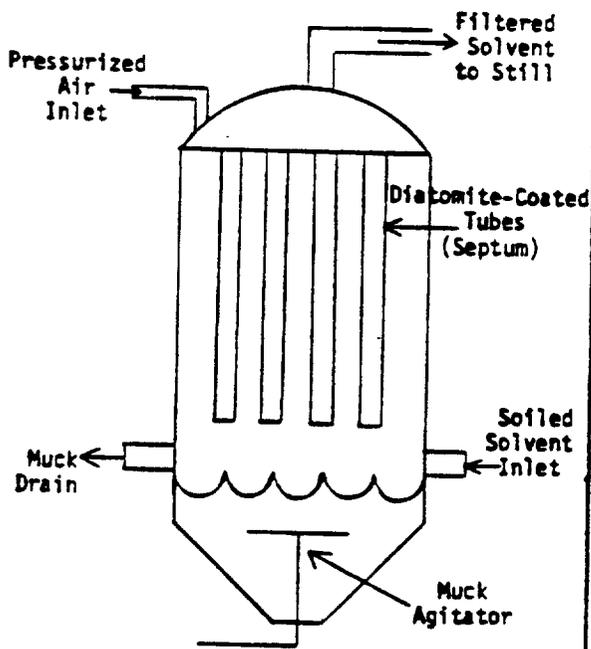
Soiled solvent extracted during the spin cycle is passed through a filter to remove insoluble soils and other suspended particles. When the soil load in the solvent is excessive, soil-laden solvent may be transferred directly from the washer to a vacuum still or to a settling tank prior to distillation. After settling (usually overnight), the heavy oils, dirt, and grease are decanted and the solvent is sent to a vacuum still where it is purified. When oil and grease loading is low, distillation is often bypassed and filtration serves as the only means of solvent replenishment. Finally, the distilled solvent is pumped into another holding tank or is returned to the washer/extractor.



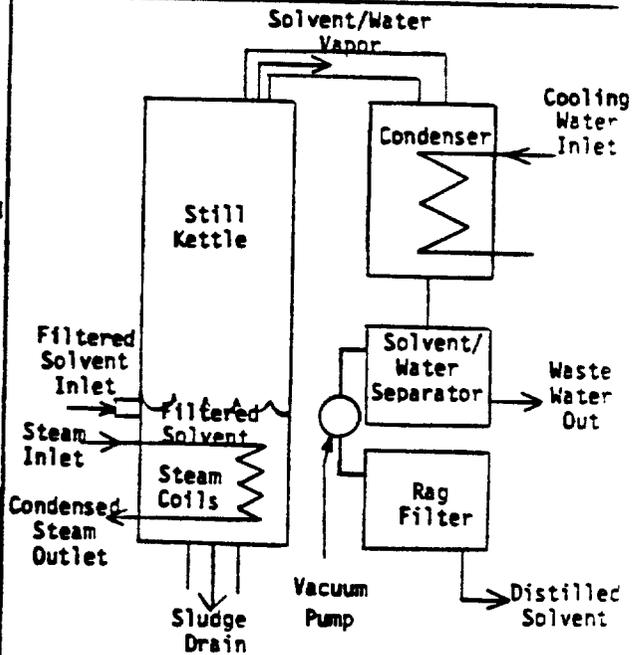
A. STANDARD DRYER



B. WASHER/EXTRACTOR



C. DIATOMITE FILTER



D. VACUUM STILL

Figure 2-2. Typical Dry Cleaning Equipment in Existing Plants.

### 2.2.1 Petroleum Dry Cleaning Solvents

The National Fire Protection Association (NFPA) classifies petroleum dry cleaning plants by the type of solvent used. Solvents, in turn, are classified by their flash points. Class II and IIIA solvents are the primary solvents used in the petroleum cleaning industry. The NFPA number 32-1974, dry cleaning solvent classification is as follows:

- Class I Solvents - Liquids having flash points below 38°C (100°F) such as 50°F flash point naphtha.
- Class II Solvents - Liquids having flash points from 38°C to 59°C (100°F to 139°F) such as quick drying solvents and Stoddard solvents.
- Class IIIA Solvents - Liquids having flash points ranging from 60°C to 93°C (140°F to 199°F) such as 140°F "safety" solvent.

Petroleum solvents, commonly called Stoddard solvents, are a mixture of mainly C<sub>8</sub> to C<sub>12</sub> hydrocarbons that are similar to kerosene. These hydrocarbons can be further subdivided into three molecular structures: aliphatics, alicyclics, and aromatics. Table 2-1 gives the chemical properties of several types of petroleum solvents including their aromatic contents.

## 2.3 EMISSION SOURCES

This section identifies dryers, solvent filtration and distillation systems, and miscellaneous (fugitive) sources as the major contributors of VOC emissions in a dry cleaning plant. The operations of these sources, their emissions, and the development of a baseline emission estimate are discussed below.

### 2.3.1 Dryers

Petroleum dryers consist of three parts that are housed in a single unit: the tumbler, blower, and steam coils (see Figure 2-2a). The tumbler is a perforated, rotating basket in which solvent-laden articles are placed. Air entering the tumbler is heated as it passes over steam-heated coils to temperatures that range from 43° to 88°C (110°F to 190°F), with optimum drying temperatures ranging from 60°C to 66°C (140°F to 150°F) (Marvel et al., 1980). Solvent in the articles is removed or volatilized by the heated air steam. The volatilized solvent

Table 2-1. DRY CLEANING SOLVENT PHYSICAL PROPERTIES

Property	Chevron		Shell		AMSCO		Ashland		Inland Oil	
	325	450	Mineral spirits 140	Mineral spirits 140	spirits	spirits	Kwik Dri	Stoddard	Stoddard	140-F
Flash point (°F)	101	146	113	113	105	103	108	108	142	
Initial BP (°F)	316	363	332	332	312	315	324	324	364	
Dry end point (°F)	366	477	392	392	390	360	390	390	399	
Specific gravity @60°F	0.784	0.809	0.786	0.786	0.786	0.750	0.784	0.784	0.784	
Heat of vaporization (Btu/lb)	119	108	-	-	-	104	-	-	-	
Average molecular weight	138	166	-	-	-	130	-	-	-	
Toxicity (ppm)	250	275	-	-	-	500	200	175		
Aromatics content (%V)	2	2	12	12	17	3	12	12	9.5	
Napthenes content (%V)	67	62	44	44	36	35	44	44	45	
Paraffins content (%V)	31	36	44	44	47	62	44	44	45	

-Data unavailable.

and heated air then are continuously vented to the atmosphere during the drying cycle at an air flow rate of from 28 to 340 cubic meters per minute (1,000 to 12,000 cubic feet per minute) and a vapor concentration of from 200 to 9,000 parts per million (ppm) of solvent by volume (Jernigan and Lutz, 1979; Lutz et al., 1980; Marvel et al., 1980).

Existing petroleum dry cleaning dryers range in capacity from 22 kg to 180 kg (50 to 400 lb) (Marvel et al., 1980). Emissions from these dryers vary depending on the extraction efficiency of the washer/extractor and the weight of articles per dryer load. The type of articles in the dryer also have an effect on emission rates and emission concentration levels. Wools have a tendency to absorb more solvent and, conversely, give up more solvent during extraction than an equal weight of silks (Wilke, 1973). This basic property may be attributed to the loose weave of wools in comparison with the tight weave of silks. Thus, loosely woven materials tend to absorb and give up solvent more readily than tightly woven material.

In an EPA demonstration test of an add-on carbon adsorber at a petroleum dry cleaning plant in Anaheim, California, a 180 kg (400 lb) dryer loaded with 115 kg (250 lbs) of work uniforms, shop towels, and fender covers emitted 14 kg VOC per 100 kg dry weight of articles cleaned (Lutz et al., 1980). Approximately 28 kg VOC per 100 kg dry weight of articles cleaned was emitted during an EPA test of a 50 kg (100 lb) dryer at a petroleum dry cleaning plant in Pico Rivera, California (Jernigan and Lutz, 1980). This dryer was loaded to 10 percent over-capacity with leather and cotton work gloves, exclusively. A study by a dry cleaning trade association indicated that petroleum solvent dryers emit approximately 14 kg VOC per 100 kg dry weight of general apparel cleaned (Fisher, 1975). Thus, the average emission rate from a dryer based on these three data sources is 18 kg VOC per 100 kg dry weight of articles cleaned.

### 2.3.2 Filters

Filtration, in dry cleaning operations, is a process used to remove most insoluble (dirt and lint) contaminants, as well as certain water-soluble contaminants (perspiration and food stains) from dry cleaning solvents. This is accomplished by rapidly passing large volumes of solvent through a porous medium that traps and thus removes contaminants suspended in the solvent.

All dry cleaning filtration systems are composed of two parts: the filter medium and the structure that holds the filter medium, known as the septum (see Figure 2-2c). The filter medium, usually diatomaceous earth (diatomite), is used to remove insoluble contaminants by entrapping them in its porous surface. The septum is a rigid, porous surface (screen, cloth, or wire mesh) to which the filter medium adheres, thereby allowing pressurized solvent to flow through while simultaneously blocking the passage of particles. Filters are sized by the volume of solvent processed, and range in size from 5,700 to 56,800 liters per hour (1,500 to 15,000 gallons per hour) (Washex, 1974).

During a wash cycle, articles are agitated in a bath of solvent. After the wash cycle, the soiled solvent is pumped to a filter for filtration. Filters vary, based on their mode of operation, septum type, and construction material. Single-charge filters (rigid tube or disc septums) have a single mass or "charge" of filter medium which is replaced after each wash load is completed. Multi-charge filters (bag, screen, and rigid tube septums) add filter medium to the initial charge of filter medium for each load of articles washed. Regenerative filters (flexible tube septums) have an initial mass of filter medium which is redistributed on the septum for each load of articles washed, without subsequent addition of filter medium. As of 1980, about 50 percent of the petroleum dry cleaning plants that utilize filtration use multi-charge diatomite filters, the remaining 50 percent employing cartridge filters (see Section 3.2) for solvent filtration (Fisher, 1980a). A trade association study has shown that initial masses of diatomite (precoats) average about 1 kg (2 lbs) per 3,800 liters (1,000 gal) of filter capacity, with diatomite being added during the operation at a rate of 0.5 kg (1 lb) per 45 kg (100 lbs) of articles cleaned (Leonhardt, 1966).

5 → 10  
2  
~ 7

Filter medium is replaced when the pressure across the filter, due to the buildup of contaminants on the medium, reaches a predetermined level (up to 40 psi or 270 kilopascals). Spent filter medium (filter muck) is usually allowed to drain in the filter housing overnight or for 24 hours before it is discarded. Discarded filter medium that has been allowed to drain for 24 hours may contain from 5 to 10 kg solvent per 100 kg dry weight of articles cleaned for regenerative and multi-charge filters, respectively (NID Research Development, 1971). Thus, after a 24-hour drain time, an average of just under 8 kg of solvent per 100 kg dry weight of articles cleaned is retained in the discarded filter muck.

### 2.3.3 Vacuum Stills

Distillation is used to remove contaminants from solvents, such as bacteria, detergents, water, oils, and dyes, that are not removed by filtration. Petroleum dry cleaning solvents have boiling ranges of from 150°C to 215°C (300 to 415°F). A steam pressure of 100 psi (670 kilopascals) or more is required to boil petroleum solvents under atmospheric conditions. Consequently, distillation of petroleum solvents takes place under a vacuum of from 75 to 92 kPa (22 to 27 inches Hg) which lowers the boiling range for petroleum solvents to 107°C to 113°C (225°F-235°F) at steam pressures of 235 to 600 kilopascals (35 to 90 psi) (Washex, 1973). Vacuum stills are sized by the volume of solvent to be processed and range in size from 190 to 2,800 liters per hour (50 to 750 gallons per hour) (Washex, 1973).

Spent solvent from a washer or filter is pumped to the boiling chamber of a still. In the boiling chamber, steam heated coils volatilize the solvent, leaving behind still residue (high boilers) composed of oils, grease, and dirt. Solvent vapor and moisture pass from the boiling chamber into a water-cooled condenser where the vapors condense to a mixture of liquid solvent and water (see Figure 2-2d). This mixture is then piped to a gravimetric separator, where the solvent and water are separated by the differences in their densities. Finally, the solvent is pumped to a tank containing cotton rags or salt pellets which absorb any remaining water.

When the concentration of high boilers has reached a specified level, as indicated by a visual inspection of solvent flow in a sight

glass between the condenser and separator (indicating that the evolution and condensation of solvent vapors is seriously impeded or halted), the solvent flow to the still is manually shut off and steam flow is increased to the maximum available level. The liquid contained in the boiling chamber is allowed to boil for 5 to 15 minutes in a process commonly called "boildown" in which most of the remaining solvent is removed by boiling. After boildown, the liquid residue is drained from the boiling chamber and still operations are resumed. Typically, still boildown is required when the solvent and water flow from the condenser are reduced by 75 percent (Washex, 1973; Rosenthal, 1980). This flow reduction is subjectively determined based on the operation of a particular still.

Depending on the design of the still, its operation, and frequency of boildown, as much as 80 percent by volume of solvent is decanted with still residue (equivalent to 6 kg solvent per 100 kg dry weight of articles cleaned) as indicated by an EPA vacuum still test of an industrial dry cleaning plant in Anaheim, California (Jernigan and Kezerle, 1980). A vacuum still test, conducted by a firm that rents and dry cleans apparel, also indicated that more than 80 percent by volume of solvent is decanted with their still residue (Burnett, 1980). A trade association study has found that approximately 1 kg of solvent per 100 kg dry weight of articles cleaned is decanted with the residue for a well-maintained and operated vacuum still (NID Research Department, 1971).

Still Residue 0.15

$$\frac{6+6}{2} = 6 \text{ max.}$$

1 well maintained operated

#### 2.3.4 Fugitive Emission Sources

There are a number of sources of fugitive emissions in a dry cleaning operation. Fugitive sources include emissions from the extraction cycle of a washer, emissions given off during the transfer of solvent-laden articles from washers or dryers, liquid and vapor leaks in tanks and piping, and the evaporation of solvent from open containers. Also included are fugitive emissions from filter muck and still residue storage tanks. Although sources of fugitive emissions can be identified, and the VOC concentrations within the vicinity of these sources can be quantified, it is virtually impossible to estimate an emissions rate for fugitive sources.

In an EPA test to determine fugitive emissions at a dry cleaning plant in Anaheim, California, it was found that more than 0.5 kg VOC per 100 kg dry weight of articles cleaned was emitted from various sources within the plant (Jernigan and Kezerle, 1980). Emissions were expected to be higher than those recorded because the doorways and windows (pathways through which emissions escaped to the atmosphere) remained open during fugitive testing. It is technically and economically infeasible to quantify all sources of emissions in a dry cleaning plant because certain emissions are prevalent only during the operation of the dry cleaning equipment, while other low-level sources emit continuously. A dry cleaning industry trade association publication assumes, however, that miscellaneous (fugitive) emissions would be approximately 1 kg of VOC emissions per 100 kg dry weight of articles cleaned (Fisher, 1975).

#### 2.4 FACILITIES AND THEIR EMISSIONS

A summation of typical emissions from the four major sources in a petroleum dry cleaning plant yields 28 kg VOC per 100 kg dry weight of articles cleaned. Of the 28 kg of total plant emissions, 65 percent originates at the dryer, 28 percent is emitted from filter muck, still residue contributes 3.5 percent, and the remaining 3.5 percent is attributable to fugitive emissions. Using 28 kg VOC per 100 kg of clothes cleaned as a baseline emission level, a typical petroleum plant would have a breakdown of emissions similar to the values shown below:

<u>Source</u>	<u>Range of emission rates (kg VOC per 100 kg dry weight of articles cleaned)</u>	<u>Anticipated emission rates (kg VOC per 100 kg dry weight of articles cleaned)</u>
Dryer	10-28	18
Filter	5-10	8
Still	1-6	1
Fugitive sources	0.5-3	<u>1</u>
Total		28

A typical commercial dry cleaning plant cleans 25 megagrams (Mg) of articles each year and emits 7 Mg of VOC each year based on the 28 kg per 100 kg dry weight of articles cleaned emission rate. This VOC emission rate equates to 43,000 Mg per year from the commercial sector of the petroleum dry cleaning industry.

The characteristics of a typical commercial dry cleaner are listed below:

- One 23 kg (50 lb) capacity washer/extractor
- One 23 kg (50 lb) capacity dryer
- One 5,700 liter/hr (1,500 gal/hr) diatomite filter system
- One 190 liter/hr (50 gal/hr) vacuum still
- Four 18 kg (40 lb) loads per day, 250 days/year

A typical industrial petroleum dry cleaning plant will process 390 Mg of articles each year. The same plant, based on a VOC emissions rate of 28 kg per 100 kg dry weight of articles cleaned, will emit 110 Mg of VOC emissions yearly. Thus, the entire industrial sector will emit an average of 25,300 Mg of VOC each year. Characteristics of a typical industrial dry cleaner include:

- One 225 kg (500 lb) capacity washer/extractor
- Four 45 kg (100 lb) capacity dryers or one 180 kg (400 lb) dryer
- Two 2,800 liter/hr (750 gal/hr) vacuum stills
- Two 56,800 liter/hr (15,000 gal/hr) diatomite filter systems
- Eight 225 kg (500 lb) loads per day, 250 days/yr

## 2.5 MODEL PLANTS

Four model plants - small commercial, large commercial, small industrial, and large industrial - have been developed to represent the petroleum dry cleaning industry; however, these models do not indicate a clear distinction as to actual plant sizes or whether a plant is a commercial or an industrial dry cleaner. These models were developed to simplify the identification of the types of existing dry cleaning plants and their equipment, throughput, and costs. The data used in the development of these model plants were derived from plant visits, dry cleaning trade association survey data, and input from industry representatives (Fisher, 1975; Marvel et al., 1980).

The model dry cleaning plants are classified by their throughput and the type of articles cleaned. Commercial dry cleaners typically have small weekly throughputs, with the fees charged for dry cleaning based solely on the type and number of articles cleaned. In contrast, industrial dry cleaners usually have large throughputs, and their fees

are based primarily on the weight of articles received at the plant. Table 2-2 lists the characteristics of each model plant, their throughput, and emissions.

#### 2.5.1 Small Commercial Plants

This category of cleaning plants comprises 4,650 establishments or approximately 75 percent of all commercial petroleum plants (Fisher, 1975). Because small commercial plants usually clean general apparel, such as suits, dresses and coats, their soil loading is relatively low. Typically, these plants use diatomite filters for the initial filtration of spent solvent, although an industry trade association estimates that as many as 50 percent of existing plants may use cartridge in place of diatomite filtration (Fisher, 1980a). Usually, a small vacuum still is employed periodically to complete solvent regeneration. (See Table 2-2 for a detailed description of a small model plant.)

#### 2.5.2 Large Commercial Plants

The large commercial dry cleaning plant services both retail and institutional or contract customers. These plants may have contracts to clean hospital uniforms or other types of uniforms as well as general apparel. There are approximately 1,506 large commercial petroleum dry cleaners in the United States (Fisher, 1980b). This number represents roughly 25 percent of all commercial dry cleaning plants. Larger equipment is used to handle their increased throughput; although, in most aspects, their operation is identical to that of the small commercial cleaner. A total throughput of 205 kg (450 lb) of cleaned articles per day is typical for these plants as indicated in Table 2-2.

#### 2.5.3 Small Industrial Plants

Small industrial dry cleaners have a daily throughput of 1,100 kg (2,400 lb) of moderately soiled institutional articles such as industrial uniforms and heavy garments such as rugs and mats. Several medium-capacity washers and dryers are used to facilitate the separation of job loads and to avoid downtime caused by equipment breakdowns. There are an estimated 60 small industrial petroleum dry cleaners in the United States (approximately 25 percent of all industrial dry cleaning facilities) (Sluizer, 1980). As indicated in Table 2-2, this is the largest model plant category that employs solvent filtration.

