GUIDE TO SOLVENT WASTE REDUCTION ALTERNATIVES

FINAL REPORT

Prepared for:

Alternative Technology and Policy Development Section
Toxic Substances Control Division
California Department of Health Services

Prepared by:

ICF Consulting Associates, Incorporated
and its subcontractors:

Jacobs Engineering Group Inc.
Versar Inc.

October 10, 1986

ICF CONSULTING ASSOCIATES, INCORPORATED
707 WILSHIRE BOULEVARD, LOS ANGELES, CALIFORNIA 90017

GUIDE TO SOLVENT WASTE REDUCTION ALTERNATIVES

FINAL REPORT

Prepared for:

Alternative Technology and Policy Development Section
Toxic Substances Control Division
California Department of Health Services

Prepared by:

ICF Consulting Associates, Incorporated
and its subcontractors:

Jacobs Engineering Group Inc.
Versar Inc.

October 10, 1986

ABSTRACT

This Guide presents the results of ICF's study of solvent waste reduction alternatives. The focus of the study is on practical waste management alternatives to land disposal that have potential for reducing the amount and/or toxicity of solvent waste generated. Several tasks were performed for this study, including: (1) identifying major solvent-user industries in California; (2) reviewing current waste management methods and technologies; (3) characterizing source reduction alternatives for minimizing solvent waste; (4) characterizing on-site and off-site solvent recycling alternatives; and (5) characterizing treatment alternatives.

The analysis of solvent waste minimization primarily focuses on in-plant changes (source reduction) that could be implemented to reduce or eliminate the generation of solvent waste. Source reduction options are described for parts cleaning, equipment cleaning, coating application and solvent air emission control operations. As a source reduction measure, good operating practice is of paramount importance in discrete operations and is described separately. The secondary focus is on recycling and treatment options. Related regulatory background is described separately.

ACKNOWLEDGEMENTS

Many people contributed to and assisted in the development of this report. In particular, we wish to thank: David Leu, Benjamin Fries, Kim Wilhelm, and Jan Radimsky of the Alternative Technology and Policy Development Section at the California Department of Health Services for their guidance and suggestions; Elaine Eby of the Environmental Protection Agency, Office of Solid Waste; Carl Fromm, Srinivas Budaraju, David Butler, Michael Callahan, and Thuy Le of Jacobs Engineering; Barry Garelick, Julia Gartseff, Robert Boggs, and Olenna Truskett of Versar; and members of the project review team including the California Water Resources Control Board and the California Air Resources Board who assisted through their review and comment on the draft of this report.

This Guide was submitted in fulfillment of Contract No. 85-86835 by ICF Consulting Associates, Incorporated under the sponsorship of the California Department of Health Services. Work for this Final Report was completed on October, 10, 1986.

DISCLAIMER

CONTRACTS

Contract No. 85-86835 provided $149,999 to prepare this report and to present two symposia on solvent waste reduction alternatives. Performance of this contract involved two subcontracts of $30,000 each.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

PAGE

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (continued)

SUMMARY AND CONCLUSIONS

The California Department of Health Services (DHS) contracted with ICF Consulting Associates, Incorporated, and its subcontractors Jacobs Engineering Group Incorporated and Versar Incorporated, to conduct a study of solvent waste reduction alternatives. The objective of this Guide is to provide industry with information regarding alternatives to land disposal for solvent waste. Specifically, this Guide presents solvent waste management techniques for source reduction, recycling, and treatment. Regulatory incentives for solvent waste reduction are also discussed. As a complement to this Guide, the Proceedings for the 1986 DHS Solvent Waste Reduction Symposium have also been published.

This study focuses on solvent wastes primarily because solvents are widely used in industry and because of their effect on human health and the environment. Solvents used in industry are essentially organic compounds such as aliphatic or aromatic hydrocarbons, esters, ethers, ketones, alcohols, amines, and halogenated hydrocarbons. Not only are many of these solvents toxic to living organisms, but the very same properties that make them useful are responsible for their potential threat to the environment and human health. In particular, their high volatility results in air emissions which can cause air pollution and flammability problems at disposal sites. The hazardous constituents of solvents persist in the environment. Finally, land disposal of solvent wastes is a problem because of the solvents' ability to dissolve or penetrate polymeric liners and to dewater clay liners.

The scope of this study includes the following components:

- Identification of major solvent-using industries in California;
- Literature and data base review of current solvent waste management methods; and
- Identification of existing solvent waste reduction alternatives including source reduction, recycling, and treatment.

The Guide addresses solvent waste reduction according to the following hierarchy of exploration:

o Source Reduction:	Source reduction focuses on in-plant changes that can be made to either reduce or eliminate the generation of the solvent waste. This alternative is the most preferable waste management option, and should be explored first.
o Recycling:	Recycling refers to the reuse of a wastestream substance as an ingredient or feedstock in a production process, or reclamation of a waste material, involving recovery of reusable constituent fractions. Recycling is less preferable than source reduction, and should be explored second.

o Treatment:	Treatment refers to destruction of wastes through the use of technologies such as biodegradation, fixation, and incineration. Treatment is the least preferable option of the three components of waste reduction, and should be explored after source reduction and recycling alternatives are addressed.

Source reduction, recycling, and treatment practices all serve to either reduce the volume or the toxicity of wastes that are generated and ultimately land disposed. The Guide provides information on source reduction, recycling and treatment with the level of detail reflecting the priority ranking given above.

S.1 Summary of Major Findings

Many solvent waste generating industries rely on relatively few solvent waste-intensive operations. Consequently, source reduction is approached in the Guide from an operation-specific (as opposed to an industry-specific) standpoint. Recycling and treatment technologies are addressed from the standpoint of available technologies. The application of such technologies are, for the most part, independent of the industrial processes that produce the waste.

S.1.1 Source Reduction

Based on frequency of occurrence, three major operations appear to be responsible for most solvent waste generation in the state. These are: 1) parts cleaning, 2) process equipment cleaning, and 3) surface coating application. In addition to these three processes, two other topics are reviewed - good operating practice and air emission control.

Parts Cleaning. For parts cleaning, solvent waste generation can be minimized by: 1) eliminating use of solvents; 2) reducing the use of solvents; and 3) increasing the recyclability of solvents. Eliminating the use of solvents can be achieved by employing non-solvent cleaning agents or by eliminating the need for cleaning altogether. Solvent elimination applications include the use of:

- o Water-soluble cutting fluids;
- o Protective peel coatings;
- o Aqueous cleaners; and
- o Mechanical cleaning or paint stripping systems.

Methods that reduce the use of solvents are ways in which the number of parts cleaned per unit of unrecycled solvent can be increased. Three general methods are: 1) conservation of solvent via prevention of evaporative losses; 2) use of multi-stage countercurrent cleaning; and 3) maintenance of solvent quality.

Increasing the recyclability of solvents can be achieved by maintaining the quality of the solvent, standardizing the solvents used, and consolidating the use of solvent inside a facility. Maintaining solvent quality can be achieved by adding chemical stabilizers to the solvent to keep it from "going acid"; properly maintaining equipment to ensure that water contamination does not occur; allowing only dry parts to enter the cleaning operation; and minimizing process solution drag-out from parts. Standardizing the solvents used in a facility often increases the potential for recycling. By reducing the number of different solvents used in cleaning operations, there is a corresponding reduction of potential cross-contamination, generation of a single wastestream with reclamation value, simplified safety and operational procedures, and increased purchasing leverage.

Process Equipment Cleaning. Process equipment cleaning is a periodic maintenance function often performed with the use of solvents. Solvent waste generation from process equipment cleaning can be minimized by: 1) eliminating the use of solvent; 2) reducing the amount of solvent used; and 3) increasing direct reuse of solvent waste. Eliminating the use of solvent can be achieved through product reformulation and the use of other cleaning agents. Reducing the amount of solvent used can be achieved through measures including:

- Maximizing dedication of process equipment;
- Avoiding unnecessary cleaning;
- Properly scheduling production;
- Reduction of clingage;
- Efficient clean-up procedures; and
- Better operating practices.

Reuse of solvent wastes can reduce or eliminate wastes and result in cost savings associated with a decrease in raw material consumption. The solvent from cleaning can be reused in the next batch formulation, or to make a low grade product.

Surface Coating Application. Coatings are applied to various surfaces for functional or decorative purposes. In the coating application operation, solvent waste reduction can be achieved by three methods: 1) eliminating the use of solvents altogether in the coating formulations; 2) reducing solvent-bearing waste by technology changes and better operating practice; and 3) direct reuse of the solvent wastes. The various options for each of these categories is presented below.

- Eliminate the use of solvents:
    - Use powder coatings;
    - Use water-borne formulations;
    - Use two-component catalyzed coatings; and
    - Use radiation-curable coatings.
- Reduce solvent usage:

  - Replace conventional spray units with electrostatic units;
  - Replace air-spray guns with pressure atomized spray guns;
  - Use high-solids formulations in place of conventional solvent-based formulations;
  - Adopt good spraying techniques;
  - Avoid adding excess thinner;
  - Avoid excessive air pressure for atomization;
  - Maintain equipment properly;
  - Proper equipment layout;
  - Isolate solvent-based spray units from water-based spray units; and
  - Purchase bulk quantities of coating formulations.

- Reuse/recycling of solvent wastes:
  - Standardize solvent usage;
  - Segregate wastes; and
  - Recycle overspray/sludge.

Good Operating Practice. Good operating practice refers to a set of source reduction practices which can be implemented through an organizational modification of a production operation. The major elements of good operating practice discussed in the Guide are:

- Personnel practices:
  - Management initiatives;
  - Employee training; and
  - Closer supervision.
- Procedural measures:
  - Waste audits and reviews;
  - Additional documentation;
  - Material/waste tracking and inventory control; and
  - Scheduling.
- Loss prevention measures:

    - Spill/leak prevention program; and
    - Preventive/corrective maintenance.
- Wastestream segregation
- Material handling and storage

Good operating practice is of special significance to waste minimization efforts. The principles are generally well understood and changes can be instituted readily at low cost. The cost-to-benefit aspect is very high.

<u>Solvent Air Emissions Control</u>. In some cases, even the most intensive efforts to reduce air emissions at the source cannot obviate the need for end-of-pipe controls required to meet the regulatory air emissions limitations. The Guide provides a brief overview of commercially available air emissions control technologies including:

- Incineration;
- Carbon adsorption;
- Liquid absorption; and
- Condensation.

The methods which allow for recycling of recovered solvent are preferable to the methods which destroy solvents (e.g., incineration), unless the cost and waste disposal aspects offset the advantages of recovery.

S.1.2 Recycling

The goal of recycling is to recover solvent of a purity similar to the virgin solvent for reuse in the same process, or at least of sufficient purity to be used in another process application. Solvents can be recovered either on site or off site.

<u>On-site Recycling</u>. In general, the advantages and disadvantages of on-site recycling are as follows:

- Advantages
    - less waste leaves the facility;
    - owner has more control over reclaimed solvent's purity;
    - reduced liability of transporting waste off site;
    - reduced reporting (manifesting); and
    - possible lower unit cost of reclaimed solvent.
- Disadvantages
    - capital outlay for recycling equipment;

- liabilities and risks as a result of improper equipment operation or solvent quality maintenance;

- possible need for operator training; and

- additional operating costs.

Off-Site Recycling. Off-site commercial recycling generally is best suited for generators that lack the resources to procure and operate an on-site recycling unit, or whose solvent waste generation rates and patterns do not justify the capital and operating costs for an on-site recycling system. Off-site recycling has the disadvantage of potentially high transportation and liability costs as a result of potential clean-up problems associated with the recycler.

Separation Techniques for Solvent Recovery. A brief overview of the techniques used to purify or concentrate solvents is presented below.

- Distillation. Relies upon the difference in volatility between the solvent and the impurities present in the mixture. Involves evaporation of the solvent with simultaneous withdrawal and condensation of overhead vapor. May use single equilibrium stage (batch or "pot" distillation), or multistage distillation (fractional distillation).

- Evaporation. Often processes solvent bearing sludges or bottoms from distillation units; best suited for low-boiling solvents without abrasive solids. Waste is spread against heated walls of cylindrical vessels to obtain solvent vapors for collection.

- Sedimentation. Process in which gravity causes particles suspended in a liquid to settle. Applicable for removing solids suspended in organic solvents, generally as a preliminary purification or pre-filtration step.

- Decantation. Gravity separation technique used to separate immiscible liquids of different densities. Often used to remove insoluble oils from spent solvents in the dry cleaning and petroleum refining industries.

- Centrifugation. Technique used to separate phases with a similar density using centripetal force. Generally used as a preliminary purification step before other recycling operations.

- Filtration. Process that separates suspended particles from a liquid by using a porous filter medium. Generally used as a preliminary treatment step before distillation.

- Ultrafiltration. Process in which solute molecules with molecular weight exceeding 500 or particles with diameter not exceeding 0.5 microns can be separated from a wastestream using semi-permeable membranes as the filtering media. Current commercial applications include paint recycling from the electrodeposition painting process.

- Solvent extraction. Process in which the separation of components is achieved by placing the wastestream in contact with a liquid that acts as a solvent to one component but is relatively immiscible with the other component.

The Guide includes a brief discussion of technical considerations in selecting commercial packaged systems for on-site solvent recovery. Because there are many factors and options to consider when specifying solvent recovery distillation equipment, the Guide provides this information in datasheets, intended to guide the buyer through the major available options and choices.

S.1.3 Treatment and Pretreatment

Treatment technologies involve the removal of solvents from wastewater streams by physical means, the destruction of solvents in wastewater by chemical or biological means, and the destruction of solvent waste by thermal means. Brief descriptions of the various technologies follow below:

Chemical Treatment

- Wet air oxidation. Process in which an aqueous wastestream containing organics is placed in contact with heated air under pressure, thus causing the organics to oxidize. Used mainly for treating wastewaters that contain easily oxidized nonhalogenated solvents.
- Chemical oxidation. Process in which oxidants (such as potassium permanganate, ozone, or hydrogen peroxide) are used to break down or oxidize organic materials contained in wastewater. Effective on aqueous wastes containing less than one percent oxidizable material.
- Supercritical water treatment. Similar to the wet air oxidation process; oxygen is mixed into the wastewater and then heated to a temperature and pressure above the supercritical point of water. Water then aids in the decomposition of these wastes.

Biological Treatment.

- Activated sludge. Two-step process consisting of digestion of organic waste by sludge in an aeration basin for two to 24 hours, followed by clarification of the wastewater. Used to treat dilute solvent-bearing wastes that contain less than one percent suspended solids.
- Aerated lagoons. Shallow biological treatment basins that are maintained in an aerobic state by mechanical agitation. Lagoons contain a wide variety of naturally occurring bacteria and algae used to digest the organic waste.
- Trickling filters. Similar to activated sludge systems except that their design exhibits increased biological degradation rates. Aeration basin filled with rocks or artificial media increases the surface area for microbial growth.
- Anaerobic treatment. Conducted in a closed vessel without agitation, anaerobic bacteria digest simple organic and nitrogen-containing compounds by a series of oxidation-reduction reactions that do not require oxygen.

Thermal Treatment.

- Boilers. Used to destroy solvent waste by using the waste as a supplement to fossil fuel.

- Rotary kiln incinerators. Incinerator consisting of a cylindrical, refractory-lined chamber tilted several degrees off the horizontal. Efficiently burns viscous still bottoms, waste solvents, and solid material such as contaminated wipers.

- Liquid injection incinerators. Incinerator consisting of a refractory-lined combustion chamber and a series of nozzles which atomize the waste and fuel as they are injected into the chamber. Incinerates a wide variety of liquid wastes including phenols, PCB's, still and reactor bottoms, solvents and polymer wastes.

- Fluidized bed incinerators. Consist of refractory-lined vessel containing an inert granular material through which combustion air is blown, thereby separating the particles and imparting mixing in the form of bubbles. Waste enters the reactor and undergoes thermal oxidation under the high turbulence and uniform temperature conditions of the fluidized bed. Used in the petroleum, paper, and sewage disposal industries.

- Fixed hearth incineration. Consists of a single steel shell lined with refractory material. Incineration of the waste takes place in stages in the primary and secondary combustion chambers. Used for incinerating mixed wastes, including waste solvents and combustible solids.

- Multiple hearth incineration. Consists of a steel shell lined with refractory material, several refractory hearths situated one above the other, a central shaft that rotates, fuel burners, an ash removal system, and a waste feeding system. Used to dispose of sewage, industrial sludges, tars, solids, gases, and liquid combustible wastes.

- Infrared incineration. Relatively new technology for pyrolysis and subsequent oxidation of hazardous wastes. Wastes are conveyed under infrared heating elements.

- Oxygen incineration. Uses oxygen instead of air to achieve a higher destruction removal efficiency.

- Plasma arc. Plasma generator pyrolizes hazardous waste. Thermal plasma with temperatures ranging from 10,000 to 20,000 degrees Centigrade created by passing an intense electrical current through air at low pressure. Once injected into the plasma, the waste molecules are broken into individual atoms.

S.1.4 Regulatory Perspective

As reference, the Guide provides an overview of regulatory programs relevant to waste minimization. The regulatory programs reviewed include: 1) federal waste minimization requirements; 2) California hazardous waste reduction regulations; 3) air quality regulations; 4) federal and California water quality guidelines; and 5) federal and California occupational safety and health regulations.

S.2 Organization of the Guide

Chapter 1 provides an overview of the objectives of the Guide. Chapter 2 provides a profile of solvent waste generation. Chapter 3 presents the basic elements of and strategies for waste minimization. Solvent waste reduction techniques for source reduction, recycling, and treatment are presented in Chapters 4, 5, and 6, respectively. Finally, Chapter 7 provides an overview of relevant regulatory programs.

S.3 Conclusions

Reduction of solvent waste can be accomplished through a wide variety of existing techniques and practices in applications involving parts cleaning, process equipment cleaning, coating applications, air emission control and other operations. Source reduction measures should be addressed before recycling options are considered. Treatment of residuals, although ultimately necessary, should be addressed last, after source reduction and recycling options are fully explored. Source reduction techniques are extremely process- or application-specific. While very effective, some source reduction techniques should be applied with caution because of cost implications. Good operational control of human factors in production is of paramount importance to discrete or batch operations, such as those analyzed. Improvement of operating practices in such areas as employee training, closer supervision and employee motivation can accomplish a lot with a minimum cost.

Solvent waste recycling options include on site or off site reclamation, primarily through distillation and burning with energy recovery. Recycling technologies mostly rely on conventional, proven techniques. Treatment alternatives rely mainly on thermal, chemical or biological oxidation of solvent wastes. Techniques are available to deal with a wide range of waste types and concentrations. The current regulatory climate provides incentives for minimizing waste.

CHAPTER 1

INTRODUCTION

The State of California Department of Health Services (DHS) is responsible for coordinating research and development to promote the reduction and recycling of hazardous waste. As part of the process of formulating a broad hazardous waste reduction program, DHS contracted with ICF Consulting Associates, Incorporated, and its subcontractors Jacobs Engineering Group Incorporated and Versar Incorporated, to conduct a study of solvent waste reduction alternatives. The study identifies waste management alternatives for industry that can reduce the amount of solvent waste generated or increase the recyclability of the solvent waste that is generated.

1.1 Objectives of the Guide

This Guide provides information for managing solvent wastes through options other than land disposal. The primary objectives of this Guide are:

- identify solvent waste reduction practices currently used in California for each major industrial process; and
- recommend management techniques for source reduction, recycling and treatment that provide alternatives to land disposal.

The Guide analyzes solvent waste management in two ways. The first approach, source reduction, focuses on in-plant changes for reducing or eliminating the generation of solvent waste. It is the ideal waste management option. The second approach focuses on solvent waste management after the waste has been generated. This waste should be recycled or treated. The primary emphasis of the second approach is on recycling practices. Recycling refers to the reuse of a wastestream substance as an ingredient or feedstock in a production process, or reclamation of a waste material, involving recovery of reusable constituent fractions. Less preferable to recycling solvent waste is treatment. Treatment refers to destruction or degradation of wastes through the use of technologies such as biodegradation and incineration. Source reduction, recycling, and treatment practices all serve to either reduce the volume or the toxicity of wastes that are ultimately land disposed and as such are all considered waste reduction efforts. The depth of discussion devoted here to the waste management options reflects the priority given to each.

The Guide also includes a discussion of environmental and regulatory incentives for reducing solvent waste. Rising disposal costs and other economic considerations make waste reduction options increasingly attractive to industry. This Guide was prepared to promote alternatives to land disposal for solvent waste.

1.2 Solvent Properties and Solvent Use

Encyclopedia Brittanica defines solvent as "a substance, especially in liquid form, capable of dissolving or dispersing other substances called solutes." Depending on the applications for which a solvent is used, certain properties are desirable, for example, high volatility for solvents used as carriers for deposition coatings, or chemical inertness for solvents used as a reaction medium. Other properties include low viscosity, low surface tension, and an outstanding ability to dissolve other substances. Many organic liquids exhibit these properties. Classes of organic compounds such as aliphatic or aromatic hydrocarbons, esters, ethers, ketones, alcohols, amines, and halogenated hydrocarbons are widely used as industrial solvents.

The following use categories are common for solvents:

- dissolving medium for cleaning applications;
- vaporizable carrier for coatings, adhesives, and man-made fibers;
- aerosol propellant;
- refrigerant;
- foam blowing agent;
- disinfecting agent;
- extraction medium;
- entrainer for azeotropic distillation;
- inert reaction medium in organic synthesis; and
- chemical intermediate.

The principal end-use markets for solvents are listed below in descending order based on their percentage of the U.S. market share.

Market	1981 Market Share (percent)
Paints, coatings, inks	44
Process use	23
Metal cleaning	17
Dry cleaning	5
Adhesives	4
Other	7
Total	100

Source: Pace Company Consultants & Engineers, Inc. "Solvent Recovery in the United States 1980-1990", Houston, TX, 1983.

A study by Science Applications International Corporation for the California Air Resources Board estimated industrial solvent use in California by industry. Data are summarized for selected solvent species including: aliphatic hydrocarbons, aromatic hydrocarbons, chlorinated hydrocarbons, alcohols, glycols, ketones, glycol ethers, esters, fluorocarbons, and paint and lacquer thinners [4].

1.3 Solvent Hazards and Solvent Waste

Many organic solvents are toxic. University of Alabama researchers compiled extensive toxicological profiles of the physical and chemical properties for 36 popular organic solvents [1,2]. Selected data are provided in Table 1.1 and Table 1.2.

The very same properties that make organic solvents so useful, create a threat to human health and the environment when solvents occur in industrial wastes. Solvent volatility can result in emissions from the waste. When the waste is land disposed, the emissions can cause air pollution and fire hazards at the disposal site. Because a solvent is chemically inert, it resists natural degradation in a land disposal site. This persistence allows the solvent to retain its hazardous properties long after disposal. Solvents have low viscosity and low surface tension, that aid in penetration and destruction of the liner that is intended to seal the bottom of a land disposal site. A solvent can dissolve a polymer plastic liner, or extract water from a clay liner, resulting in liner leakage. The threat is compounded by the ability of solvents to dissolve and transport other hazardous materials in the disposal site.

In program activities, DHS staff includes the following partial list of solvent wastes:

1. Spent solvents from dry cleaning, parts degreasing, and electronics manufacture.

2. Solvent wastes from pharmaceutical, food, or chemical separation; extraction refining purification; or reaction processes.

3. Liquids and sludges from manufacture and use of paints, inks, and other solvent-bearing products.

4. Clean, unused solvent or solvent-bearing products in leftover batches too small to sell economically.

5. Solvent that has deteriorated in storage or has otherwise become contaminated during handling.

6. Semi-solid solvent residues such as tank bottom sludge, still bottoms, recovery sludge, and pre-treatment wastes.

7. Solvent-contaminated industrial refuse such as rags and filter cartridges.

8. Contaminated soils or water from solvent spills.

9. Dilute aqueous wastestreams containing solvents at very low concentration, resulting from washing parts, equipment, tanks, and process lines.

A 1981 California study on land disposal alternatives [3] identified solvent waste as a "high-priority" waste. High-priority wastes are those having the following characteristics:

- toxicity;

- persistence in the environment;

- ability to bioaccumulate; and

TABLE 1.1
SELECTED PHYSICAL PROPERTIES OF COMMONLY USED SOLVENTS

Solvent (a)	Molecular Weight	Normal Boiling Point (deg F)	Vapor Pressure Antoine's Constants (b)				Density (lb/cu ft) (@20 deg C)	Viscosity (cp) (@20 deg C)	Surface Tension (dyne/cm) (c)		Solubility in Water (ppm) (@20 deg C)	Heat of Vaporization (Btu/lb)
			Range (deg C)	A	B	C			a	b		
Acetone	58.08	133.0	liq	7.11714	1210.595	229.664	48.94	0.337	26.26	0.1120	miscible	215.45
n-Butyl Alcohol	74.12	243.0	15-131	7.47680	1362.390	178.770	50.11	3.379	27.18	0.0898	(f) 70,800	250.38
Carbon Tetrachloride	153.84	170.2	-	6.87926	1212.021	226.410	98.03	0.965	29.49	0.1224	(e) 880	83.78
Chlorobenzene	112.56	269.6	62-131	6.97808	1431.050	217.550	68.46	0.799	35.97	0.1191	1000	139.61
Cyclohexanone	98.15	312.1	94-161	6.25530	912.870	109.130	58.55	2.453	37.67	0.1242	(f) 50,000	165.05
Diethyl Ether	74.12	94.1	-61 to 20	6.92032	1064.070	228.800	(d) 44.51	(d) 0.247	18.92	0.0908	(e) 60,050	154.94
Ethyl Acetate	80.10	170.7	15-76	7.10179	1244.950	217.880	(e) 55.36	(e) 0.426	26.29	0.1161	85,300	173.48
Hexane	86.00	156.0	-25 to 92	6.87601	1171.170	224.410	40.81	0.313	20.44	0.1022	140	144.33
Isobutanol	74.12	226.6	20-115	7.32705	1248.480	172.920	(e) 49.37	(e) 3.910	24.53	0.0795	87,000	237.99
Methanol	32.04	148.5	-14 to 65	7.89750	1474.080	229.130	(e) 48.68	(e) 0.544	24.00	0.0773	miscible	462.92
Methyl Ethyl Ketone	72.12	175.3	43-88	7.06356	1261.340	221.970	49.80	0.423	26.77	0.1122	270,000	186.56
Methyl Isobutyl Ketone	100.16	242.2	22-116	6.67270	1168.400	191.900	49.54	0.542	23.64	19.6200	19,000	144.21
Methylene Chloride	84.93	104.0	-40 to 40	7.40920	1325.900	252.600	(d) 82.60	(d) 0.449	30.41	0.1284	13,200	250.38
Perchloroethylene	165.83	249.8	37-120	6.97683	1386.920	217.530	(d)100.94	(d) 1.932	32.86	31.2700	150	90.09
Toluene	92.15	231.1	6-137	6.95464	1344.800	219.480	(e) 53.36	(e) 0.552	30.90	0.1189	500	154.90
1,1,1- Trichloroethane	133.42	165.4	-6 to 17	8.64340	2136.600	302.800	83.49	0.903	28.28	0.1242	700	107.39
m-Xylene	106.17	282.4	28-166	7.00908	1462.266	215.110	53.48	0.617	31.23	0.1104	(e) 146	147.33
o-Xylene	106.17	291.9	32-172	6.99891	1474.679	213.690	54.47	0.809	32.51	0.1101	(e) 170	149.19
p-Xylene	106.17	280.9	27-166	6.99052	1453.430	215.310	53.29	0.644	30.69	0.1074	(e) 156	145.80

(a) Molecular weight and normal boiling point properties were taken from Hughes et al.'s "A Descriptive Survey of Selected Organic Solvents" (1985), with the exception of hexane for which these properties were taken from the NIOSH/OSHA Pocket Guide to Chemical Hazards (1978). Other properties were taken from Lange's Handbook of Chemistry (1979).

(b) Log 10 P (mm Hg) = A - B/[T(oC) + C].

(c) (dyne/cm) = a - bt(oC).

(d) Property is at 15 oC

(e) Property is at 25 oC.

(f) Property is at 30 oC.

TABLE 1.2
SELECTED HAZARDOUS PROPERTIES OF COMMONLY USED SOLVENTS

Solvent (a)	LD50 (Oral,rat) (g/Kg)	IDLH (ppm)	Threshold Limit Values		Ignitability	Reactivity
			TWA (ppm)	STEL (ppm)		
Acetone	(b) 10.70	20,000	750	1000	High	None
n-Butyl Alcohol	4.36	8,000	50	-	High	None
Carbon Tetrachloride	2.80	300	5	20	None	None
Chlorobenzene	2.90	2,400	75	-	Low	None
Cyclohexanone	(b) 1.62	5,000	25	100	Medium	None
Diethyl Ether	1.70	19,000	-	-	High	Low
Ethyl Acetate	11.30	10,000	400	-	High	None
Hexane	-	5,000	500	-	Medium	High
Isobutanol	2.46	8,000	50	75	High	None
Methanol	13.00	25,000	200	250	High	None
Methyl Ethyl Ketone	(b) 6.86	3,000	0.2	300	High	None
Methyl Isobutyl Ketone	2.08	3,000	50	75	High	None
Methylene Chloride	(b) 1.60	5,000	100	500	None	Low
Perchloroethylene	8.85	500	50	-	None	None
Toluene	(b) 7.53	2,000	100	150	High	None
1,1,1- Trichloroethane	10.30	1,000	350	450	None	Medium
m-Xylene	5.00	10,000	100	150	High	None
o-Xylene	5.00	10,000	100	150	High	None
p-Xylene	5.00	10,000	100	150	High	None

(a) Toxicological properties were taken from Hughes et al.'s "A Descriptive Survey of Selected Organic Solvents" (1985), with the exception of hexane for which these properties were taken from the NIOSH/OSHA Pocket Guide to Chemical Hazards (1978).

(b) Unit of property is in ml/Kg.

- mobility in a landfill environment.

In the study, DHS noted that solvent waste (halogenated and non-halogenated organics) comprises about 10 percent of all hazardous waste generated in California and nearly 30 percent of all high-priority waste. DHS also reported that technically and economically feasible source reduction, recycling, and treatment methods for solvent waste exist. Based on these observations, the state government enacted a ban on the land disposal of liquid solvent waste. The State of California now requires that all recyclable waste be recycled whenever it is economically feasible to do so.

1.4 Solvent Waste and Air Quality Control

Solvent wastes have impacts that extend far beyond hazardous waste management. One major impact is on facility air emissions and ambient air quality. Less solvent use by a facility means lower probability of solvent escaping from that facility. Substituting for solvents in product formulations means no solvent emissions when the product is used.

Other impacts involve worker health and safety, reduced material handling and storage risks, and conservation of resources.

1.5 Regulatory Trends in Solvent Waste Management

The 1984 amendments to the 1976 Resource Conservation and Recovery Act (RCRA) impose a national ban on the land disposal of halogenated and non-halogenated solvent waste (RCRA waste nos. F001-F005). This ban is scheduled to go into effect in November 1986 (RCRA Sec. 3004(e)). In the opening clauses of RCRA, Congress declared that "certain classes of land disposal facilities are not capable of assuring long-term containment of certain hazardous wastes...and land disposal, particularly landfill and surface impoundment, should be the least favored methods for managing hazardous wastes" (RCRA Sec 1002(a)(7)). Congress further stated that "alternatives to existing methods of land disposal must be developed..." (RCRA Sec. 1002(a)(8)).

1.6 Scope and Approach of the Study

The scope of this study is to characterize solvent waste generation, methods for reduction within processes, and methods for management of waste that is generated. Specifically, the scope includes the following components:

- Identification of major solvent-user industries in California;
- Literature and data base review of current solvent waste management methods;
- Identification of existing solvent waste reduction alternatives; and
- Identification of on-site and off-site solvent recycling alternatives.

The primary approach to the study was first to conduct a review of existing data and literature pertaining to solvent waste generation and waste management methods. Solvent waste generation was characterized by industrial categories, in large part, by examining the California manifest data. Industries generating the greatest volumes of solvent waste were examined further to determine if they could be categorized as major solvent users in the state.

Also identified were solvent using operations that generate solvent waste and that are common to all or most industries. Since many solvent-waste-generating industries rely on relatively few solvent-waste-intensive operations, this study was able to approach source reduction from an operation-specific (as opposed to an industry-specific) standpoint.

Each of the operations identified was then evaluated in terms of three basic source reduction objectives:

1) eliminate solvent use;
2) reduce solvent use or loss; and
3) increase solvent recyclability.

The degree to which any waste reduction alternative met these three objectives was evaluated for each of the following source reduction components:

- Product reformulation;
- Process modification;
- Substitution;
- Segregation;
- Standardization;
- Contaminant reduction;
- Inventory control;
- Spill/leak control; and
- Procedure alteration.

On-site and off-site recycling alternatives were examined and categorized in terms of direct reuse and reclamation processes (or recovery processes). Each technology or method was further characterized based on the prevalence of such techniques with respect to on-site and off-site applications. To characterize the use of off-site recycling alternatives, various recycling/treatment firms in California were contacted by telephone. Information was collected on expected costs, design capacity, and actual capacity.

1.7 Organization of the Guide

The first part of the Guide provides a profile of solvent waste generation (Chapter 2). Specifically, Chapter 2 provides a basic understanding of how, why, and where solvents are used. Information on the types and amounts of solvent waste generated in California is also given for specific industries. Chapter 3 of the Guide provides a general discussion of the causes of solvent waste generation and the basic elements of and strategies for waste minimization. Chapter 3 also discusses the typical cost components that are considered in the analysis of the economic feasibility of waste minimization projects.

Chapter 4 describes the various source reduction techniques that can be used in conjunction with major solvent waste intensive operations, such as parts cleaning, equipment cleaning, surface coating and solvent air emissions control operations. Chapter 4 discussion focuses on the specifics of source reduction as applied to major industrial operations and practices common to solvent waste generating industries. Where possible, each method or approach has been illustrated with actual application examples and supplemented with cost data.

Chapter 5 provides a discussion of basic principles and technologies used in solvent recycling for both on-site and off-site recycling operations. The discussion of recycling contains a description of commonly used separation techniques, such as distillation and evaporation. Additionally, the chapter includes a discussion of waste exchange operations in California.

Chapter 6 provides a discussion of on-site treatment options and is primarily focused on destruction technologies for solvent waste (e.g., incineration, bio-oxidation and chemical oxidation of solvent wastes).

Finally, Chapter 7 provides an overview of specific regulatory programs in terms of their effect on generators' decisions to employ solvent waste reduction practices. The regulations that are examined include EPA's scheduled land disposal ban and California's hazardous waste management requirements, which include specific recycling provisions. Recently enacted California legislation promoting waste reduction and recycling alternatives are also presented as well as applicable air and water regulations.

It should be noted that because of the size, diversity, and complexity of the subject matter, this Guide is best viewed as an informational tool allowing one to scan through the identified alternatives and obtain references for further information. The Guide is not intended to provide definitive design data or rigid operational parameters. These are case-specific and cannot be meaningfully addressed in a general way.

REFERENCES FOR CHAPTER 1

1. George, W. J., L.A. Martin, L.E. White. Toxicity Profiles of Selected Organic Solvents, Open File Report, No. 4, Environmental Institute for Waste Management Studies, University of Alabama, Tuscaloosa, Alabama, June 1984.

2. Hughes, T.H., K.E. Brooks, B.W. Norris, B.M. Wilson, B.N. Roche. Descriptive Survey of Selected Organic Solvents, Open File Report, No. 1, Environmental Institute for Waste Management Studies, University of Alabama, Tuscaloosa, Alabama, August, 1985.

3. Stoddard, S.K., G.A. Davis, H.M. Freeman. Alternatives to Land Disposal of Hazardous Wastes: An Assessment for California, Toxics Waste Assessment Group, Governor's Office of Appropriate Technology, Sacramento, CA, 1981.

4. Science Applications International Corporation. Development and Improvement of Organic Compound Emission Inventories for California, Prepared for the California Air Resources Board, January 22, 1985.

CHAPTER 2

SOLVENT WASTE GENERATION

This chapter provides an overview of solvent use and waste generation in California. Section 2.1 describes industries that manufacture or use solvents, as well as the solvent types, properties, and applications used by these industries; the number of establishments by Standard Industrial Classification (SIC) code; and their geographical distribution. Section 2.2 provides a summary of solvent-use-intensive operations by industry.

2.1 Solvent Use Intensive Industries

The purpose of this section is to identify the industries in California that manufacture or use organic solvents. Solvents are commonly used in dry cleaning, cold cleaning, solvent extraction, and vapor degreasing. Solvents are also essential to the production of coatings, stains, wood-treatment chemicals, printing inks, pesticides, and agricultural chemicals. Solvents are used as inert reaction media in chemical and pharmaceutical formulation [1].

Solvents are incorporated into a manufactured product for several of the applications, such as printing ink. The volatility of solvents imparts fast-drying properties in the ink. In other applications, such as vapor degreasing of metal parts, the use of the solvent is confined to the cleaning process, and the solvent becomes "spent" as it picks up oil and grease from the metal parts.

Most applications result in generation of solvent waste and, therefore, most user industries are also generators of solvent waste. Solvent wastes include off-specification batches of products containing solvents, and contaminated or spent solvents from process applications. One method to identify solvent-user industries is to identify solvent waste generators and assume that high-volume solvent waste generators are high-volume solvent users.

Solvent waste generators by industry were identified in large part from California manifest data. Because the manifest data base currently does not categorize industry information by Standard Industrial Classification codes, it is difficult to obtain a precise breakdown of waste generation by industry. The results presented here, therefore, should be considered exploratory estimates rather than precise counts.

The 1984 California manifest data for hazardous wastes disposed off site were examined to identify high-volume generators of solvent wastes. "High-volume generator" was defined as a facility that generated 50 tons or more of solvent waste during a specified reporting period (01-01-84 to 12-31-84). Standard Industrial Classification codes were assigned to individual facilities identified from the manifest records, and reported waste volumes were summed for all facilities within an SIC category. Those SICs with the highest total volume of solvent waste generated (all greater than 1,000,000 gallons in 1984) were selected as probable high-volume solvent-user industries.

The list of SICs compiled from the manifest data does not necessarily account for high-volume solvent-user industries that consume or treat most of their solvents on site, or for small quantity users. Therefore, the list of SICs identified from the manifest records were checked against other data sources [1,2] to verify that all probable high volume users of organic solvents are included. These sources list industries commonly known to use organic solvents as part of their manufacturing, fabrication, or maintenance processes. Information sources for point source category volatile organic compounds (VOC) emissions were also consulted [16]. Small quantity solvent-user/generator industries were identified from a study of small quantity generators in Southern California [3]. Finally, the number and distribution of establishments for each solvent-user industry was estimated by consulting the U.S. Bureau of the Census, County Business Patterns database (Appendix A).

The following industries were identified as probable high-volume users of organic solvents based on the methodology described above:

Business Services Including Solvent Reclamation Facilities (SIC 7399). There is no SIC code that applies solely to solvent reclamation facilities. SIC 7399, Business Services, Not Elsewhere Classified, consists of approximately 120 services (e.g., bondsmen, drafting services, and interior decorators) including solvent recovery services on a contract basis. Although this SIC code is appropriate for inclusion in this study, the number of facilities listed in Appendix A may be overstated. It is not possible for the Bureau of Census data base to differentiate among the services within SIC 7399. Thus, this SIC code includes facilities other than solvent recylcing firms.

This industry was identified by the large volume of solvent waste reported in the California waste manifest data. Some quantity of recycled solvent wastes may be double counted, once by the user industry and once by the recycling firms. Wastes of concern for this industrial group are halogenated organic still bottoms, which are residues from distillation of halogenated solvent wastes. A listing of California commercial recycling facilities is provided in Chapter 5, Table 5.2.

Manufacture of Paints, Varnishes, Lacquers, Enamels, and Allied Products (SIC 2851). Solvents are used in the paint-formulating industry as carriers for resins. Solvents are also used to clean the formulating equipment between batches. Although cleaning solvents are often distilled and recycled, a paint sludge residue is formed. This residue is contaminated with solvents and, for some paints, with toxic metals, such as mercury, chromium and lead. The spent cleaning solvents and solvent-contaminated paint sludges must be disposed of as hazardous wastes.

Of the estimated 219 paint manufacturing facilities in California, 101 are in Los Angeles County. Orange, Alameda, San Francisco, and Santa Clara counties have an estimated 22, 20, 10, and 10 facilities, respectively.

The paint manufacturing industry was the highest-volume generator of all California industries reporting manifested solvent wastes in 1984. The industry disposed of 21,000 tons of solvent waste off site. The wastes reported were either unspecified mixtures of solvents, paint sludges, or halogenated organics.

Cyclic (Coal Tar) Crudes and Cyclic Intermediates Dyes and Organic Pigments (SIC 2865) and Wood Preserving (SIC 2491). Facilities in SIC 2865 typically manufacture a wide variety of coal tar products and intermediates, including protective enamels, paints and varnishes, polyester resins, creosote oil, roof felt, and pressure-treated wood. Wood-preserving oils are one of the principal bulk commodities derived from coal tar [4], and, therefore, the wood-preserving industry is included in this group. There are only seven coal tar product manufacturing facilities in California distributed among Alameda, Contra Costa, Los Angeles, Orange, and San Bernardino counties. The solvent wastes manifested by these industries in 1984 include unspecified mixtures of solvents. There are an estimated 27 wood-preserving facilities in California, but these are not high-volume solvent waste generators.

Industrial Organic Chemicals Manufacture (SIC 2869). Products manufactured by this category include halogenated and nonhalogenated solvents, plasticizers, synthetic perfume and flavoring chemicals, synthetic tanning agents, and esters and amines of polyhydric alcohols and fatty acids. Off-specification products and equipment cleaning wastes may be among the solvent wastes disposed of by this industry category. In California there are approximately 57 manufacturing facilities in this category, one-third of which are located in Los Angeles County.

Pesticides and Agricultural Chemicals (SIC 2879). Facilities in this SIC code manufacture and formulate ready-to-use pesticides and agricultural chemicals. Insecticides or herbicides are dissolved in solvents containing emulsifiers to allow dilution with water for field application. Kerosene, xylenes, related petroleum fractions, methyl isobutyl ketone, and amyl acetate are the most commonly used solvents for these applications [5].

There are approximately 40 pesticide and agricultural chemical formulation companies in California, distributed among 16 counties. Thirteen of the companies are located in Los Angeles County.

Manufacture of Printing Ink, Gravure Ink, Screen Process Ink, and Lithographic Ink (SIC 2893). The type of solvent used in the manufacture of ink products depends on the printing process and surface to which the ink will be applied. Aliphatic hydrocarbon solvents are used to dissolve various resins in the formulation of letterpress and litho newsprint inks [6]. Low boiling-point alcohols, esters, aliphatic and aromatic hydrocarbons, or ketones, are used for their fast-drying properties in formulating flexographic and rotogravure inks. In contrast, high-boiling point (280-370° C) hydrocarbon solvents are required for duplicator and business form inks [6]. Diethylene, dipropylene, or triethylene glycols are used to make corrugated and Kraft-liner container inks [6]. Manufacturers of printing ink generate and dispose of large volumes of sludges and unspecified mixtures of solvents.

There are 54 facilities designated in SIC 2893 in California. Thirty-three of the facilities, over 50 percent, are located in Los Angeles County.

Chemicals and Chemical Preparations, Not Elsewhere Classified (SIC 2899). Companies in this category include manufacturers of pigment dispersions for plastics, paint, and urethane foam; oil field emulsion-breaking compounds; corrosion inhibitors; anti-foamers; water-treating compounds; and laboratory chemicals. Companies that produce vegetable oils (e.g., soybean oil) are also included in this category. Hexane, used for extraction of soybean oil, is commonly recovered for reuse by evaporation and drying [7]. Wastes manifested in 1984 are classified as unspecified mixtures of solvents. There are an estimated 173 establishments that formulate chemicals in this industry in California. Centers of activity are in Los Angeles County (66 facilities); and Orange, Alameda, San Diego, and Contra Costa counties (21, 17, 10, and 8 facilities, respectively).

Petroleum Refining (SIC 2910). Petroleum distillate solvents such as paint thinner and Stoddard solvent used in dry cleaning are end products of petroleum refining [8]. In addition, large quantities of solvents are used in petroleum refining for purification. Solvent extraction is used to remove aromatic constituents from naphtha fractions and in preparation of high-quality lubricating oils. In a process called solvent deasphalting, propane, phenol, or furfural are used to separate asphalt from oil that is then fed to catalytic cracking processes. Solvents such as toluene are also used as additives in unleaded gasoline [8].

Fifty-two establishments including several major oil refineries generate a variety of solvent wastes, including hydrocarbons, degreasing sludges, and paint sludges. Centers for petroleum refining by number of establishments include Los Angeles, Kern, and Contra Costa counties. These counties have an estimated 22, 12, and 6 establishments, respectively.

Semiconductors and Related Devices (SIC 3674). Manufacturers of semiconductors and other closely related manufacturing processes generate large volumes of unspecified mixtures of solvent waste, halogenated, oxygenated, hydrocarbon, and paint sludges. Solvents are used during the etching of silicon wafers. Between processing steps, wafers are rinsed in several solvent or solvent mixture baths of high purity. Since the rinse waters must be changed frequently, high volumes of waste solvents are generated. Control of VOCs by adsorption of the gaseous wastestream from these processes results in an additional volume of solvent waste for most facilities.

There are approximately 127 establishments manufacturing semiconductors in Santa Clara County. Los Angeles County (42 facilities) and Orange and San Diego counties (25 and 21 facilities, respectively) are minor centers for this industry in California. There are a total of 237 such establishments in California.

Electronic Components and Accessories (SIC 3679). This industry includes manufacturers of receiving antennas, printed circuits, switches, magnetic recording tape, microwave components, ceramic capacitors, and other electronic components. There are 1,033 establishments that manufacture electronic components in California. The counties with the greatest number of establishments are Los Angeles (279), Santa Clara (251), and Orange (182), with minor centers in San Diego, San Mateo, Alameda, and Ventura counties (72, 37, 32, and 31 facilities, respectively). In 1984, halogenated and unspecified mixtures of solvents were disposed of by this industry.

Manufacture of Motor Vehicles and Passenger Car Bodies (SIC 3711). Motor vehicle manufacturing is a high-volume solvent-user/generator industry in California. Surface coating operations and degreasing of metal parts are solvent-use-intensive operations in motor vehicle manufacturing. VOC emissions from these processes require air pollution control devices at most facilities. There are 31 motor vehicle manufacturing facilities in California. Twelve of the facilities are in Los Angeles County and seven in Orange County. Solvent wastes reported by this industry group include halogenated and oxygenated solvents, degreasing residuals and paint sludges.

Aircraft Manufacture (SIC 3721). Facilities engaged in the manufacture or assembly of complete aircraft are high-volume solvent users as indicated by waste manifests for 1984. The types of waste generated are similar to those for the automotive manufacturing industry, suggesting similar uses such as degreasing and surface coating applications. There are 37 aircraft manufacturing facilities in California, distributed among 14 counties; 17 of the facilities are located in Los Angeles County.

National Security (SIC 9711). United States Department of Defense (DOD) installations in California are high-volume solvent-user facilities as indicated by the volumes of solvent waste generated. Six U.S. Air Force and Naval Air Station installations accounted for 2,350 tons of solvent waste in 1984. Building, equipment, and vehicle maintenance account for a large volume of the solvents used.

Other Solvent-User Industries. A number of industries other than those identified as high-volume waste generators are known to use solvents in their normal operations. They are important to the profile of solvent use in the state either because they represent a large number of small quantity users/generators or because their recovery of solvents minimizes waste generation. They provide a model that may be transferrable to other industries that generate large volumes of solvent waste. These industries and their use of solvents are briefly discussed below:

> Dry Cleaning (SICs 7215, 7216, 3582). This category includes coin-operated dry cleaners, dry cleaning except rugs, and rug cleaning, respectively. Perchloroethylene (tetrachloroethylene) is used in approximately 70 percent of dry cleaning operations and Stoddard solvent, a petroleum distillate, is used in approximately 28 percent of operations [9]. Petroleum distillates are too flammable for use in coin-operated dry cleaning machines. Solvents are routinely recycled to the cleaning process by evaporation and condensation [7]. Solvents not recycled on site are accepted for recycling by commercial recyclers, such as Reclamar Inc., a commercial recycling company established in 1984 [10].
>
> Motor Vehicle Dealers and General Automotive Repair Shops (SICs 5511 and 7538). Solvents are used by these industries for parts cleaning in vehicle maintenance activities. Establishments in this category are small quantity generators (SQGs) of mostly nonhalogenated solvents. A 1982 survey of small quantity generators in North Hollywood and the surrounding area determined that the automobile industry accounts for 50 percent of all SQGs in the study area as compared with an average of 24 percent nationwide [3]. There are 2,530 auto dealerships (it is not known how many of these have automotive repair shops) and 4,888 general automotive repair shops in California, 1,736 of which are in Los Angeles County.

Pharmaceutical Manufacture (SIC 2834). Solvent recovery by liquid-liquid extraction is commonly performed by this industry [7]. Ethyl alcohol and triethylamine are recovered in closed-loop processes in antibiotic manufacture [7]. There are 75 pharmaceutical manufacturing facilities in California. Manufacturing centers are in Los Angeles, Orange, and Santa Clara counties (35, 17, and 10 facilities, respectively).