Table 2-2. MODEL PLANT PARAMETERS  
(existing equipment)

Model plant	Small commercial	Large commercial	Small industrial	Large industrial
Number of existing plants nationwide in 1979	4,650	1,500	60	170
Annual plant throughput, in kg (lbs)	18,000 (40,000)	51,000 (112,500)	272,000 (600,000)	435,300 (960,000)
Throughput description	General apparel	General apparel and institutional	Institutional articles	Industrial articles
Number of washers	1	1	2	1
Washer capacity (each), kg (lbs)	18 (40)	45 (100)	115 (250)	225 (500)
Number of recovery dryers	1	1	4	1
Dryers capacity (each), kg (lbs)	23 (50)	45 (100)	45 (100)	180 (400)
Number of regenerative filters	1	1	2	0
Regenerative filter capacity (each, L/hr (gal/hr))	5,700	5,700	5,700	-
Vacuum still capacity (each), L/hr (gal/hr)	190-375 (50-100)	750-1,150 (200-300)	5,700 (1,500)	19,000 (50,000)
Number of loads per day	8	9	8	8
Average load weight, kg (lbs)	9 (20)	23 (50)	135 (300)	180 (400)
Days of operation per year	250	250	250	300
Wash cycle time, minutes	10	15	25	25
Dry cycle time, minutes	20	30	40	40
Average baseline emissions per plant, megagrams, VOC/year (tons VOC/year)	5.1 (5.6)	14.3 (15.7)	76 (84.0)	122 (134)
Average baseline emissions nationwide, megagrams VOC/year (tons VOC/year)	23,400 (26,000)	21,400 (23,500)	4,600 (5,000)	20,700 (22,800)

#### 2.5.4 Large Industrial Plants

Large industrial dry cleaning plants are typically associated with firms that rent uniforms, cleaning cloths, floor mats, work gloves, dust mops, or similar items. These plants have a throughput of 7,400 kg/day (3,300 lb/day) or more of heavy fabrics that are heavily soiled. Since these plants often operate on multiple shifts, they require sturdy equipment with large capacities for almost continuous operation. There are an estimated 170 large industrial petroleum dry cleaners in the United States representing 75 percent of the total number of industrial plants (Sluizer, 1980). Table 2-2 presents additional information on large industrial plants.

The combined emissions from small commercial, large commercial, small industrial, and large industrial plants result in a nationwide VOC emission level of 70,500 megagrams per year from the petroleum dry cleaning industry.

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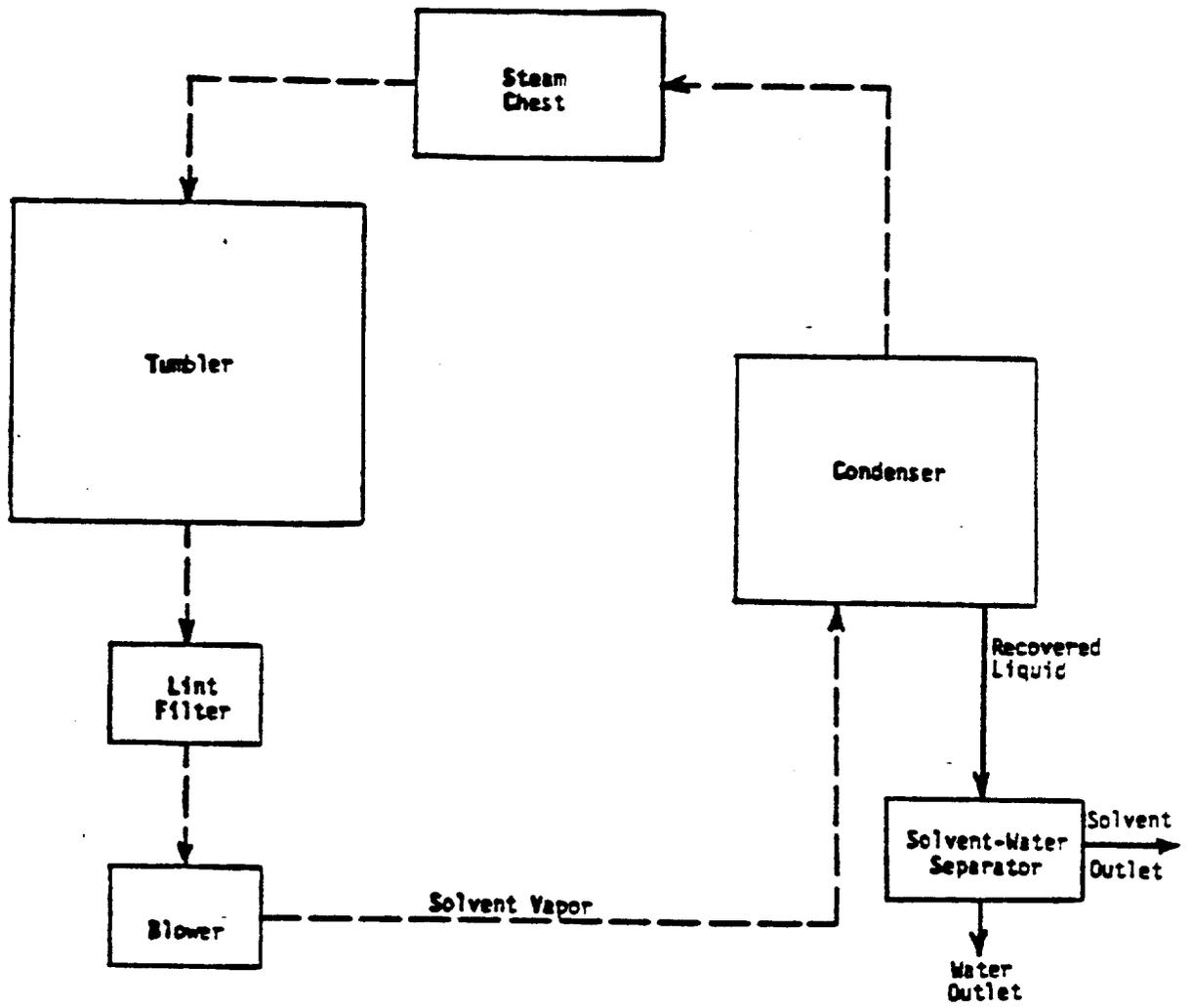


Figure 3-1. Solvent Vapor Flow Diagram for a Recovery Dryer.

### 3. EMISSION CONTROL TECHNIQUES

Equipment and procedures selected as representing reasonably available control technology (RACT) for the petroleum dry cleaning industry are described in this chapter. Particular attention is given to the design, operation, and VOC emission-reduction performance of RACT equipment, with verification of these criteria being supported, where possible, by engineering analyses and field test data (see Appendix A). Finally, the effects of variations in and deviations from the equipment configurations and operating procedures, characteristic of the four model plants developed in Chapter 2, are analyzed in relation to their impacts on VOC emission reduction and overall equipment performance.

#### 3.1 RECOVERY DRYER

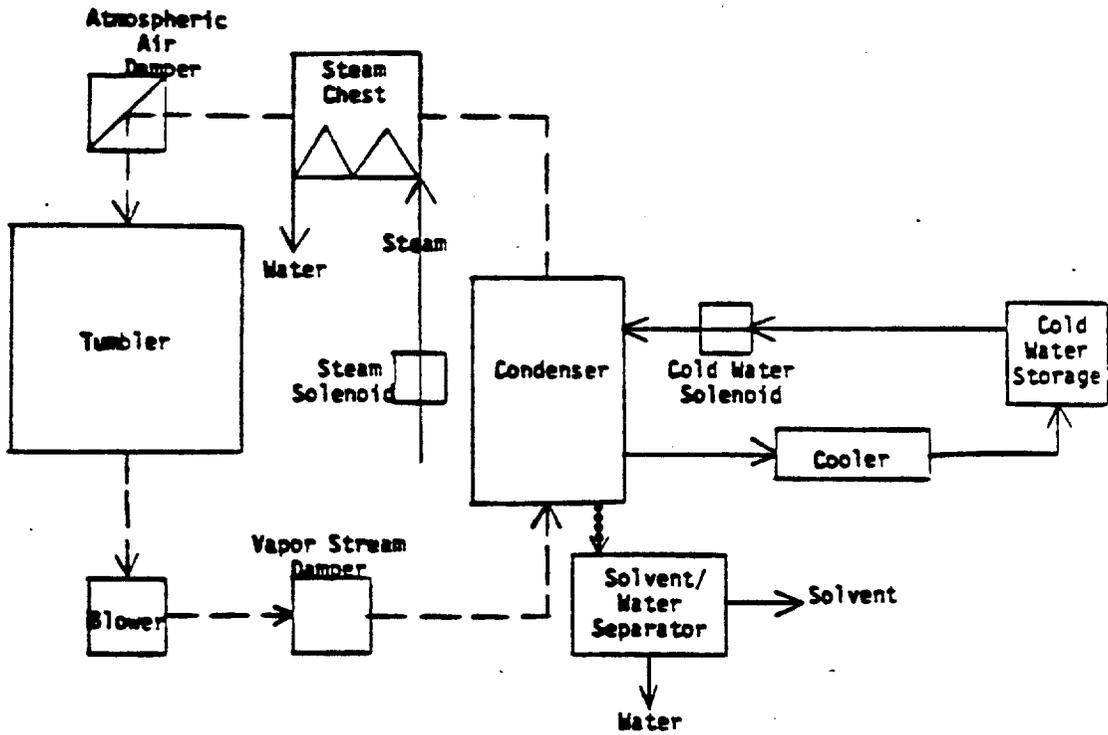
Essentially, a solvent recovery dryer is a standard dryer that has been fitted with a condenser to remove solvent vapor from the dryer exhaust by condensation (see Figure 3-1). In the current configuration of this machine, a steam-heated air stream is directed around and through a tumbling load of drying articles by a blower that forces the solvent-laden air stream through a lint filter and then to a condenser. After partial removal of both solvent and water vapors in the condenser, the air stream is ducted from the condenser to a steam chest where it is reheated and the cycle of solvent evaporation repeats.

The most important component of this system is the condenser, which gradually reduces the concentrations of both solvent and water vapors in the air stream during every evaporation-condensation cycle. The currently marketed recovery dryer employs a condenser to remove both solvent and water from the incoming vapor stream by steadily reducing the vapor temperature (under the existing conditions of vapor flow and pressure).

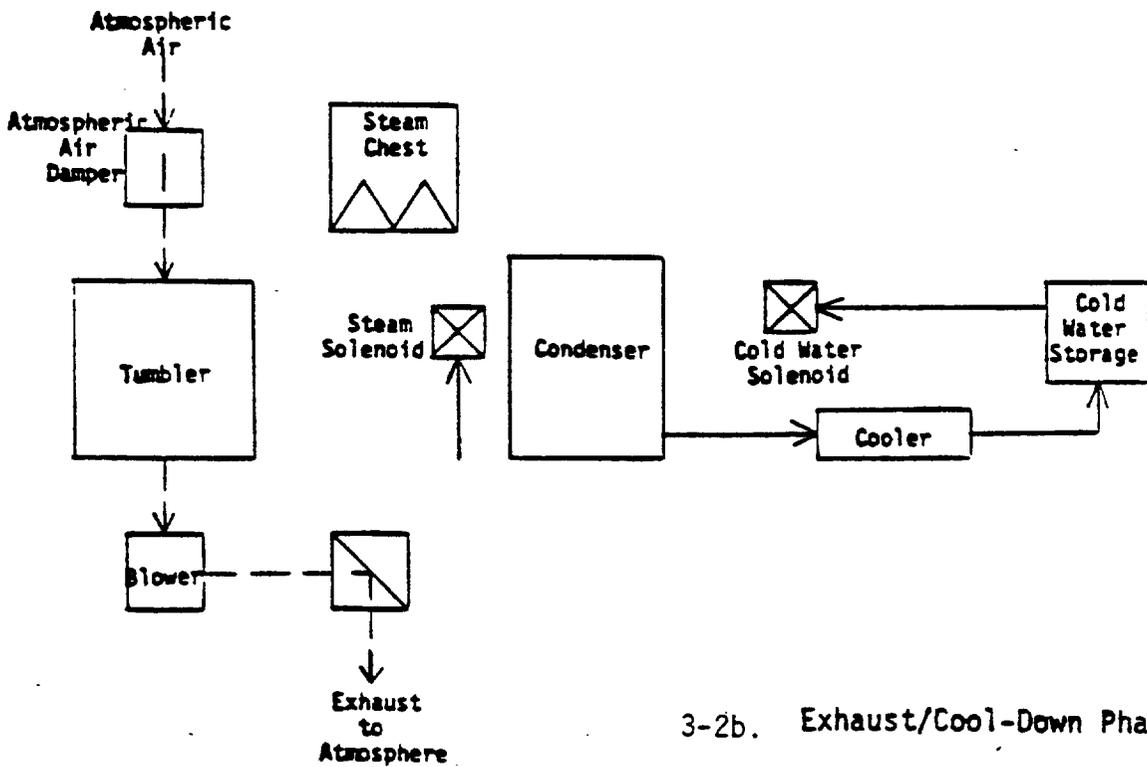
As the vapor stream is forced through a condenser, chilled water circulates downward through the tube structure and cools the vapor stream until a liquid solvent and water mixture condenses (as heat is transferred from the vapor stream to the chilled water). This mixture flows to the bottom of the condenser where it is piped to a solvent water separator. Because petroleum solvent has a specific gravity of about 0.75, the water contained in the condenser runoff forms the bottom liquid phase, and water is removed from the bottom of the unit, while solvent flows from the top.

To prevent the excessive wrinkling of clothes, the recovery dryer has a second, exhaust/cool-down phase similar to that found in some of the more sophisticated standard dryers. In the solvent recovery phase (Figure 3-2a), the air stream flows from the steam chest through the tumbler, to the condenser, and then back to the steam chest. The cooling water flow during this phase is from the cooler to a storage tank, to the condenser, and then back to the cooler. Solenoid valves, controlling both steam and cooling-water flows, are intermittently open in response to thermostats that maintain both a tumbler temperature sufficiently high enough to promote solvent evaporation from tumbling fabrics, and a condenser water inlet flow rate great enough to ensure adequate condenser heat-removal for optimum VOC emission reduction/ recovery. At the onset of the exhaust/cool-down phase (see Figure 3-2b), both the steam and cooling water solenoids close while atmospheric air and vapor stream dampers divert vapor flow from the condenser loop; thereby permitting the intake of atmospheric air which is forced over the tumbling articles and exhausted to the atmosphere.

Control of the duration of these two phases is accomplished by two timers that can be individually set for a wide range of recovery and exhaust/cool-down periods. Typically, the duration of the recovery phase ranges from 20 to 45 minutes, while that of the exhaust/cool-down phase ranges from 2 to 6 minutes (Plaisance, 1981a). Thermostatically controlled shutoff valves that govern tumbler temperatures (steam flow) and condenser water inlet temperatures (water flow) can be adjusted to protect drying articles from overheating and to maintain optimum VOC



3-2a. Recovery Phase



3-2b. Exhaust/Cool-Down Phase

Figure 3-2. Operating Cycles of the Existing Recovery Dryer.

emission reduction/recovery. A manually-adjustable valve in the condenser water inlet line permits regulation of the water flow rate. A manually-adjustable pressure control in the steam chest inlet provides a controlled rate of steam pressure for the heating of the vapor stream.

Safety from fire and explosion is a key factor in recovery dryer design based on the obvious dangers of vaporizing a combustible liquid that is heated in an enclosed space. Preventative measures focus on maintaining solvent concentrations in the circulating vapor stream at less than the recognized lower explosive limit (LEL) for petroleum solvent, which is typically 1 percent by volume of vapor (Ashland, 1980). Ignition sources, such as static electricity and internal machine wiring, are controlled by proper dryer grounding and the containment of wires and electrical components in explosion-proof enclosures; however, random ignition sources such as matches or lighters that are left in garments could, in the presence of flammable vapors, trigger both explosions and fires. This hazard can be eliminated by a thorough inspection of articles before drying.

In the recovery dryer, the concentration of solvent vapors is controlled by the temperature and flow rate (both water and vapor) of both the tumbler and the condenser, as well as by the weight of articles (solvent) placed in the tumbler. In the unlikely event of an explosion in the dryer, the pressure of the blast is released upward from the tumbler through vents specifically designed for this purpose, while steam is automatically injected into the tumbler. In addition, a fusible wire spanning the condenser vapor inlet will melt above a predetermined temperature, shutting down the electrical system and terminating dryer operations.

The level of emissions reduction attained by the recovery dryer is based on the assumption that all solvent entering the dryer in garments is either recovered or emitted to the atmosphere during the cool-down/exhaust phase (in contrast to standard dryers which emit their entire solvent content to the atmosphere). Thus, the VOC emission reduction is equal to the solvent recovery. Furthermore, it is assumed that garments leaving the dryer are "dry" (contain no solvent), and that there are no random or unspecified losses within the evaporation-condensation system.

(Results of recovery dryer field tests are inconclusive concerning the solvent content of dried items; however, there are indications that drying time, load weight, fabric type, and condenser temperature and flow (both vapor and liquid) all cause variations in the solvent content of dried articles.) Based on these assumptions, the recovery dryer performance parameters of primary importance are VOC emission reduction, recovery, and the ability of the dryer to operate with solvent vapor concentrations less than the LEL of 1 percent solvent by volume.

Two EPA test programs have been completed at facilities operating domestically-manufactured 48 kg (105 lb) capacity recovery dryers. The first test was conducted at a large industrial dry cleaning facility (see Appendix A, Test 1) in Pico Rivera, California that processes approximately 1,300 kg (2,900 lbs) of heavy work gloves each day. Analysis of the vapor concentrations at the condenser inlet and exhaust outlet, together with a determination of the mass of solvent recovered, resulted in an average VOC emission of 0.96 kg VOC per 100 kg dry weight of articles cleaned. Furthermore, the dryer appeared, at times, to operate at or above 90 percent of the 10,000 parts per million LEL concentration for petroleum solvent; although the existence and extent of the excursions above 90 percent were not verified because the solvent concentrations exceeded the capacity of the detection instrument. Possible explanations for this apparent excursion center around the fact that the dryer was typically loaded beyond manufacturer's specifications (by as much as 20 percent), with articles (gloves) having the unusually high solvent retention of as much as 40 percent by weight (Jernigan and Lutz, 1979).

A second EPA recovery dryer test was undertaken at a large commercial plant in Lakeland, Florida (see Appendix A, Test 2) that processes approximately 180 kg (400 pounds) of general apparel each day. Again, solvent vapor concentrations in the condenser vapor inlet and atmospheric exhaust were monitored, as were the flow rate and mass of recovered solvent. The average VOC emission was found to be 3.85 kg VOC per 100 kg dry weight of articles cleaned. Solvent vapor concentrations in the condenser inlet stream never exceeded 95 percent of the solvent LEL. The reduced VOC emission reduction, value was possibly due to the

processing of small loads (typically 50-60 percent of dryer capacity) of garments (principally synthetics) having a low solvent retention. Also, recovery phase durations were relatively brief (usually lasting no more than 30 minutes), resulting in the premature termination of the recovery phase and a corresponding increase in the solvent content of dried articles (Jernigan and May, 1980). Thus, the average VOC emissions per 100 kg dry weight of articles cleaned for the recovery dryer is 2.4 kg VOC per 100 kg articles cleaned, this value is the average of the results from the previously discussed tests of 1.0 kg and 3.85 kg VOC per 100 kg dry weight of articles dry cleaned.

The installation of currently-manufactured recovery dryers in existing petroleum dry cleaning plants would involve the replacement of standard dryers with recovery units. Although steam and electrical demands and connections would be similar for both units, the recovery dryer would require additional connections of pressurized air and cooling water. The demand for cooling water in the 48 kg (105 lb) recovery dryer is typically satisfied by municipal water, a cooling tower, or a chiller with a minimum output capacity of 0.8 liters per minute (3 gal/min), and a temperature of 13°C (55°F) (Hoyt, 1979). Meeting these cooling water specifications in cool, dry climates may involve only a connection to municipal water or the installation of a relatively inexpensive cooling tower; but hotter, humid climates may require the lower temperatures associated with a chiller, which is inherently more expensive to buy and operate (costing up to 250 percent more than a cooling tower).

Floor and overhead space requirements are similar for standard and recovery dryers and present little difficulty for smaller, single-dryer facilities; however, the replacement of a single 180 kg (400 lb) capacity standard dryer with four 48 kg (105 lb) capacity recovery dryers (currently, recovery dryers are made in only 23 and 48 kg capacities) would necessitate increasing the floor area required for dryers by approximately 30 percent from approximately 28 to 37 square meters (300 to 400 square feet). The need for additional floor space could force some large industrial plant operators to restructure the layout of their dry cleaning equipment, and may require an addition to an existing

building or the acquisition of additional space by lease, purchase, or construction. Most of these facilities, however, should have sufficient space in their existing plants to accommodate the recovery dryers.