Manufacture of Metal Household Furniture (SIC 2514) and Metal Office Furniture (SIC 2522). Surface coating (spray painting) of metal furniture and cleaning of parts and equipment are operations that require organic solvents. There are 74 metal household furniture manufacturing facilities in California, 54 of which are located in Los Angeles County. Twenty-two of the 34 metal office furniture manufacturing facilities in California are also located in Los Angeles County.

Photo Finishing Laboratories, Commercial Photographers, and Related Services to the Motion Picture Industry (SICs 7395, 7333, and 7819). Solvents used in black-and-white film developing or after-treatment (e.g., retouching) include acetone, methanol, polyether alcohol, toluene, xylene, trichloroethylene, ethylene glycol, and mineral spirits. In color film developing, benzyl alcohol, ethylene glycol, or cellosolve solvents are used in developing solutions and 2,5 dimethoxytetrahydrofuran is used as a solvent for hardener/prehardener treatments [11]. There are 678 photofinishing laboratories, 1,066 commercial photographers, and 924 motion picture service industry establishments in California that are probable users of the solvents listed above.

The Environmental Protection Agency identified the following industries as small quantity generators of spent solvents or still bottoms [12]:

- Printing and publishing;
- Rubber and miscellaneous plastic products;
- Fabricated metal products;
- Machinery, except electrical;
- Trucking and warehousing;
- Health services; and
- Lumber and wood products.

Additional information regarding solvent use and waste generation by industry may be found in references 13, 14, and 15.

2.2 Solvent Use Intensive Operations

Compared to the number of industries that use solvents and generate solvent waste, the number of specific types of operations in which solvents are used is relatively small. For example, one of the solvent-use intensive operations, parts cleaning, is performed in electronic components manufacturing, vehicle manufacturing, aircraft manufacturing, metal finishing industries, and in equipment maintenance shops of almost any industrial facility. Similarly, equipment cleaning is performed in paint manufacturing, pesticide formulation, semiconductors manufacturing and other manufacturing processes. Table 2.1 lists these common solvent-use intensive operations along with the industries in which they occur.

TABLE 2.1 SOLVENT-USE INTENSIVE OPERATIONS

		Operation Type					
Industry	SIC	Parts Cleaning	Equipment Cleaning	Surface Coating Application	Reaction Medium	Entrainer Azeotropic Distillation	Extraction Medium
Solvent Reclamation	7399		x			x	x
Coatings Manufacturing	2851		x				
Cyclic Compounds & Intermediates	2865		x		x		x
Industrial Organic Chemicals Manufacturing	2869		x		x	x	x
Pesticides & Agricultural Chemicals Formulation	2879		x				
Inks Manufacturing	2893		x				
Chemicals Preparations	2899		x				
Petroleum Refining	2910		x			x	x
Semiconductors Manufacturing	3674	x	x	x			
Electronic Components Manufacturing	3679	x	x	x			
Motor Vehicles Manufacturing	3711	x	x	x			
Aircraft Manufacturing	3721	x	x	x			
National Security	9711	x	x	x			
Dry Cleaning	7215,7216,3582		x				
Automobile Service	5511,7538	x	x	x			
Pharmaceuticals Manufacturing	2834		x		x		x
Metal Furniture Manufacturing	2514,2522	x	x	x			
Photographic Processing	7395,7333,7819	x			x		

Source: Jacobs Engineering - project staff estimates.

Source reduction techniques specific to parts cleaning, equipment cleaning, and surface coating application are discussed in Chapter 4.

REFERENCES FOR CHAPTER 2

1. Parrish. "Solvents, Industrial." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 21, pp. 377-401. 1983.

2. U.S. Environmental Protection Agency (U.S.EPA). Analysis of Treatment and Recycling Technologies for Solvents and Determination of Best Available Demonstrated Technologies (BDAT), In Background Document for Solvents to Support 40 CFR Part 268 Land Disposal Restrictions, Volume II, Washington, D.C. February 1986.

3. SCS Engineers. Hazardous Waste Management Plan for Small Quantity Generators, Final Report, Submitted to the Southern California Association of Governments, Los Angeles, CA, 1985.

4. Kalfadelis, C. D., and H. Shaw. "Fuels, Synthetic (Liquid)." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 2, pp. 447-489. 1980.

5. Metcalf, R. L. "Insect Control Technology." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 13, pp. 413-485. 1981.

6. Burachinsky, B. D. Hugh, and J.K. Ely. "Inks." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 13, pp. 374-398. 1981.

7. Cooper, C.M. "Solvent Recovery." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 21, pp. 355-376. 1983.

8. Jahnig, C.E. "Petroleum (Refinery Processes, Survey)." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 17, pp. 183-256. 1982.

9. Reich, D. A., and C.L. Cormany "Dry Cleaning and Laundering." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 8, pp. 50-68. 1979.

10. Radimsky, J.K. Wilhelm, R. Boggs, M.R. Eriksson, R.E. Marx, R. Piacentini, and S.P. Wilslow (editor). Recycling and/or Treatment Capacity for Hazardous Wastes Containing Halogenated Organic Compounds. Draft report submitted to the State of California Department of Health Services, Toxic Substances Control Division, Alternative Technology and Policy Development Section, November 1984.

11. Versar Inc. Hobbyist exposure. Draft report submitted to the U.S. Environmental Protection Agency, Office of Toxic Substances, August 30, 1985.

12. U.S. Environmental Protection Agency (U.S. EPA). Regulatory Analysis of Proposed Restrictions on Land Disposal of Certain Solvent Wastes, Washington, D.C.: January 13, 1986.

13. Science Applications International Corporation. Development and Improvement of Organic Compound Emission Inventories for California, prepared for the California Air Resources Board, January 22, 1985.

14. U.S. Environmental Protection Agency (U.S. EPA). National Air Toxics Information Clearing House, Data Base Report, Research Triangle Park: July 1986.

15. KVB Inc. Airborne Toxic Materials Study for Sacramento County, prepared for the Sacramento Air Pollution Control District, Sacramento, CA: July 1983.

16. Franklin, K., U.S. Environmental Protection Agency (U.S. EPA), Office of Toxic Substances, Chemical Engineering Branch. Memo to staff of Chemical Engineering Branch, March 28, 1986.

CHAPTER 3

WASTE MINIMIZATION - GENERAL PERSPECTIVE

This chapter provides a brief general discussion of solvent waste generation, basic elements and strategies for conducting waste minimization programs, and an overview of incentives for and barriers to waste minimization.

3.1 Waste Generation

Solvent waste generation varies depending on the type of operation in which solvents are used. For parts cleaning operations, for example, solvent waste is generated because solvents are used to clean parts that have, through repeated use, become laden with grease or other deposits. If the cleaning method is inefficient, more waste than necessary will be generated. An example of an inefficient cleaning practice is the use of a single cold wash in an application where a more efficient approach based on two (or more) washes staged counter-currently can be used.

Equipment cleaning generates solvent waste because solvent solutions are used to remove residuals that remain inside the equipment. The frequency of cleaning can be reduced by dedicating the equipment to a single process medium or by maximizing compatible batch sequencing. Also, waste reduction can be accomplished by reducing the amount of residual (e.g., by additional draining or pigging of lines) prior to cleaning or by employing staged counter-current rinsing techniques.

In surface coating operations, generation of solvent waste is attributable to overspray, cleaning of application equipment and transfer lines, and disposal of residuals in storage or transfer containers.

In addition to inherent process-related causes, solvent waste generation is often caused by operators not adhering to good operating practices or by neglecting the housekeeping aspect of production. For example, poorly maintained solvent transfer pumps have frequent seal failures, which in turn lead to leaks. Adherence to good operating practice (see Section 4.4 for details) will reduce the waste attributable to human error, poor organizational controls, faulty maintenance, or the lack of effective loss prevention programs.

A good understanding of the origins of solvent waste generation is central to successful implementation of waste reduction efforts via source control.

3.2 Elements of Waste Minimization

The general concept of waste minimization is not new. In the past it has been referred to as better utilization of raw material or as yield improvement. Because less than 100 percent of all materials that are input into a manufacturing process are converted into the final product, industrial wastes are generated. The greater the product yield, the less waste is generated. In recent years, however, as the management and disposal of hazardous industrial wastes has become an important national issue, the term "waste minimization" has become more prominent. The 1984 federal Hazardous and Solid Waste Amendments (HSWA) established as a national policy that hazardous waste generation be reduced or eliminated as expeditiously as possible whenever practicable.

Formal definitions of waste minimization and source reduction have not as yet been issued by EPA, nor has any other definition been universally accepted. EPA has recently completed its Report to Congress on waste minimization which contains working definitions used for purposes of developing the report. The definitions are based on information contained in the legislative history of the Hazardous and Solid Waste Amendments of 1984 (HSWA), on discussions with EPA personnel, and on the language of HSWA. These definitions follow below:

- Waste minimization: The reduction, to the extent feasible, of hazardous waste that is generated or subsequently treated, stored, or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste, or (2) the reduction of toxicity of hazardous waste, or both, so long as such reduction is consistent with the goal of minimizing present and future threats to human health and the environment.
- Reduction of total volume or quantity: The reduction in the total amount of hazardous waste generated, treated, stored, or disposed of as defined by volume, weight, mass, or some other appropriate measure.
- Reduction of toxicity: The reduction or elimination of the toxicity of a hazardous waste by (1) altering the toxic constituent(s) of the waste to less toxic or nontoxic form(s) or (2) lowering the concentration of toxic constituent(s) in the waste by means other than dilution.
- Source reduction: Any activity or treatment that reduces or eliminates the generation of a hazardous waste within a process.
- Source control: Any activity or treatment classifiable under source reduction with the notable exception of product substitution.
- Product substitution: The replacement of any product intended for an intermediate or final use with another product intended and suitable for the same intermediate or final use.

In the broadest sense, the language of HSWA implies that waste minimization includes any action taken to reduce the volume or toxicity of wastes. Thus, waste minimization includes the concept of waste treatment, which encompasses such technologies as incineration, chemical detoxification, biological oxidation and others (Section 1003(a)(6)).

Waste minimization includes three types of activities that reduce the volume and/or toxicity of any hazardous waste. In order of preference these are (1) source reduction, (2) recycling, and (3) treatment. An illustration of this hierarchy is presented as Figure 3.1.

It is important to note that waste minimization does not always mean a reduction in volume of waste generated. For example, in some cases, a reduction in waste volume may result in increased toxicity. Likewise lowering toxicity by dilution also does not constitute waste minimization. On the other hand, waste concentration may be a useful waste minimization technique (e.g., in preparing materials for recycling). The key concept of the definition, however, is that waste minimization must be protective of human health and the environment.

Source reduction, the single most preferable waste minimization approach, can be viewed as any activity that reduces or eliminates the generation of hazardous waste at the source within a process. Recycling, which includes both reuse and reclamation, can be viewed as any activity that reduces hazardous waste volume and/or toxicity with the attendant generation of a valuable material or energy stream that is subsequently utilized.

Treatment, the last option to explore in the context of waste minimization activities, can be viewed as any activity that reduces hazardous waste volume and/or toxicity without attendant generation of a reusable material or energy stream.

3.2.1 Source Reduction

Elements of source reduction are depicted in Figure 3.2. These encompass source control (in-plant changes) and product changes. Source control appears to be more easily implementable. Source control, in turn, has three major elements: 1) changes in input materials, 2) technology changes, and 3) procedural or organizational changes, including good operating practices.

Changes in input materials. Solvent waste generation may be reduced by substituting other materials for solvents. For example, aqueous, biodegradable detergents could be substituted for solvents used in parts cleaning. A separate approach relies on purification of raw materials to limit the impurities introduced to a process. This approach may be important in solvent extraction applications.

Technology changes. Technology changes include:

- Shifting to a less waste-intensive process, such as use of powder coating in place of solvent-based product finishes.
- Equipment changes, such as use of seal-less pumps to avoid seal leakage.
- Additional automation to limit human error (e.g., automatic batch sequencing).
- Changing equipment settings without changing the equipment, such as lowering air back pressure in spray guns to reduce overspray.

FIGURE 3.1

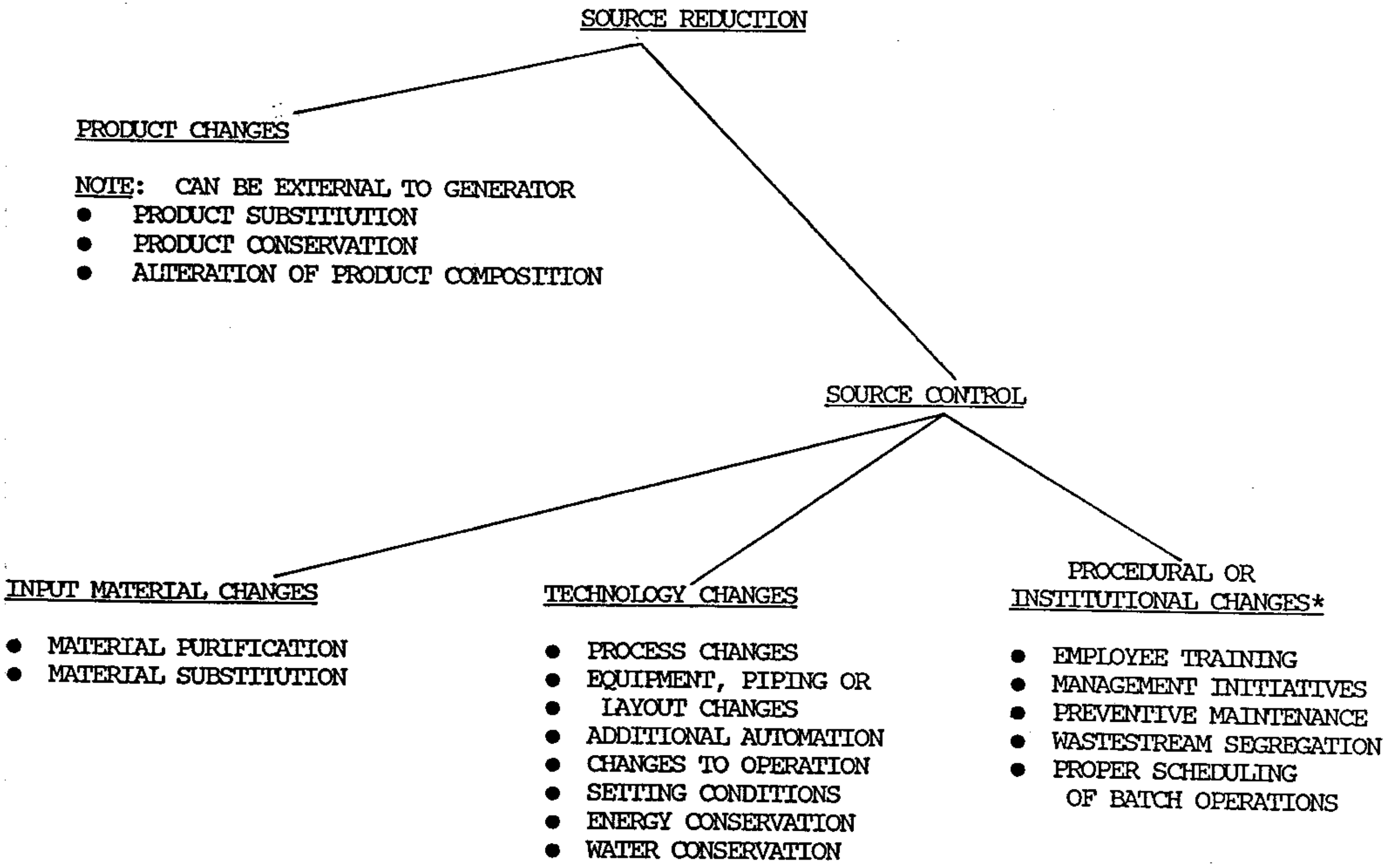
ELEMENTS OF WASTE MINIMIZATION

WASTE MINIMIZATION

REDUCTION TO THE EXTENT FEASIBLE OF HAZARDOUS WASTE THAT IS GENERATED OR SUBSEQUENTLY TREATED, STORED, OR DISPOSED OF. INCLUDES ANY SOURCE REDUCTION, RECYCLING, OR TREATMENT ACTIVITY THAT REDUCES TOTAL VOLUME AND/OR TOXICITY OF HAZARDOUS WASTE.

SOURCE REDUCTION	RECYCLING	TREATMENT
ANY ACTIVITY THAT REDUCES OR ELIMINATES THE GENERATION OF HAZARDOUS WASTE WITHIN A PROCESS.	ANY ACTIVITY THAT INVOLVES USE, REUSE, OR RECLAMATION OF WASTE MATERIAL.	ANY ACTIVITY THAT REDUCES VOLUME AND/OR TOXICITY OF HAZARDOUS WASTE WITHOUT ATTENDANT GENERATION OF A REUSABLE MATERIAL OR ENERGY STREAM.
Address first	Address second	Address last.

FIGURE 3.2
ELEMENTS OF SOURCE REDUCTION



SOURCE REDUCTION

PRODUCT CHANGES

NOTE: CAN BE EXTERNAL TO GENERATOR
- PRODUCT SUBSTITUTION
- PRODUCT CONSERVATION
- ALTERATION OF PRODUCT COMPOSITION

SOURCE CONTROL

INPUT MATERIAL CHANGES

- MATERIAL PURIFICATION
- MATERIAL SUBSTITUTION

TECHNOLOGY CHANGES

- PROCESS CHANGES
- EQUIPMENT, PIPING OR
- LAYOUT CHANGES
- ADDITIONAL AUTOMATION
- CHANGES TO OPERATION
- SETTING CONDITIONS
- ENERGY CONSERVATION
- WATER CONSERVATION

PROCEDURAL OR
INSTITUTIONAL CHANGES*

- EMPLOYEE TRAINING
- MANAGEMENT INITIATIVES
- PREVENTIVE MAINTENANCE
- WASTESTREAM SEGREGATION
- PROPER SCHEDULING
  OF BATCH OPERATIONS

*ALSO REFERRED TO AS "GOOD OPERATING PRACTICES" OR "GOOD HOUSEKEEPING".

- o Energy conservation to reduce wastes associated with utilities generation.

- o Water conservation which can reduce carryover of organics into treatment and thus limit generation of treatment residuals.

Energy and water conservation are viewed as being less relevant to solvent waste minimization compared to the preceding four categories and were included for the sake of completeness.

Procedural or Organizational Changes. Human aspects of industrial activity can be extremely important in waste reduction. Often termed "good operating practices" or "good housekeeping", this aspect includes improved employee training, management initiatives to increase employee awareness of the need for and benefits of waste minimization, and requiring increased use of preventive maintenance in an effort to reduce the number of leaks and spills.

Segregation of wastes increases the recyclability and treatability of materials such as solvents. It is another example of a good operating practice. Proper scheduling of batch operations can reduce equipment cleaning frequency and the associated waste load. It is noteworthy that organizational changes to promote good operating practices can be fairly readily implemented and are generally cost effective.

3.2.2 Recycling

Recycling can be characterized by three primary practices: 1) the direct reuse of a waste material (for example, spent solvent from cleaning electronic components is relatively pure and can be used as a paint thinner); 2) reclamation by recovering secondary materials for a separate end use (for example, recovering metals from sludge); and 3) removing impurities from a waste to obtain a relatively pure and reusable substance (for example, regeneration of spent solvents). EPA has defined recycling, used or reused, and reclaimed as follows:

- o Recycled: A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1(b)(7)).

- o Used or reused: A material is "used or reused" if it is either (1) employed as an ingredient (including use as an intermediate) in an industrial process to make a product (for example, distillation bottoms from one process used as feedstock in another process). However, a material will not satisfy this condition if distinct components of the material are recovered as separate end products (as when metals are recovered from metal-containing secondary materials) or (2) employed in a particular function or application as an effective substitute for a commercial product (for example, spent pickle liquor used as phosphorous precipitant and sludge conditioner in wastewater treatment) (40 CFR 261.1(b)(5)).

o Reclaimed:	A material is "reclaimed" if it is processed to recover a usable product or if it is regenerated. Examples are recovery of lead values from spent batteries and regeneration of spent solvents (40 CFR 261.1(b)(4)).

3.2.3 Treatment

Treatment refers to destruction or degradation of wastes to yield less toxic residuals, which when discharged to the environment pose a much lower risk to public health or the environment than would a discharge of the original waste. Treatment, in contrast to recycling and as the term is used in this report, does not generate reusable material or energy.

3.3 Incentives for and Barriers to Waste Minimization

Despite its implicit cost-effectiveness, waste minimization as an explicit operating practice is a relatively new concept for industry. Habits and attitudes developed through long experience with existing production processes and land disposal can be barriers to implementing waste minimization. There is a natural tendency to preserve practices and designs that work well, even though they may generate relatively large waste volumes (the "if it ain't broke, don't fix it" attitude). Familiarity with existing ways of doing business and unfamiliarity with innovative technologies or approaches can lead to rejection of new concepts.

Lack of awareness of waste minimization alternatives among the corporate management and middle-managers can be a major inhibiting factor. Changes in the way business is conducted require leadership from the top. To stimulate action within a firm, waste minimization initiatives should originate from the corporate decision makers and be mandated as a clear corporate policy.

Other factors can inhibit waste minimization. Technical and often financial resources must be invested in order to produce a future return. In many cases, resources are unavailable or are invested in areas that are considered a higher priority. A common reason for rejecting the use of recycled or reused feedstocks is the fear of reduced product quality and lower customer satisfaction.

For a waste minimization effort to be successful, it must be systematically approached. The initial step, a waste minimization audit, involves a systematic review of existing process operations and practices to identify a comprehensive set of waste minimization options [1]. These options then must be screened to select those that deserve more in-depth evaluation.

The most promising options must be subjected to a feasibility analysis. Technical viability, ease of implementation, cost-effectiveness, and environmental implications should be evaluated and compared. Once the most practical and profitable option(s) is chosen and implemented, performance must be monitored so that refinements can be made and performance quality maintained.

There are a number of key components for success in implementing waste minimization projects. Management must make waste minimization a high-priority endeavor. Both the technical (human) and financial resources must be made available for the waste reduction effort. Finally, a systematic and coherent methodology or approach is required.

3.4 Waste Minimization - Economic Perspective

There have been frequent claims that waste minimization efforts reduce operating costs by minimizing disposal or treatment costs. A review of a recent compilation of waste minimization cases reveals that for more than 80 percent, the payback period was less than three years. Such a short time span is indicative of high profitability. The summary of these results is provided in Table 3.1.

TABLE 3.1 PAYBACK PERIODS REPORTED FOR TWENTY-EIGHT WASTE MINIMIZATION CASES

	TOTAL REPORTED	
PAYBACK PERIOD (YEARS)	NO. OF CASES	PERCENT
1	15	54
1-2	6	21
2-3	2	7
3-4	3	11
4	2	7
Total	28	100

Source: Compilation of Waste Minimization Cases, Jacobs Engineering, 1986

The profitability of waste minimization options may be evaluated by standard techniques such as payback period, internal rate of return, or net present value methods. Usually, the alternatives are compared to a do-nothing base option. What makes the analysis unique are the avoided cost elements one must consider. These cost components include:

- Generators fees and taxes;
- Transportation;
- On-site storage and handling;
- Pre-disposal treatment;
- Permitting, reports, and recordkeeping;
- Emergency preparedness and disposal site clean-up contingency;
- Pollution liability insurance;
- Raw materials;
- Operating and maintenance costs; and
- Disposal fees.

Of all the listed avoidable cost components, the most important are the last three, especially the disposal fees which have increased considerably in recent years.

In addition to cost components that can be quantified, there are also components that are not easily quantifiable. The following intangible components that favor waste minimization projects must also enter the economic analysis:

- Future liabilities;
- Public relations;
- Future land disposal restrictions; and
- Protection of employee health and public health.

There are also intangible factors that work against waste minimization projects, specifically those involving source reduction and recycling. These include:

- Risk of lower product quality; and
- Risk of incurring unforeseen research and development, and corrective action expenses.

The intangibles usually enter the analysis though adjustment of the hurdle rate (the minimal return required for the investment) [2].

REFERENCES FOR CHAPTER 3

1. Fromm, C.H., and M.S. Callahan. "Waste Reduction Audit Procedure - A Methodology for Identification, Assessment, and Screening of Waste Minimization Options." Proceedings, Hazardous Materials Control Research Institute Conference, Atlanta, Georgia, March 4-6, 1986, pp. 427-435.

2. Fromm, C.H., and D. Butler. "Practical Guidelines for Estimating the Profitability of Waste Minimization Measures." Paper presented at Hazmat Conference, Atlantic City, New Jersey, June 3, 1986

3. Driessen, A.W., and B.W. Doyle. "Design of a Specific System for Waste Solvent Combustion." Paper presented at Engineering Foundation Conference on Alternative Technologies for Hazardous Waste Management, Henniker, New Hampshire, June 15-20, 1986.

CHAPTER 4

SOURCE REDUCTION

Many solvent waste generating industries rely on relatively few solvent waste-intensive operations. Consequently, this Guide approaches source reduction from an operation-specific (as opposed to industry-specific) standpoint.

Table 2.1 presents the eighteen industries responsible for most of the solvent waste generation in California. They are matched with waste-intensive operations or solvent use categories. Based on frequency of occurrence, three major operations were deemed responsible for most of the solvent waste generation in the state and, thus, selected for analysis in this chapter:

- Parts cleaning;
- Process equipment cleaning; and
- Surface coating application.

In addition to these three processes, two other topics are reviewed - air emissions control and good operating practice. Air emissions control often results in generation of solvent-bearing waste that, in turn, requires handling and disposal. Good operating practice is relevant to all industries and has a special significance to waste minimization.

Each of the five areas reviewed in this chapter is structured to provide approaches, techniques, equipment, and examples relating to solvent waste reduction at the source. The material presented here is offered as a guide, and not as a definitive technical information source. As source reduction is highly application-specific, detailed technical coverage of all possible applications exceeds the scope of this Guide. The reader is encouraged to use the information sources provided to construct an adequate basis for a detailed engineering evaluation of his/her particular application.

4.1 Parts Cleaning

Solvents are used by a variety of industries for removing grease, fats, oils, wax, and/or soil from various metal, glass, or plastic parts. Some of the major solvents used are petroleum distillates, oxygenated solvents (esters, ethers, ketones, and alcohols), and halogenated solvents. The type(s) of solvent used in the parts cleaning process usually depends on the nature of the contamination, the type and composition of the part being cleaned, and the properties of the solvent itself (stability, toxicity, flammability, cost, etc.). Cold cleaning or soak tank operations can employ both halogenated and nonhalogenated solvents. Most vapor degreasing operations employ halogenated solvents.

4.1.1 Industries and Equipment Use Patterns

Parts cleaning is an integral process operation used by industries involved in the repair, maintenance, or manufacture of parts and equipment. Over one million cold cleaner soak tanks and 47,000 vapor degreasers were in operation in the United States in 1977 [1]. Repair and maintenance users include automobile repair, equipment repair, and transportation maintenance (trucks, trains, ships, and aircraft) industries. Major manufacturing user groups of solvent cleaning operations [2] are: Furniture and Fixtures (SIC 25); Primary Metal Industries (SIC 33); Fabricated Metal Products (SIC 34); Machinery, Except Electrical (SIC 35); Electric And Electronic Equipment (SIC 36); Transportation Equipment (SIC 37); Instruments And Related Products (SIC 38); and Miscellaneous Manufacturing Industries (SIC 39).

Of the total number of cold cleaner soak tanks in use, seventy percent are used for maintenance operations [2]. Typically, most tanks hold thirty or more gallons of solvent and have about four square feet of open area. The types of cold tanks used in manufacturing operations vary widely from desktop sized units used for cleaning small parts to units designed to clean large sections of aircraft. In industries that perform a large amount of cleaning, vapor degreasing systems are common. Open-top units, as opposed to conveyorized systems, accounted for eighty-nine percent of the degreasers in use [1]. Available sizes for open-top units range from one foot by two feet, up to six feet by one hundred feet. The typical unit size is approximately three feet by six feet [2]. Open-top units are commonly employed in the electroplating and electronics industries where easily handled parts are cleaned. Conveyorized (or fully automated) units are more common in the aerospace and large appliance product coating industries.

4.1.2 Solvent Selection

Choosing a particular solvent for a given cleaning application can involve a considerable amount of work. There are many questions that must be answered before any one particular solvent can be selected. Some of these questions are:

- Will the solvent clean the part adequately?
- Is the solvent compatible with the part's material of construction?
- Will the solvent interfere with or contaminate subsequent processing operations?
- What is the solvent's cost and replacement frequency?
- Is the solvent volatile, flammable or toxic?
- Is the solvent photochemically reactive?
- What are the rules and regulations regarding the solvent's use and disposal?

All of the nonhalogenated solvents and a third of the halogenated solvents purchased for cleaning are used in cold cleaning applications [3]. The types of nonhalogenated solvents used are aliphatic hydrocarbons, aromatic hydrocarbons, ketones, and alcohols. In maintenance operations, mineral spirits (petroleum distillates or Stoddard solvents) are exclusively used due to their low cost and suitability for the job. A wider selection of solvents is used in manufacturing operations because a higher degree of cleaning is often required and the types of contamination encountered are more varied. Because it is seldom practical to analyze every potential candidate, solvent selection is usually based on past experience. Therefore, it is not uncommon to find many different solvents being employed in similar cold cleaning operations throughout an industry or even a single facility.

In addition to parts cleaning, many nonhalogenated solvents are used for paint stripping. Some of these solvents include acetone, methyl ethyl ketone, toluene, or xylene. Shellacs and lacquers can be stripped with alcohols and with blends of alcohols and acetates (e.g., butyl acetate) respectively. Other solvents that can be used on shellacs and lacquers are 2-nitropropane, tetrahydrofuran, dimethyl formamide, and 1,1,2-trimethoxyethane. Alkyl enamels can be stripped from wood by using diacetone alcohol and aromatic naphtha or xylene [4]. A low toxicity organic stripper (n-methyl-2-pyrrolidinone) has been developed and is commercially available [5].

Chlorinated solvents are also used for cold tank paint stripping. The most widely used stripping agents are based on mixtures of methylene chloride and chromates, phenols, and strong acids. In order to reduce the hazardous nature of stripping waste, several non-phenolic/non-acidic strippers have recently been developed. Tests performed with these strippers, such as Sparzee (made by BASF), T-5873 (made by Turco), and 766 (made by Magnus), show that they are just as effective in removing epoxy primer and polyurethane topcoat from aluminum and steel panels [6]. However, based on impending California Occupational Safety and Health Administration regulations regarding the permissible exposure level of methylene chloride in the workplace [7], and the increasing cost for solvent waste disposal, the use of methylene chloride based strippers is likely to decrease.

Solvent selection for vapor degreasers, which employ halogenated solvents, tends to be more standardized. Halogenated solvents are employed due to their characteristics of non-flammability (reduced risk of fire) and high vapor density (ease of emission control). The most commonly used solvents are 1,1,1-trichloroethane (1,1,1-TCE), trichloroethylene (TCE), perchloroethylene (PCE), methylene chloride, or trichlorotrifluoroethane. Prior to 1970, trichloroethylene was the dominant vapor degreasing solvent. Today, due to more stringent air quality regulations regarding the use of reactive solvents (solvents which undergo a chain of photochemical reactions in the atmosphere and lead to ozone formation) and safety considerations, 1,1,1-TCE has replaced TCE in many applications. Selection of a particular vapor degreasing solvent usually depends on a part's sensitivity to heat (PCE boils at 250 degrees Fahrenheit while methylene chloride boils at 104 degrees Fahrenheit) and the availability of appropriate utilities.

4.1.3 Process Description

The three most common solvent cleaning systems are cold tank cleaning, diphase cleaning, and open-top vapor degreasing. While maintenance operations tend to be singular in their use of solvent, manufacturing operations often involve a complex sequence of cleaning steps. Usually, removal of several different contaminants is required to assure a clean part. This may require the use of one particular solvent for each contaminant present. If water-based contamination is present, then aqueous cleaners (alkalis or acids) may be used. This cleaning operation might be performed either before or after solvent cleaning and is almost always followed by one or two stages of water rinsing. Therefore, solvent cleaning is often only a part of an overall cleaning operation.

4.1.3.1 Cold Cleaning Operations

Cold cleaning operations can be divided into four distinct methods or systems. These are: wipe cleaning, soak or dip tank cleaning, diphase cleaning, and steam gun stripping. Each method is discussed in the paragraphs that follow.

Wipe cleaning consists of soaking a clean rag with solvent or cleaning solution and then wiping the part clean. Usually, wipe cleaning is associated with maintenance operations or processes that fabricate parts on a single item basis (parts manufactured in a machine shop, for example). Since the operation is strictly manual, there is little control over the amount of solvent used for cleaning. Solvent use tends to be high because the only way to assure cleanliness is to use a liberal amount of solvent. Other disadvantages of wipe cleaning are that rags must be replaced frequently, the probability of leaving lint on the part is high (unless lint-less wipes are used), increased air emissions and fire hazards can result from rag drying, and dirty rags can present a serious waste disposal problem.

Soak cleaning consists of soaking parts in a tank of cold solvent or cleaning solution. Small parts are usually handled in a barrel or wire-mesh basket while larger parts are placed on racks. Cold cleaning dip or soak tanks, and much smaller spray sinks are widely used in maintenance and manufacturing operations. Maintenance cleaning usually employs mineral spirits (petroleum distillates and Stoddard solvents) while manufacturing operations employ a wider variety of solvents. When both water-based and oil-based contaminants are present on the parts, emulsion cleaners may be used. Emulsion cleaners consist of a mixture of solvent and aqueous cleaner and hence, result in fewer potential air emissions. Because emulsion cleaners tend to leave a film of oil on parts, additional cleaning might be required.

Heating units may be employed to heat the solvent when a higher degree of cleaning efficiency is required. Additional gains in efficiency can be achieved by means of agitation. Common methods to increase the level of agitation in the tank are installation of a pump and spray unit, use of air sparging, or installation of an ultrasonic unit. While spraying and air sparging are useful on many parts, only ultrasonic units are particularly effective in cleaning parts with many small crevices or hidden areas.

Ultrasonic cleaning relies on the use of high frequency sound waves to produce cavitation in a solvent or cleaning solution. Cavitation results in the formation of small vacuum bubbles which immediately collapse after formation. The rapid implosion of these bubbles creates a vigorous cleaning and scrubbing action throughout the liquid. Because cavitation occurs throughout the tank, and not just in one localized area, any surface in contact with the liquid is effectively cleaned. This is extremely important when dealing with parts that have many crevices or hidden surfaces. Ultrasonic units can be used in conjunction with a pump and spray unit but not with air sparging. Air sparging disrupts the formation of the vacuum bubbles and their subsequent cleaning action.

Diphase cleaning combines into one operation a water rinse both before and after the solvent cleaning step. Halogenated solvents and water are relatively insoluble so that when they are placed together in a tank, they will separate. The water, being less dense than the solvent, will float on top. Therefore, the parts to be cleaned must pass through the water bath before reaching the solvent below. Upon removing the parts, they are again rinsed by the same water. In more complex units, the parts can be subjected to a solvent spray and water rinse following the initial cleaning step. The solvent used in the spray portion drops into the water and sinks to the bottom of the tank. A small pump recirculates solvent from the solvent bath up to the spray unit. The spray operation is totally enclosed to reduce air emissions and fully automated (parts pass from the water bath, up into the spray unit, and back down into the water). Very little evaporation of the solvent bath occurs because the solvent bath is blanketed by water. Solvent loss, by way of the dirty water discharge, can be sizable (amount depends on water discharge rate, solvent's solubility in water, and degree of physical entrainment).

Steam gun stripping is most often used for the removal of paint from a metal surface. A mixture of solvents, usually non-halogenated, is fed from a storage tank into a steam gun. By way of a special valve and hose arrangement, either solvent and steam or just steam can be passed to the gun. The object to be stripped is first sprayed with the mixture of solvent and steam and then cleaned using pure steam. This operation is strictly manual and the amount of solvent used per part cleaned is very high. In addition, this method can generate large quantities of rinsewater that must be collected and properly treated before being disposed.

4.1.3.2 Vapor Phase Cleaning

Vapor phase cleaning relies on hot solvent vapor condensing directly on cold parts that are inserted into the vapor space of a degreaser. When solvent vapors condense on dirty parts, the contamination is dissolved and then rinsed away. The dirty solvent liquid falls back into the tank, is reheated and vaporized, leaving the contamination behind. As opposed to cleaning parts in a soak tank with previously used solvent, vapor phase systems maintain their cleaning efficiency over time, because the parts are always exposed to clean solvent vapors.

Vapor degreasing, as shown in Figure 4.1, usually consists of a tank of halogenated solvent that is heated to the solvent's boiling point. Parts to be cleaned are placed in a basket or on a rack and lowered into the vapor zone. As the solvent condenses, the contamination is dissolved and the parts are rinsed and cleaned. To increase cleaning efficiency, the parts may be immersed into the solvent bath or a solvent spray unit may be employed. When the temperature of the parts finally reaches the temperature of the solvent vapor, condensation of the vapor onto the parts ceases. The parts can then be removed from the unit cleaned and dryed. System designs include batch-operated open-top units and continuously loaded hooded or enclosed conveyorized units.

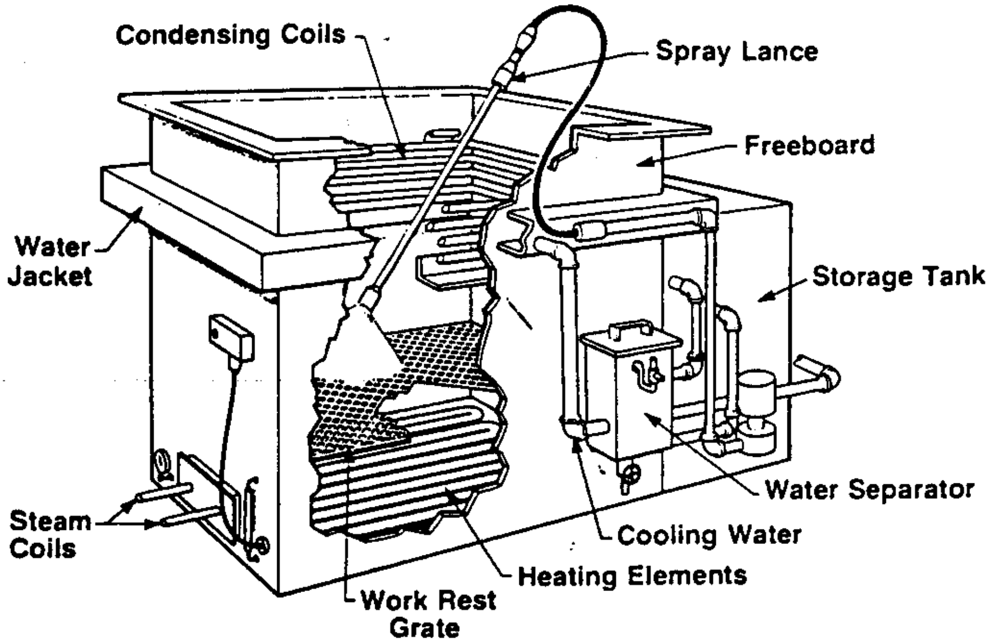
The potential for air emissions is greater with vapor degreasing operations than with cold cleaning operations. Because of this, emission control is one of the major focuses of concern to equipment designers. The first control unit, a cooling jacket, is usually placed around the tank and located at the vapor/air interface. By cooling the air above the solvent vapor, a blanket is formed which helps to prevent the escape of solvent vapor. The second control unit, a finned coil condenser, is placed in the tank close to the vapor zone. Vapors that reach this unit are condensed, along with any water removed from the parts or condensed from the air blanket (frost formed on the coil is removed during the coil's defrost cycle). Located below the condenser, a solvent/water separator decants the water from the solvent. The water is discharged to the facilities' wastewater system and the solvent flows back into the tank or into a sump for use by the spray unit.

4.1.4 Waste Minimization Through Source Reduction

There are three distinct approaches to source reduction - eliminate the use of solvents, reduce the use of solvents, and increase the recyclability of

FIGURE 4.1

VAPOR DEGREASER WITH SPRAY ATTACHMENT



Reprinted by permission of Metal Finishing Guidebook and Directory, 1984.

solvents. These three approaches, along with specific applications, are discussed below.

4.1.4.1 Eliminating the Use of Solvents

Eliminating the use of solvents avoids the generation of wastes associated with spent solvent. Elimination can be achieved by employing non-solvent cleaning agents or by eliminating the need for cleaning altogether. Since the degree of cleaning required and the methods used to achieve that degree are highly process and product specific, application of solvent elimination measures can only be made on a case by case basis. Solvent elimination applications include use of water-soluble cutting fluids, protective peel coatings, aqueous cleaners, and mechanical cleaning or paint stripping systems. These methods are described briefly below.

Water-soluble cutting fluids can often be used in place of oil-based fluids. When metal parts are machined, friction between the cutting tool and the metal generates a substantial amount of heat. This heat can reduce tool life and degrade the part's finish or hardness. To prevent the build-up of heat, special oil-based cutting fluids have been formulated to reduce friction and dissipate heat. These fluids usually consist of an oil-in-water emulsion. If the oil interferes with subsequent processing operations, then vapor degreasing is required to remove the oil from the parts.

In an effort to eliminate the need for vapor degreasing, special water-soluble cutting fluids have been developed [8]. Systems are available that can clean the cutting fluid and recycle the material back to the cutting operation. The only major organic wastes produced are those oils that enter the system on the parts or hydraulic fluids that enter by way of equipment leaks. Solvent waste, due to vapor degreasing, is reduced or eliminated. Obstacles to implementing this method are cost (water-soluble cutting fluids are more expensive than their oil-based counterparts), procurement (there are only a few suppliers of water-soluble cutting fluids), and the inability to quickly switch between fluid types without having to thoroughly clean the equipment [9].

Peel coatings can be used in place of protective oils and thereby eliminate the need for cleaning with solvent. If a facility or manufacturer handles parts that require the involvement of several manufacturers (for example, metal parts may be machined by one facility, electroplated at another, and assembled at a third), then the parts may be coated with a protective oil by the previous facility. Metal parts are often coated with oil before shipment to prevent rust from forming during transit and subsequent storage. An alternative measure is to coat the parts with a protective organic coating which is peeled off when the part is ready for assembly. Such a coating prevents air and moisture from reaching the part and forming rust. At the receiving facility, the need for vapor degreasing is reduced or eliminated. In considering possible differential benefits, one must weigh the handling of solvent waste loads associated with application of certain peel coatings against waste loads from oil removal using solvents. Peel coatings are limited to applications where the cost of labor to remove the coating is not significant. Examples include polyethylene shrink-wrapping of sheetwork and high value added products.

Aqueous cleaners, including alkali and caustic, are often viable substitutes for solvents. There are a wide variety of formulations available that can deal with many different cleaning requirements. Some manufacturers of aqueous cleaners claim that their products are just as effective at cleaning as several of the halogenated solvents commonly employed by industry. These same people have indicated that several cleaners have shifted from solvent to aqueous cleaning and foresee further growth in this area [10,11,12].

The advantages of substituting aqueous cleaners for solvents include minimizing worker's exposure to solvent vapors, reduced liability and disposal problems associated with solvent use, and cost. Aqueous cleaners do not emit fumes or vapors and are usually biodegradable. Therefore, except for the organic and inorganic contaminants removed during cleaning, most of the spent cleaning solutions should not represent a long term liability problem with respect to disposal.

The use of aqueous cleaners can result in cost savings. The cleaning efficiency (number of parts cleaned per gallon of cleaner) and cost per gallon (an aqueous cleaning formulation marketed by J. Hall Marketing, sells for $300 per 55 gallon drum versus $275 to $375 per drum for 1,1,1-TCE) of aqueous cleaner and solvent are roughly equivalent. The costs of waste treatment and disposal, however, favor aqueous cleaners. Case studies have reported such savings, but detailed economic comparisons can only be made on a per facility basis.

The disadvantages of using aqueous cleaners in place of solvents may include: possible inability of aqueous cleaners to provide the degree of cleaning required, incompatibility between the part's material of construction and the cleaning solution, need to modify or replace existing equipment, and presence of moisture on parts leaving the cleaning operation (to obtain dry parts, an air blown or heated drying unit is required). If problems concerning cleanliness or compatibility arise, then the use of aqueous cleaners is definitely ruled out (provided that no suitable formulations can be found). Problems related to equipment modification or the unacceptability of wet parts require the expenditure of capital.

Cold cleaning soak or dip tanks can usually be modified to use aqueous cleaners. Aqueous cleaners can be corrosive to a tank's material of construction. Modification, therefore, may involve inserting a protective liner into the tank. For tanks with internal baffles and heating coils (this also includes open-top vapor degreasers), installing a protective liner may present a problem. An easier solution might be to choose an aqueous cleaner that is non-corrosive. After narrowing down the choice of cleaners, a single cleaner that satisfies all of the key requirements of cleaning in fact may not be available. For facilities purchasing new cold cleaning equipment, several manufacturers design equipment that can use either solvents or aqueous cleaners [13].

Regardless of the type of unit to be modified, aqueous cleaners usually require a fair degree of agitation to assure effective cleaning. Modifications to provide for agitation of the liquid include adding a liquid recirculating pump or compressed air blower.

Oils removed from the parts during cleaning may float on the surface of the aqueous cleaner and interfere with subsequent cleaning. Oil skimmers are usually required. They consist of internal floatable pumps or external cyclonic units. Cyclonic units consist of a small pump and hydrocyclone. The aqueous cleaner is continuously pumped into the cyclone and the cleaned overflow is returned to the tank. Underflow, consisting mainly of removed oils, is stored in a fifty-five gallon drum. Users of this system have reported savings in chemical cleaner costs and the manufacturer reports that systems are available for use with solvent cleaners [14].

Rockwell International conducted a study at the Rocky Flats nuclear weapons facility in Golden, Colorado to compare the effectiveness of aqueous versus solvent cleaners. The results of the study indicated that alkaline degreasing (aided by ultrasonic agitation) was more effective than ultrasonic vapor degreasing employing TCE or 1,1,1-TCE. The metals tested were stainless steel, berylium, uranium-niobium alloy, and unalloyed uranium. Based on the findings of the study, ultrasonic vapor degreasing was replaced by ultrasonic aqueous cleaning [13]. A similar study conducted at the General Electric Company in Waynesboro, Virginia concluded that aqueous cleaning of printed circuit boards was more effective than solvent based cleaning [13].

The Torrington Company in Walhalla, South Carolina replaced their vapor degreasing units with an alkaline cleaning system. The vapor degreasers, using 1,1,1-TCE, were used to clean metal bearings for the automobile industry. Increasing prices for 1,1,1-TCE and concerns about worker health hazards prompted the company to look for a viable alternative. The new unit (an alkaline degreaser) is a two-stage washer with hot air drier. The alkaline cleaner used is considered to be non-hazardous so that wastewater from the washer can be discharged directly to the sewer system [15].

Even though the above examples indicate successful application of aqueous or alkaline cleaners in place of solvents, there have been instances where aqueous cleaners were found to be ineffective. Boeing Military Airplane Co. in Wichita, Kansas found that aqueous cleaning was inadequate for cleaning printed wiring assemblies. To assure that the military specifications calling for super-critical cleaning would be met, Boeing switched to a chlorofluorocarbon solvent [13]. Another company, Scovill, Inc. in Clinton, North Carolina, found that water-soluble synthetic cleaners could replace 1,1,1-TCE only in some of their cleaning operations [16]. The water-soluble cleaner was found to corrode galvanized metal and, therefore, could not be used for cleaning those parts. However, Scovill did use the aqueous cleaner in several other applications and reduced 1,1,1-TCE consumption by 30 percent.

<u>Non-solvent based paint stripping</u> methods are viable substitutes for solvent cleaning (especially methylene chloride). In many instances, paint must be stripped from parts in order to examine the surface of the substrate or to remove a substandard coating (see section on coating application). Paint stripping is normally performed by soaking, spraying, or brushing the parts with a stripping agent (most often a mixture of methylene chloride and chromates, phenols, or strong acids). After the agent is allowed to remain on the parts for a specific period of time, the parts are rinsed with water and the loosened paint is sprayed or brushed off. Brushing or spraying is used for small jobs or for items that cannot be immmersed. Immersion or soaking is used whenever it is more cost effective and practical to install the required stripping equipment.

There are several alternatives that can be used in place of solvent based stripping agents. These options include the use of aqueous stripping agents, cryogenic stripping, use of abrasives, molten salt stripping, and thermal stripping. The following paragraphs discuss each of these options.

Aqueous stripping agents, such as caustic soda (NaOH), are very often employed by industrial operations in place of methylene chloride based strippers. Caustic is usually preferred for immersion type stripping operations because the use of caustic eliminates the need to control solvent vapor emissions. A typical caustic bath consists of 40 percent caustic solution heated to about 200 degrees Fahrenheit. Caustic strippers are generally effective in dealing with alkyl resins, oil paints, cellulosics, and phenolic/gum varnishes [4].

Surface coatings on metal objects can be removed by the use of liquid nitrogen and non-abrasive plastic particles or "shot". The method, known as "Cryogenic Stripping", relies on the freezing effect of liquid nitrogen and the impact force of the plastic shot. Subjecting the object to extremely low temperatures creates stress between the coating and the substrate and causes the coating to become brittle. When the plastic shot hits the brittle coating, debonding occurs. The removed coating and plastic shot are then separated and the shot returned to the process. The process is non-abrasive and does not damage the metal surface although attention must be paid to mechanical effects of metal shrinkage. This technique has been tested and implemented by a major domestic auto manufacturer [17].