Proper operation of a currently-manufactured recovery dryer would be based primarily on maintaining high VOC emission reduction/recovery, while preventing the buildup of unsafe solvent vapor concentrations. Adherence to dryer manufacturer's specifications in the areas of steam pressure, condenser water inlet flow rate and temperature, tumbler drying temperature, and tumbler load weight should ensure adequate performance and safety. Operating within the range of manufacturer's specifications, tests have shown that VOC emission reduction/ recovery can be maximized by optimizing heat transfer within the condenser while extending the duration of the recovery phase to allow time for a more complete removal of solvent from drying articles (Jernigan and May, 1981).

Heat transfer in the recovery dryer condenser was found to be at its maximum (defined as the highest average VOC emission reduction/ recovery per dry weight of articles cleaned) when the condenser gas outlet temperature was at its maximum of 94°F to 97°F (34°C to 36°C). Under these conditions, however, the concentration of solvent vapor at the condenser inlet was in excess of 90 percent of the solvent LEL during 4 of the 10 loads monitored at this temperature range, but this concentration never exceeded 95 percent of the LEL. Thus, maintaining a condenser gas outlet temperature no greater than 94°F (34°C) can ensure that solvent concentrations in the dryer do not exceed 95 percent of the solvent LEL, thereby promoting safe operations.

Figure 3-3 illustrates a typical recovery phase that meets the conditions stated previously. The initial rapid solvent recovery gradually decreases to a near constant value (little or no additional recovery with time). Concurrently, the average condenser gas outlet temperature remains at or below 94°F (34°C). The concentration of solvent vapor in the condenser gas inlet also is shown for the same recovery phase. Initial high concentrations correspond to rapid increases in the volume of recovered solvent; however, as the duration of the recovery phase increases, the concentration of solvent vapor tends to level off, thus

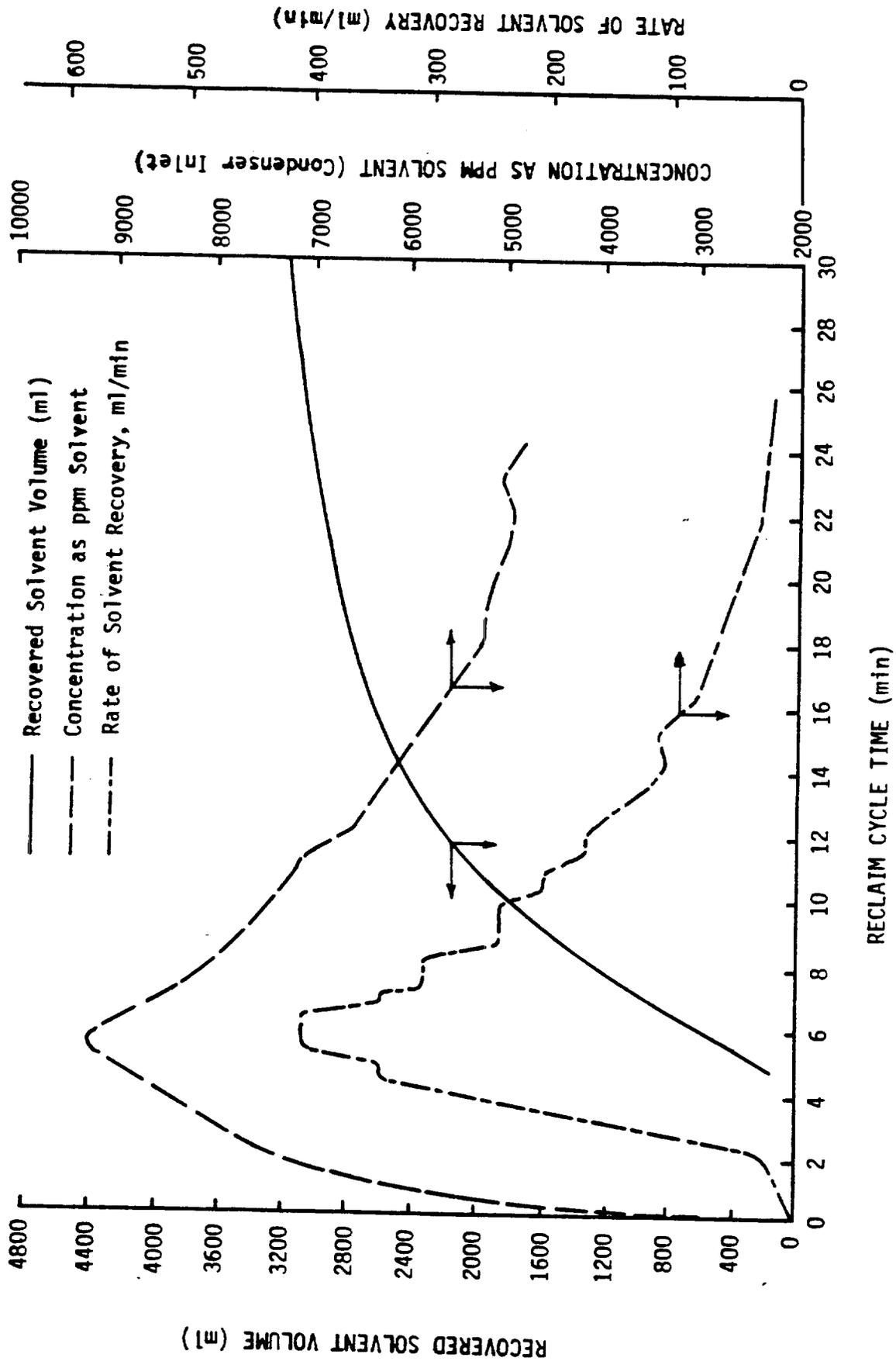


Figure 3-3. Solvent recovery and concentration curve for the recovery dryer.

indicating a minimum recovery phase duration necessary for optimization of VOC emission reduction/recovery. The rate of solvent recovery at the termination of the recovery phase was approximately 0.02 liters per minute. This corresponds to a reclaim cycle duration that is sufficient to yield a total VOC emission rate of approximately 2.4 kg VOC per 100 kg dry weight of articles cleaned. This criterion could be applied to differing load weights and fabrics, and would result in varying recovery phase durations of approximately the same optimized VOC emission reduction (Jernigan and May, 1981). In addition, solvent vapor concentrations could be limited to less than 95 percent of the solvent LEL of 10,000 ppm by volume. Thus, both safety and efficient operation might be maintained.

The change in the solvent recovery rate is illustrated in Figure 3-3. The initially high rate of recovery during the first 10 minutes gradually falls to the final value of approximately 0.02 liters per minute at the termination of the recovery phase.

### 3.2 CARTRIDGE FILTRATION

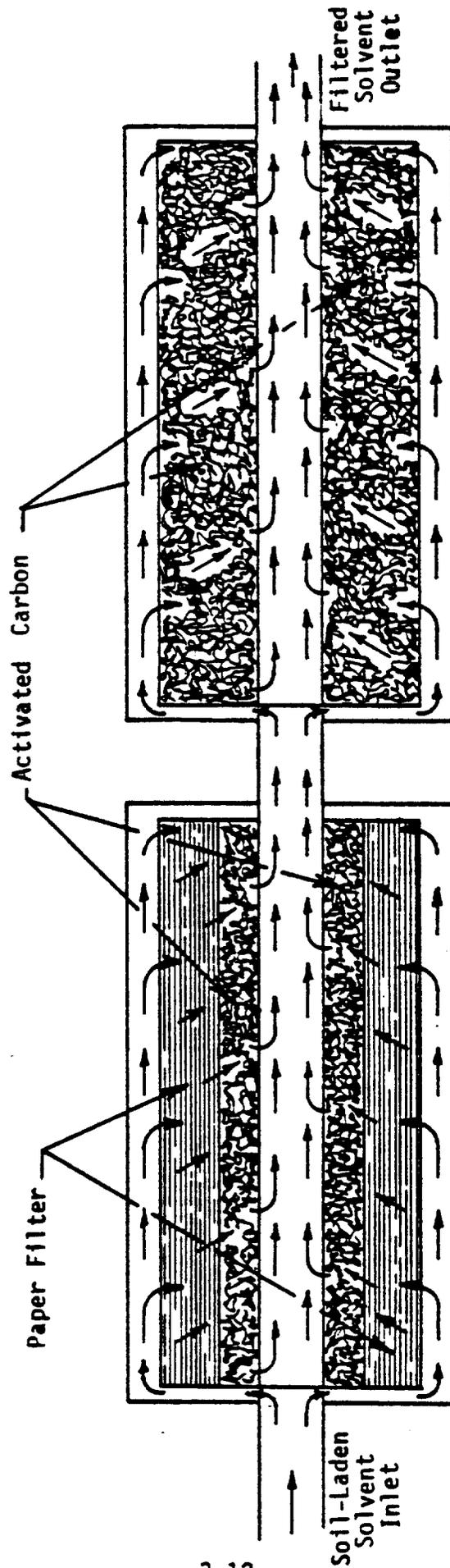
Cartridge filtration is a continuous, two-stage process of filtration in which soil-laden liquid is forced under pressure first through a paper filter to remove entrained solids and then through a layer or layers of activated carbon which selectively entrap molecules of impurities in their porous surface. The term "cartridge" is used to denote replaceable units or cartridges containing filtration paper and carbon or only carbon. Currently, it is estimated that 50 percent of the approximately 6,000 commercial petroleum dry cleaning plants use cartridge filtration (Fisher, 1980).

Cartridge filtration, as applied to the petroleum solvent dry cleaning industry, is a process in which soil-laden solvent is pumped from a washer to a vessel housing filter cartridges (see Figure 3-4). This vessel normally has a removable, pressure-sealed lid or top and can contain from 2 to 36 cartridges. Soil-laden solvent is initially forced under pressure through dual-component cartridges that contain both filter paper and carbon. In this process, solid particles of lint and dirt are trapped in the paper, and the included activated carbon serves

to remove impurities such as fabric dyes. Next, the solvent is diverted to one or more filter cartridges containing only activated carbon which continue the initial removal of insoluble impurities. After passing through this final stage, the solvent is transferred to storage to await distillation and reuse (Puritan, 1980).

Currently-manufactured filter cartridges fall into two distinct categories: carbon-core cartridges and all-carbon cartridges. Carbon-core cartridges (see Figure 3-4) are encased in an outer metallic housing that is perforated around its circumference to permit solvent in-flow. Beneath this outer rigid structure lies a circumferential layer of filtration paper that is folded accordian-style into a deeply-corrugated cylinder surrounding the inner core. This fibrous paper, similar to that found in an automotive oil filter, permits the pressurized solvent to flow inward to the core while trapping particles of dirt and lint along its extensive surface. Beneath this layer of filter paper lies the slotted metal surface of the core tube which contains granular activated carbon (Puritan, 1980). In passing through this material, the larger molecules of impurities such as fabric dyes become lodged in the porous, chemically-active surface of the carbon granules. The all-carbon cartridge (see Figure 3-4) continues the purification of the solvent which began at the carbon-core cartridge. Solvent flowing through the slots of the metal cannister is forced through the enclosed activated carbon, resulting in additional removal of impurities and the outflow of a solid-free, purified solvent.

Although the process flow of carbon-core to all-carbon is typical of most cartridge filter installations, the containment, number, and physical arrangement of the cartridges varies widely as a function of the system's capacity. Cartridge filtration systems are "sized" by their manufacturer, based on the dry-weight load capacity of the existing washer (Puritan, 1980). The size of the system usually refers to the total number of filter cartridges it contains. The actual distribution of these cartridges ranges from a group of small, interconnected vessels containing one or two cartridges to one or more cylindrical tanks containing as many as 36 carbon-core cartridges that are connected to an additional vessel or vessels containing multiple all-carbon cartridges (Puritan, 1980).



All-Carbon Cartridge

Carbon-Core Cartridge

Figure 3-4. Cartridge Filtration System Schematic.

The operation of a cartridge filtration system can be based on either the continuous (during washer operation) or batch (at predetermined intervals) processing of spent solvent. In continuous operations, the spent solvent in the washer is pumped through the filter and back to a filtered solvent tank. As this process continues on a day-to-day basis, the outer surfaces of the filter paper in each carbon-core cartridge become clogged with dirt and lint, while the carbon granules contained in both types of cartridges become coated with dyes and particulates until they no longer purify the solvent stream. Dry cleaning trade association tests have shown that, under typical commercial conditions of soil-loading and throughput, the "life" of a filter cartridge is somewhere between 450 kg (1,000 lbs) and 500 kg (1,100 lbs) of articles washed (Bee and Fisher, 1976). Under conditions of heavy soil loading, however, the need for cartridge replacement is best indicated by the buildup of solvent pressure in the vessel due to the flow restriction posed by the clogged cartridges.

Atmospheric emissions from cartridge filters are limited to fugitive emissions that evolve from leaks and filter cartridge replacement, as well as from the evaporation of solvent contained in disposed cartridges. An EPA test of the amount of solvent contained in discarded filter cartridges was conducted at a Wilmington, North Carolina petroleum solvent dry cleaning plant that processes approximately 180 kg (400 lbs) of general apparel per day in a single 27 kg (60 lb) capacity washer (Plaisance, 1981b). A 14-element cartridge filtration system was operated without cartridge replacement over a period of time when the plant had a throughput of approximately 8,600 kg (19,000 lbs.) of clothes washed. Results of this test indicated that draining the filter cartridges in their closed housing for at least 8 hours would result in an average solvent emission per cartridge of 1.6 kg (3.4 lbs). Based on an assumed cartridge life of 450 kg (1,000 lbs) of throughput, this would result in 0.35 kg of solvent being emitted per 100 kg of clothing throughput (Plaisance, 1981b). Figure 3-5 illustrates the effect of drainage time on VOC emissions from discarded filter cartridges. The majority of the drainage takes place during the initial few minutes when liquid solvent is running freely from the cannisters. After 8 hours of

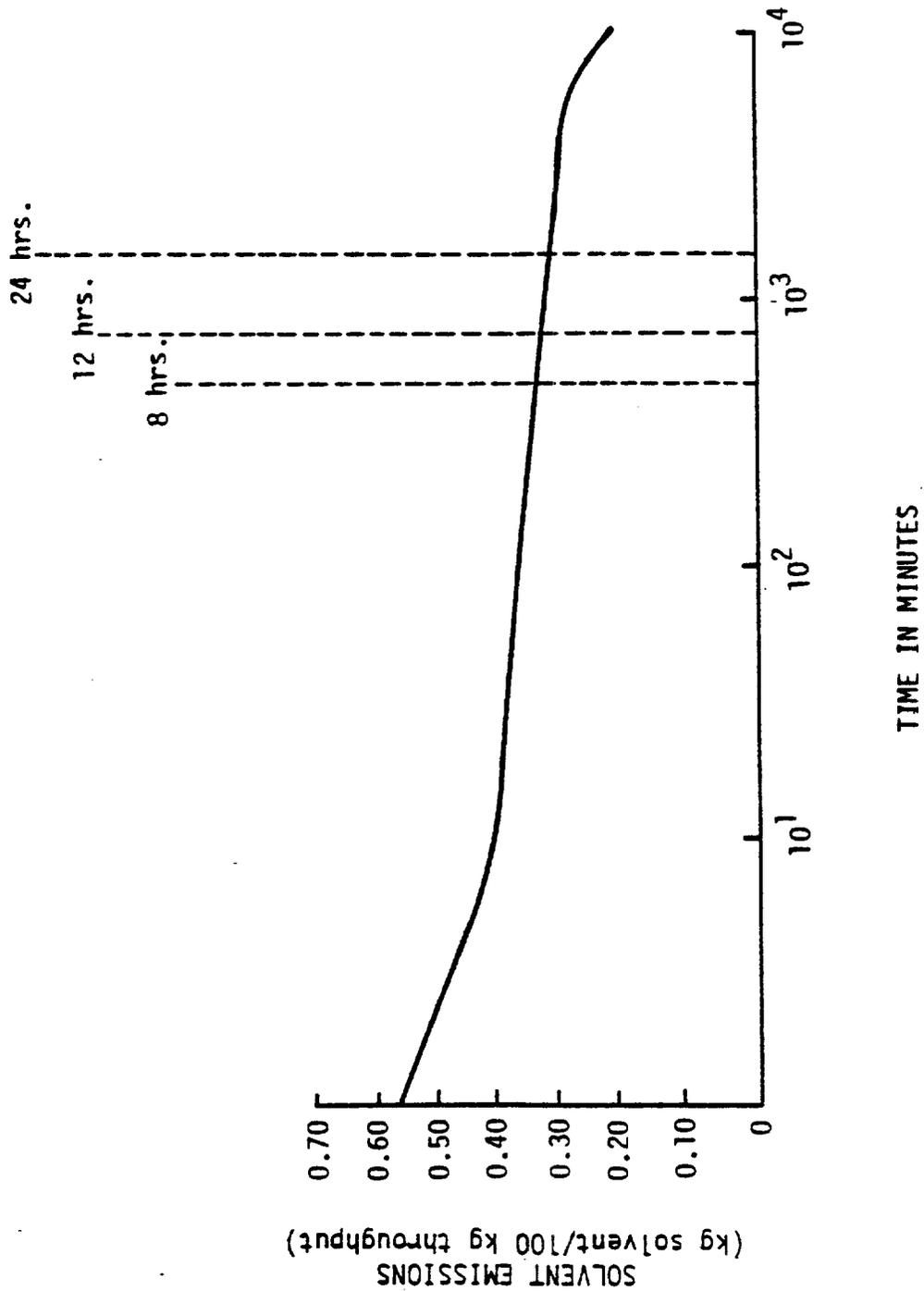


Figure 3-5. Solvent Emissions for Filter Cartridges as a Function of Drainage Time.

drainage, the cartridges have lost 37 percent of their undrained solvent content. After an additional 4 hours, they have lost only 3 percent more, thus, illustrating that extended drainage periods are unnecessary.

The value of cartridge VOC emissions per 100 kg dry weight of articles cleaned, obtained above, is in general agreement with a dry cleaning trade association estimate of 0.4 kg per 100 kg of articles cleaned (NID, 1971). However, the previously described EPA-sponsored test could have been more in agreement with the industry estimate if the emissions from carbon-core cartridges alone had been considered. Also, in the determination of cartridge weight losses, it was assumed that all weight losses were due to solvent evaporation, thus ignoring the presence of water and its evaporation. However, this is considered insignificant.

The emission reduction/recovery efficiency of the cartridge filter compared with the diatomite filter is 88 percent, based on average VOC emissions for cartridge and diatomite filters of less than 1 kg and 8 kg, respectively, per 100 kg dry weight of articles cleaned. This major emission reduction primarily results from diatomite filter emissions that typically occur daily, while cartridge filter emissions result from infrequent cartridge element replacement.

Installation of a cartridge filtration system would require the removal of the existing filtration system (usually a diatomite filter) and the connection of the cartridge vessel to existing lines. No utility connections (steam or electricity) are normally required, and the only retrofit problems that might be encountered concern the allocation of space (larger cartridge systems can occupy a substantial area) and the possibility of replacing the filter feed pump (maintains solvent pressure to the filter).

There is a current controversy in the dry cleaning industry concerning the cartridge filter's ability to provide filtration and eliminate the need for distillation. Although some plants have ceased their vacuum still operations after the installation of cartridge systems (Plaisance, 1981b), both cartridge filter manufacturers (Puritan, 1980) and dry cleaning trade associations (Bee and Fisher, 1976) maintain that distillation is a necessary part of the process of solvent rejuvenation and that it is the only method for removing solvent-soluble impurities such

as grease and oil. The installation of cartridge filtration equipment could, however, decrease the frequency of solvent distillation, and thus reduce not only filtration emissions, but also emissions associated with still wastes. Small plants with light soil loadings, in particular, could reduce their frequency of distillation by using cartridge filters to maintain the clarity of their solvent.

### 3.3 VACUUM DISTILLATION

Atmospheric emissions resulting from the operation of vacuum stills (see Section 2.3.3 for a distillation process description) are a function of the still design, operation, and the frequency of still utilization. To maintain the color (purity) of the solvent used in washing, a dry cleaning plant operator often will adhere to a still boildown schedule that requires solvent distillation at intervals ranging from daily to weekly. Also, the design of some stills is such that, regardless of the boildown period, there will be a fixed volume of solvent-laden residue at the end of the operation. Under these conditions of daily boildown in a still with a fixed minimum volume of undistilled waste, the atmospheric VOC emissions from these wastes (assuming they were dumped and allowed to evaporate) could range from 1 kg VOC per 100 kg dry weight of articles cleaned for a well designed and maintained still (Fisher, 1975), to 6 kg VOC per 100 kg dry weight of articles cleaned (Jernigan and Kezerle, 1980).

An EPA-sponsored test that examined the potential for reducing solvent emissions from vacuum stills in an Anaheim, California industrial dry cleaning plant, first identified the previously-mentioned design problem (Jernigan and Kezerle, 1980). The still used in this facility was constructed so that there was a large volume of space beneath the boildown steam coils. No matter how long the still was in operation, the solvent-laden residues in this region remained unaffected. Thus, every time the still was boiled down, the volume of waste expelled, together with its associated solvent content, remained constant. Based on this finding, the frequency of still boildowns was decreased until a 25 percent reduction in the solvent content of still wastes was achieved using an interval between boildowns of 10 working days (Jernigan and Kezerle, 1980).

Little can be done about the design of existing stills, except for replacement. Furthermore, VOC emissions resulting from vacuum stills are limited to the storage and disposal of still wastes. Within the confines of the dry cleaning plant, still waste VOC emissions are a direct result of their improper storage, which allows the evaporation of solvent to the atmosphere. Accordingly, reductions in still waste VOC emissions can be attained by both decreasing the frequency of still boildowns and by storing still wastes in a manner that prevents VOC emissions to the atmosphere. By decreasing the frequency of still boildowns, the dry cleaning plant operator would reduce the overall quantity of solvent in still waste and reduce the volume necessary for still waste storage.

### 3.4 FUGITIVE EMISSION SOURCES

Fugitive emissions essentially encompass all remaining emission sources not included as dryers, filters, or stills. The EPA-sponsored test program conducted at the Anaheim, California dry cleaning facility included a sampling and evaluation of VOC concentrations in the general dry cleaning environment. Significant concentrations of solvent vapor, at times approaching 70 percent of the solvent LEL, were found around both the settling tank and the new solvent tank vents. Another significant source of VOC emissions was the washer which produced concentrations nearing 10 percent of the solvent LEL in its immediate vicinity. Additional measurements of VOC concentrations in dry cleaning room roof exhaust vents yielded a VOC emission rate of 0.7 kg solvent per 100 kg of articles cleaned (Jernigan and Kezerle, 1980).

Solvent vapor losses from settling and storage tanks occur as a result of "breathing" and "working" losses. Breathing losses occur when storage tanks expand or contract during changes in temperature, resulting either in air being drawn into the tank (vapor contraction) or solvent vapor being expelled to the atmosphere (vapor expansion). In contrast, working losses result from changes in the vented free volume above the stored liquid solvent, which expels solvent vapor when the tank is filled and draws in atmospheric air when the tank is drained, thereby producing additional breathing losses as the air becomes

saturated with solvent vapor. In either case, steps should be taken to either remove the solvent vapor from the expelled air or prevent the tank contents from being exposed to the atmosphere.

The broad category of "leaks" can contribute significantly to overall plant fugitive VOC emissions. Liquid solvent drips from pipes, fittings, valves, hoses, couplings, and pumps add to the constant background of solvent vapor inherent to many dry cleaning plants. Vapor leaks from dryers, exhaust ducts, filter housings, stills, and open or improperly sealed containers of solvent all contribute to the quantity of solvent impacting the environment.

The only way to eliminate the general class of fugitive emissions is with an effective program of maintenance and training. A dry cleaning trade association has estimated that approximately 0.6 kg of VOC are emitted by fugitive sources for every 100 kg of articles cleaned in a typical dry cleaning facility (Fisher, 1975). This level of VOC emissions could be reduced by effecting a maintenance program that would completely eliminate liquid leaks and solvent standing open to the atmosphere, while also striving to eradicate vapor leaks by repairing gaskets and seals that obviously expose solvent-rich environments to the atmosphere. Training of dry cleaning personnel also could help in attaining this reduction, particularly by eliminating the practice of allowing solvent-laden loads of articles to be exposed to the atmosphere while awaiting drying.

### 3.5 COMBINED CONTROL TECHNIQUES: RACT

A combination of the previously discussed control techniques would result in an optimum emission reduction that could be achieved by employing currently available equipment and methods. RACT for the petroleum dry cleaning industry is based on a combination of equipment and operating procedures that result in reasonable costs to the industry for a major overall reduction in emissions. The following list tabulates the control techniques and the anticipated level of post-RACT emissions.

<u>Control techniques</u>	<u>Emissions, kg solvent/100 kg articles cleaned</u>
Recovery dryer	2.4
Cartridge filter	<1.0
Vacuum still	0
Fugitive emissions	<u>&lt;1.0</u>
Total	<4.4

Implementation of the above RACT processes and methods in the four model plants, as illustrated in Table 3-1, would result in an overall dry cleaning plant emission reduction of 84 percent over the existing levels discussed in Chapter 2. The large industrial plant does not benefit from the 88 percent VOC emission reduction resulting from the replacement of diatomite with cartridge filters. However, the overall RACT VOC emissions reductions for this size plant are equal to that of smaller plants because very high VOC emissions from vacuum still wastes and fugitive sources (approximately 7 kg VOC and 3 kg VOC, respectively, per 100 kg dry weight of articles cleaned) are virtually eliminated by requiring that still wastes be stored in a manner that will eliminate atmospheric VOC emissions and by requiring that fugitive emissions be minimized.

### 3.6 EVALUATION OF CONTROL TECHNOLOGY TRANSFER

Control of dryer emissions in the perchloroethylene (perc) dry cleaning industry has been accomplished for many years by application of existing carbon adsorption technology. Currently, 35 percent of perc dry cleaning plants (5,400) use carbon adsorption (EPA, 1980). The application of this technology to petroleum dry cleaning dryer VOC emissions reduction could result in savings due to reductions in development and testing time and costs.

An EPA demonstration program was undertaken at an Anaheim, California industrial petroleum dry cleaning facility (Lutz et al., 1980) to evaluate the performance of carbon adsorption as a means of reducing VOC emissions from a standard petroleum solvent dryer (see Appendix A, Test 5). An adsorption system with two carbon vessels was connected to the exhaust of a 180 kg (400 lb) capacity standard dryer, and the VOC concentrations at the adsorber inlet and exhaust were monitored throughout the course

Table 3-1. MODEL PLANT PARAMETERS  
(RACT EQUIPMENT)

Model plant	Small commercial	Large commercial	Small industrial	Large industrial
Number of existing plants nationwide in 1979	4,650	1,500	60	170
Annual plant throughput	18,000	51,000	272,000	435,300
Throughput description	General apparel	General apparel and institutional	Institutional articles	Industrial articles
Number of washers	1	1	2	1
Washer capacity (each), kg (lbs)	18 (40)	45 (100)	115 (250)	225 (500)
Number of recovery dryers	1	1	4	4
Dryers capacity (each), kg (lbs)	23 (50)	48 (105)	48 (105)	48 (105)
Total number of filter cartridges	10	21	84	0
Cartridge changes per year	4	5	7	-
Vacuum still capacity (each) in L/hr (gal/hr)	190-375 (50-100)	750-1,150 (200-300)	5,700 (1,500)	19,000 (50,000)
Number of loads per day	8	9	8	8
Average load weight in kg (lbs)	9 (20)	23 (50)	135 (300)	180 (400)
Days of operation per year	250	250	250	300
Wash cycle time (minutes)	10	15	25	25
Dry cycle time (minutes)	20	30	40	40
Average baseline emissions per plant, megagrams VOC/year (tons VOC/year)	0.8 (0.9)	2.3 (2.5)	12.2 (13.5)	19.6 (21.6)
Average baseline emissions nationwide, megagrams VOC/year (tons VOC/year)	3,700 (4,200)	3,500 (3,800)	700 (800)	3,300 (3,700)

of normal daily operations in which approximately 1,600 kg (3,500 lbs) of general apparel were cleaned. Results of the test program indicated that the average difference in VOC concentrations between the adsorber inlet/dryer exhaust (2,100 ppm as solvent) and outlet (100 ppm as solvent) over the duration of typical drying cycles represented an overall reduction in VOC concentration of 95 percent.

A comparative analysis of the overall potential for reducing dryer VOC emissions from the carbon adsorber and the recovery dryer indicates that the carbon adsorber produces nearly twice the total amount of VOC emissions compared to the recovery dryer. This drastic difference is due to the continuous, high-volume exhaust flow from the adsorber. Although the adsorber unit produces a 95 percent reduction in the VOC concentration emitted to the atmosphere, this concentration is maintained for the duration of the dry cycle and results in total VOC mass emissions nearly twice as high as those of the recovery dryer, which expels its VOC contents to the atmosphere only during the relatively brief exhaust/cool-down phase. This analysis is based on the assumption that, in both cases, articles removed after drying have the same solvent content.

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## 4. ENVIRONMENTAL ANALYSIS OF RACT

The environmental impacts of RACT implementation on air, water, and solid-waste disposal are discussed in this section. In addition, the effects of RACT equipment operation on overall energy consumption are detailed based on the four model plants that were discussed in Chapter 2, and these values are compared with those of uncontrolled model plants. Finally, beneficial and adverse effects from the installation of RACT equipment are assessed in relation to emissions and energy consumption in these model plants.

### 4.1 AIR POLLUTION

As previously discussed, the installation of RACT equipment and the implementation of RACT procedures in a typical dry cleaning plant involve the replacement of existing dryers, the replacement of existing filtration systems, the storage of vacuum still wastes in a manner that eliminates VOC emissions, and the modification of operating and maintenance procedures governing fugitive sources. Table 4-1 lists the estimated uncontrolled VOC emissions for each of these primary areas and indicates the range (or average value) of post-RACT emissions per 100 kg of articles cleaned. Because the uncontrolled dryer provides approximately 65 percent of the total emissions, effective control and reduction (86 percent) of VOC emissions from this source provides the greatest direct impact on overall plant emissions.

Filtration system VOC emissions in dry cleaning facilities with existing non-RACT diatomite filters account for nearly 30 percent of the total uncontrolled emissions. Filtration emissions in these facilities will be reduced by as much as 88 percent as a direct result of cartridge filter installation. The RACT-recommended procedure of storing vacuum still wastes in containers that will eliminate VOC emissions from this

Table 4-1. EMISSIONS FACTORS FOR EXISTING AND RACT EQUIPMENT  
 (in kg VOC emitted per 100 kg dry weight of articles cleaned)

Source	Existing equipment emissions	RACT equipment emissions	VOC emission reduction	Percent reduction
Dryer	18	2.4	15.6	86
Filter	8	<1	>7	88
Still	1	0	1	100
Fugitive sources	1	<1	b	b
Total	28	<4.4	>23.6	

<sup>a</sup>Existing equipment emission estimates are based on industry association data and EPA plant tests, and represent approximate midrange for most sources. See Section 2.0 for complete explanations of controlled emissions sources and levels.

<sup>b</sup>Indeterminate quantity.

source will reduce overall plant VOC emissions by approximately 4 percent. In addition, the VOC emissions resulting from fugitive sources could be directly reduced by improvements in maintenance and operating procedures. Thus, RACT equipment and procedures would produce an average direct VOC emissions reduction of approximately 84 percent.

Table 4-2 illustrates the VOC emissions reductions that result from the installation of RACT equipment and the adoption of RACT operating and maintenance procedures in four model plants. Based on uncontrolled emissions of 28 kg VOC per 100 kg dry weight of articles cleaned and RACT emissions of 4.4 kg VOC per 100 kg dry weight of articles cleaned, each model plant shows an 84 percent reduction in VOC emissions with RACT equipment and procedures. The specific reductions in VOC emissions range from 4,300 kg per year in a small commercial plant to 102,700 kg per year in a large industrial plant. Because emission rates are based on plant throughputs, the larger plant sizes (in mass of articles cleaned) show the greatest VOC emission reductions.

#### 4.2 WATER POLLUTION

Increases in water pollution, due to RACT implementation in petroleum dry cleaning plants, would result primarily from inefficient separation of condensed solvent and water. Recovery dryers employ gravimetric separators to remove water from the reclaimed solvent. This unit uses the difference in density between petroleum solvent and water to separate and divert them. Typically, water collected in this manner is dumped into a sewer. The leveling of the separator is critical to the optimization of its performance. If it is not level at installation or is bumped during maintenance, the quantity of solvent in the sewer water could increase to the point of becoming a significant source of water pollution.

Insufficient drainage of RACT filter cartridges could prove to be a minor source of groundwater pollution, especially if the cartridges were buried in an improperly located or maintained landfill or dump. RACT procedures for cartridge drainage would decrease the overall volume of solvent exposed to groundwater and would, therefore, reduce water pollution by petroleum solvent.

Table 4-2. TYPICAL ANNUAL VOC EMISSIONS FOR FOUR MODEL PLANTS EMPLOYING EXISTING AND RACT EQUIPMENT AND PROCEDURES

Type of plant nationwide	Estimated number of plants	Plant throughput, kg/yr (lb/yr)	Emissions factors in kg VOC emitted per 100 kg dry weight of articles cleaned		Average VOC emissions, kg/yr (lb/yr)		Annual VOC emission reductions resulting from RACT implementation, kg/yr (lb/yr)
			Existing equipment	RACT equipment	Existing equipment	RACT equipment	
Small commercial	4,650	18,000 (40,000)	28	4.4	5,100 (11,200)	800 (1,800)	4,300 (9,400)
Large commercial	1,500	51,000 (112,500)	28	4.4	14,300 (31,500)	2,200 (5,000)	12,100 (26,050)
Small industrial	60	272,000 (600,000)	28	4.4	76,200 (168,000)	12,000 (26,040)	64,250 (141,600)
Large industrial	170	435,400 (960,000)	28	4.4	121,900 (268,800)	19,200 (42,200)	102,700 (226,600)

#### 4.3 SOLID WASTE DISPOSAL

Implementation of RACT in existing petroleum dry cleaning facilities would result in a net reduction in both the mass and solvent content of solid wastes. Installation of RACT cartridge filters would produce a dramatic decrease in emissions from solid wastes in petroleum dry cleaning plants. Cartridge filters, when compared with diatomite filters, have been shown to reduce solvent content of disposed filter wastes by 80 to 90 percent (Plaisance, 1981), thereby decreasing the overall quantity of solvent-laden solids introduced to the environment. In addition, the replacement of diatomite with cartridge filters will produce a 60 percent reduction in the mass of solid waste generated, based on an average industry estimate of 3.57 kg of waste generated per 100 kg of throughput with a diatomite filter (Fisher, 1975) and a similar value of 1.47 kg solid waste per 100 kg of throughput for a cartridge filter (Plaisance, 1981).

Storage of vacuum still wastes in a manner that eliminates VOC emissions would have no direct effect on the quantity or disposal of still wastes; however, the additional cost and time required for this procedure could induce plant owners to operate their stills in a manner that would reduce the overall mass of waste generated. A primary means of accomplishing this reduction would be to decrease the frequency of still boildowns which also would decrease the quantity of solvent contained in the waste.

#### 4.4 ENERGY

Energy savings result from the implementation of RACT guidelines in all four model plant sizes. With the installation of RACT recovery dryers and cartridge filters in four model plants, annual expenditures for both steam and electricity are reduced by a combined average of 70 percent over utility costs for existing standard dryers and diatomite filters.

The energy value of recovered solvent is included in the overall analysis of petroleum dry cleaning plant energy consumption. One approach to this analysis that would be meaningful to the dry cleaning industry is to assume that all recovered solvent is resold at its current market value (\$0.53 per kg) and that the proceeds are used to purchase electricity

Table 4-3. ENERGY IMPACT OF EXISTING AND RACT EQUIPMENT<sup>a</sup>  
(in Gigajoules per year)

Model plant	Existing equipment	RACT equipment <sup>c</sup>	Percent reduction
Small commercial	240	(18) <sup>b</sup>	110
Large commercial	620	(190)	130
Small industrial	2,500	(1,200)	150
Large industrial	3,000	(1,400)	150

<sup>a</sup>Based on 0.00314 GJ/kg steam and 0.0036 GJ/kWh electricity (Baumeister et al., 1978), and utility consumption and solvent recovery values calculated in Chapter 5.

<sup>b</sup>Numbers in parentheses represent overall energy savings, based on savings from solvent recovery (at \$0.53 per kg) to purchase electricity at a cost of \$0.0603 per kWh.

<sup>c</sup>For small and large commercial facilities with existing cartridge filters, the annual energy impact of RACT equipment installation (recovery dryers) is 26 and 75 Gigajoules, respectively.

at its current market value of \$0.0603 per kilowatt-hour (Vatavuk, 1980). This approach to energy conservation by solvent recovery illustrates a savings of energy accrued directly to the individual petroleum dry cleaning plant.

Table 4-3 delineates the impact of RACT implementation on model plant energy consumption per year based on the previously discussed approach. Considerable energy savings (an average of 135 percent for all four model plants) arise from the installation of RACT equipment. A maximum annual energy savings of 4,400 GJ takes place in the large industrial facility, where solvent recovery in the dryers is optimized by the plant's high throughput without the additional solvent recovery due to the installation of cartridge filters. The small industrial plant shows an annual energy savings of 3,700 GJ, resulting in a 150 percent reduction in energy consumption. Finally, the small and large commercial plants have overall energy savings of 258 GJ and 810 GJ, respectively, due to solvent recovery in both recovery dryers and cartridge filters. The lower throughputs characteristic of these plants result in correspondingly lower reductions in energy consumption, with the above savings representing reductions of 110 percent and 130 percent, respectively, over the energy demands of existing equipment.

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## 5. CONTROL COST ANALYSIS OF RACT

### 5.1 BASIS FOR CAPITAL COSTS

Estimated capital costs of RACT implementation are based on equipment suppliers' prices, as well as on EPA cost factors for taxes, freight, instrumentation, and installation (Vatavuk, 1980). All cost estimates are based on June 1980 prices and values.

Equipment costs are taken from manufacturers or suppliers and include all major equipment necessary for compliance under the RACT standards (see Table 5-1 for a summary of existing and RACT equipment costs). It is assumed that condenser water cooling towers will be required for the operation of recovery dryers and the costs of these units are included in the capital costs of RACT equipment. This represents a compromise between no additional water cooling equipment and the installation of a refrigerated chiller, with the chiller unit costing an average of 250 percent more than the cooling tower.

Taxes, freight, and instrumentation are lumped together as 18 percent of the equipment costs (Vatavuk, 1980). While this factor may be excessive for a simple, unitized device such as a recovery dryer or cartridge filter, variations in shipping distance, method of transportation, and local taxes could increase this portion of the capital costs beyond this percentage.

Installation (retrofit) costs are estimated on the basis that all RACT-associated equipment will be installed by maintenance personnel at a cost of 5 percent of the equipment cost, or by an outside contractor at 10 percent of the equipment cost. The difference between these cost factors is related to the availability of qualified maintenance personnel. For the purpose of cost estimation, a factor of 7.5 percent of the equipment cost has been used (Bunyard, 1980) to approximate the costs of removing existing equipment and replacing it with RACT equipment.

Table 5-1. EQUIPMENT COSTS IN FOUR MODEL PLANTS  
 (Costs in thousands of June 1980 dollars)

Equipment	Small commercial	Large commercial	Small industrial	Large industrial
Existing Equipment				
Standard dryer	3.51 <sup>a</sup>	5.05 <sup>a</sup>	20.21 <sup>a</sup>	34.00 <sup>b</sup>
Diatomite filter	4.20 <sup>c</sup>	4.20 <sup>c</sup>	8.4 <sup>c</sup>	-- <sup>d</sup>
RACT Equipment				
Recovery dryer	14.48 <sup>e</sup>	14.98 <sup>e</sup>	59.92 <sup>e</sup>	59.92 <sup>e</sup>
Cooling tower	1.25 <sup>e</sup>	1.25 <sup>f</sup>	2.18 <sup>g</sup>	2.18 <sup>g</sup>
Refrigerated chiller	2.15 <sup>h</sup>	2.38 <sup>h</sup>	7.00 <sup>h</sup>	7.00 <sup>h</sup>
Cartridge filter	1.40 <sup>i</sup>	3.0 <sup>i</sup>	12.0 <sup>i</sup>	-- <sup>d</sup>

<sup>a</sup>Gardner, 1980.

<sup>b</sup>Moles, 1980.

<sup>c</sup>Kelly, 1980.

<sup>d</sup>Not applicable.

<sup>e</sup>Methe, 1980.

<sup>f</sup>Hayworth, 1980.

<sup>g</sup>Adams, 1980.

<sup>h</sup>Chaffee, 1981.

<sup>i</sup>Kirk, 1980.

## 5.2 BASIS FOR ANNUALIZED COSTS

Annualized operating costs are the sum of operating costs and capital charges. Operating costs include utilities, operating labor, and maintenance (labor and materials). Capital charges include capital recovery, as well as taxes, insurance, and administration. Credits for the value of recovered solvent are included in the total annual operating costs (Neveril, 1980).