The use of abrasives, such as plastic beads propelled by high pressure air jets (bead blasting), has been found to be an effective substitute for solvent stripping. Commercial portable equipment is available for handling a wide variety of items both in the shop or in the field [18,19]. Advantages of using plastic bead blasting over solvent stripping include elimination of solvent fume generation, reduced liability and disposal problems, control over the amount of coating removed, reduced raw material costs, and faster stripping times. The main disadvantage of using bead blasting is that it is inappropriate for easily deformed objects or objects with intricate shapes.

Both the United States Air Force and several commercial airline companies are actively introducing the use of plastic bead blasting in place of solvent stripping agents to remove paint from aircrafts. Hill Air Force Base in Ogden, Utah has successfully used bead blasting to strip paint from aircraft exteriors [20,21,22]. The conventional paint stripping method used about 8000 gallons of solvents per aircraft, such as acidic methylene chloride or hot caustic. The advantages of bead blasting, as realized by Hill Air Force Base, included: improved working conditions for personnel involved in the stripping operation; easier operation of the new equipment as compared to the conventional equipment; reduced raw material and stripping costs; and virtually no generation of hazardous liquid wastes. Based on this favorable experience, it was recommended that all Department of Defense (DOD) facilities install bead blasting systems [9].

DOD estimates indicate that solvent stripping generates about 7 million gallons of solvent/paint waste and 100 million gallons of wash water each year. Using bead blasting, the total annual amount of waste generated would be approximately 500,000 pounds of dry waste (paint plus spent plastic beads). Annual savings of $100 million would be expected due to the reduction in costs for raw materials and disposal.

Molten salts such as sodium metasilicate, sodium phosphate, sodium bicarbonate, and sodium hydroxide can be used effectively to remove heavy films of epoxy and silicon coatings [4]. While the method is very effective, it does have several disadvantages that prohibit its wider use. Some of these disadvantages are cost related (it can be expensive to maintain temperatures that are typically between 480 and 540 degrees Centigrade) and some operational - namely, the limited applicability to items that can be immersed and that are not heat sensitive.

For objects that cannot be immersed due to their large size, hot stripping (or thermal) methods are useful. In this process, superheated air is directed against the surface of the object. With some paints, the high temperatures cause the paint to flake off. Removal results from the drying effect of the air and the uneven expansion of the paint and the substrate. With other paints, the hot air melts the paint and allows for effective scraping of the paint from the substrate. Hand-held units are available that produce a jet of hot air (much like a hair dryer) to effect removal. In addition to electric units, open flame or torch units are sometimes used. While this method is easy to implement, its use is limited to items that are not heat sensitive or where rigorous cleaning standards are not required.

4.1.4.2 Reducing the Use of Solvents

Reducing the use of solvents, in the context of this study, is defined as only including the ways in which the number of parts cleaned per unit of unrecycled solvent can be increased. It is important to stress in this context that recycling is not viewed as a way to reduce solvent use (though it does reduce the amount of solvent purchased and waste produced). Solvent use may increase after a facility installs a recycling system. With increased solvent use, the potential for air emissions (and the wastes associated with air pollution control equipment such as scrubbers) also increases. Therefore, reducing the use of solvent is viewed as taking priority over the option to recycle.

Ways to reduce solvent use can be divided into three broad categories: source control of air emissions, use of multi-stage countercurrent cleaning, and maintenance of solvent quality. Source control of air emissions addresses ways in which more of the solvent can be kept inside the cleaning unit where it belongs. Once the solvent is confined, use of multi-stage countercurrent rinsing can reduce the amount of solvent required for cleaning. Maintenance of solvent quality covers the ways in which the lifetime or effectiveness of the solvent inside the unit can be extended. Since maintaining solvent quality is also crucial to increasing a solvent's recyclability (solvent that degrades excessively cannot be recycled), discussion of this measure is deferred to subsequent sections of this study.

<u>Source control of air emissions</u> can be achieved through equipment modification and proper operation of the equipment. Applicable control measures include installation and use of lids, an increase of freeboard height (the distance from the top of the liquid to the top of the tank), installation of freeboard chillers, and reducing solvent drag-out from tanks. The available literature has focused on ways to reduce emissions from vapor degreasing operations (if uncontrolled, vapor degreasers have a much greater potential for emissions). There is no reason to believe, however, that the measures just listed would not reduce emissions from cold cleaning operations as well.

All units, including cold cleaning soak or dip tanks, should have lids installed. In the past, units were supplied with metal single-piece unhinged covers. The inconvenience of using these covers led to general disuse [2]. Today, most units are supplied with manually operated roll-type plastic covers or hinged metal covers. When viewed from the standpoint of reducing air emissions, the roll-type cover is preferable to the hinged type. Lids that swing down can create a piston effect and force the escape of solvent vapor. By using lids on vapor degreasers, solvent loss can be reduced by twenty-four to fifty percent. For tanks that are used continuously, covers have been designed that allow for work pieces to enter and leave the tank while the lid remains closed [23]. Known as "silhouette entries", these covers have openings that closely match the shape of the item being cleaned [24]. A "silhouette entry" reduces the open area of the tank so that less of the solvent vapor leaves the confines of the degreaser. Due to the reduced area, care should be taken when raising and lowering items into the tank since the likelihood of piston or drag-out effects can increase.

In an open-top vapor degreaser, freeboard is defined as the distance between the top of the tank and the top of the vapor zone. For tanks constructed before the 1970's, the standard design required a freeboard equivalent to fifty percent of the tank's width. Later, in the mid-1970's, the U.S. Environmental Protection Agency recommended a freeboard equivalent to seventy-five percent. Based on experimentation, the increase in freeboard reduced solvent emissions twenty-seven to forty-six percent. Other sources [23] recommend that facilities with air turbulence problems increase the freeboard to one hundred percent. The additional freeboard was reported to reduce emissions an additional thirty-nine percent.

Once the freeboard space has been increased on a vapor degreaser, a freeboard chiller can be installed. A freeboard chiller is a refrigerated coil installed above the primary condenser coil. This refrigerated coil, much like the cooling jacket, chills the air above the vapor zone and creates a secondary barrier to vapor loss. As measured in practice, reduction in solvent consumption of up to sixty percent has been achieved. The major drawback with a freeboard chiller is that it introduces a large amount of water (due to condensation from the air) into the tank. Usually, special water collection equipment must also be installed. If the solvent being used is sensitive to water contamination or is water soluble (such as alcohols), then chillers are impractical [23].

In addition to measures that reduce air emissions by way of equipment modification, it is also possible to reduce emissions by way of proper equipment layout, operation, and maintenance. Cleaning tanks should be located in areas where ambient air turbulence and temperature do not promote vapor loss. It has been reported [25] that a facility located a soak tank of halogenated solvent near their paint curing oven. The vapors from the tank entered the oven and decomposed into hydrochloric acid. The acid vapors altered the cure rate of the paint being dried in the oven and as a result, all of the finishes were ruined. In addition to the solvent vapor losses incurred by the facility, paint stripping and paint application wastes increased because all of the parts being painted had to be stripped and repainted.

Good operational measures include proper control of heat supplied to a vapor degreaser, avoidance of spraying parts above the vapor zone or cooling jacket, and avoidance of drag-out of solvent (both liquid and vapor). Drag-out of liquids can be reduced through proper handling of the parts being cleaned and by allowing parts to drain adequately.

Drag-out of vapor is caused by the rapid insertion and/or removal of an item from a tank. Generally, the speed of the workpiece into and out of the tank should not exceed eleven feet per minute [26]. Also of importance is the geometry of the piece being handled. If the space between the wall of the tank and the object is too narrow, a piston effect can be created. This is especially important when dealing with small tanks, large objects, or "silhouette covers". As a general rule of thumb, the cross-sectional area of items to be cleaned should not exceed fifty percent of the tank's open area [27].

Multi-stage countercurrent cleaning reduces the amount of solvent used by allowing the solvent to reach a much higher level of contamination before requiring replacement or treatment. Parts enter a first cleaning stage where the bulk of the contamination is removed using dirty solvent. Next, the parts enter a second stage where clean solvent is used to remove any remaining contamination. When the level of contamination in the clean solvent bath exceeds the level specified for assuring that the part is adequately cleaned, dirty solvent is removed from the first stage and the solvent from the second stage is used as dirty solvent make-up. Following this step, virgin solvent is added to the second stage as fresh solvent make-up.

Multi-stage cleaning reduces solvent use by reducing the waste load placed on the final cleaning stage and by allowing the solvent in the first stage to become very dirty before being disposed or treated. Very often, solvent is replaced when the level of contamination prevents adequate cleaning of the part. In a cold tank operation, all of the solvent is replaced when this occurs. With a multi-stage operation, only some of the solvent is replaced and at a much higher level of contamination as compared to waste solvent from a cold tank. Multi-stage countercurrent cleaning systems can be designed using individual cold cleaning tanks or by welding dividing walls inside an existing tank.

4.1.4.3 Increasing the Recyclability of Solvents

Increasing the recyclability of solvents can be achieved by maintaining the quality of the solvent, standardizing the solvents used, and consolidating the use of solvent inside a facility. While maintaining solvent quality can be viewed as a measure that reduces the amount of solvent used, solvent quality is much more critical when solvents are recycled. This aspect is highlighted in the following paragraphs along with the two other major areas of concern: standardization and consolidation.

Maintaining solvent quality relies on the ability of the operator to prevent undue contamination of the solvent. Contamination of solvent usually occurs from addition of other solvents to the tank, drag-in of water or aqueous cleaning solutions from other processes, or failure to remove sludge from the tank.

When incompatible solvent or water is added to a tank of chlorinated solvent, the formation of hydrochloric acid can occur. Metal particles and organic-based sludges can act as catalysts and accelerate the formation of acid. When a tank of solvent becomes acidic or "goes acid", the solvent can no longer be recycled and extensive maintenance procedures are required to restore the tank to a usable condition. The solvent is removed from the tank and several caustic washes and water rinses are required to neutralize any acid remaining inside the tank. To help prevent solvent from "going acid", chemical stabilizers are usually added to the solvent before it is sold. As solvent is used and recycled, the ability of the stabilizers to prevent acid formation lessens. Therefore, maintaining the quality of the solvent is essential to maintaining the recyclability of the solvent.

Very often, contamination of solvent with other solvents occurs. When solvents have very similar names, such as 1,1,1-trichloroethane and trichloroethylene, the probability of cross-contamination increases. It has been reported that as little as one-tenth of one percent 1,1,1-TCE, mixed into a tank of TCE, can cause an acid condition [27].

Contamination of some chlorinated solvents with water can also lead to formation of undesirable chemical compounds. In addition to acid formation, water and solvent can form minimum boiling azeotropes (an inseparable mixture with a lower boiling point than that of water or solvent alone). During distillation or recycling, these azeotropes get carried over with the pure solvent and can interfere with the cleaning operation.

To avoid or reduce the possibility of water contamination, equipment maintenance is essential. On vapor degreasers, the water separator should be checked frequently to ensure that it is clean and free of debris. Next, the temperature of the water exiting the condenser coils and cooling jacket should be maintained between ninety to one hundred degrees Farenheit. If the temperature falls too low, an excessive amount of water can be condensed out of the air. As a final measure, parts should not be allowed to enter the cleaning operation while wet.

Parts from a cleaning/surface finishing operation are often rinsed with water to remove any process solutions that adhere to the surface. When solvent cleaning follows an aqueous cleaning/surface finishing operation or water rinse, drag-out from these operations can lead to water contamination of the solvent. The degree of drag-out should be minimized so that the need for rinse water is lessened, less depletion of the cleaning/finishing process solution occurs, and the activity or efficiency of both the process solutions and the solvents is maintained. Methods that reduce the degree of drag-out rely mainly on the proper design and operation of the equipment.

The design and operation of a rack system can have a significant impact on drag-out. Table 4.1 presents average amounts of drag-out (gallons of solution per thousand square feet of surface) for parts racked in various configurations.

It is important to follow some generalized guidelines regarding system design and operation to ensure the proper draining of parts. Parts should always be racked so that the surfaces are as vertical as possible and the longest dimension should be horizontal. The lower edge of the part should be tilted from the horizontal to allow for run-off during removal from the tank. Solutions should drain from a corner rather than the entire edge of the part.

For parts with cup-shaped recesses, measures such as tilting the parts during withdrawal or drilling small holes in the part to provide for drainage of accumulated cleaner solution have proven effective. Pioneer Metal Finishing Inc., in Franklinville, New Jersey, reported that improved rack design (proper tilting of long horizontal bars) reduced the amount of drag-out experienced in an electroplating operation [28].

TABLE 4.1

DRAG-OUT FOR VARIOUS RACK CONFIGURATIONS

Item	Drag-out, gal/1000 ft2
Vertical parts,well drained	0.4
Vertical parts,poorly drained	2.0
Vertical parts,very poorly drained	4.0
Horizontal parts,well drained	0.8
Horizontal parts,very poorly drained	10.0
Cup-shaped parts,very poorly drained	8.0 to > 24.0

Source: Electroplating Engineering Handbook [23].

Other mechanical measures to reduce cleaning solution drag-out and subsequent solvent bath contamination include installing air jets to blow parts dry and the use of fog nozzles on rinse tanks. Use of air jets is limited to cases where dried cleaning solution on the part does not interfere with subsequent operations. This should not be a problem after or following a water rinse operation.

Fog nozzles are specially designed high pressure spray units. They provide a high degree of rinsing while using a small amount of water. Fog nozzles are especially useful over heated processing baths where the small amount of water introduced into the bath compensates for losses due to evaporation [23].

Prompt removal of sludge from solvent tanks is also vital to the maintenance of cleaning efficiency and the prevention of acid formation. Stripped paint and other organic contaminants can dissolve in the solvent and reduce cleaning efficiency. Contamination by organic materials should never be allowed to exceed ten percent by weight in a cold cleaning operation or twenty-five percent in a vapor degreasing operation. If these levels are exceeded, acid formation can occur. Metal fines, such as zinc and aluminum, are very reactive in chlorinated solvents and should always be removed promptly.

As previously mentioned, stabilizers are added to chlorinated solvent to help prevent the formation of acid. These stabilizers break down with use and over time. As a consequence, their ability to neutralize acid lessens. Also, their proper concentration level is not always maintained following reclamation.

Usually, when an acid acceptance test indicates that the solvent is close to the point of becoming acidic, fresh solvent is added to boost the level of stabilizers. This is a poor solution because the addition of fresh solvent, as opposed to adding a stabilizer formulation alone, cannot restore the level to full strength. A better solution is to analyze the solvent and add specific compounds as required. Based on the cost analysis, the economic break-even point is for solvent batches of five hundred gallons or more [25]. One obstacle to implementation of this measure is that stabilizer formulations are not always readily available as separate products and that these formulations are viewed as proprietary by the solvent suppliers.

Standardizing the solvents used in a facility can often increase the potential for recycling. Many times, the type of solvent used is based on a person's past experience and does not necessarily reflect the actual needs of the operation. It is not uncommon to find many different solvents being used in the same facility for similar operations. Because many different types of solvent are being used, and the amount of waste solvent generated from any one operation is small, the potential for recycling is seldom considered.

An electronics company in Massachusettes replaced the use of three solvents (mineral spirits, perchloroethylene, and a fluorocarbon-methanol blend) with a mixture of 1,1,1-trichloroethane and alcohol [29]. Originally, mineral spirits were used to degrease machine parts, perchloroethylene was used in a vapor degreaser for cleaning computer housings, and the blend was used to clean flux from printed circuit boards. With the new solvent mixture, fresh solvent is now used to clean the printed circuit boards. The same solvent is then used to degrease the computer housings and then the machine parts. Reusing the solvent sequentially in less demanding cleaning operations has reduced the overall amount of solvent consumed (and waste produced) by the facility. Additional benefits included elimination of potential cross contamination, generation of a single wastestream with reclamation value, simplified safety and operational procedures, and increased purchasing leverage.

4.1.5 Summary

The source reduction methods for minimizing solvent wastes associated with parts cleaning are summarized in Table 4.2. The potential for application of these measures is highly plant- and product-specific. Therefore, detailed analysis of the methods is required before implementation can be undertaken.

4.2 Process Equipment Cleaning

Process equipment cleaning is a periodic maintenance function often performed with the use of solvents. Equipment cleaning waste may, in some instances, be a small fraction of the total waste generated by a facility. Nonetheless, the total amount of solvent wastes generated by this operation is usually quite significant. In some cases, such as paint formulation and application, and agricultural chemicals formulation, equipment cleaning is responsible for the majority of solvent waste generation.

Process equipment cleaning is of particular importance in batch processes such as surface coating or agricultural chemicals formulation. Batch processes require a much higher cleaning frequency as compared to continuous processes. Whether the cleaning is performed using solvent or an aqueous cleaner depends on the nature of the operation, the product, and the preference of the operator.

This section reviews source reduction measures to decrease solvent waste from process equipment cleaning. A discussion of the reasons for process equipment cleaning and the methods used is also presented.

TABLE 4.2
SUMMARY OF SOURCE REDUCTION METHODS FOR PARTS CLEANING

Source Reduction Technique	Options
Eliminate the use of solvents	-Replace oil-based cutting fluids with water-soluble cutting fluids. -Use peel coatings in place of oils. -Use aqueous cleaners instead of solvent. -Use non-solvent based paint stripping methods such as: caustic strippers, Cryogenic stripping, plastic bead blasting, molten salt, thermal or hot air.
Reduce solvent usage	-Source control of air emissions from cold tanks and vapor degreasers by: installing and using lids, increasing freeboard height, installing freeboard chillers, reducing solvent drag-out. -Replace single stage with multi-stage countercurrent cleaning.
Improve solvent recyclability	-Maintain solvent quality by: preventing cross-contamination, reducing drag-in of water, removing sludge promptly from tank, monitoring stabilizer concentration. -Standardizing the solvents used.

The discussion is primarily oriented towards three processes: paint manufacture, paint application, and agricultural chemicals formulation. These processes are of commercial importance in California and generate large quantities of solvent wastes.

4.2.1 Reasons for Equipment Cleaning

The reasons for cleaning process equipment are related to the process function of the equipment. For example, in processes such as paint or agricultural chemicals formulation, the production of many different products in the same equipment requires the mixing equipment to be cleaned between batches in order to avoid cross-contamination of the products. Table 4.3 lists the reasons for cleaning process equipment. In general, equipment cleaning is performed to maintain or restore the operating efficency of the equipment, to prevent product contamination and to maintain product quality, to extend the lifetime of the equipment by minimizing erosion or corrosion, to allow for inspection and repair of equipment, and to improve the appearance of equipment [1].

Process equipment cleaning can be accomplished by using organic solvents or inorganic acid/alkali cleaning agents. Solvents are used for the following reasons:

- Solvents have a gentle cleaning action and are not as corrosive as acid/alkali cleaning agents.
- Solvents are non-reacting and can be used to clean many materials that may react with alkali/acid cleaners. For example, aluminum reacts with concentrated caustic solution. Solvent cleaning may be recommended for cleaning heavily fouled aluminum surfaces.
- Possible damage to surfaces from mechanical cleaning methods is avoided by solvent cleaning.
- Solvent cleaning is preferred for processes which use solvent as a raw material because contamination of the subsequent batches can be avoided by cleaning the equipment with a solvent that is a part of the product formulation.
- Deposits may be soluble only in the solvent.
- Aqueous cleaners take longer to dry than solvents; consequently, cleaning times are longer for aqueous cleaning. Often the acid/alkali/water rinse sequence is followed by solvent rinse to speed up drying.
- Economics may favor use of solvent.

4.2.2 Cleaning Methods

There are many different methods employed in process equipment cleaning. Some of these methods include mechanical cleaning techniques, the "fill-and-empty" technique, the circulation technique, the "flow-over"

TABLE 4.3
REASONS FOR CLEANING VARIOUS TYPES OF PROCESS EQUIPMENT

Process Equipment	Reasons for Cleaning
Raw material storage containers	- require cleaning before reuse to prevent contamination of the subsequent batches - require cleaning before disposal - require cleaning before equipment inspection - to prevent settled solids from clogging process lines
Mixing tanks	- require cleaning between subsequent batches to prevent product contamination - to prevent settled solids from clogging process lines - require cleaning before equipment inspection - require cleaning when the heavy build-up of residue interferes with the process
Filling/packaging equipment	- requires cleaning between batches of different product - requires cleaning when the residues decrease operational efficiency
Application equipment	- requires cleaning to maintain the operational efficiency

technique, and onstream cleaning techniques [1,2]. Method selection usually depends on the type of equipment being cleaned, the nature of the deposits being removed, the type of cleaning solution being employed, the ease and safety of the operation, and the overall economics of the method. The following paragraphs briefly discuss the cleaning methods mentioned above.

Mechanical cleaning involves physically breaking deposits from the equipment walls. Examples of this method include manual wiping or squeegeeing of process vessels, pigging of process pipelines, and use of high velocity water jets (hydroblasting). Manual wipers are widely used for cleaning small portable tanks in the paint industry.

"Fill-and-empty" involves filling the process vessel with cleaning agent followed by heating and agitation of the contents. After a period of time, the solution is drained and sent for disposal. The cleaning agent is water, alkali, organic/inorganic acid, or an organic solvent. This method typically requires a large quantity of cleaning solution and requires substantial equipment down time. It is generally used for cleaning small vessels, tanks or heat exchangers and is widely used in the paint and agricultural chemicals formulation industries.

Circulation also known as flow-through cleaning, is a modification of the "fill-and-empty" method discussed previously. The process vessel is filled with the cleaning solution and allowed to stand for a short period of time. Solution is then circulated with an auxiliary pump. Fresh make-up solution may be pumped in if the used solution is withdrawn. This method can be used for cleaning small process vessels.

"Flow-over" is used for cleaning large storage tanks or process vessels. The equipment is cleaned by spraying cleaning liquid via high velocity jets and allowing it to flow off. If the cleaning agent is flammable, an inert atmosphere such as carbon dioxide or nitrogen is provided. This method can be applied for cleaning smaller process vessels. Paint application booths and large pesticide formulation tanks are generally cleaned using this method.

On-stream cleaning generally involves the use of additives in the process fluids to accomplish cleaning. Chelants such as ethylene diamine tetra acetate, when added to the process stream, can dissolve deposits. The advantage of on-stream cleaning is that equipment need not be taken out of service for cleaning. On-stream cleaning is used for cleaning reactor jackets, and large gas-compressor-station engines. Another way to accomplish on-stream cleaning is to use mechanical devices, such as moveable tube inserts propelled by process fluids, to remove tube-side deposits in heat exchangers.

4.2.3 Waste Minimization through Source Reduction

When process equipment is washed with a solvent, a solvent-laden wastestream is generated. This stream is typically handled by one of the following methods:

- It is collected and used in the next compatible batch as a part of the product formulation.
- It is collected and distilled to recover and reuse the solvent; the distillation being done on-site or off-site.

- It is collected and used with or without treatment for subsequent equipment cleaning; when it cannot be reused any further, it is drummed for disposal.
- It is used to make a low grade product.
- It is drummed for disposal.

The solvent wastes generated by process equipment cleaning can be minimized through the following waste minimization approaches:

- eliminating the use of solvent;
- reducing the amount of solvent used; and
- increasing the use of the solvent waste.

The feasibility of these options as they pertain to the paint and agricultural chemicals formulation industries and surface coating application processes is discussed below.

4.2.3.1 Eliminating the Use of Solvent

Eliminating the use of solvent can be achieved through product reformulation and the use of other cleaning agents.

Product reformulation involves a major change in the manufacturing process. If the process for which the equipment is used employs a solvent, then a solvent-based cleaning agent is often picked to clean the equipment. By changing the process to a non-solvent based process, the need to use a solvent cleaner is eliminated.

Manufacture of water-based paint as opposed to a solvent-based paint is an example of product reformulation. The substitution of solvent-based paints by water-based latexes has already taken place to a large extent with architectural paints. Solvent-based paints cannot be eliminated altogether, however, as effective water-based substitutes cannot always be found. In addition, product formulation is not usually in the hands of the manufacturer - it is determined by market or customer demands.

The use of non-solvent-based coating formulations in place of solvent-based formulations is discussed in detail in Section 4.3 (Surface Coating Application) of this Guide. The possible substitutions include powder coatings, alternate water-based formulations, two-component catalyzed coatings, or radiation-curable coatings. In the case of powder coatings, solvent-based equipment cleaning is eliminated, since the overspray of the powder is collected and reused by mechanical means. Water-based coating applications in most instances involve an aqueous cleaning agent for process equipment cleaning. Solvent wash is sometimes used with water-based coating processes for heavy-duty deposit removal [4]. Preventing the build-up of the deposits ensures that solvent-based cleaning is not required.

The use of other cleaning agents needs to be considered by all facilities employing solvent-based cleaning. Usually, the same degree of cleaning can be achieved by using aqueous cleaning agents. The use of a high pressure alkali cleaning system for small paint plants is described by Morris [5]. The caustic cleaning solution is pumped under pressure and sprayed into the tank using a rotating nozzle. When the cleaning operation is complete, the dirty caustic is filtered and sent to the storage tank to be reused. The system can be modified to wash 5-gallon pails and 55-gallon drums by inverting them over a spray nozzle. Organic/inorganic acids can sometimes be used for equipment cleaning [6].

4.2.3.2 Reducing the Amount of Solvent Used

Reducing the amount of solvent used can be achieved through measures such as:

- maximizing the dedication of process equipment;
- avoiding unnecessary cleaning;
- properly scheduling production;
- inhibiting deposit build-up rate(s);
- choosing the proper equipment;
- efficient clean-up procedures; and
- better operating practices.

Maximizing the dedication of process equipment generally reduces the need for frequent cleaning. By using a mix tank consistently for the same formulation, the need to clean equipment between batches is eliminated. The utilization of equipment, however, is determined by factors other than waste minimization, including: equipment cost, availability, equipment downtime, production demands, and drying or deterioration of residual clingage. Often, installation of additional equipment is severely constrained by lack of floor space.

Avoiding unnecessary cleaning also offers potential for waste reduction. For example, paint mix tanks are sometimes cleaned between different batches of the same product, even though cross-contamination is not a problem. The effect of cross-contamination between batches should be examined from a product quality control viewpoint to see if a cleaning step is in fact necessary.

Proper production scheduling can reduce cleaning frequency. By scheduling paint production from light to dark colored paints, some equipment clean-up steps can be eliminated. Such a production schedule, however, may conflict with the timing of orders for specific paints [10].

Reduction of clingage decreases clean-up requirements and thus contributes to a reduction in clean-up wastes. In paint manufacture and application, exposure of the paint to atmosphere can cause the formation of dry paint films, which deposit on tank internals. This exposure can be avoided by using closed paint storage and transfer systems. This procedure was implemented by The Ford Motor Company. It resulted in less frequent and easier cleanups and an improvement in paint quality [13]. PPG Industries, Inc., reported that the use of closed process equipment with an inert atmosphere to prevent paint drying reduced equipment clean-up wastes [14].

When liquid is drained from a mix tank at the end of a batch, sufficient drain time should be provided in order to minimize the amount left over in the tank.

Rubber wipers can be used manually to scrape the sides of paint mixing tanks to remove deposits. The efficiency of cleaning depends on the operator. Use of mixers equipped with mechanical wall scrapers can reduce or eliminate clingage on tank walls. Dual shaft mixers with slow scraper blades wiping the walls and the bottom of mixing tanks are common in applications involving viscous liquids [7,15]. The use of Teflon-lined tanks reduces adhesion, improves drainage and thus reduces deposit clingage. This method is probably more applicable to small tanks amenable to manual cleaning. Choosing cylindrical tanks with low height-to-diameter ratios (preferably equal to unity) to minimize the wet surface area also results in lower clean-up requirements.

A cleaning method that is of use in the paint application process involves coating the inner surfaces of the spray booths. When a layer of waste paint has accumulated on the coating, the coating is peeled off along with the waste paint and replaced with a new coating. The disadvantage of this method is that overspray collected in this manner is not recyclable. However, the solvent-based cleaning is avoided [6].

Process pipelines are generally flushed with solvent to remove deposits on the pipe walls. Cleaning of the pipelines can be achieved by using plastic or foam "pigs" (slugs). The "pig" is forced through the pipe using an inert gas propellant to remove deposits [8,9]. This method can only be used if the pipelines do not have too many bends or sharp turns. Where possible, pipelines should be designed so as to facilitate such cleaning methods [10].

Efficient clean-up methods can minimize the solvent consumption for a given cleaning operation and thus decrease the waste quantity. When solvent-based cleaning is employed, preference should be given to "flow-over" methods which require less solvent than "fill-and-empty" methods. The use of high pressure spray nozzles for tank rinsing contributed to a reduction of 80 to 90 percent in aqueous wastes in the paint industry [11]. The same spray nozzle system when employed with solvent could have a similar impact on waste reduction. 3M Corporation's plant in Hilden, West Germany developed a fully-automated cleaning system that uses a rotating spray head to clean tanks containing coating formulations. The portable spray head reduced the clean-up time from 3 hours to 15-25 minutes and resulted in an annual savings of $61,500 in solvent and labor costs [13]. Portable or permanently installed clean-in-place spray systems for cleaning tanks are commercially available - for example, from Spraying Systems Co., in Wheaton, Illinois [14], or from Hydro-Services, Inc., in Missouri City, Texas [15].

For facilities that have additional storage space available, a countercurrent rinsing scheme may be practical. Countercurrent rinsing consumes smaller amounts of cleaning solvent compared with conventional co-current rinsing and can be utilized with clean-in-place systems.

Better operating procedures can minimize equipment clean-up wastes. Some of the points already discussed in this section - such as efficient cleaning methods - qualify as better operating practices. Other operating procedures that could be effective are discussed below. Detailed discussion of good operating practices is provided in Section 4.4.

Better operator training, education, closer supervision, tighter equipment inspection and maintenance, and increased use of automation are extremely effective in waste minimization. As the cost of digital electronic controls declines further, their use is expected to increase. Automation reduces generation of spoiled batches or off-specification products in addition to routine clean-up requirements. Computerized process control methodology applicable to formula-based manufacturing processes such as paint or agricultural chemicals formulation is described by Kennedy [16].

Cleaning equipment immediately after use prevents deposits from hardening, thus avoiding the consumption of larger quantities of solvent. Many times, dirty equipment is sent to a central cleaning facility where it is stored, until a given shift (usually night), to be cleaned. Proper planning can eliminate such situations.

4.2.3.3 Reuse of Solvent Wastes

Reuse of solvent wastes can reduce or eliminate wastes and result in cost savings associated with a decrease in raw material consumption. The solvent from the cleaning can be reused in the next batch formulation, or to make a low grade product.

The use of cleaning wastes in the formulation of subsequent batches is practiced to some extent in the paint and agricultural chemicals formulation industries [11,12]. If a facility employs a large variety of solvents in the batch formulations, the cleaning solutions must be segregated in separate tanks in order to reuse solvent-laden cleaning wastes. This may prove to be expensive.

At Desoto, Inc., in Greensboro, North Carolina, the wash solvent from each solvent-based paint batch is separately collected and stored. When the same type of paint is produced, waste solvent from the previous cleaning operation is used in place of virgin solvent. By implementing this measure, waste solvent was reduced from 25,000 gallons to 400 gallons. The same technique is followed for water-based latex paint production processes [12].

Similar measures were reported by Rexham Corporation, in Mathews, North Carolina. The company uses toluene to clean ink from the printing press, and runoff toluene is collected as waste. Rexham has nearly eliminated its toluene waste by segregating cleanup toluene according to the color and type of ink cleaned and then reusing the collected wastes to thin future batches of the same ink. The procedure has no effect on product quality and has resulted in almost 100 percent reuse of the toluene solvent [17].

ICI Americas, Inc., in Goldsboro, North Carolina initiated the practice of segregating spent chlorinated and non-chlorinated solvents used in the formulation of agricultural chemicals. This practice facilitated their reuse of solvent and contributed to a decrease in raw material consumption and waste disposal costs [17].

At Thiele-Engdahl, Inc., in Winston-Salem, North Carolina, similar solvent waste segregation and reuse was attempted without much success. Due to the wide variety of products made and solvents employed, segregation proved complicated and expensive. In addition, the risk of contaminating the entire batch was significant enough that this solvent reuse method was discontinued [12].

The use of solvent-laden wastes to make a low grade product has some potential applications. At the Major Paint Co., a division of Standard Brands Paint Co., in Torrance, California, the wash waters from cleaning water-based latex paint mix tanks were mixed to produce a beige-colored product that has sold successfully as a maintenance paint. Similar use of the waste from the solvent-based formulations is under investigation [10].

4.2.4 Summary

Source reduction measures for minimizing solvent-laden wastes from process equipment cleaning are summarized in Table 4.4. The potential for application of these measures is highly plant specific. Detailed analysis is necessary before implementing any of the measures. Additional sources of information from trade associations and journals are provided in Appendix C.

4.3 Surface Coating Application

Coatings are applied to surfaces for functional purposes (water-proofing, flameproofing, abrasion resistance, rust proofing, magnetizing, reflecting, insulating, or adhesion), or for decorative purposes. Coating formulations often involve the use of solvents as carriers for film-forming binders, pigments, powders, and adhesives. Some of the major solvents used for coatings include acetone, n-butanol, o-dichlorobenzene, diethyl ether, ethyl acetate, i-butanol, methyl ethyl ketone, methyl isobutyl ketone, methylene chloride, 1,1,1-trichloroethane, trichlorofluoromethane, tetrahydrofuran, cyclohexanone, and petroleum derivatives such as naphtha, xylene, toluene, or hexane [1]. The choice of solvent depends on the type of coating that is required, drying speed, the nature of the substrate material, and the properties of the solvent. The coating method depends on the coating formulation. The solvent content in the formulation can vary from 85 percent (acrylic lacquers) to 0 (powder or water-borne coatings).

The advantages of using a solvent-based coating are:

- durability;
- fast drying time;
- low corrosivity to substrate; and
- high gloss finish.

The disadvantages include:

- emission control problems;
- worker exposure hazards;

TABLE 4.4
SUMMARY OF SOURCE REDUCTION METHODS FOR PROCESS EQUIPMENT CLEANING

Source Reduction Technique	Options
Eliminate the use of solvents	- Reformulate product - Use other cleaning agents
Reduce solvent usage	- Maximize dedication of process equipment - Avoid unnecessary cleaning - Schedule production properly - Inhibit deposit buildup rate - Choose equipment properly - Establish efficient cleanup procedures - Establish better operating practices
Improve solvent reuse	- Use in the next batch formulation - Use to make a low grade product

- fire hazards; and

- problems associated with waste management, disposal, and liability.

Source reduction techniques for minimizing solvent-bearing wastes associated with surface coating applications are discussed in this section. A review of coating usages, types and processes is also discussed.

4.3.1 Coating Use Profile

Coatings are routinely applied to a wide spectrum of products, including automobiles and book bindings. Based on their function, surface coatings can be classified into three broad categories:

- architectural;

- original equipment manufacture (OEM); and

- special purpose.

Architectural coatings are used in building construction, painting, and repair. OEM coatings are used by industries engaged in the manufacture of automobiles, appliances, and furniture. Special purpose coatings are used for industrial, military, or highway maintenance. Tables 4.5 thru 4.8 list the 1985 consumption patterns of industrial coatings, use patterns of various architectural coating formulations, use patterns of coatings by OEM, and the use patterns of special purpose coatings, respectively.

4.3.2 Coating Types

A coating formulation generally consists of a carrier fluid (such as solvent or water) and various additives. The carrier fluid serves as a solvent or dispersion medium for film-forming binders, pigments, and fillers. The additives impart desired rheology, durability, texture, adhesion, and other attributes. Based on their composition, coating formulations can be grouped into three categories:

- solvent-borne formulations;

- water-borne formulations; and

- formulations without water or solvents.

<u>Solvent-borne coating formulations</u> usually contain 60 to 80 percent solvent depending on the application. <u>Special high-solids coatings</u> contain twice the amount of pigments for the same quantity of solvent, compared to conventional solvent-borne formulations. The main advantage of high-solids formulations is that they contain smaller quantities of solvents. The high viscosity of formulations makes their application difficult. To reduce viscosity, high-solids coatings are formulated as emulsions or non-aqueous dispersions (as opposed to solutions) of resins in the solvent.

TABLE 4.5

CONSUMPTION PATTERN OF INDUSTRIAL COATINGS IN 1985

Coating Type	Consumption (million lbs)	Value (billion $)
Architecural Coatings	540	3.5
OEM Finishes	385	3.5
Special Purpose Coatings	165	2.0
Total	1,090	9.0

Source: Reference [2]

TABLE 4.6

FORMULATION OF ARCHITECTURAL COATINGS IN 1985

Formulation Type	Percent Usage
Interior water-borne	37
Exterior water-borne	24
Exterior solvent-borne	20
Interior solvent-borne	17
Architectural lacquers	2

Source: Reference [2]

TABLE 4.7

USE PATTERN OF PAINTS/COATINGS BY ORIGINAL EQUIPMENT MANUFACTURERS IN 1985

Application	Percent Usage
Automotive	20
Metal	15
Wood	10
Coil coating	9
Industrial lacquers	8
Miscellaneous machinary	6
Marine Coatings	4
Appliances	4
Others	24

Source: Reference [2]

TABLE 4.8

USE PATTERN OF SPECIAL PURPOSE COATINGS IN 1985

Application	Percent Usage
Automotive	44
Industrial maintenance	18
Aerosols	12
Traffic paints	8
Marine shelf goods	4
Metallic paints	2
Others	12

Source: Reference [2]

Water-borne coating formulations contain up to 80 percent water in which polymeric film-forming binders such as alkyl, polyester, vinyl acetate, acrylic, or epoxy resins can be dissolved, dispersed, or emulsified along with color-bearing pigments and various additives. Water-borne coatings are available as air-drying formulations as well as baked finishes.

Formulations without water or solvent include two-component catalyzed coatings, radiation-curable coatings and powder coatings.

Two-component catalyzed coatings consist of two separately packaged reactive resin formulations, neither of them containing a solvent, which react on the surface of the substrate to produce a coating. An example of this process is the reaction between isocyanates and hydroxyl compounds to produce a polyurethane coating. The catalyzed polyurethane coatings contain up to 80 percent or more solids.

Radiation-curable coatings contain liquid reactive monomers that polymerize in the presence of ultraviolet, electron-beam or infrared radiation. These formulations contain no solvent. Pigments are dispersed directly in the mixture of a monomeric resin and a cross-linking agent in which a photoinitiator and various other additives are dissolved.

Powder coatings are 100 percent solids. They are based on finely divided powders of polymerized thermoset plastics containing polymerized resin, filler, pigments and various additives designed to impart stability (e.g., UV stabilizers). The basic types of resins include epoxies, acrylics and polyesters. In recent years, hybrid-type resins have experienced growth in application - for example, epoxy-polyester, polyester-glycidyl ester, or polyester-urethane hybrids. More information on powder coatings can be obtained from The Powder Coating Institute in Washington, D.C. (Tel. 202-429-1779).

4.3.3 Coating Application Processes

The basic steps involved in a coating application are:

- substrate surface preparation by stripping off the old coating and/or surface finishing;
- application of the coating; and
- curing.

Paint stripping is achieved by a brush, spray or dip method. The objective of the surface preparation step is to clean the surface and make it more amenable to adhesion of the coating to be applied. Surface preparation is achieved by using abrasives, alkalies, acids, or solvents. Solvent-based stripping usually involves the use of a methylene chloride based formulation. Many cleaning operations may be necessary, depending on the degree of contamination. After cleaning, surface treatments - such as phosphating - may be necessary to improve adhesion of the coating.

After the surface is ready ,the coating is applied. The choice of coating method depends on the size, shape, complexity, and quantity of items to be coated. For example, when a large number of small items need coating, methods such as tumbling, barreling, or centrifuging can be used.

Once coated, objects are usually sent to a curing oven to remove excess solvent and to make the coating more uniform. In the coating and curing steps, evaporated solvent can be recovered and recycled. A brief review of commonly used coating application methods is provided below.

Dip coating is often used for objects that provide good drainage. Here the coating formulation is held in a tank and the object to be coated is lowered into the tank and withdrawn after a period of time. Items as large as refrigerators, washing machines, and automobile bodies have been dip painted. A variation of dip coating is electrocoating, where a water-borne coating is applied to metals by electrically coagulating paint solids on the metal surface. The coated objects from the dip tank are rinsed to remove excess coating and then cured in a drying oven. Another variation of a dip coating technique is the use of fluidized beds for application of powder coatings. Here, the object to be coated is heated above the fusion temperature of the coating and then inserted for 2 to 3 seconds into an air-fluidized bed of the finely divided powder coating.

Flow coating is often used for items that cannot be dipped in tanks due to their size or weight, or when installation of dip tanks is not cost-effective. The items are flooded with a coarse (unatomized) shower of coating formulation. The excess paint is drained off to be recirculated. The items are then oven dried.

Roll coating, also known as coil coating, is used for coating flat surfaces or continuous flexible sheets. The coating is applied to a roller and is transferred to the object by contact. Roll coating is used for coating cans and paper boards.

Curtain coating is used in the food industry (to coat candies with chocolate) and by the furniture and electronic industries. A curtain of coating formulation is allowed to fall from a pressurized container, perpendicular to the direction of work flow. The items that pass through the curtain are coated. The coating thickness is controlled by the thickness of the curtain and by the speed of the conveyer which moves the parts.

Spray coating is the most widely used method for paint application. Spraying can be manual or automatic. A spray gun powered by compressed air is generally used to atomize the coating agent. Some variations of this method include airless spray and electrostatic spray. In airless spray, the coating agent is forced out of the gun at high pressures so that air is not required for atomization. In the electrostatic spray, the coating agent leaving the gun is given a positive charge. The object to be coated is connected to the electrical ground to attract the coating agent.

The drawback of spray coating is overspray - i.e., the amount of dispensed coating that does not reach the object. Overspray can be as high as 50 to 70 percent of the applied paint. It is sometimes recycled, but more often is disposed of as waste. Overspray is reduced to 30 to 35 percent in airless spray and to 10 to 15 percent in the electrostatic method [5]. Other disadvantages of spray coating include worker's exposure to fumes and fire/explosion hazards. The spray coating technique is used with powder coatings and nearly all other types of coating formulations, with the exception of water-borne enamels.

Bulk coating methods are used to coat a large number of very small parts. The most commonly employed methods are tumbling, barreling, or centrifuging. In all three methods, the parts are placed inside a barrel, the coating formulation is poured onto the items, and the barrel is then rotated. After a short time and at the correct point of tackiness, the parts are transferred to an oven in a wire basket. If the time in the barrel is too short, the parts leaving the oven will be stuck together. If the time in the barrel is too long, the finish will be damaged and marred. Proper control of coating is thus achieved by controlling the residence time of the parts in the barrel.

Table 4.9 summarizes the various types of coating methods discussed above. The single most important parameter related to waste generation from coating application is the transfer efficiency, defined as the fraction of total coating formulation used that actually remains on the target surface to form a coating. Table 4.10 provides a list of transfer efficiency values associated with various painting methods.

4.3.4 Waste Minimization Through Source Reduction

Solvent waste results from three operations in the overall coating application process: paint stripping, coating application, and equipment cleaning. Paint stripping and equipment cleaning are discussed in detail in Sections 4.1 (Parts Cleaning) and 4.2 (Equipment Cleaning), respectively. This section reviews waste minimization pertaining only to coating application.

Source reduction of solvent waste can be achieved by:

- eliminating the use of solvents altogether in the coating formulations;
- reducing solvent-bearing waste by technology modifications, and employing better operating practices; and
- reuse/recycling of the solvent wastes.

4.3.4.1 Elimination of Solvent Usage in Coating

Elimination of solvent usage in coating can be accomplished by employing powder coating, water-based coating, two-component catalyzed coating, or radiation-cured coating and aqueous powder suspensions. The following paragraphs discuss each of these alternatives with the exception of aqueous powder suspensions. These are still in the development stage.

Powder coating is an effective alternative to solvent-based paint application. Powder coating has been found to be effective in painting a wide variety of products and components [6]. Powder coating formulations are available in various colors and can be applied to various substrates.

To powder coat, a specially formulated fusible paint powder is applied to a surface, usually by electrostatic spray gun. The powder is pneumatically conveyed to the spray gun using air as the carrier fluid, thus eliminating the need for a solvent carrier. The electrostatic forces ensure that the powder adheres properly to the surface of the substrate. Excess powder that does not

TABLE 4.9

SUMMARY OF COATING METHODS

Basic Type	Variations
Dip Coating	Conventional dip tank Fluid bed (powder coatings) Electrodeposition
Flow Coating	
Roll Coating	
Curtain Coating	
Spray Coating	Air,presssure,or centrifugally atomized Conventional or electrostatic
Bulk Coating	Tumbling,barreling,centrifuging

TABLE 4.10

TRANSFER EFFICIENCIES OF VARIOUS PAINTING METHODS

Method	Percent Transfer Efficiency
Conventional air-atomized spray	30 - 60
Electrostatic air-atomized spray	65 - 85
Conventional pressure-atomized spray	65 - 70
Electrostatic centrifugally-atomized spray	85 - 95
Roll coating	90 - 98
Electrocoating	90 - 99
Powder coating	90 - 99

Source: Reference [5]

adhere to the surface falls down on the bottom of the paint booth and can be recycled. The coated objects are then heated in a curing oven to fuse the powder to the surface.

Applying powder coating through the use of fluidized beds involves the immersion of heated objects into an air fluidized bed of powder coating particles. The particles fuse to the surface of the object and the object is withdrawn from the bed after a short residence time.

The advantages of powder coatings are:

- Powder coatings contain no solvents, thus emissions of volatile organic compounds and the related air pollution problems are eliminated.
- Preliminary toxicological studies indicate that many of the commercial powder formulations are non-toxic [7].
- Since the overspray powder can be recycled, material utilization is high and solid waste generation is minimal.
- The process has a high transfer efficiency.
- Powder costs are minimally affected by petroleum prices.
- Messy clean-up operations present with liquid-based paints are avoided.
- Coating quality is claimed to be better than with the solvent-based coating.
- The reject ratio of parts is lower.
- Powder coating is easier to apply and it is easier to train people to use it.
- Waste disposal and liability problems are reduced.
- The operation is less labor intensive.
- Maintenance is easier.
- Overall operating costs are lower.
- Fire hazard and insurance rates are reduced.
- The operation is more flexible to changing coating requirements.
- Better operator attitudes result, as the operation is less messy.
- Better neighborhood relations result as the odor problems associated with the solvent-based application are eliminated.

The disadvantages of powder coatings are:

- Application equipment is more expensive to install (compared to a solvent-based or a high solids coating system) [8]. Table 4.11 compares the economics of four coating operations: powder coating, conventional solvent-based coating, water-based coating, and high solids coating.
- Since powder coating is done at elevated temperatures, it is, at present, not usable on heat sensitive substrates such as plastics, wood, and assemblies containing non-metal parts. Formulations with lower cure temperatures (275° F) are being developed [9].

There are numerous examples of successful substitutions of powder coating for solvent-based processes. Some of these are described in Table 4.12.

<u>Water-borne formulations</u> used in place of solvent-borne coatings are another way of eliminating solvent wastes from the coating application process. The advantages of using a water-based coating are:

- Solvent air emissions are eliminated.
- Solvent based paint application equipment can be easily modified to apply water-based paints/coatings.
- Paint overspray can be easily collected with water in the spray booth and recycled. Though this can also be done in a solvent-based process, a difficult-to-treat aqueous wastestream may result due to direct contact with the solvent.
- Disposal and liability issues associated with wastes from the solvent-based formulation may be reduced.
- Energy savings can be achieved by recirculating hot air in the ovens used to cure the paint. Similar recirculation is not possible in a solvent-based operation as the solvent levels in the recirculated air may reach explosive levels.
- The installed capital cost of water based units is lower than that for high solids or powder coating (as seen in Table 4.11) [8].
- The fire and explosion hazards present with the solvent-based process are eliminated.
- Concerns about worker exposure to solvents are eliminated.