Primary utilities included under annual operating costs are steam and electricity. Annual steam costs are based on equipment manufacturers' estimates of steam demand (in boiler horsepower or weight of steam per hour), estimates of operating hours as a function of model plant throughput, and a cost of steam (in dollars per kilogram generated) derived from current fuel cost estimates (Vatavuk, 1980) (see Table 5-2, Equation 1). Electrical requirements are derived from manufacturers' electrical demand specifications (usually in motor horsepower), operating time estimates as a function of model plant throughput, and a national average cost of electricity (in dollars per kWh) for commercial customers (Vatavuk, 1980). An operating efficiency of 60 percent is assumed for electric motors (Neveril, 1978) (see Equation 2) and electrical demand from cooling towers and refrigerated chillers is assumed to remain constant over the same duration as that of steam (6 hours per day).

Operating labor cost estimates are derived from national statistics for average hourly wages in the "Wholesale and Retail Trade Category" with the addition of 56 percent for payroll and plant overhead (Vatavuk, 1980). A work time of 1 worker-hour of operating labor per dryer per day (see Equation 3) is assumed (Jernigan and Lutz, 1979).

Estimated annual maintenance costs include both labor and materials. Maintenance labor costs are calculated from hourly rates that include a 26 percent plant overhead factor, with hours based on field test and plant survey data (Vatavuk, 1980). Maintenance materials costs are determined as 100 percent of annual maintenance labor costs (see Equation 4) in the absence of exact materials cost data (Vatavuk, 1980). If materials cost data are available, maintenance costs are represented as twice the cost of labor or materials, whichever is higher. The costs of 55 gallon drums for still waste storage are included in the materials costs.

Table 5-2. COST EQUATIONS

Equation 1: STEAM

$$= \text{boiler hp} \times \frac{34.5 \text{ lbs steam/hr}}{\text{boiler hp}} \times \frac{\text{operating days}}{\text{yr}} \times \frac{\text{operating hrs}}{\text{day}} \times \frac{\text{cost}}{\text{lb steam}}$$

- o Steam demand assumed continuous over a 6 hour day.
- o Steam cost per kg (pound) = \$0.02 (\$0.009).
- o Operating days per year is 250 (except large industrial which is 300).
- o 34.5 lbs steam per hour per boiler horsepower is a constant of conversion (Babcock, 1978).

Equation 2: ELECTRICITY

$$= \text{motor hp} \times \frac{0.746 \text{ kW}}{\text{hp}} \times \frac{1}{60\% \text{ efficiency}} \times \frac{\text{operating hrs}}{\text{day}} \times \frac{\text{operating days}}{\text{yr}} \times \frac{\text{cost}}{\text{kWh}}$$

- o Assuming lower value of typical motor efficiency range of 60% to 70%.
- o Operating hours per day based on model plant dry-cycle time per load and number of loads per day.
- o Operating days per year same as steam (see above).
- o Electricity cost per kWh = \$0.06.
- o 0.746 kW per horsepower is a constant of conversion (Babcock, 1978).

Equation 3: OPERATING LABOR

$$= \frac{1 \text{ worker-hr operating labor}}{\text{dryer-day}} \times \frac{\text{operating days}}{\text{yr}} \times \frac{\text{dryers}}{\text{plant}} \times \frac{\text{labor cost}}{\text{worker-hr}}$$

- o Operating days per year same as steam (see above).
- o Labor cost per worker-hour = \$8.42.

(continued)

Table 5-2. Concluded

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Equation 4: ANNUAL MAINTENANCE

$$= \frac{1 \text{ worker-hr}}{\text{dryer-week}} \times \frac{\text{operating days per yr}}{5 \text{ days per week}} \times \frac{\text{dryers}}{\text{plant}} \times \frac{\text{maintenance labor cost}}{\text{worker-hr}} \times 2.0 \text{ materia supplement}$$

- o Maintenance labor cost per worker-hour = \$8.30.
- o Maintenance labor and materials costs are equal (based on computed costs of hourly labor or required materials, whichever is greater).

Equation 5: TAXES, INSURANCE, AND ADMINISTRATION

$$= (0.04) \times (\text{total capital cost})$$

Equation 6: CAPITAL RECOVERY FACTOR

$$= \frac{i(1+i)^n}{(1+i)^n - 1} \times (\text{total capital cost})$$

- o Assuming interest rate  $i = 10\%$ .
- o Assuming equipment life  $n = 30$  yrs.

Equation 7: RECOVERED SOLVENT VALUE (CREDIT)

$$= \frac{\text{total emission reduction in}}{\text{kg VOC/kg throughput}} \times \frac{\text{kg throughput}}{\text{yr}} \times \frac{\$0.53}{\text{kg}}$$

- o Assuming 86% reduction of total uncontrolled emissions for the recovery dryer (15.6 kg VOC per 100 kg dry weight articles cleaned).
  - o Assuming 88% reduction of total uncontrolled emissions for the cartridge filter (7 kg VOC per 100 kg dry weight of articles cleaned).
  - o Average solvent cost = \$0.53/kg (\$1.55 gallon).
-

Capital costs resulting from property taxes and insurance costs are each estimated as 1 percent of the total annual capital costs, and administration costs are 2 percent of total annual capital costs (see Equation 5) (Neveril, 1978). The capital recovery cost is based on an annual interest rate of 10 percent (Vatavuk, 1980) and a projected life of 30 years (see Equation 6) for the dry cleaning equipment.

Annual credits for recovered solvent are based on experimentally determined solvent recovery efficiencies for RACT equipment. For example, the emission reduction resulting from the installation of RACT equipment is the difference between the existing emission rate of 28 kilograms of VOC emitted per 100 kilograms dry weight of articles cleaned and the RACT equipment emission level of 4.4 kilograms of VOC per 100 kilograms dry weight of articles cleaned. Furthermore, it is assumed that a specified percentage of the 28 kilograms of VOC (solvent) per 100 kilograms dry weight of articles cleaned is recovered in a reusable form (Jernigan and Lutz, 1979). Solvent costs are taken from industry quotations, the average being \$1.55 per gallon (see Equation 7) (Carson, 1980). The difference from existing control costs is computed as the difference in total annual operating costs between existing and RACT equipment.

### 5.3 EMISSION CONTROL COSTS

The costs of RACT implementation in the four model plants are based on the installation and operation of recovery dryers (and their associated water-cooling towers) and a cartridge filtration system where solvent filtration is in use. Tables 5-3 and 5-4 summarize the results of applying the previously defined cost equations to four model plants with both existing and RACT equipment. These tables also show the cost of existing cartridge filters, as well as those related to the installation of refrigerated chillers.

While capital costs of RACT equipment range from 1.8 to 2.6 times those for existing equipment, the cost credits gained from the value of recovered solvent result in decreases in total annual operating costs ranging from 37 percent (small commercial) to 110 percent (large industrial) over the total annual operating costs of standard dryers and diatomite filters (where applicable).

Table 5-3. CAPITAL AND ANNUALIZED COSTS OF EXISTING EQUIPMENT IN FOUR MODEL PLANTS  
(costs are in thousands of June 1980 dollars)

Cost parameters	Small commercial <sup>a</sup> (18,000 kg/yr)	Large commercial <sup>a</sup> (51,000 kg/yr)	Small industrial <sup>a</sup> (272,000 kg/yr)	Large industrial <sup>a</sup> (435,300 kg/yr)
<b>Capital costs</b>				
Equipment	7.71	9.25	28.61	34.00
Taxes, freight, and instrumentation	1.39	1.67	5.15	6.12
Direct and indirect installation	0.68	0.82	2.53	3.01
Total capital costs	9.78	11.74	36.39	43.13
<b>Annualized costs</b>				
<b>Operating costs</b>				
Steam	1.50	3.88	15.53	17.96
Electricity	0.03	0.17	0.80	3.60
Operating labor	4.22	4.22	12.64	2.53
Annual maintenance (labor and materials)	1.26	2.02	9.70	1.00
Subtotal, direct costs	7.01	10.29	38.67	25.09
<b>Capital charges</b>				
Capital recovery	1.04	1.25	3.85	4.58
Administration taxes, and insurance	0.39	0.47	1.45	1.73
Subtotal, indirect costs	1.43	1.72	5.30	6.31
Recovered solvent value (credit)	0	0	0	0
Total annual operating cost	8.44	12.01	43.97	31.40
Total annual operating cost with existing cartridge filters instead of diatomite filters	5.24	7.93	31.45	31.40

<sup>a</sup> Annual kilograms of articles cleaned.

<sup>b</sup> Not applicable.

Table 5-4. CAPITAL AND ANNUALIZED COSTS OF RACT EQUIPMENT IN FOUR MODEL PLANTS  
(costs are in thousands of June 1980 dollars)

Cost parameters	Small commercial (18,000 kg/yr) <sup>a</sup>	Large commercial (51,000 kg/yr) <sup>a</sup>	Small industrial (272,000 kg/yr) <sup>a</sup>	Large industrial recovery dryer (435,300 kg/yr) <sup>a</sup>
<b>Capital costs</b>				
Equipment	17.13	19.23	74.10	62.10
Taxes, freight, and instrumentation	3.08	3.46	13.34	11.18
Direct and indirect installation	1.51	1.71	6.56	5.50
Total capital costs	21.72	24.40	94.00	78.78
<b>Annualized costs</b>				
<b>Operating costs</b>				
Steam	0.70	1.05	4.21	5.05
Electricity	0.06	0.16	0.94	1.12
Operating labor	2.12	2.13	8.54	10.10
Annual maintenance (labor and materials)	1.40	2.28	11.33	5.03
Subtotal, direct costs	4.28	5.62	25.02	21.30
<b>Capital charges</b>				
Capital recovery	2.30	2.59	9.97	8.36
Administration, taxes, and insurance	0.87	0.98	3.76	3.15
Subtotal, indirect costs	3.17	3.57	13.73	11.51
Recovered solvent value <sup>b</sup>	(2.15)	(6.08)	(32.44)	(35.77)
Total annual operating cost	5.30	3.11	6.31	(2.96)
Difference from existing equipment annual costs	(3.14)	(8.90)	(37.66)	(34.36)
<b>Total annual operating cost with a refrigerated chiller instead of a cooling tower</b>	5.59	3.52	8.13	(1.69)
Difference from existing equipment annual costs <sup>b</sup>	(2.85)	(8.49)	(35.84)	(33.09)
Total annual operating cost without the addition of cartridge filters	5.19	3.10	5.91	-- <sup>c</sup>
Difference from existing equipment annual costs <sup>b</sup>	(3.25)	(8.91)	(38.06)	-- <sup>c</sup>

<sup>a</sup>Kilograms of articles cleaned.

<sup>b</sup>Numbers in parentheses represent savings or credits.

<sup>c</sup>Not applicable.

The small commercial model plant shows a modest decrease in total annual operating costs due to installation of RACT equipment rather than standard dryers and diatomite filters. With capital costs of RACT recovery dryers and cartridge filters totaling nearly 2.2 times those of standard dryers and diatomite filters, the annual capital charges also are increased. The low throughput of this model plant further precludes the rapid offsetting of the above additional cost with credits for recovered solvent, the amount of solvent recovered being a direct function of throughput. Thus, the installation of RACT equipment in a small commercial plant would result in a 37 percent decrease in annual operating costs.

Capital costs of RACT equipment for a large commercial model plant are about twice (2.1 times) those for existing equipment, and therefore produce a similar increase in the annual cost of RACT implementation based on higher annual capital charges. However, increases in annual costs are more than offset by credits for recovered solvent, the overall effect being a 75 percent decrease in the total annual operating cost of a large commercial plant with RACT equipment.

The installation of RACT equipment in a small industrial model plant is based on the operation of four 48 kg (105 lb) capacity recovery dryers and a cartridge filtration system, instead of four standard dryers of the same capacity with diatomite filters, resulting in a 160 percent increase in capital costs when compared with capital costs of existing equipment. While operating costs are reduced by the recovery dryer's lower demand for steam and the cartridge filter's reduced materials and labor outlays, gross annual capital charges are increased by the effects of greater capital costs. Total annual operating costs for a small industrial plant with RACT equipment are reduced by 86 percent as a result of credits for recovered solvent.

Single, 400 lb capacity standard dryers used in large industrial model plants are replaced by four RACT recovery dryers at a capital cost of approximately 1.8 times that of new standard dryers. Again, the annual cost of steam is significantly lower for recovery dryers, but their labor and maintenance costs are higher than those of existing equipment, with four dryers requiring more operator and maintenance time. Increases in annual capital charges are offset by substantial

cost reductions from recovered solvent credits. Thus, the installation of RACT equipment (recovery dryers) in a large industrial plant yields a 110 percent reduction in total annual costs when compared with standard dryer installation and operation costs.

#### 5.4 COST EFFECTIVENESS

The cost effectiveness of RACT equipment installation and operation is defined as the annual dollars expended beyond the costs of existing equipment per unit mass of emission reduction achieved. A combination of high emission reduction and low annual cost (high annual credit) results in maximum cost effectiveness. The cost effectiveness of RACT equipment in four model plants is summarized in Table 5-5, which also includes cost effectiveness data for facilities with existing cartridge filters as well as those requiring refrigerated chillers for recovery dryer cooling water supply.

Both small and large commercial model plants show the same high cost effectiveness, with annual savings of \$740 per megagram of emission reduction. Capital costs of RACT equipment in these facilities are proportionally lower than those in industrial plants, and the combined credits due to solvent recovery in both recovery dryers and cartridge filters result in a net return per unit of emission reduction. Thus, the owner of either a small or large commercial dry cleaning facility would save \$3,140 or \$8,900, respectively, per year by replacing a standard dryer and diatomite filter with a recovery dryer and cartridge filter, while simultaneously reducing the annual VOC emissions from the plant by 4.2 Mg and 11.99 Mg, respectively.

The replacement of existing equipment with RACT equipment in a small industrial plant would result in an annual cost effectiveness of \$590 saved per megagram of emission reduction. This reduced cost effectiveness, in comparison with both commercial model plants, results from the burden of capital costs that increase dramatically with the installation of four recovery dryers and one cartridge filter. The owner of a small industrial dry cleaning plant could expect to save \$37,660 per year by replacing existing equipment with RACT equipment, while reducing the annual VOC emissions from the plant by approximately 63.9 megagrams.

Table 5-5. COST EFFECTIVENESS OF RACT EQUIPMENT IN FOUR MODEL PLANTS  
(costs are in thousands of June 1980 dollars)

Cost parameters	Small commercial (18,000 kg/yr) <sup>a</sup>	Large commercial (51,000 kg/yr) <sup>a</sup>	Small industrial (272,000 kg/yr) <sup>a</sup>	Large industrial recovery dryer (435,300 kg/yr) <sup>a</sup>
Emission reduction (Mg VOC/yr)	4.23	11.99	63.92	102.32
Annualized cost decrease with RACT	3.14 <sup>b</sup>	8.90	37.66	34.36
Cost effectiveness of RACT implementation (thousands of dollars saved/Mg of VOC emission reduction)	0.74	0.74	0.59	0.34
Cost effectiveness of RACT implementation in plants with a refrigerated chiller instead of a cooling tower	0.67	0.71	0.56	0.32
Cost effectiveness of RACT implementation in plants with existing cartridge filters	1.09	1.06	0.85	-- <sup>b</sup>

<sup>a</sup>Kilograms of articles cleaned.

<sup>b</sup>Not applicable.

The cost effectiveness of replacing existing equipment with RACT equipment in a large industrial plant yields an annual savings of \$340 per megagram of VOC emission reduction. This is the lowest value among the four model plant sizes, and is due to the high capital costs of four recovery dryers. Unlike the other model plants, however, the large industrial facility has no diatomite filtration system and there are no additional savings from solvent recovery by installation of cartridge filters. (Proper storage of still wastes contributes to overall emission reduction but not to recovery.) Therefore, the owner of a large industrial plant could expect to save \$34,360 per year after installing RACT recovery dryers, while experiencing a 102.32 megagram reduction in annual VOC emissions.

The results of a best case/worst case analysis of RACT equipment installation are illustrated in Figure 5-1. The best case is defined as the installation of RACT equipment at a plant in which the existing equipment is completely paid for and contributes no additional capital burden (assuming no resale value for old existing equipment). In contrast, the worst case assumes that the plant has recently purchased and installed standard dryers and diatomite filters (where applicable). Upon replacement with RACT equipment, the capital costs of the new existing equipment must be added to the capital costs of the RACT equipment. Finally, as a basis for comparison, the annual costs for facilities using existing equipment are included (no regulation).

In all four model plant sizes, the greatest annual costs are those associated with the operation of existing equipment. Although the differences among the three cost alternatives are small in the small commercial plant, their magnitude increases with the increased throughput of larger model plants. Also, the difference between best and worst case annual costs is minor in comparison with the annual costs of existing equipment. Therefore, the installation of RACT equipment will result in savings in annual operating costs regardless of the age or condition of existing equipment.

BC - Best case, RACT equipment installed, all existing equipment paid in full.

WC - Worst case, RACT equipment installed, existing equipment newly purchased.

NR - No regulation, existing equipment remains in service.

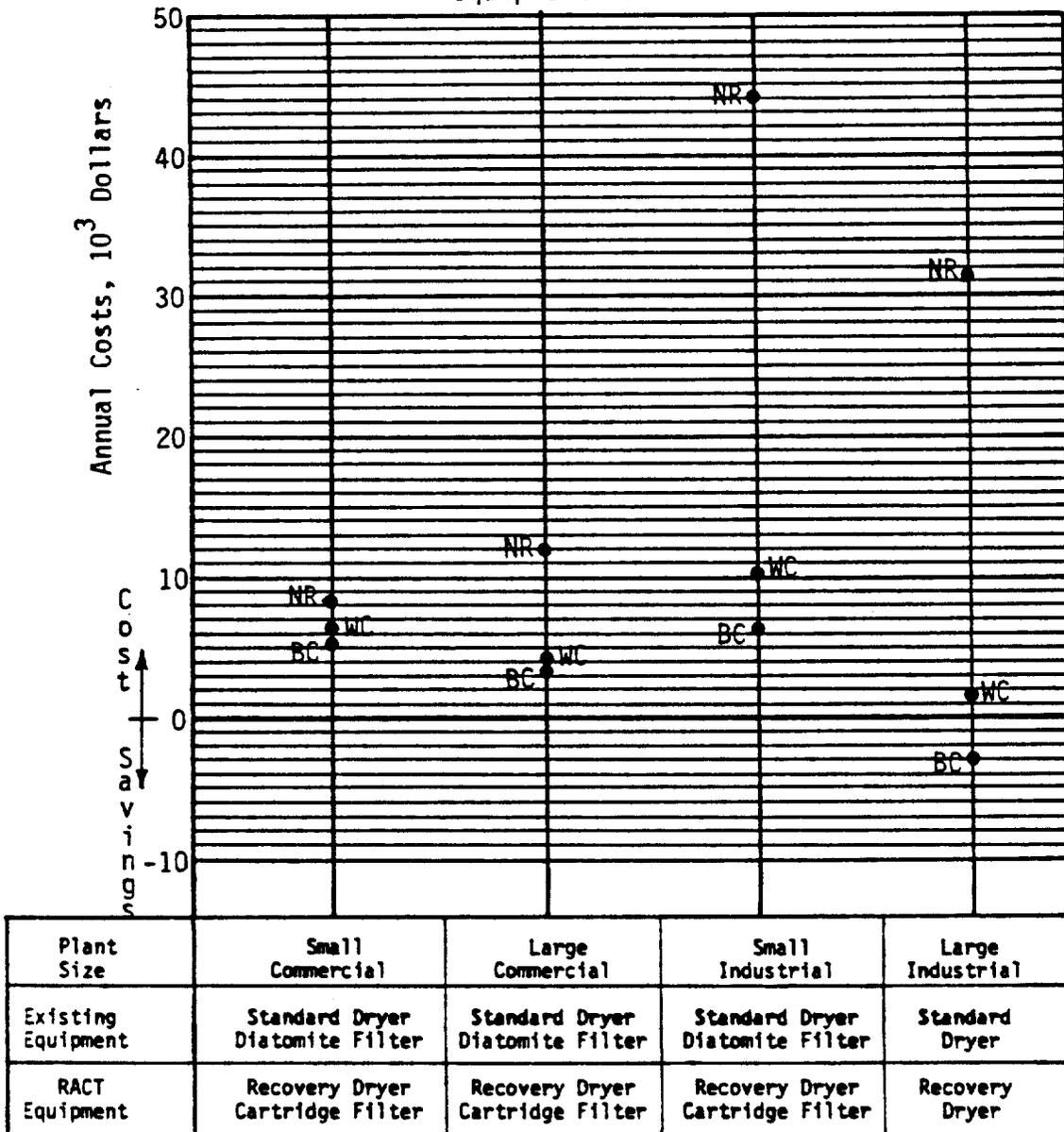


Figure 5-1. Effects of RACT Equipment Installation on Operating Costs of Four Model Plants.

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## 6.0 MODEL REGULATION AND DISCUSSION

This chapter includes a model regulation based on the "presumptive norm," which is considered broadly representative of RACT for the petroleum dry cleaning industry. The model regulation is included solely as guidance to assist state and local agencies in drafting their own specific RACT regulations. Consequently, the model regulation is illustrative in nature and is not to be construed as rulemaking by EPA.

### 6.1 MODEL REGULATION

#### §XX.010 Applicability.

(A) This Regulation applies to washers, dryers, solvent filters, and vacuum stills that are used in petroleum solvent dry cleaning facilities.

(B) This Regulation applies to all petroleum solvent dry cleaning facilities described in §XX.010(A) that consume 123,000 liters or more of petroleum solvent annually.

(C) This Regulation applies to all petroleum solvent dry cleaning facilities described in §XX.010(A) and (B) located in the following areas:

§XX.020 Definitions.

(A) Except as otherwise required by the context, terms used in this Regulation are defined in the [General Statutes], the [General Provisions], or in this section as follows:

"Cartridge filter" means perforated cannisters containing filtration paper and/or activated carbon that are used in a pressurized system to remove solid particles and fugitive dyes from soil-laden solvent.

"Dry cleaning" means a process for the cleaning of textiles and fabric products in which articles are washed in a nonaqueous solution (solvent) and then dried by exposure to a heated air stream.

"Petroleum solvent" means organic material produced by petroleum distillation comprising a hydrocarbon range of 8 to 12 carbon atoms that exists as a liquid under standard conditions, frequently called "Stoddard" solvent.

"Solvent recovery dryer" means a class of dry cleaning dryers that employs a condenser to liquify and recover solvent vapors evaporated in a closed-loop, recirculating stream of heated air.

"Vacuum still" means a device that distills solvent by depositing it in a heated, partially evacuated vessel in which evaporated (boiled) solvent and water vapors are successively pumped through a condenser to liquify the solvent and water vapors, a gravimetric separator separates solvent from wastewater, and a rag filter removes final traces of water before reuse.

"Volatile organic compounds" means any organic compound that participates in atmospheric photochemical reactions or is measured by a State or EPA test method.

§XX.030 Standards.

(A) Each owner or operator of a petroleum solvent dry cleaning dryer shall either:

(1) Limit emissions to the atmosphere to 2.4 kilograms of volatile organic compounds per 100 kilograms dry weight of articles dry cleaned.

(2) Install and operate a solvent recovery dryer as follows:

(a) The condenser vapor outlet temperature shall not exceed 34 degrees centigrade during the recovery phase, and

(b) The dryer shall remain closed and the recovery phase shall continue until a final recovered solvent flow rate of 0.02 liters per minute is attained.

(B) Each owner or operator of a petroleum solvent filtration system shall:

(1) Discharge to the atmosphere no more than 1.0 kilogram of volatile organic compounds per 100 kilograms dry weight of articles dry cleaned, or

(2) Install and operate a cartridge filtration system, and drain the filter cartridges in their sealed housings for 8 hours or more before their removal.

(C) Each owner or operator of a petroleum solvent vacuum still shall store all vacuum still wastes in a manner that minimizes emission of volatile organic compounds to the atmosphere.

(D) Each owner or operator shall repair all petroleum solvent vapor and liquid leaks within 3 working days after identifying the leaks. If necessary repair parts are not on hand, the owner or operator shall

order these parts within 3 working days, and repair the leaks no later than 3 working days following the arrival of the necessary parts.

§XX.040 Testing and monitoring.

(A) To be in compliance with §XX.030(A)(1) the owner or operator shall:

(1) Calculate, record, and report to the Director the weight of volatile organic compounds vented from the dryer emission control device calculated by using EPA Reference Test (40 CFR, Part 60) Methods 1, 2, and 25A, with the following specifications:

(a) Field calibration of the flame ionization analyzer with propane standards,

(b) Laboratory determination of the flame ionization analyzer response factor of propane gas to volatile organic compounds, prepared according to EPA Reference Test Method 25A, and

(c) Determination of the weight of volatile organic compounds vented to the atmosphere by the multiplication of the flame ionization analyzer response factor of propane gas to volatile organic compounds and the concentration of propane gas as indicated by the flame ionization analyzer output record.

(2) Calculate, record, and report to the Director the dry weight of articles dry cleaned.

(3) Repeat §XX.040(A)(1) and (2) for 5 days of normal operating conditions and at least 30 dryer loads, totaling not less than 1,800 kg dry weight, that represent a typical industry range of variations in fabrics, solvents, load weights, temperatures, flow rates, and process deviations.

(B) To determine compliance with §XX.030(A)(2), the owner or operator shall perform a visual inspection of the recovery dryer condenser vapor outlet temperature and the final recovered solvent flow rate at the termination of the recovery phase.

(C) The owner or operator shall show compliance with §XX.030(B)(1) as follows:

(1) Calculate, record, and report to the Director the weight of volatile organic compounds contained in at least five one-kilogram samples of filtration waste material taken at intervals of at least 1 week, by employing ASTM Method D322-67 (Gasoline Diluent in Used Gasoline Engine Oil by Distillation).

(2) Calculate, record, and report to the Director the total dry weight of articles dry cleaned during the intervals between removal of filtration waste samples, as well as the total mass of filtration waste produced in the same period.

(3) Calculate, record, and report to the Director the weight of volatile organic compounds contained in filtration waste material per 100 kilograms dry weight of articles dry cleaned.

(D) Compliance with §XX.030(C) and (D) requires that each owner or operator make weekly inspections of still waste storage containers and other equipment to identify and eliminate volatile organic compounds vapor or liquid leaks.

§XX.050 Compliance schedules.

(A) The owner or operator of a petroleum solvent dry cleaning facility subject to this regulation shall meet the applicable stages of progress contained in the following schedule:

(1) Submit to the Director final plans for the emission control equipment \_\_\_\_\_ (3 months after implementation of the regulation).

(2) Award contracts for the emission control equipment \_\_\_\_\_ (2 months after the final submission of the control equipment plans).

(3) Complete onsite construction or installation of the emission control equipment \_\_\_\_\_ (12 months after award of the contract).

(4) Achieve final compliance with the regulation \_\_\_\_\_ (2 months after installing the control equipment).

(5) In the event that the control equipment cannot be delivered within 12 months after award of the contract, and the owner or operator placed the order within the required time, the final compliance date shall be 3 months following delivery of the equipment.

## 6.2 DISCUSSION

Enforcement and compliance verification procedures associated with the model regulation would rely on visual inspection of all affected facility components. This section includes a discussion of the enforcement approaches for a VOC emissions regulation based on RACT.

The determination of the annual solvent consumption of individual petroleum dry cleaning plants should be based on the plants' records of total solvent purchases over a period of at least one year. Records of these purchases should be readily available at the individual plant, and questionable or incomplete solvent purchase data could be verified through solvent suppliers' sales records.

### 6.2.1 Dryers

The availability of domestically produced recovery dryers could strongly influence the enforcement of a RACT regulation. Currently, there is only one manufacturer of recovery dryers in the United States, and the lag time between order placement and dryer delivery may be substantial. The advent of a RACT regulation requiring recovery dryers

could extend this delay. For this reason, the model regulation contains a provision [§XX.050(A)(5)] that would postpone the compliance deadline for control equipment not delivered within 12 months of ordering to 3 months after its delivery.

Recovery dryer emissions reduction performance would be determined by observing two primary operating parameters (see Appendix B): the condenser gas outlet temperature and the solvent recovery rate. The outlet gas temperature (not to exceed 34°C) would indicate that the dryer is operating within an acceptable range of emission reductions, and the maximum final recovery rate (0.02 liters per minute) would define a minimum time that the dryer must operate to ensure sufficient recovery of the solvent evaporated from the drying articles. Recovery dryer condenser outlet gas temperature and maximum final recovered solvent flow rate should be monitored frequently during the initial period of recovery dryer operation following installation. This will familiarize the operator with the effects of load weight, fabric type, and ambient (air and water) temperatures on these two parameters. After this initial period of training (possibly lasting 2 weeks or more), the operator could monitor the above parameters during the course of one dryer load per day which would represent conditions of load weight, fabric type, and temperature typical of the particular dry cleaning facility.

Application of carbon adsorption technology to standard dryer VOC emissions may be possible. Although an analysis of the only current application of this technique (see Appendix A, Test 5) has shown that it is less effective in reducing overall dryer VOC emissions, modifications to the system could result in equivalence with the recovery dryer. For example, a substantial increase in the mass of activated carbon available for adsorption could result in sharply reduced adsorber exhaust VOC concentrations. Also, a decrease in the flow rate of the vapor through the system would increase the VOC adsorption by the carbon.

Verification of the compliance of a dryer emission control device other than the recovery dryer would be based on a one-time test of the maximum dryer VOC mass emissions per unit mass of articles cleaned after installation of the alternative control device (see Appendix B). The

determination of this mass emission rate would require the use of EPA Reference (40 CFR Part 60) Test Methods 1, 2, and 25A (modified). While Methods 1 and 2 would govern the selection of atmospheric vapor exhaust sampling points and the procedure for determining the exhaust flow rate, respectively, modified Method 25A would govern the measurement of the VOC (solvent) vapor concentrations in the control device atmospheric exhaust by a flame ionization analyzer (FIA). The FIA would be calibrated to measure concentrations of propane gas, and a response factor of the FIA's measurement of propane to that of VOC would be calculated and multiplied by the indicated concentrations of propane in the control device exhaust, determining the concentration of VOC and thereby the mass of VOC emitted. This procedure should be carried out under various conditions of fabric type, load weight, and temperatures that are typical of the range encountered in the dry cleaning industry. The results of this procedure should be reported as kilograms VOC emitted per 100 kilograms dry weight of articles dry cleaned. Compliance would be established if the maximum VOC mass emissions per 100 unit mass of articles cleaned did not exceed 2.4. Subsequent changes in the design or performance of the control device could necessitate a reevaluation of the device's maximum VOC emissions.

#### 6.2.2 Filters

Verification of compliance with the section of the regulation governing solvent filters would be based on visual observation of the proper installation, operation, and maintenance of a cartridge filtration system. The manufacturer's manual for the particular system should be consulted for proper procedures, sizing of connections, and parameters requiring inspection or monitoring to ensure satisfactory operation. The operator's familiarity with the system's performance, safety, and maintenance requirements should be evaluated as an important aspect of overall compliance.

Plant records detailing the date and time of cartridge replacements could be used to verify compliance with the mandated 8-hour minimum drainage time. If these records are lacking, and there is some suspicion that the cartridges are being drained improperly, it may be necessary to require valid proof of compliance by proper record keeping over a specified period.

A solvent filtration system VOC emissions control device other than the cartridge filter would require a one-time verification of its compliance with maximum emissions (solvent content of waste) of no more than 1.0 kilograms VOC per 100 kilograms dry weight of articles dry cleaned prior to its use in a petroleum dry cleaning facility. The testing procedure would be based on the determination of the VOC (solvent) content of five one-kilogram samples of filtration waste from the control device taken over one-week intervals during which conditions of soil loading, load weight, and fabric type vary in a manner typical of the industry. ASTM Test Method D322-67 (Gasoline Diluent in Used Gasoline Engine Oil by Distillation) should be used to determine the solvent content of each sample. The total masses of articles cleaned and filtration waste generated between waste samplings should be recorded and multiplied by the sample ratio of solvent-to-waste content (as determined by the ASTM Method), resulting in a determination of the mass of VOC emitted (solvent generated) per 100 unit mass of articles dry cleaned. The compliance verification resulting from this test would apply only to the existing control device configuration, and would be invalidated by significant changes in the design or performance of the device.

#### 6.2.3 Still Wastes

Visual inspection of waste storage facilities would form the basis for verification of compliance with the section of the regulation governing vacuum stills. The equipment used should be resistant to petroleum solvents and should conform to applicable fire and building codes.

The transfer of wastes from the still to the storage facility should be completed quickly and with no spillage to minimize solvent evaporation to the atmosphere. A pump, either manual or electric (explosion-proof), would facilitate this transfer and lessen the likelihood of spills and evaporation from buckets or siphons.

#### 6.2.4 Fugitive Emissions

Location of fugitive emission sites would rely on a visual inspection of the overall dry cleaning system components. Sources of VOC liquid leaks would be identified directly, and the operation and maintenance of devices known to be sources of VOC vapors would be evaluated.

Dry cleaning system components found leaking liquid solvent should be repaired immediately. Pipes, hoses, and fittings should be examined for active dripping or dampness. Pumps and filters should be closely inspected for leaks around seals and access covers. In general, there should be no visible signs of liquid solvent.

Solvent vapor leaks would be reduced by eliminating the sources where solvent is exposed to the atmosphere. Under no circumstances should there be any open containers (cans, buckets, barrels) of solvent or solvent-containing material. Equipment containing solvent (washers, dryers, extractors, and filters) should remain closed at all times other than during maintenance or load transfer. Lint filter and button trap covers should remain closed except when solvent-laden lint and debris are removed. Gaskets and seals should be inspected and replaced when found worn or defective. Solvent-laden clothes should never be allowed to sit exposed to the atmosphere for longer periods than are necessary for load transfers. Finally, vents on solvent-containing waste and new solvent storage tanks should be constructed and maintained in a manner that limits solvent vapor emissions to the maximum possible extent.

APPENDIX A  
SUMMARY OF FIELD TESTS

This appendix provides detailed descriptions of EPA tests conducted in support of petroleum dry cleaning new source performance standard (NSPS) and control techniques guideline (CTG) development.

A.1 TEST 1 (PICO RIVERA)

EPA contracted an engineering analysis of a solvent recovery dryer to determine its emission reduction potential and establish the capital and operating costs associated with its use (Lutz and Jernigan, 1980). The test site for this program was an industrial petroleum dry cleaning plant located in Pico Rivera, California. Testing was conducted at the plant from October 9 to November 21, 1979. This dry cleaning facility utilized both a Cissell standard dryer and a Hoyt "Petro-miser" solvent recovery dryer to process approximately 6,350 kg (14,000 lbs) of industrial work gloves per week. The standard dryer had a dry weight load capacity of 45 kg (100 lbs), and the recovery dryer had a dry weight load capacity of 48 kg (105 lbs). To reflect normal operating conditions, each dryer was loaded an average of 10 percent over its rated capacity with work gloves made of cotton and leather. The recovery dryer had three operating sequences - a Reclaim-Dry Cycle, Perma-Cool Cycle, and a Deodorizing (exhaust) Cycle. Solvent emissions from the recovery dryer were not restricted solely to the exhaust cycle. Any time the dryer loading door was open, an exhaust fan was activated and ambient room air was pulled into the dryer and exhausted to the atmosphere via the exhaust duct. This also occurred when the door to the lint filter compartment was open. In comparison, the standard dryer continuously exhausted to the atmosphere during the dryer cycle.

The solvent recovery dryer's emission reduction performance was established by comparing its measured emission rate with the emission rate of a standard dryer. During the testing period, both dryers were operated simultaneously and processed similar loads. The average flow rate through the exhaust ducts during the recovery and standard dryer drying cycles was determined using EPA Method 2. The average solvent concentration in the recovery and standard dryer exhausts was determined during each exhaust cycle by analyzing the strip chart recordings from a Beckman 400 flame ionization analyzer (FIA). The average concentration for each dryer, multiplied by the total gas volume throughput for each dryer, yielded the total solvent emitted for each dryer in kilograms per cycle. Dividing this value by the weight of gloves dried for each dryer cycle yielded the solvent emissions for the recovery and standard dryers expressed in kilograms of solvent per 100 kilograms of gloves dried.

The average emission rates for the recovery and standard dryers were determined and expressed in kilograms of solvent per 100 kilograms of articles cleaned. Table A-1 indicates that the recovery dryer had an average emission rate per drying cycle of 0.96 kg solvent per 100 kg dry weight of articles cleaned, and the standard dryer had an average emission rate per drying cycle of 30 kg solvent per 100 kg dry weight of articles cleaned. Recovery dryer solvent emissions per 100 kilograms of articles cleaned ranged from 0.68 to 1.25 kilograms, and appeared to vary with the load weight. The total weight of solvent recovered ranged from 8 to 17 kilograms (18 to 37 pounds) and did not appear to be a direct function of the load weight. In contrast, standard dryer solvent emissions per 100 kilograms of articles cleaned ranged from 20.8 to 47.2 kilograms, and appeared to increase with smaller load weights. The trend toward higher emissions per weight of articles cleaned in smaller loads held true for both standard and recovery dryers, and indicated that the rate at which fabrics release solvent could have a significant effect on overall solvent emissions.

The annualized operating cost of the recovery dryer was calculated to be \$1,400, which represents a savings of \$3,900 per year over the operating cost of the standard dryer. This savings was due primarily to the value of the recovered solvent, estimated at \$0.24/liter (\$0.92/gallon).

Table A-1. DRYER EMISSIONS DATA<sup>a</sup>

Recovery Dryer						Standard Dryer				
Date	Load #	Load dry weight (kg)	Solvent emitted (kg)	kg solvent emitted/100 kg articles cleaned	Solvent recovered (kg)	Date	Run #	Load weight (kg)	Solvent emitted (kg)	kg solvent emitted/100 kg articles cleaned
10/09/79	2	51.9	0.352	0.68	14.85	10/10/79	4	50.79	15.80	31.1
10/16/79	2	50.8	0.496	0.98	11.11	10/11/79	1	53.52	13.99	26.1
10/17/79	2	49.0	0.598	1.22	11.34	10/11/79	2	51.93	14.56	28.0
10/17/79	3	51.4	0.462	0.90	11.56	10/11/79	3	49.43	17.80	36.0
10/17/79	4	53.7	0.486	0.91	9.75	10/12/79	1	50.57	14.88	29.4
10/17/79	5	53.3	0.471	0.88	11.11	10/12/79	2	48.98	16.57	33.8
10/18/79	2	56.2	0.424	0.76	8.73	10/12/79	3	51.02	15.65	30.7
10/18/79	3	51.7	0.407	0.79	11.68	10/12/79	4	54.88	11.40	20.8
10/18/79	4	49.8	0.611	1.23	14.06	10/12/79	5	48.66	18.72	38.5
10/18/79	5	49.2	0.569	1.16	8.16	10/15/79	3	52.38	16.11	30.8
10/22/79	2	52.1	0.448	0.86	11.45	10/15/79	4	50.93	16.41	32.2
10/22/79	3	46.2	0.577	1.25	16.78	10/15/79	5	46.49	21.94	47.2
10/22/79	4	48.9	0.471	0.96	14.29	10/16/79	2	50.79	15.80	31.1
AVERAGE				0.96		10/16/79	3	53.29	13.21	24.8
						10/17/79	1	52.38	13.56	25.9
						10/17/79	2	51.02	16.88	33.1
						10/17/79	3	52.15	12.68	24.3
						10/17/79	4	53.65	14.00	26.1
						10/19/79	1	53.51	12.12	22.7
						10/19/79	4	48.89	14.64	29.9
										30.1

<sup>a</sup>Data tabulated only for dryer loads in which all relevant parameters were successfully monitored.

The mass balance and hydrocarbon analysis from this test program demonstrated that recovery dryers could achieve a 97 percent reduction in solvent emissions as compared with a standard dryer. The economic analysis of this type of control system indicates that it is a cost-effective means of solvent emission control, providing an actual reduction in operating costs.

One problem that was not resolved during this test was whether the recovery dryer operated above the lower explosive limit (LEL) of the solvent (1 percent by volume or 10,000 parts per million). FIA chart recordings of the vapor concentrations in the recovery dryer during the reclaim-dry cycle indicated that the vapor concentration rose until it peaked at 9,000 to 9,300 parts per million (ppm) as solvent. The vapor concentration remained at this peak throughout most of the drying cycle. After the testing was completed, careful analysis of the chart recordings revealed that these peak readings were not the maximum concentration levels, but the level at which the FIA became saturated; thus, indicating only the maximum monitoring levels of the calibrated FIA. Therefore, the actual concentrations of the solvent vapors in this particular recovery dryer were higher than the peak range of 9,000 to 9,300 ppm.