TABLE 4.11

THE ECONOMICS OF VARIOUS COATING OPERATIONS

Description	Conventional solvent	Water-borne	High solids	Polyester powder
Coating cost, $/gal	12.00	11.00	17.00	2.30
Volume of solids, %	47	35	63	98
Reducing agent cost, $/gal	1.55	----	----	----
Mix ratio	3.1	----	----	----
Mixed coating cost, $/gal	9.38	11.00	17.00	2.30
Coverage at 100% efficiency, sq ft/gal/mil	561	561	1011	118
Dry film thickness, mils	1.0	1.0	1.2	1.5
Utilization efficiency, %	60	60	70	97
Actual coverage, sq ft/gal	337	337	590	76
Applied cost, $/sq ft	0.0278	0.0326	0.0288	0.0303
Annual cost of coat, $/ 12,000,000 sq ft-yr	333,600	391,200	345,600	363,600
Equipment required		2 water wash booths, 1 dry filter booth, 4 automatic electrostatic guns, 2 manual electrostatic guns, 2 reciprocators, safety interlocks & stand-offs	2 water wash booths, 1 dry filter booth, 4 automatic electrostatic highspeed atomizers, 2 manual electrostatic guns, paint heating equipment	2 ES powder spray booths, 4 electrostatic automatic guns, 1 manual electrostatic gun, 2 reciprocators, 2 powder recovery systems with automatic recycle
Installed capital cost, $		108,000	110,000	150,000
Labor and cleanup cost, $/yr	132,100	132,100	128,400	75,600
Maintenance cost, $/yr	18,000	18,000	18,000	10,000
Energy costs, $/yr	29,100	31,100	27,100	15,700
Sludge disposal cost, $/yr	10,800	10,800	7,100	1,100
Depreciation(10 years, straight line)	----	10,800	11,000	15,000
Total annual cost, $/yr	523,600	594,000	537,200	481,000
Applied cost, $/sq ft	0.0436	0.0495	0.0448	0.0401

Sources: References [8, 9]

TABLE 4.12

EXAMPLES OF SUCCESSFUL SUBSTITUTION OF POWDER COATING FOR SOLVENT BASED COATING PROCESSES

COMPANY	PROCESS MODIFICATION	REPORTED BENEFITS
Bolden Products Division Belding, Michigan	Substituted solvent based alkyds, used for coating wrappers by hand spray and interior and kit parts by dip painting, with powder coating employing polyester.	-The quality of paint improved. -The disposal costs were decreased. -The new process is less labor-intensive. -Emission control problems were eliminated.
Whirlpool, Inc. St.Paul, Minnesota	The appliance coating was changed from solvent based to acrylic powder coating.	-Reduction in VOC emissions from 75 tons/yr to 5 ton/yr. -Rejection rate decreased from 25% to 1%. -Major savings in maintenance and energy. -Required 7 less operators.
General Electric Switchgear	Replaced a high solids spray method by manual electrostatic spray powder lines.	-Reduction in annual VOC emissions from 9 tons to 0.2 tons. -Reduction in annual sludge volume from 112 drums to 28 drums. -Savings in labor, material, utilities, maintenance,and reduced floor space. -Ability to coat a greater variety of parts.
BDP Company	Replaced solvent based acrylic painting by thermosetting polyester powder coating.	-Reduced annual emissions from 121 tons to virtually zero. -Saved over $10,000/yr on disposal costs. -The new coating is tougher and more weather durable. -Better control of film thickness.
Lawn Boy, Inc.	Replaced liquid based coating of power lawn mower housing parts by polyester powder coating	-Easier operator training. -Eliminated liquid sludge disposal problems.
Lee L. Woodward, Inc.	Replaced medium to high solids solvent based method for coating tubular steel and aluminum furniture with polyester powder coating.	-Superior finishing. -Reduction in emissions. -Reduction in disposal costs.

TABLE 4.12
EXAMPLES OF SUCCESSFUL SUBSTITUTION OF POWDER COATING FOR SOLVENT BASED COATING PROCESSES (continued)

Hobart (Kitchen-Aid)	Replaced solvent based coating of zinc, aluminum, and stell die-cast appliance mixer parts with powder coating.	-The finish is better and much harder. -Reduction in VOC emissions. -Rejects decreased from 15-17% to less than 5%. -Better neighborhood relations as there is no paint odor. -Much better employee attitudes as there are no messy liquid paint booth cleanup requirements.
Meco, Inc.	Replaced preheated high solids liquid paint coating used for coloring grills, furniture, an patio products with powder coating.	-A more durable finish. -The reject rate went down by 30%. -Less labor intensive. -Expect lower indirect costs. -The operation is cleaner. -Expect higher material utilization.
Revere Extruders, Inc.	Replaced high solids coating for extruded aluminum by powder coating.	-Energy savings due to the elimination of spray booth make-up air. -Complete environmental compliance. -Increased production time due to decreased emissions rate. -More durable finish. -Greater variety of colors and gloss finishes now accessible for architectural products.

Sources: References [8,9]

The disadvantages associated with the water-based paint application are:

- The annual cost to coat using water-based coating was found higher compared to conventional solvent, high solids, or powder coating (as seen from Table 4.11) [8].
- The applied coating cost per square foot for a water based unit is higher than that for conventional solvent based coating, high solids, or powder coating [8].
- The coating may be of inferior quality.
- As water is not as volatile as most organic solvents, the drying time is longer and could be a bottleneck in the production line. It may necessitate the installation of a drying unit.
- Surface treatment procedures may need extensive modification to convert to a water-based coating method.
- The quality of water-based coatings varies with ambient conditions such as room temperature and humidity.

Several case examples of successful conversion from solvent to water-based coatings are provided below for perspective.

The Emerson Electric Company in Murphy, North Carolina, replaced an organic solvent paint system by a water-based anodic electrostatic immersion paint system to coat die-cast aluminum pieces [10,11]. The benefits from this process modification were:

- The quality of paint application improved greatly.
- The system saved $1,680,000/yr on labor, raw materials, and other operating costs.
- Equipment downtime decreased from 3% to 1%.
- The water based system allowed for the recovery of 99.5% of the paint, which resulted in a raw material savings of $600,000/yr.
- Hazardous waste disposal costs decreased from $10,000/yr to $300/yr.
- Personnel and maintenance costs decreased by 40%.
- Worker exposure to organic paint solvents was eliminated.

In another example, Caterpillar Tractor Company in Mossville, Illinois used a water-based formulation for painting engines. The company realized energy savings by recirculating the hot air from the drying ovens. In addition, fire hazards and insurance costs were reduced [3].

The Fisher Body plant in Lansing, Michigan, replaced a solvent-based coating for painting automobile bodies with an electrocoat unit. As the electrocoat unit employs a water-based dip coat, solvent emissions were totally eliminated. In addition, as the parts prepared for the electrocoat process need not be dry, the drying that was necessary for the solvent-based process, was avoided resulting in energy savings [3].

At 3M's Riker Laboratories in Northridge, California, a solvent-based tablet coating process was replaced by an aqueous process. Though the modification initially posed problems, such as soggy tablets, the aqueous process saved many thousands of dollars [12].

The Naval Air Rework facilities in Pensacola and Jacksonville, Florida are converting to a water-based system for parts repainting. The modification, eliminates solvent wastes from paint application and equipment cleaning, and reportedly improves product quality [12].

Water-borne coatings for magnetic tape manufacture have been demonstrated at the research level but have not yet found commercial use. The commercial use depends, to a certain extent, on the availability of water-active binders that are close in tensile properties to polymers used in organic solvent based processes [13].

Some companies, such as Ciba-Geigy Corporation, supply dyes that can be used in aqueous- or solvent-based formulations. These dyes offer water bleed resistance, lightfastness and heat stability [14].

There are instances when the use of a water-based formulation in place of solvent-based formulation is impractical. For example, Carrier Corporation in Syracuse, New York attempted such a substitution, without much success. The following problems were encountered with the water-based formulation [15]:

- The increased drying time led to production scheduling problems. The new system took several hours for drying, compared to the time required for the solvent based process (less than 30 minutes).
- It required an increased amount of surface cleaning before the water-based coating could be applied. The time and cost involved in the extra cleaning were found to be prohibitive.
- The water coating did not have the same hardness, durability, or gloss.
- The quality of the water-based paint varied with ambient conditions such as humidity and room temperaure.
- The water environment was corrosive to galvanized steel. The existing equipment made of galvanized steel needed to be modified to stainless steel, which involved considerable capital expense.

Because of these problems, Carrier Corporation switched back to the solvent-based "compliance" coating employing a less toxic 1,1,1-TCE solvent.

In another example of an unsuccesful attempt to convert to a water-based coating, the Polaroid research and development group worked for more than 5 years to find a water-based formulation for photographic film coating. The research group did not find a satisfactory formulation that would not compromise product quality [16].

Two-component catalyzed coatings such as isocyanates and hydroxyl compounds which polymerize on a surface to form a polyurethane coating have been investigated by the automobile industry [3]. The high toxicity associated with the isocyanates, however, does not justify their use as substitutes for conventional solvent-based acrylic lacquers.

Radiation-curable coatings are solvent free and could be effective substitutes for the solvent-based agents. Degussa Ltd., in Burlington, Ontario developed a liquid prepolymer and a mixture of reactive thinners that are crosslinked in ultraviolet light. The thinners do not evaporate, but react to form the film. This coating method has been found to be useful for coating steel, chipboard, laminates, cardboard, and polystyrene [3].

4.3.4.2 Reducing Solvent-Bearing Waste From Coating Operations

Reducing solvent-bearing waste from coating operations should be considered whenever a solvent-based coating is used. Technology modifications and good operating practice options are discussed below.

The proper choice of equipment is an important factor in waste reduction. The following paragraphs discuss the equipment modification/replacement options that can minimize solvent wastes.

As mentioned previously, overspray is the chief cause of waste generated during coating application. Choice of equipment and application technique characterized by higher transfer efficiency (see Table 4.12) can be an effective approach to reducing overspray.

In a case example, Flexsteel Industries in Dubuque, Iowa, replaced a conventional spray unit with an electrostatic system [3]. The reported advantages were a 40 percent reduction in overspray, and a savings of $15,000/yr, with a two year payback period. A similar substitution was reported by Thomasville Furniture in Thomasville, North Carolina. In addition to the improvements in transfer efficiency, the overspray was collected on the spray booth walls. The walls electrically grounded to attract the particles. As a result, residues are absent in the rest of the work area [10].

Conversion from one spray unit to another is often easier and less costly than converting to totally different types of equipment. Though the roll and flow coating machines have 90 to 98 percent efficiency, and electrocoat machines have 90 to 99 percent efficiency, their applicability is limited to the size, shape and quantity of parts.

The electrostatic spray methods are usually applied to coat conducting materials such as metals. Non-conducting substrates can be coated by applying a sensitizer to make the surface conductive. The use of such sensitizers by the wood, plastic, and rubber furniture industry is discussed by Scharfenberger [17]. The sensitizer can be applied by wiping, dipping, flow-coating, or spraying. The cost of applying the sensitizer is said to be a small fraction of overall operating costs [17].

Kemp Manufacturing Industries in Goldsboro, North Carolina replaced its air-spray guns with air-assisted airless spray guns for spraying sealer on the printed finish of the bedroom suites. With a capital investment of $23,000, a 23 percent reduction in materials saving was reported due to increased transfer efficiency. In addition, cleaning frequency decreased to one week from 3 weeks [10].

Similar substitution was attempted by Nordic Ware in Minnesota for coating plastic bacon/meat racks. After testing the efficiency of three different air assisted airless spray units, there was no improvement in paint transfer efficiency and coating quality. The complicated geometry of the bacon/meat racks required a highly atomized spray, which could not be achieved with the tested airless spray units [18].

The use of high solids formulations in place of conventional solvent-based formulations is another possibility. As the high solids formulations contain a lower quantity of solvents, lower emissions and a lower quantity of wastes result.

The conversion of the coating process involves more than a simple replacement of equipment. There may be a considerable amount of time and work involved in testing, retesting, visiting other plants, engineering, and maintenance. The General Motors assembly plant in Van Nuys, California has successfully converted to high-solids formulation, however, not without considerable effort to maintain the coating quality. The change from a conventional spray coating to water-borne, high solids or powder coat for a large scale installation involves about 18 months of work by several people [5].

Good operating practices can be effective in waste reduction from coating operations. For example, preventing the contamination of nonhazardous waste with potentially hazardous materials such as solvent-based paint, can decrease the waste generation rate.

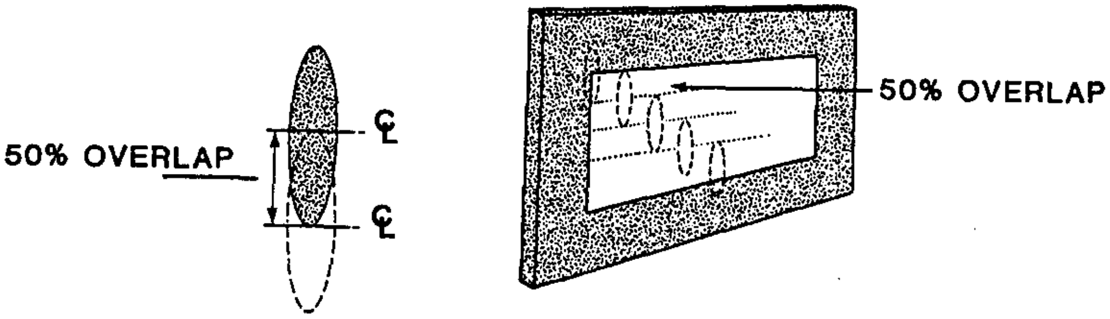
A good manual spraying technique is very important in reducing waste quantity. Additional benefits include increased production rates due to a decrease in the rejection rate. The basic fundamentals of good spraying techniques [19] are:

- a 50% overlap of the spray pattern;
- maintaining a 6-8 inch distance between the gun and the workpiece;
- maintaining a gun speed of about 250ft/min;
- holding the gun perpendicular to the surface; and
- triggering the gun at the beginning and end of each pass.

An overlap of 50 percent (see Figure 4.2) means that for every pass that the operator makes with the spray gun, 50 percent of the area covered by the previous pass is also sprayed. If less than 50 percent overlap is used, the coated object looks streaked. If more than 50 percent overlap is used, the coating material is wasted and it takes more passes than necessary to coat the object.

FIGURE 4.2

FIFTY PERCENT OVERLAP IN
THE SPRAY PATTERN



Reprinted from Kohl, et. al., Managing and Recycling Solvents in the Furniture Industry. North Carolina State University, Raleigh, NC, 1986.

To obtain a uniform finish, the gun distance should be kept constant from the workpiece (see Figure 4.3). If the gun is placed more than 8 inches, the coating may dry before it reaches the surface. If the gun is placed too close to the object, the coating material splashes on the surface resulting in an uneven coating. The recommended gun distance is 6 to 8 inches.

In order to get a uniform finish, the gun must be moved at a constant speed over the surface to be coated. High gun speed results in inadequate film build and requires more passes to finish coating. It also fatigues the operators. Low gun speed results in too thick a film. Therefore, there is an optimum gun speed, generally accepted to be about 250ft/min.

To obtain a uniform coating, the spray gun should be kept perpendicular to the surface of the object to be coated. Tilting the gun (see Figure 4.4) results in excess material being deposited in some areas and overspray. When the gun is arched 45 degrees away from the surface, the overspray can be as high as 65 percent in addition to getting an uneven coat. Proper training of the operators or using robots can eliminate excessive overspray [20].

At the beginning and the end of each pass, the gun must be triggered to avoid loss of material to the atmosphere. If the gun is not triggered at the end of a stroke, a pile-up of material results at the point where the gun reverses direction. To avoid this, some operators carry the gun beyond the surface of the workpiece before reversing the direction of gun movement. This action results in some material being lost to the atmosphere. A preferable alternative is triggering the gun to stop the spray at the end of the stroke and reversing the direction after triggering to start the spray.

When a spray coat method is used, the amount of air used to achieve atomization of the particles should not be excessive. Many operators often use excessive air pressures, which results in increased overspray and emissions. The 70 percent overspray in some instances can be lowered to 40 percent by air pressure adjustment.

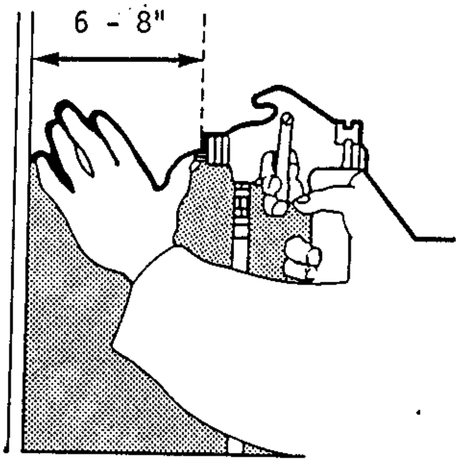
The paint or coating system should be as simple as possible and convenient to use without modifications. If the coating is difficult to apply, the tendency may be to add more thinner. However, addition of about 10 percent thinner may result in a 25 to 40 percent decrease in coating performance. Excessive thinning affects the film thickness, density, and durability [21].

Preventive maintenance plays a critical role in reducing the amount of overspray, stripping waste, and equipment cleaning wastes produced. Whenever a bad finish is produced, the paint is normally stripped off and the entire paint application procedure is redone. By maintaining all application equipment in good working order, the likelihood of producing a bad finish is decreased.

To ensure the most efficient use of spraying equipment, spray guns should be cleaned after use or whenever there is an appreciable interval between use. For hand-held units, a solvent rinse with occasional blow-back (cover the fluid tip and operate the trigger; this blows the paint back to its container) is adequate. A spray gun should always be able to provide a smooth change from solid fan to round cone by adjustment of the controls [19].

FIGURE 4.3

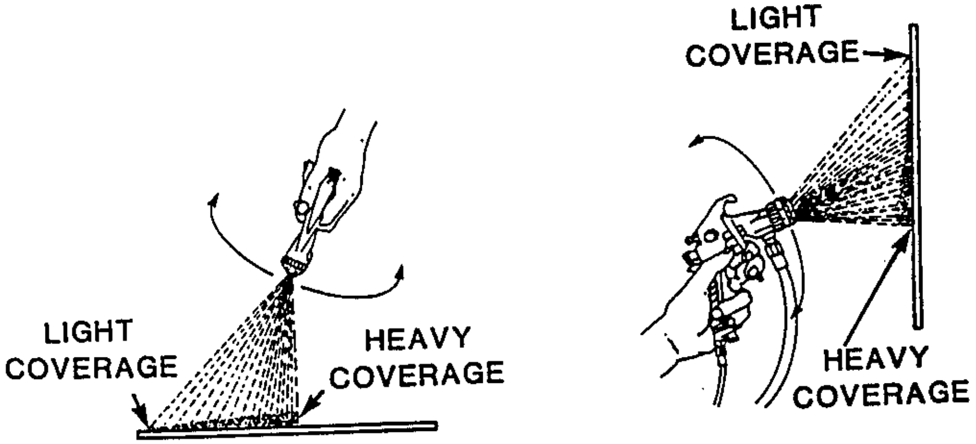
SPRAY GUN DISTANCE FROM
THE SUBSTRATE



Reprinted from Kohl, et. al., Managing and Recycling Solvents in the Furniture Industry. North Carolina State University, Raleigh, NC, 1986.

FIGURE 4.4

EFFECT OF NOT KEEPING THE
SPRAY GUN PERPENDICULAR
TO THE SURFACE



Reprinted from Kohl, et. al., Managing and Recycling Solvents in the Furniture Industry. North Carolina State University, Raleigh, NC, 1986.

Roller coating and flow coating machines must also be properly maintained if they are to produce good finishes. Rollers on roller coating machines should be cleaned regularly to remove dried paint and inspected for swelling of the material. If swelling is evident, the rollers should be replaced immediately. Curtain or flow coating machines have a curtain head that must be kept clean at all times. If this aperature becomes blocked, the curtain will break and give an uneven finish. Installation and proper maintenance of filter to remove solid particles, capable of plugging the curtain head, reduces the need for cleaning. To clean the machine, solvent should first be circulated through the machine, then, the aperature should be fully opened and cleaned with a soft rag or brush. Metal instruments should never be used for cleaning the curtain head.

Proper layout of equipment is important in waste minimization. Solvent soak tanks should be kept away from heat sources, or evaporation losses can occur. In a case example, the presence of the solvent soak tank near a curing oven caused the heavier-than-air vapors to enter the curing oven affecting the cure rate and resulting in bad finishes [22].

Operating schedules can be modified to minimize equipment cleaning. By producing large batches of similarly painted objects instead of small batches of differently painted items, cleanup frequency can be lowered. The cleaning step can be avoided by painting light colored items before dark colored items, if quality control can still be met.

In facilities where several spray operations are simultaneously taking place, the water-based spray units should be isolated from the solvent-based spray units. This will ensure that overspray from both operations does not mix causing a nonhazardous waste to be listed as hazardous. In addition, the recyclability of the overspray will be reduced, and the nonhazardous filter wastes from the water based spray unit will not be classified as hazardous. This procedure was recommended for the Gage Tool Co., in Minnesota. Their operation uses three water-based electrostatic spray units and a solvent-based spray unit [23].

Segregating the wastes is important in improving the recyclability of the solvent. If several solvents are used at a facility, solvent wastes should be segregated to the maximum extent possible. This practice facilitates direct reuse of spent solvent in addition to aiding solvent recovery operations.

All the containers must be labeled properly. Improper labelling may result in nonhazardous wastes being disposed of as hazardous, at considerable additional cost.

Standardizing solvent usage can be of benefit to facilities where surface coating is performed in multiple departments. Often, each department purchases their own thinner. As a result, an unnecessarily wide variety of thinners are used. This, in turn, often results in comingling wastes, rendering them non-recyclable. Standardization, in this context, means an effort to minimize the number of different types of thinners, as well as solvents used in coating formulations.

Closing the floor drains in the production area discourages use of water to clean up spillage. Any spills that do occur in such areas need to be cleaned by dry cleaning methods such as the use of rags. This reduces the solvent-laden wastes that would otherwise be generated [12].

Purchasing coating material in large bulk containers is generally preferable to buying an equivalent volume of small cans. For a given volume, the surface area of a large tank will be lower than that of the small cans, and thus the amount of residual material is lower. Large containers can often be returned to the coating manufacturers for cleaning and reuse. Though the waste volume is the same whether the cleanup is performed by the coating facility or the paint manufacturer, the manufacturer may be in a better position to handle the wastes. When purchasing the materials in bulk quantities is impractical, efforts should be made to minimize the amount of paint left over in smaller containers. This can be done by avoiding ordering extra paint for a given application.

4.3.4.3 In-Process Solvent Waste Reuse/Recycling

Solvent waste reuse/recycling options should be examined by coating facilities. Chapter 5 deals with the recycling issue from a global perspective. In the context of coating applications, however, direct reuse of solvent waste should be considered before attempting any recycling. For example, equipment washing may generate a stream that could directly be reused as the thinner in the next coating operation.

Recycle of overspray can be achieved by a water wash employing a curtain of water flowing over a series of baffles. The stray paint impinges on the water curtain and is carried down with the stream of water to a separator. When used with paints that are immiscible with water, the paint can be decanted in the separator and recycled. The water from the separator can then be reused in the washing process. This process is available commercially from Ultrafilt Inc. in Troy, Michigan.

The 3M Co., in St.Paul, Minnesota redesigned a spray booth to limit and recycle overspray. It is reported that the company saved 500,000 pounds/yr of the paint resin. With a capital investment of $45,000, an annual savings of $125,000 was reported [3].

Oshkosh Truck Corporation in Oshkosh, Wisconsin sends paint-laden air to a venturi scrubber. The water from the scrubber is then sent through two electrostatic water treaters, where the overspray is skimmed off and recycled. The water is then sent to the sewer without additional treatment [3].

Carbon adsorption employing granular carbon beds is often used to control emissions from the coating process. When the bed is saturated with solvent, the solvent is often removed by steam stripping. The regenerated carbon can then be reused. The solvent can be recovered by condensing and decanting the condensate [24]. More detail on carbon adsorption is provided in Section 4.5.

Ultrafiltration can be used to filter solvent-laden sludges using membranes with small pore sizes. The pores of ultrafiltration membranes are typically on the order of 0.01 microns. Paint particles are typically bigger than 1 micron in diameter [24]. With ultrafiltration, the solvent wastestream is first allowed to settle in a tank where large particles separate out. The solution from this tank is then sent through a series of membranes to obtain a purified solvent. The solids that accumulate on the membranes are removed on a continuous basis.

There is experience purifying paint wastes by ultrafiltration [24]. The installation of a unit for $41,500 at an automobile manufacturing plant resulted in a savings of $7,850/month. The payback period was estimated at 5.3 months. For paint solvent recovery, it is estimated that 1000 gallons/month of solvent waste could be processed to yield 750 gallons/month of pure solvent, with a payback period of less than one year [25]. Additional information on ultrafiltration is provided in Chapter 5.

<u>Distillation</u> can be used to recover the pure solvent from the spent solvent. Distillation can be accomplished using a wet process or a dry process. In the wet process, the waste solvent is contacted with live steam. The vapors are condensed and separated to give pure solvent. The disadvantage of the wet process is that the solvent is contaminated by water, and in turn the water contaminated with solvent may require treatment. The procedure is generally used with solvents that are immiscible with water. In the dry method, the solvent wastes are distilled by indirect heating [25].

Additional information on distillation can be found in Chapter 5.

<u>Evaporation</u> can be used to recover solvent from spent solvent. Evaporation can be performed by using drum dryers or thin-film evaporators. Thin-film evaporators are generally used for dealing with large quantities of wastes and are used mostly by professional solvent recyclers. Section 5.4 provides more detail on evaporation.

Reclaimed Energy Company in Connersville, Indiana uses a mechanically agitated thin-film evaporator to continuously evaporate 2,000 to 40,000 gal of waste solvent [26]. It is especially suited for handling heat-sensitive solvents since the contact time in the evaporator is small. Diamond Shamrock Chemicals Company in Ashtabula, Ohio uses a vacuum-assisted mechanically agitated thin-film evaporator to recover high-boiling solvents from 50,000 to 100,000 lb/yr of heat sensitive specialty chemicals [27].