The high vapor concentrations during the reclaim cycle may be attributed to a number of factors. Overloading of the dryers, as was the case during this test, may have caused the high concentrations. Fabric with high solvent absorption, such as cotton and leather, give off more solvent vapors than an equal weight of synthetic fabrics, thereby creating higher concentrations. Also, high condenser inlet water temperatures may contribute to high vapor concentrations during the reclaim cycle.

## A.2 TEST 2 (LAKELAND)

An EPA-sponsored testing program was performed at a commercial petroleum dry cleaning facility to investigate the solvent emission reduction/recovery, operational costs, and safety of petroleum solvent recovery dryers (Jernigan and May, 1981). The host plant for this test program was a large commercial dry cleaning plant located in Lakeland, Florida. This facility cleaned 1,100 kg (2,500 lbs) of general apparel

each week. The dry cleaning equipment consisted of a 48 kg dry weight (105 lb) capacity Hoyt recovery dryer, a 30 kg (65 lb) capacity Washex washer/extractor, an 11,000 liter per hour (3,000 gph) Washex tube filter, and a 48,000 Btu (50 MJ) Rite Temp refrigerated water chiller. Testing was conducted at this facility from July 21 to August 8, 1980.

Test procedures included monitoring exhaust gas and condenser gas inlet solvent concentrations using a Beckman 400 flame ionization analyzer (FIA). Also, temperatures of condenser inlet and outlet (water and gas) and dryer exhaust gas were monitored during this program. Chiller outlet (condenser water inlet) temperatures were increased in 5°F increments with a constant reclaim cycle duration (28 minutes), and solvent recovery rate and concentration data were recorded for several clothing loads at each of the chiller temperatures. The total recovery of both solvent and water, as well as the total flow of cooling water through the condenser during the reclaim cycle, were recorded and are listed on Table A-2.

The mass balance and hydrocarbon analysis results from this test program indicated that the average VOC emissions rate from the recovery dryer was 3.85 kg VOC per 100 kg dry weight of articles cleaned. The solvent concentration at the condenser gas inlet never exceeded 95 percent of the solvent's lower explosive limit (LEL) during the portion of the test in which the condenser water inlet temperature was varied.

Data collected during the test is summarized in Table A-2. As condenser water inlet temperatures were increased, condenser vapor outlet temperatures increased and solvent emissions per 100 kg of articles cleaned decreased. Uncontrolled theoretical solvent emissions (defined as the sum of recovered and emitted solvent) per 100 kg of articles cleaned varied from 23.73 kg to 11.59 kg, with an overall test average of 14.24 kg per 100 kg of articles cleaned. Recovery dryer emissions per 100 kg of articles cleaned, measured at the dryer exhaust by the FIA, varied from 9.45 kg to 2.34 kg, with an overall test average of 3.85 kg solvent emitted per 100 kg of articles cleaned. This relatively high emission rate may result from the typically small load weights (25 kg average) of synthetic fabrics that have a low solvent

Table A-2. RECOVERY DRYER DATA COMPILATION

Start time	Date and run	Condenser inlet water temp (°F)	Average condenser vapor outlet temp (°F)	"Dry" load weight (kg)	Recovery (kg) Water / Solvent	Solvent emitted (kg)	kg solvent emitted/100 kg articles cleaned
0829	8/4-2	64	87	31.29	0.010	3.21	3.71
0905	3	64	--	29.93	0.155	3.19	4.12
0941	4	64	89	26.30	0.350	2.59	4.78
1034	5	66	89	23.13	0.255	2.18	4.92
1113	6	65	89	17.23	0.245	1.52	5.95
1154	7	66	91	24.94	0.440	2.36	4.27
1240	8	65	89	39.00	0.599	4.18	3.24
1321	9	65	89	9.98	0.220	1.43	9.45
0719	8/5-2	63	88	19.95	0.315	2.25	5.20
0812	3	66	91	27.66	0.420	2.91	4.13
0856	4	68	92	30.39	0.499	3.19	4.00
0941	5	68	92	29.02	0.335	3.13	4.63
1020	6	68	92	34.01	0.499	3.60	4.19
1058	7	68	92	29.93	0.450	3.22	4.38
0727	8/6-1	64	87	23.13	0.165	2.06	3.12
0815	2	68	91	29.48	0.370	3.34	3.03
0857	3	70	94	29.02	0.499	3.07	3.02
0939	4	71	94	26.30	0.450	2.83	2.97
1028	5	70	93	22.68	0.360	2.25	3.22
1109	6	70	94	26.76	0.467	2.44	2.49
1152	7	72	95	24.04	0.375	2.63	2.60
1233	8	72	94	20.86	0.385	2.15	3.11
0706	8/7-1	70	94	27.66	---	--	2.56
0754	2	73	95	20.86	0.240	1.97	3.22
0834	3	73	96	28.12	0.370	2.93	2.79
0924	4	75	97	31.29	0.467	3.26	2.51
1009	5	74	95	---	---	--	--
1048	6	74	95	24.04	0.370	2.74	2.34
Averages				25.10		0.96	3.85

<sup>a</sup>Data not used in computing averages.

retention. Also, the typical recovery phase duration of 28 minutes may be insufficient time for a more complete recovery.

Figures A-1, A-2, and A-3 represent a typical range of recovery dryer loads and emissions. A dryer load with relatively high emissions (approximately 5.2 kg solvent emitted per 100 kg of articles cleaned) is illustrated in Figure A-1. The gradual increase in the volume of solvent is reflected in the narrow peak of the solvent recovery rate. Simultaneously, the concentration of solvent vapor in the condenser inlet climbs steadily during the first 7 minutes of recovery and then levels off at a near constant concentration of 4,400 parts per million (ppm) as solvent. The curve, representing the volume of recovered solvent, has a brief initial period of rapid recovery that is followed by a gradual increase in total volume that reflects a low, nearly constant rate of recovery.

Recovery and concentration curves in Figure A-2 illustrate a dryer load in which solvent emissions were below those of the test average (approximately 2.4 kg solvent emitted per 100 kg of articles cleaned). The graph of condenser inlet vapor concentration shows a much higher (9,358 ppm as solvent) and more pronounced peak than Figure A-1, in addition to much higher concentrations throughout the entire cycle. Concurrently, the curve illustrating the volume of recovered solvent shows an initial period of very rapid recovery that gradually decreases to a lower, near constant rate later in the drying cycle than in the high-emission load. Finally, the curve representing the solvent recovery rate shows a more gradual decrease in recovery rate than that illustrated in Figure A-1, although the peak rate is approximately the same. At the termination of the recovery cycle, the rate of solvent recovery had decreased to a final value of 20 milliliters (0.02 liters) per minute. The average condenser gas outlet temperature for this dryer load did not exceed 34°C (94°F).

Figure A-3 illustrates a dryer load that had total solvent emissions (3.71 kg solvent per 100 kg articles cleaned) approximately equal to the overall test average of 3.85 kg solvent per 100 kg articles cleaned. The curve representing the condenser inlet vapor concentration shows somewhat more of a peak than that of Figure A-1, but a much less pronounced and lower (5,810 ppm as solvent) peak than that of Figure A-2.

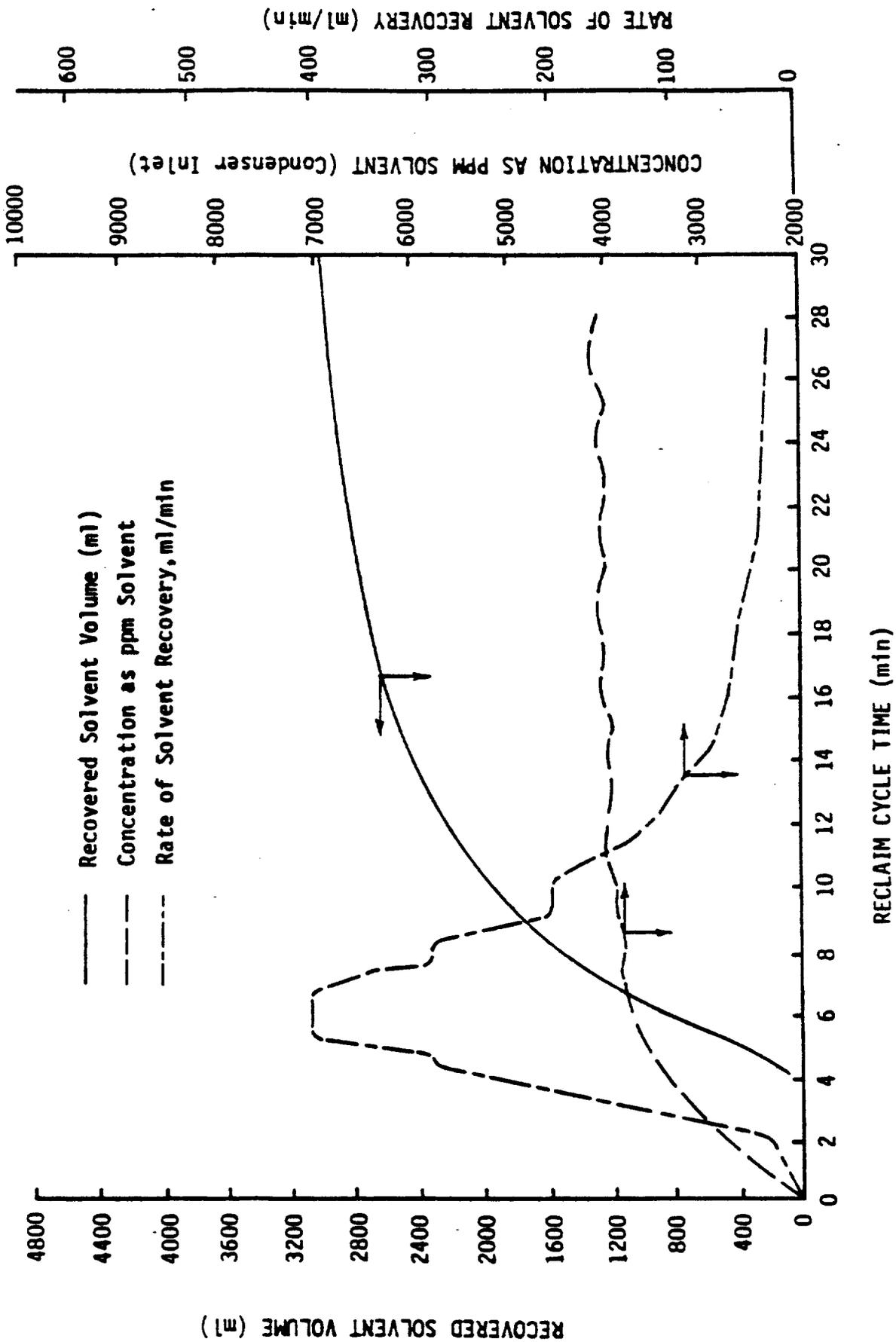
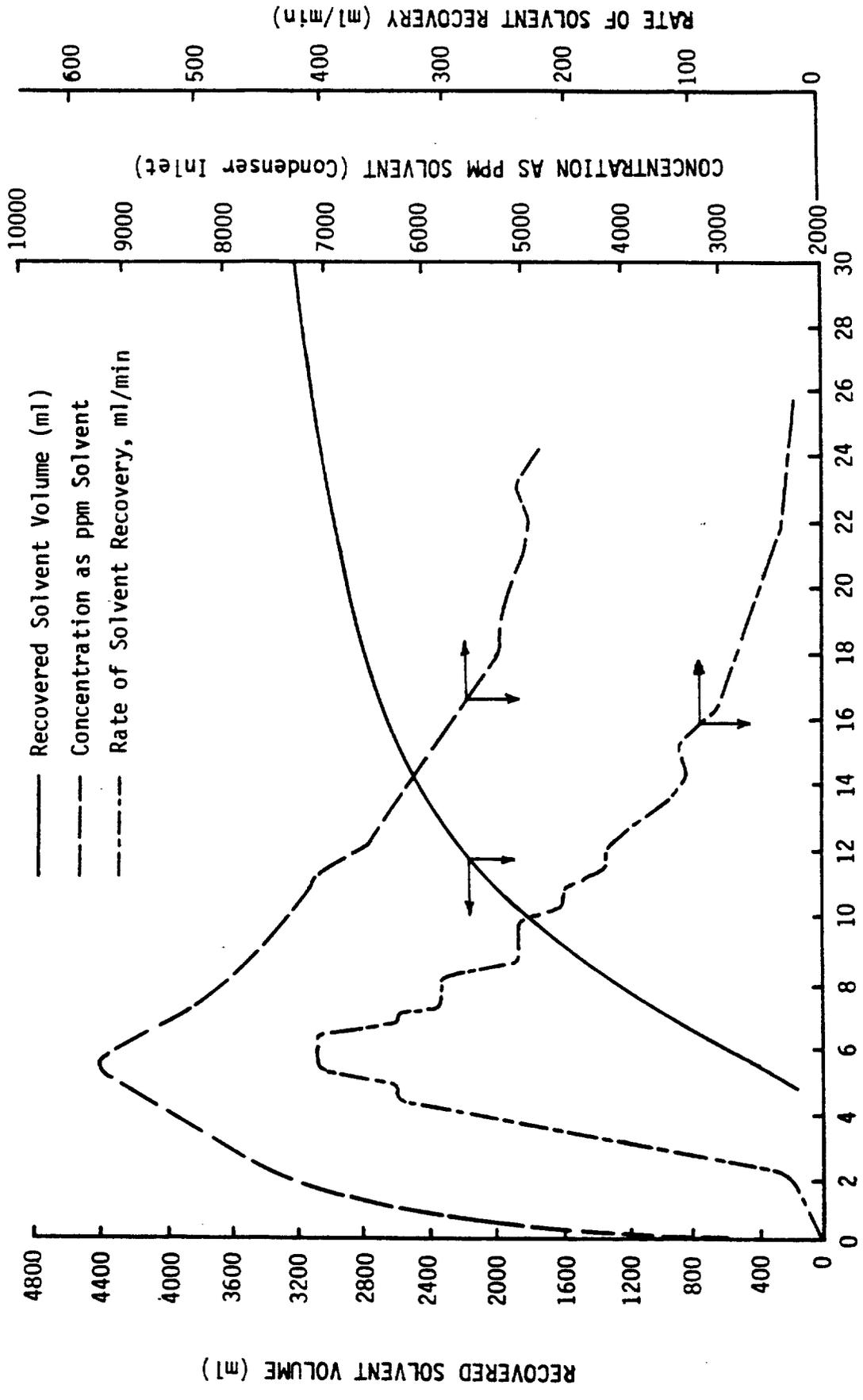
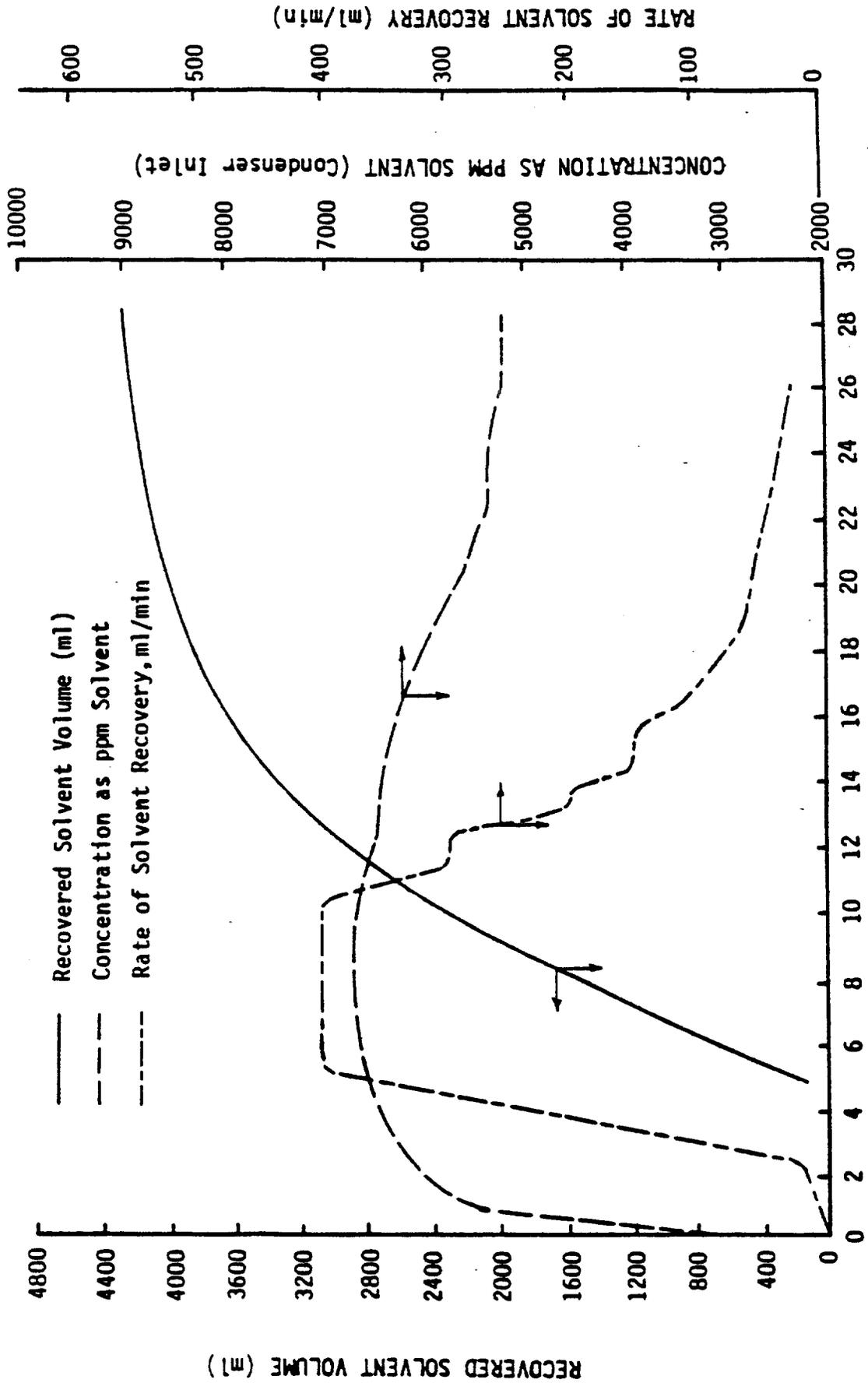


Figure A-1. Recovery and Concentration Curves for a High-Emission Recovery Dryer Load.



RECLAIM CYCLE TIME (min)

Figure A-2. Recovery and Concentration Curves for a Low-Emission Recovery Dryer Load.



RECLAIM CYCLE TIME (min)

Figure A-3. Recovery and Concentration Curves for a Recovery Dryer with Test-Average Emissions.

Simultaneously, the curve illustrating the volume of solvent recovered (Figure A-3) shows a rapid, sustained increase in total reclamation. This rate is further illustrated in the graph of the recovery rate which stays at a higher rate over the total cycle due to the heavier weight of this dryer load.

The overall decrease in solvent emissions per weight of articles cleaned that accompanied the increase in condenser water inlet temperature appeared to result from the higher solvent vapor concentrations associated with higher temperatures in the dryer tumbler. The rate of solvent condensation in the condenser appeared more dependent on the rate at which solvent was evolved from the drying articles than on the temperature of the cooling water. The 10° actual increase in the condenser water inlet temperature did not appreciably hamper solvent condensation. Thus, emission reduction might be enhanced by increasing the temperature within the dryer; either by increasing the pressure (temperature) of the steam, or by increasing the cooling water temperature. The limiting factor in this process is the solvent concentration in the tumbler which approaches, and may exceed, the solvent LEL of 1 percent by volume (10,000 ppm). To eliminate the possibility of explosion in the presence of an ignition source, the dryer should be operated at temperatures that produce solvent concentrations less than the LEL, while maintaining a high rate of solvent evolution in the drying articles.

One of the objectives of the test was to determine a "uniform dryness," a level of solvent concentration that would indicate sufficient dryness and solvent recovery. This goal was not attained because of difficulties encountered in the test contractor's equipment and the lack of control over the weight and fabric composition of drying loads. Also, the determination of the solvent content of the dried articles was hampered by the limited accuracy of the plant scales used to weigh the washed and dried loads.

### A.3 TEST 3 (WILMINGTON)

An EPA-sponsored study was conducted to determine the rate of solvent drainage from heavily soiled cartridge filter elements and to

compare the drainage rates of new and soiled cartridges. A recommendation was made for a minimum drainage time for these elements based on the total maximum solvent emission from the entire filtration system (Plaisance, 1981).

The host plant for this study was a petroleum dry cleaning facility located in Wilmington, North Carolina. This plant cleaned approximately 900 kg (2,000 lbs) of lightly soiled general apparel each week, expending about 380 liters (100 gallons) of Ashland Kwik-Dri solvent. Dry cleaning equipment used at this facility was limited to a single 27 kg (60 lb) capacity Marvel Matic washer and two 22 kg (50 lb) capacity Heusch Originator dryers. Spent solvent was filtered and purified by a 14-element cartridge filter (Puritan Vanguard 14) which employed 12 carbon-core and 2 all-carbon filter cartridges. The carbon-core filter elements served to both remove solids and provide initial purification, while the all-carbon filter element provided final solvent purification.

The test program for this study consisted of removing two filter cartridges (one carbon-core and one all-carbon) that contained heavy concentrations of lint and dirt from the cartridge filtration system. These elements, along with two new cartridge elements (one of each type), were soaked in sealed containers of solvent and then were allowed to drain while weight loss readings were recorded. The cartridge elements then were placed under an exhaust hood where the solvent was allowed to evaporate freely at room temperature, each sample cartridge was weighed twice each day for 7 days.

A comparison of the percent solvent loss, as a function of drainage time between new and used cartridges, indicated that the soil and residue loadings of both used cartridges caused a lower rate of solvent drainage. The largest differences in drainage rates occurred between new and used all-carbon cartridges, while a similar comparison of carbon-core cartridges resulted in a more equal percent drainage of initial solvent content over the entire drainage period. In general, carbon-core cartridges gave up solvent at a higher rate than all-carbon cartridges over extended periods of drainage and evaporation.

The results of this test indicate that a solvent drainage duration of 8 to 12 hours (overnight) would be sufficient to produce a minimal total emissions (see Figure A-4), while being brief enough to prevent disruption of normal plant operation. The undrained system emission rate of 0.56 kg solvent per 100 kg dry weight of articles cleaned would be reduced by 37 to 40 percent after drainage durations of 8 to 12 hours, respectively. Table A-3 shows emissions from cartridges over a period of several days. Comparison of solvent retention in new and used cartridges indicates that new cartridges having no soil and residue loading would have initial (undrained) emission roughly equivalent to those of the used cartridges. Therefore, general results gained in this test could be applied to facilities having lower throughputs between cartridge replacements and/or lower soil loading.

#### A.4 TEST 4 (ANAHEIM)

EPA contracted a study to collect and analyze data at a large industrial dry cleaning facility to evaluate the technical and economic feasibility of reducing the solvent content of still wastes through: (a) operating procedure modifications, and by (b) installing a densiometer in the still bottom to control the boildown schedule. In addition, hydrocarbon concentrations were measured from fugitive sources within the dry cleaning plant during the testing period (Jernigan and Kezerle, 1980).

The host plant for this test was a large industrial laundering and dry cleaning facility located in Anaheim, California. This facility utilized a 230 kg (500 lb) Washex washer/extractor and a 180 kg (400 lb) Challenge-Cook dryer to clean approximately 8,700 kg (19,000 lbs) of articles per week. In addition, the facility had two solvent stills, each with a 1,900 liter (500 gal) per hour capacity, manufactured by Washex. Data were collected at the plant for this evaluation from November 5 to November 19, 1979.

Procedures used to accomplish the test objectives included the determination of the boildown time for the vacuum still and the determination of the specific gravity of the solvent/still waste mixture during distillation by using a densiometer. Plant records were examined

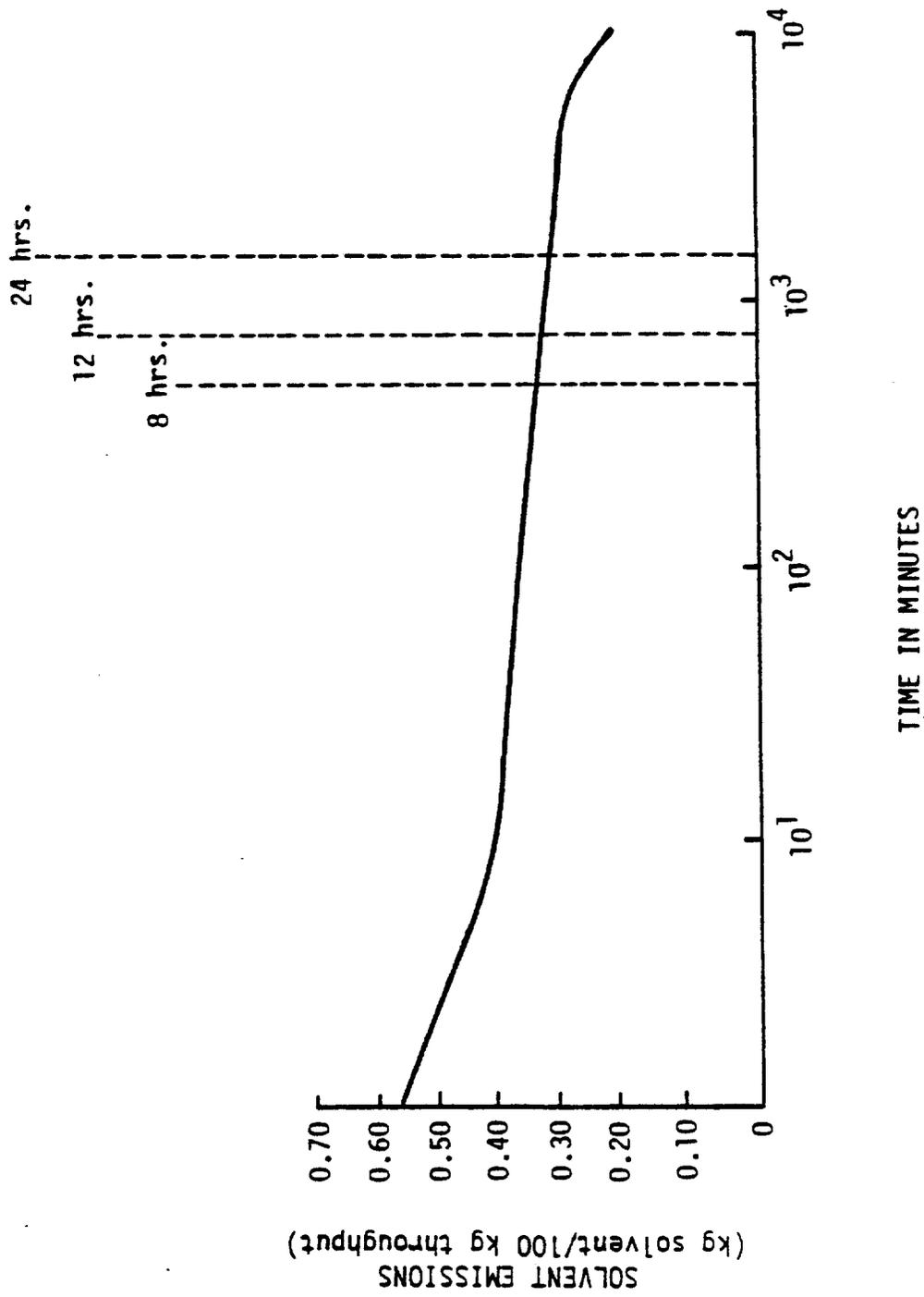


Figure A-4. Solvent Emissions for Filter Cartridges as a Function of Drainage Time.

Table A-3. TOTAL SOLVENT EMISSIONS DUE TO DISPOSAL OF  
 14 FILTER CARTRIDGES (12 CARBON-CORE AND 2 ALL-CARBON)  
 AS A FUNCTION OF DRAINAGE TIME

Elapsed drainage time	Solvent emissions (in kg solvent emitted per 100 kg of articles cleaned)	Percentage of undrained emissions
0	0.56	100
8 minutes	0.41	73
8 hours	0.35	63
12 hours	0.34	62
8.25 days	0.22	39

to determine the frequency of still boildowns. In addition, fugitive solvent emission levels at various locations in the plant were measured using a Beckman 400 flame ionization analyzer (FIA).

Hydrocarbon concentrations in and around the work area in the dry cleaning facility were reported as parts per million (ppm) of propane. (A standard conversion factor from propane to Stoddard of 3.36 was calculated.) Emissions could be approximated only for the roof exhaust, where approximately 1.56 kg (3.43 lbs) of Stoddard solvent was emitted per hour. The highest solvent vapor levels in the workplace were recorded around the washer, averaging about 3,300 ppm as propane or 980 ppm as Stoddard. Hydrocarbon concentrations at the clean solvent tank were an order of magnitude higher, reaching as high as 24,000 ppm as propane or 7,150 ppm as Stoddard solvent.

Results of this test indicated that measuring the specific gravity of the still contents during distillation with a densiometer was not feasible or even desirable, due to the adverse thermal and mechanical effects of rapid boiling on the sensitive densiometer mechanism. However, the solvent content of the still waste generated at this petroleum dry cleaning facility could be reduced, with no adverse effects, by boiling down the stills less frequently. At the time of this test program, the stills were boiled down and the waste in the sump was discarded daily. This meant that 144 liters (38 gal), or 115 kg of still waste, containing approximately 90 percent pure solvent by volume was discarded each day. Table A-4 records the samples of still waste that were analyzed for solvent content before and after boildown. On the first day (11-07-79) the still waste (sample VIS-4) contained more than 99 percent by volume (97% by wt) solvent. Still waste sample VIS-21 on the seventh day (11-14-79) represents the typical volume of solvent discarded daily at this plant and has the highest daily throughput. This sample contained approximately 90 percent by volume (91% by wt) solvent, representing a reduction of 5 percent over sample VIS-4, due to the reduced boildown frequency.

Table A-4. RECORD OF STILL WASTE BOILDOWN SAMPLES

Date	Military time	Sample no.	Throughput (kg)	Still waste (kg)	Weight percent solvent in waste	Solvent loss with waste (kg)	(kg) solvent loss/ 100 kg articles cleaned
11/07/79	0730	VIS-4	1360	115	97.40	112	8.20
11/14/79	1245	VIS-21	1588	115	92.20	106	6.70
11/15/79	1230	VIS-23	1360	115	91.30	105	7.70
11/16/79	1200	VIS-26	1425	115	93.00	107	7.50
11/19/79	1320	VIS-30	1425	115	73.00	84	5.90

Results from solvent content analyses conducted on 11-15-79 and 11-16-79 (VIS-23 and VIS-26, respectively) showed no appreciable difference in their solvent contents. Instead of a decrease in solvent content from samples VIS-23 to VIS-26, there was actually a 2 percent increase. This increase is considered insignificant on a day-to-day basis and may be attributable to a number of factors such as a change in the type of articles cleaned, still operation, or a slight variation in laboratory procedures for analyzing the still waste.

Still waste was allowed to accumulate for 10 days (11-09-79 to 11-19-79) before the still was boiled down again. On the last day of testing, the still was boiled down and sample VIS-30 was analyzed for its solvent content. This sample contained 25 percent less solvent, on a mass basis, than VIS-4 and 21 percent less solvent than VIS-26, as shown in Table A-4.

The analytical procedures used to determine the solvent content in each sample involved determining the moisture content by the Carl-Fisher Method and gravimetrically determining (at 103°C) the nonvolatiles in the samples. The solvent content then was determined by a process of elimination, in which the quantity of nonsolvent components was determined and then was subtracted from the total sample mass.

An alternate method to decrease solvent losses would be to reduce the total volume of still waste, by eliminating the inactive space in the still below the steam chest. In the tested still design, liquids below the steam chest did not receive sufficient heat to vaporize during boildown. These liquids, which contained a high concentration of solvents, were discarded daily after boildown procedures. The more frequently the still was boiled down, the greater the amount of solvent discarded with the wastes.

A VOC emission rate of 1.53 kg per hour was recorded (11-09-79) during the course of a 6 hour dry cleaning day when approximately 1,360 kg (3,000 lbs) of pants were dry cleaned. This equates to 227 kg of articles cleaned per hour. Thus, the ratio of the mass of fugitive solvent emitted per hour to the mass of articles cleaned per hour is 0.687 kg of fugitive VOC emitted per 100 kg of articles cleaned. Two access doors were open (front and rear of the dry cleaning area) during the fugitive

emissions test. It is assumed that the recorded fugitive emissions rate would have been higher if these doors were closed.

#### A.5 TEST 5 (ANAHEIM)

EPA contracted the evaluation and demonstration of carbon adsorption technology at an industrial dry cleaning facility in Anaheim, California (Lutz et al., 1980). This program was developed to determine the effectiveness of carbon adsorption in controlling VOC emissions. It consisted of fitting a prototype carbon adsorption unit, purchased from VIC Manufacturing Company of Minneapolis, Minnesota, to the dryer exhaust of a petroleum solvent industrial dry cleaning dryer; operating the system to collect performance data; and evaluating the economics of operation at this establishment.

The host dry cleaning plant in Anaheim, California, is a large, industrial facility utilizing a 230 kg (500 lb) Washex washer/extractor and a 180 kg (400 lb) Challenge-Cook dryer to process approximately 8,700 kg (19,000 lbs) of general apparel per week. This throughput represents about 50 percent of the 8-hour capacity of the dry cleaning dryer. Data were developed to determine the effect of the different utilization rates on the various parameters under evaluation. After installation of the carbon adsorption unit, testing was conducted at the facility from July 24, 1978 to March 23, 1979.

Test procedures used during the carbon adsorption test program included a determination of hydrocarbon concentrations by continuously sampling the gas streams to and from the carbon adsorption unit. This was accomplished using two Beckman 400 flame ionization analyzers (FIA). Both the inlet and exhaust gas stream flow rates were continuously monitored, as were the temperatures of the various liquid and gas streams. Other parameters measured during the test program included: electricity consumption, natural gas consumption, water usage, steam flow rate to adsorption unit, and solvent recovery rate. In addition, samples of solvent and samples of carbon from the carbon bed were analyzed infrequently during the test period.

The carbon adsorber system (see Figure A-5) was initially operated in strict compliance with the recommendations and instructions of the adsorber manufacturer and his field representatives. Early in this test

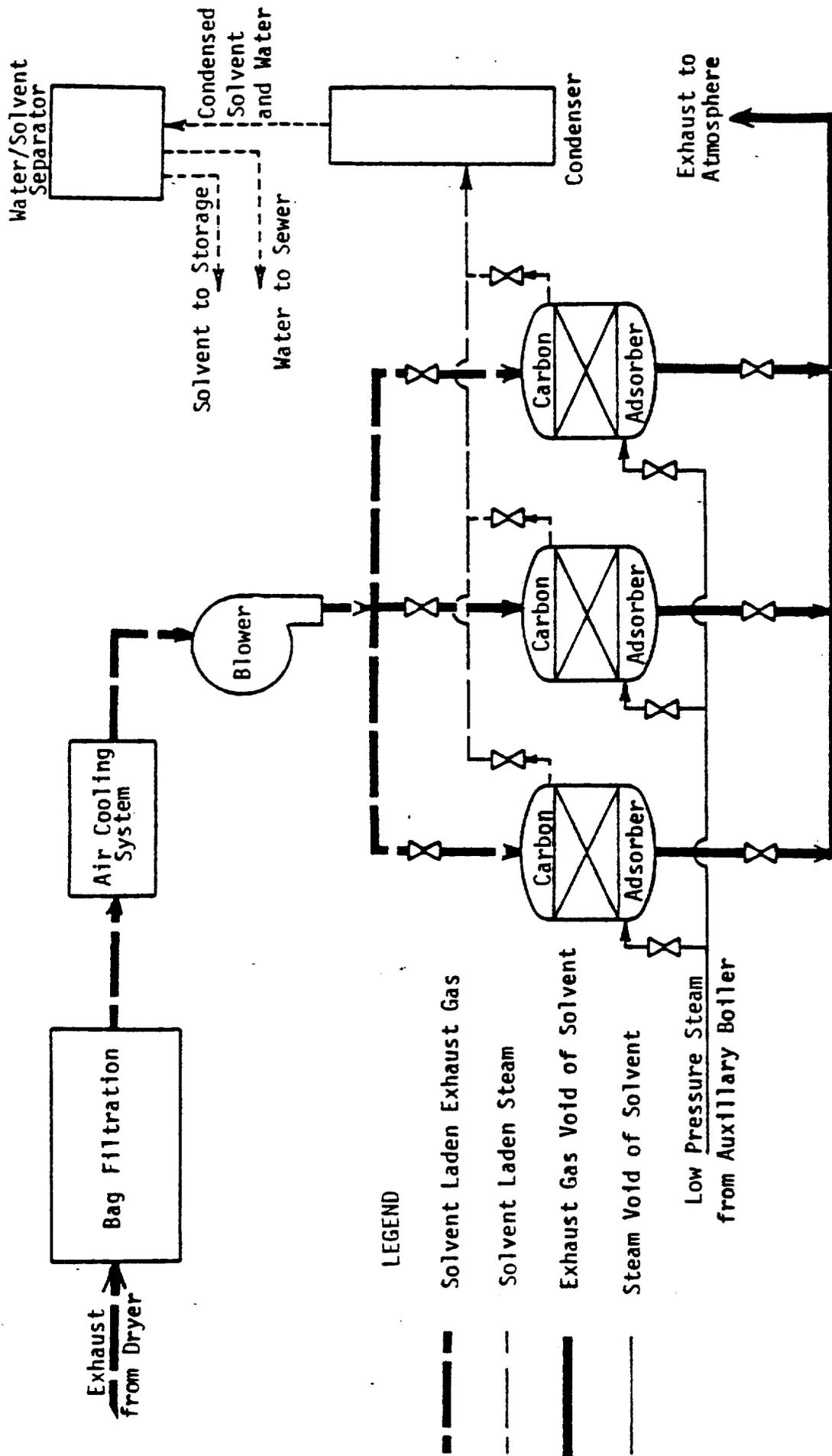


Figure A-5. Carbon Adsorption System Schematic.

period, it became apparent that the adsorption system had been oversized, resulting in removal efficiencies far in excess of the specified performance guarantee of 90 percent solvent removal on a 24-hour average. The test program was, therefore, amended to include an evaluation of changes to the design and operating procedures for the carbon adsorption system. Various design parameters were modified to determine their effect on the performance and cost of the adsorption system. From these studies, an optimized system was established for use in evaluating the performance, cost, and cost effectiveness of utilizing carbon adsorption technology for the reduction of VOC emissions from petroleum dry cleaning plants.

The following alterations to the original adsorber design resulted from the optimization: (1) the lint filter area was increased by 80 percent to facilitate daily cleaning; (2) the blower that forces the dryer exhaust through the adsorber was modified to operate only when the dryer was running, rather than continuously; (3) the original system of three carbon beds was reduced to two beds; (4) desorption steam pressure, flow rate, and duration were optimized at 103 kilopascals, 590 kg/hr, and 60 minutes, respectively; and (5) the adsorber inlet (dryer exhaust) vapor cooler was eliminated, because dryer exhaust temperatures were insufficient to damage the carbon beds.

The hydrocarbon emission reduction efficiency for the optimized design (applied to the dryer exhaust) was 95 percent, and varied from 93 percent for a plant with 100 percent utilization to 97 percent at 25 percent utilization. Capital costs for this system, including site preparation and equipment installation, are estimated at \$128,000 (mid-1978 dollars). Cost effectiveness, defined as the annual operating cost divided by the quantity of emission reduction, is a function of equipment utilization rates, and additionally exhibits a strong dependence on the market value of the recovered solvent. A solvent cost of \$0.16/liter (\$0.61/gal) was assumed for the basic analysis, but the effect of increases in petroleum costs on annualized operating costs was investigated. The cost effectiveness of the optimized design was \$560/Mg (\$510/ton), and was estimated as \$1,090/Mg (\$980/ton) and \$220/Mg (\$200/ton) for 25 percent and 100 percent utilization, respectively. When the value of Stoddard solvent reaches \$0.60/liter (\$2.30/gal), the optimized system (50 percent

utilization) will have zero annual operating costs, neglecting the rise in other operating expenses.

The results of this project demonstrate the technical feasibility of applying carbon adsorption technology to reduce the emission of hydrocarbon solvents from dryer exhausts at petroleum solvent dry cleaning plants. The cost effectiveness of this technique, \$560/Mg (\$510/ton), is expected to drop significantly as the value of the reclaimed solvent, a petroleum distillate, increases. Even at its present cost effectiveness, carbon adsorption is economically comparable with the cost of emission reduction required in other industries. An additional benefit, provided by the application of carbon adsorption technology to the petroleum dry cleaning industry, is the reduction in overall consumption of petroleum products by these plants. The demonstration plant recovered solvent at a rate of 61,000 liters (16,000 gals) per year which otherwise would have to be replaced with new solvent purchases.

#### A.6 REFERENCES FOR APPENDIX A

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