4.3.5 Summary

The various source reduction techniques discussed above are summarized in Table 4.13. Additional sources of information that could prove useful are listed in Appendix C.

TABLE 4.13
SUMMARY OF SOURCE REDUCTION METHODS FOR SURFACE COATING APPLICATIONS

Source Reduction Technique	Options
Eliminate the use of solvents	- Use powder coating - Use water-based formulations - Use two-component catalyzed coatings - Use radiation-curable coatings
Reduce solvent usage	- Choose proper coating equipment - Replace conventional spray units with electrostatic units - Replace air-spray guns with pressure atomized spray guns - Use high-solids formulations in place of conventional solvent-based formulations - Adopt good manual spraying techniques - Avoid adding excess thinner - Avoid excessive air pressures for atomization - Maintain equipment properly - Lay out equipment properly - Isolate solvent-based spray units from water-based spray units - Close floor drains in the production area - Purchase proper quantities of coating agent - Segregate wastes - Standardize solvent usage
Reuse/recycle solvent waste	- Recycle paint overspray/sludge - Reclaim and reuse solvent from wastes using ultrafiltration, distillation or evaporation

4.4 Good Operating Practice

Good operating practice is a set of source reduction measures that relate to an organizational aspect of a production operation. In numerous case studies of successful source reduction efforts, a factor weighing heavily in the achievement of waste reduction has been a procedural or policy change within the plant or firm. In the context of waste minimization, the general objective of good operating practice or procedure is to minimize material losses and the probability of their occurence. It may be something as simple as a change in the method of accounting for hazardous materials, or something as complex as a change in management outlook. Proper procedures and policies leading to reductions in the amount of hazardous wastes generated should be considered in a company's overall operating plan.

A good operating practice is defined in this report as a procedure or organizational policy within a service or manufacturing operation which results in a reduction of hazardous waste generation. Thus, good operating practice encompasses changes to the personnel side of production as opposed to technology or materials aspects. The following is a list of the major elements of good operating practice discussed in this chapter:

1) Personnel practices
   - Management initiatives
   - Employee training
   - Closer supervision
2) Procedural measures
   - Waste audits and reviews
   - Additional documentation
   - Material/waste tracking & inventory control
   - Scheduling
3) Loss prevention measures
   - Spill/leak prevention program
   - Preventive/corrective maintenance
4) Wastestream segregation
5) Material handling & storage

Note that other classifications or groupings are possible and certain practices do not yield themselves readily to rigid classification schemes. For example, the labels that aid in material handling serve also to track materials and control inventory. Good material storage practices and preventive maintenance can be part of a spill or fire prevention program. Management initiatives and employee training affect all facets of plant operations.

The following sections describe each of the above five elements. Actual case examples are provided in order to illustrate the concept, or its application, and also to provide references to those who seek additional information.

4.4.1 Personnel Practices

4.4.1.1 Management Initiatives

The need to head off rising disposal costs and to confront environmental issues and responsibilities has encouraged many firms to institute self-standing environmental programs and policies. These include in-house chemical waste management programs. Waste management programs can take the form of on-going waste management/reduction programs, auditing programs, or periodic environmental reviews of operations.

Management initiatives most often result in actions taken either to start recycling solvent, or to eliminate/substitute solvent-based process/material with non-solvent alternatives. The following case studies illustrate the effectiveness of waste reduction programs.

Emerson Electric Company manufactures stationary power tools, which involves both metal finishing and painting operations. The company developed a chemical waste management program on the initiative of its Special Products Division with the support of the president and vice president. In addition to having addressed several immediate waste management concerns, the program seeks to 1) eliminate unauthorized dumping of spent chemicals, 2) educate employees on the proper disposition of waste chemicals, 3) prevent chemical spills, and 4) comply with environmental laws and regulations. Through its waste management program, Emerson has been able to adjust its effluents to conform to effluent guidelines, to reduce its downtime, and to implement various pollution reduction measures. Among numerous sucessful projects, the company was able to reduce chlorinated solvent usage by 80 percent following its decision to switch from solvent degreasing to an alternative cleaning method using alkaline detergent and steam. Emerson maintains an incentive awards program to encourage new ideas for cost savings or new product development. Items such as color television sets, radios, and stereos are awarded to acknowledge employee contributions [1].

Another excellent example is the waste reduction effort undertaken by the Scovill Company. Scovill uses 1,1,1-trichloroethane solvent to degrease metal stampings produced in their manufacturing process. Until it implemented a recycling program, the company had been accumulating waste solvent in 55-gallon drums. In order to avoid the responsibility and expense of landfilling the wastes, Scovill collaborated with the Fayetteville Office of the North Carolina State Solid and Hazadous Waste Management Branch to develop a plan to recycle the waste solvent. The company reported that the substitution of recycled solvent for the virgin product has resulted in an overall annual cost savings of $8260 and a payback period of under 6 months. Scovill has also instituted an employee incentive cost savings program which they hope will lead to other pollution prevention projects. Under this program, six-member teams are randomly selected and team membership is changed each year. The team responsible for the greatest annual cost savings to the company receives bonus checks [1].

4.4.1.2 Employee Training

An effective "good operating" campaign to reduce the amount of hazardous waste generated in a plant must incorporate an employee training program. The personnel responsible for operating and monitoring process equipment, for off- and on-loading hazardous materials, for storing and transfering toxic substances during plant operations, and for similar tasks, need to be trained to adhere to safe operating procedures, proper equipment use recommendations, correct process control specifications, and good industrial hygiene practices.

According to recommendations made by the National Agricultural Chemicals Association, the training of employees in safe hazardous materials handling should take place in three stages: 1) prior to job assignment, 2) during on-the-job training, and 3) ongoing during the employee's tenure with the company [5]. Prior to assuming a position, an employee should be given a review of the types of materials to be handled, including their toxic properties, the health consequences if exposed, and any byproducts resulting from fire or explosion. The care and fit of any protective equipment required should also be covered.

When the employee begins working, the focus should turn to safe operation of equipment, proper materials handling, and spill clean-up procedures. Techniques should be demonstrated for minimizing the amount of material allowed to escape and human exposure to it. Employees should also be taught the signs and methods of detecting releases of toxic material into the work environment.

On-going training should consist of regularly scheduled drills and safety meetings in conjunction with supervisory reviews of industrial hygiene, materials handling, and emergency practices. In this manner, the procedures in effect will always correspond to the chemicals and equipment in use.

To be effective as a waste preventive measure, employees must be made aware of the waste disposal costs and liabilities that a company incurs. Additionally, employees must understand the causes of waste generation as they relate to their individual areas of responsibility.

Within high labor-intensive operations such as paint/coating application or metal parts and equipment cleaning, an effective employee training program can often significantly reduce the amount of solvent waste generated. For example, in a painting operation, since many spray systems are manually operated, the equipment operator's action has a major impact on the amount of waste produced.

D. Lenchkus reports that spray operators generally believe that a large amount of air is required to achieve proper atomization of the paint [6]. However, when air pressures are set too high, the paint has a tendency to bounce off the surface and increase overspray. By providing the proper training for spray system operators, waste generation can be minimized.

Standardizing solvents at facilities using a large number of cold cleaning tanks increases the potential for recycling, and reduces the amount of solvent waste requiring disposal. Standardizing solvents, in this context, means using a minimum (preferably one) number of solvent types in all operations at a plant. Many times, the decision to use a certain type of solvent over another is based on an operator's preference, rather than on a technical need or requirement. Increased awareness of the necessity to reduce hazardous waste generation helps the operator make better choices.

4.4.1.3 Closer Supervision

In conjunction with an effective employee training program, good operating practice dictates that emphasis should be placed on providing the operators with closer supervision. For those operations in which a high level of human involvement is required, closer supervision inevitably leads to an increase in production efficiency as well as a substantial reduction in inadvertent waste generation. These improvements come about through 1) better coordination among the various interrelated parts of an overall operation, 2) increased opportunity for a mistake to be detected promptly, and 3) lessened chance for material losses resulting from spills and off-spec products due to the carelessness of the operators.

4.4.2 Procedural Measures

4.4.2.1 Waste Audits and Reviews

Two types of audits are distinguished: environmental audits and waste minimization audits. While environmental audits are primarily compliance-oriented, waste minimization audits are oriented primarily toward delineating waste reducing options. Periodic audits of both types are considered good operating practice.

Environmental audits are intended to improve environmental quality management and to check environmental performance [2]. Environmental audits can be carried out by firms themselves, using their own employees or outside contractors, or can be imposed or conducted by regulatory agencies.

The environmental facility audit provides a complete listing of all discharges from the plant - gas, liquid and solid. In a review of plant discharges (hazardous, as well as nonhazardous), each stream is identified and quantified as to what and how much is being discharged, and where it goes. The ultimate disposition of waste is also cataloged (e.g., impoundment, discharge to a stream, or deep-well injection). Conducting the audit may require chemical analysis of stack effuents, water discharge streams, and other plant wastes. Some data will already exist, but the accuracy required for the audit precludes accepting all available data at face value. Downstream analysis determines if in-plant data requires verification.

Basically, there are three types of environmental audits [3]:

- Emergency audit

During an emergency audit, the auditing team is situation-oriented to eliminate a specific problem which may threaten plant closure. If the plant has had an unpermitted discharge in the past, the reasons for the discharge can be determined and corrective actions can be initiated to reduce or eliminate the discharge in an expeditious fashion.

- Specific audit

A specific audit is generally short-range, aimed at easily identifiable problems. Often, management realizes a problem exists but needs a starting point. A specific audit produces a list of things to do. For example, when management at one company realized that water discharge from the operating units was excessive, a two-day audit was performed that listed and estimated quantities on all discharges that were visible during that period. Within ten days after the audit was published, a 50 percent reduction in water-discharge volume was realized. Corrections ranged from replacing leaking valves and repairing cracked pipes, to simply closing valves [3].

- General audit

The general audit takes a complete look at a facility, at a portion of a facility, or at a general problem within a plant. Such an audit attempts to quantify accurately discharge volumes, indicate any immediate action required, and possible methods of regulatory mitigation or applications of source reduction or treatment technologies to discharge streams. Accuracy distinguishes the general audit from a specific audit. A general audit often requires more time spent at an operating unit (over all work shifts covered) so that extensive data can be collected. Specific solutions are then sought to eliminate waste problems.

The size and composition of an internal audit team depends upon the resources available to the company, the size of the waste problem, the objective of the audit, and other similar factors. A team composed of outsiders to the plant usually performs best, since plant personnel have lived with situations to the point that they underestimate, overlook or downplay certain operations. For a large company, personnel from a central engineering department can perform the audit function competently. The audit team can be supplemented by employing consulting engineers as needed [3].

Through environmental audits, firms can rectify problems before being forced to do so by regulatory agencies. This helps to avoid unnecessarily high compliance costs and fines for violations.

Auditing can increase a firm's efficiency and profitability by:

- Spotting opportunities to reduce waste and, therefore, disposal costs.
- Lessening the likelihood of an environmental accident.
- Compiling environmental cost information for financial purposes.
- Teaching employees to be alert to environmental requirements and the cost of materials lost through poor practice and carelessness.

<u>Waste minimization audits</u> are fairly new in concept and practice. They are designed to develop and screen waste minimization options through source reduction, recycling, and treatment (in that order of preference). Waste minimization audits are not oriented toward current or potential evaluation and mitigation of regulatory compliance problems as are environmental audits. They

are a first step in a "look - think - do" sequence leading to reduced waste generation.

Periodic environmental/safety reviews of operations are necessary to ensure that a company's hazardous substances management and control system remains abreast of modifications in plant operations and of developments in hazardous substance management technology. These reviews are important for worker health and safety, environmental compliance and waste reduction.

The National Agricultural Chemicals Association recommends regular meetings of supervisory personnel on the subject of safety and health rules [4,5]. These meetings are held to evaluate current rules and to formulate new procedures that reflect changes in operations. The review procedure itself is carried out in conjunction with a program of employee drills and safety meetings covering a range of hazardous substance handling topics.

An example of an environmental safety review program is the Toxic Chemicals Review Committee of West Point Pepperell, a textile manufacturer with 22,000 employees and 40 manufacturing facilities [1]. In response to a suggestion by the Director of the Medical Department, the committee was formed in 1976 and contained the following personnel:

- an industrial hygienist,
- three research chemists,
- a professional engineer,
- a corporate attorney,
- a corporate safety officer,
- a chemical production representative, and
- a corporate information specialist.

The committee began in 1976 to review chemicals in current use and proposed for use. It based its analysis of each chemical on the following criteria:

- personnel safety considerations,
- fire hazard potential,
- hazardous properties (ignitability, toxicity, corrosivity, reactivity),
- availability of less hazardous alternatives,
- biodegradability,
- heavy metal content,
- potential for accumulation in the facility,
- potential for release to the environment,

- hazard potential when reacted or mixed with other chemicals,
- proposed manner of use,
- ultimate destination of the chemical, and
- hazard potential to the consumer.

Since 1976, the company has rejected or substituted a number of chemicals deemed inappropriate for its operations. Procedures were established for the purchasing of chemicals allowing a portion of the burden of reviewing chemicals to be passed on to the individual manufacturing operations. All chemical purchases may be made only on approval of the Corporate Research Chemist, who follows committee guidelines.

A large part of the waste reduction or waste prevention at West Point Pepperell has come about by replacing hazardous chemicals with safer ones and by preventing hazardous chemicals from being brought into use in the first place. West Point Pepperell now generates only a small amount of solvent waste which is sent off site to a refining company.

Environmental/safety reviews of operations can be conducted at low cost depending on the size of a company's hazardous material problem, the amount of in-house resources that can be committed to the effort, and other similar considerations. A review procedure can be used in conjunction with safety audits to preserve worker health, and/or with environmental audits for ensuring compliance with environmental regulations. The potential benefits from adopting this procedure are therefore significant.

4.4.2.2 Additional Documentation

Documentation of process procedures in a manual or set of guidelines ensures that job duties are precisely defined. This documentation is especially important in an integrated production process where unsatisfactory performance during one step can adversely affect the remaining steps of the process. In general, a well-written operating manual or set of instructions [7]:

- Informs the employee how his job fits into the overall process;
- Describes startup and shutdown procedures, normal operating procedures, emergency procedures, and special procedures;
- Identifies important control parameters, including target emission or effluent levels;
- Defines operator's job responsibilities; and
- Describes potential personnel hazards.

Employees should be made aware of the difference between planned and inadvertent releases, the target waste generation rates for the process, and the consequences of not meeting targeted rates. Effluent sampling procedures and control equipment failure procedures should also be outlined. Adherence to procedures and use of the information provided can contribute to reduced waste generation.

Process documentation of the type described also promotes product consistency, decreasing the likelihood of producing an unacceptable product that must be discarded. Moreover, procedural guidelines can be helpful in reducing waste generation during maintenance or emergency shutdowns. The following case study illustrates the role of documentation in a sucessful waste reduction program.

The Rexham Corporation facility in Matthews, North Carolina, is part of the company's Industrial Division. It is involved in the laminating and coating of paper, film, and foil products, and in printing film substrates for the photography industry. Wastestreams are generated from several routine operations as well as from intermittent or one-time-only services for customers. At the Matthews plant, a Manager of Safety and Evironmental Affairs oversees a number of activities to monitor and reduce waste generation. A hazardous waste manual has been developed for use by plant personnel. The manual sets forth Rexham's contingency plan for accidents and spills and identifies the response team's activities. The plant's major wastestreams are also reviewed in the manual. Included are descriptions of what constituents are present in each stream, what constituents are not permitted in a given stream, and how each stream is to be handled. All waste materials are tracked through the system to ensure proper handling and to identify possible problems. Coupled with other waste reduction practices such as wastestream segregation and resource recovery/reuse, Rexham was able to substantially reduce their solvent waste generation rate [1].

4.4.2.3. Material/Waste Tracking and Inventory Control

Accurate material, product, and waste tracking provides operation supervisors with information on the inventories of hazardous chemicals at each location on a plant site. This information enhances the development of material handling and storage procedures to avoid hazards. The availability of information on the quantities of waste being generated from discarding unused chemicals may also contribute to concerned management implementing a waste reduction program.

Computers are increasingly being used in industry to monitor inventories and track materials through processes. Material tracking computer software is available. This software can list the names and locations of all hazardous materials on site in addition to maintaining environmental monitoring, employee health, and chemical exposure information [8]. Existing computer modules can be used to control spare parts and maintenance materials to ensure successful maintenance programs.

In a typical inventory control software module, standard reports can be generated to include item catalogs, deficiency lists and inventory forms. User-defined special reports can be generated on stocked items and materials, and their usage. Stock levels can be maintained by means of materials requisitions and parts receipts. An efficient module can often provide the user with a wide variety of useful functions, such as: displaying any item number on a daily basis; maintaining data on multiple vendor sources; automatically issuing purchase requisitions when inventories fall below specified minimums; and printing purchase orders for submittal to selected vendors [9]. The ability to automatically monitor and control stocked materials can significantly benefit waste reduction programs, since a substantial portion of hazardous waste often results from overstocking. The following case studies provide some insights into the problem of overstocking materials.

Century Furniture Company of Hickory, North Carolina, produced large quantities of solvent waste from unused materials required in finishing operations. When a new manager took over the finishing operation, he noticed that many drums of unused coating material were over two years old. The coating materials had degraded over time to the point that they were unusable. Since Century Furniture deals with a wide variety of colors, the coating inventory of unused material could increase substantially over time. Efforts to clean up the inventory and to get rid of old drums resulted in a big expense. The coating suppliers would not take back old drums to recover solvents or coating materials. After disposing of the old coating materials, Century Furniture made a committment to control inventory, to avoid over-purchasing, and to ensure the remaining quantity does not go to waste. Periodic inventory of bulk materials now is inventoried periodically to ensure that no containers stay in inventory for more than a few months, and that new materials are ordered on an as-needed basis [10].

Similarly, large quantities of hazardous waste can be generated from the disposal of expired materials. The Defense Property Disposal Office (DPDO) at Norfork, Virginia, handles large quantities of hazardous waste generated by the Naval Ship Yard and Naval Air Rework Facility. In April of 1981, the Atlantic Division, Naval Facilities Engineering Command, conducted a survey to determine the impact of expired shelf-life items on the Hazardous Waste Disposal Facility administered by Norfolk Public Works Center (PWC). Approximately 27,100 gallons of hazardous waste were accepted in April 1981. It was estimated that 13 percent of these materials (3,600 gallons) consisted of shelf-life materials. The total cost of initial purchase and disposal of this expired shelf-life material was approximately $38,000. This cost estimate did not reflect intermediate handling costs or administrative costs. If these costs were considered, disposal of expired shelf-life material at Norfolk would cost well over a half million dollars a year. Corrective measures were proposed which suggested that an extensive study of the shelf-life problem be performed to review procurement specifications, validate shelf-life expiration dates, and, where feasible, eliminate shelf-life requirements on stable compounds. These steps would then help reduce overstocking of specific items [11].

Implementing extensive material tracking procedures can often result in prompt detection of a problem which would otherwise go unnoticed and result in the generation of large quantities of hazardous wastes. For example, at one Union Carbide manufacturing plant, a materials audit revealed an unexpected solvent loss of up to 20,000 pounds per day. By plugging up leaks, the company saved $2,000 a day in lost solvents. Now Union Carbide policy mandates a computer-assisted plant evaluation system to identify and correct pollution problems before they become expensive [12].

IBM, like Union Carbide, makes use of computer technology to safeguard the environment. Many of IBM's manufacturing processes (such as polishing, machining, and cleaning, used in the production of magnetic discs) require the continuous use of solvents. Solvents are also used in batches in the mixing of coatings. The solvents are supplied from remote tank farms. Previously, solvent from the remote tanks was piped to a day tank just outside the plant building. The tank became an emission source of hydrocarbons since saturated vapor was released to the atmosphere as the day tank was filled and the air space was displaced by solvent. IBM has since implemented a computer-assisted solvent control system to meter solvents as they enter the building, thereby eliminating the need for day tanks and associated solvent loss. The computer can shut off the line from the tank farm, warn the operator that excessive solvent has been used, and indicate that a check for leaks is required [12].

In addition to problem detection, process control equipment allows process specifications to be controlled using sensors; when undesired changes occur, corrections are sent to control instruments. The number of discards are reduced by increasing the quantity of on-specification product.

4.4.2.4 Scheduling

Timing often plays an important role in the production of waste generating products. It has a special significance in batch production operations, where equipment cleanup waste volumes are directly related to cleaning frequency. To reduce cleaning frequency, it is necessary to maximize batch size and equipment dedication to a single product. Good scheduling and planning are required.

Scheduling improvements can reduce waste solvent generation in labor-intensive industries such as paint and coating application. For example, by producing large batches of similarly painted items instead of small batches of differently painted items, a large reduction in the need for cleaning can be achieved. Some reductions are also possible by scheduling paint production for longer runs or to cycle from light to dark colors to reduce cleaning wastes. In addition, many times dirty equipment is sent to a central cleaning operation where it waits until a given shift (usually night) to be cleaned. For facilities using small portable mix tanks, however, immediate cleaning after use reduces the amount of paint drying in the tank, and hence reduces the need for and extent of cleaning.

4.4.3 Loss Prevention Practices

4.4.3.1 Spill and Leak Prevention

Spillage of a hazardous chemical results in hazardous waste. Washdowns of spilled toxic chemicals creates liquid hazardous wastes, which are often transferred off site for disposal. Cleanups using absorbent materials create hazardous solid waste which must also be disposed. To minimize the costs incurred in chemical spill incidents (which can range from disposal fees to employee care to fines from enforcement actions) the best practice is to prevent spills from occurring in the first place.

The likelihood of a spill can be lessened by: 1) conducting hazard assessment studies at appropriate points in the design and operation phases, 2) using properly designed storage tanks and process vessels only for their intended purposes, 3) equipping all such containers with overflow alarms, 4) testing the alarms periodically, 5) maintaining the physical integrity of the containers over time, 6) setting up administrative controls for all loading/unloading and transfer operations, 7) installing sufficient secondary containment facilities, 8) having a good valve layout, 9) having interlock devices to stop flow to leaking sections, 10) disallowing the operators to bypass the interlock or to alter the set points, 11) isolating equipment or process lines that are not in service, and 12) documenting spillages and related dollar values [13,14]. These measures can be implemented through a spill prevention program that provides input into plant design as well as the administration of plant operations. Spill prevention control and countermeasure (SPCC) plans are required by law (40 CFR 112) for oil storage facilities; however, such plans are often developed and offer benefit for other hazardous chemicals, including solvents.

To prevent material losses, sound practice dictates that storage tanks and process vessels containing hazardous chemicals be properly designed and used only for their intended purpose. They should also have, as a minimum, overflow alarms. Once these conditions are met, one must still ensure the structural soundness of the containers, enforce proper hazardous materials handling procedures, and construct and maintain secondary containment and collection facilities [15].

The structural soundness of the tanks and vessels can be assured through an inspection and record-keeping initiative. Monthly visual inspections of tanks, including all equipment connected to them, the tank's seams, and the supporting structures should be conducted. Physical inspection and testing should take place at the half-life of each tank, or more frequently if the tank materials are subject to attack by the chemicals in the tank. Discharges from internal heating and cooling coils should be monitored and tested at least quarterly. All these efforts can be conducted in coordination with other existing safety and operating checks.

Spills are most likely to occur during loading/unloading operations and in-plant transfer activities. For this reason, written procedures should be kept current and easily accessible to all employees. A spill response plan should be formulated, and employees should be trained both in routine operating procedures and in correct implementation of emergency spill measures. A policy of taking disciplinary action on violations, if strictly enforced, can ensure employee adherence to procedures.

The volatile nature of solvents contributes significantly to both environmental pollution and economic losses. Solvents that escape into the atmosphere do so at the expense of the business using them. A first step in any good operating practice strategy is to identify and prevent unnecessary solvent emissions. Solvent inputs and waste solvent outputs should be compared routinely to estimate the quantity of solvents unaccounted for, and hence leaking unnoticed into the environment.

To prevent solvent losses due to leaks, solvents should be stored in properly equipped drums or tanks. Fixed-roof storage tanks need venting systems to prevent excessive build-up of vapor pressure. Floating-roof tanks have lids which move on the surface of the solvent while forming an air-tight seal with the tank walls. Floating-roof tanks are superior to fixed-roof tanks because they allow only 1/20 as much solvent vapor to escape. Fixed-roof tanks, however, can be retrofitted with special conservation vents which limit fugitive emissions [12]. For example, in 1975, Exxon Chemical installed 11 floating roofs over its volatile solvent tanks at a cost between $500 and $1000 per tank. This prevented the loss of more than $1.5 million worth of solvents. Concurrently, Exxon installed conservation vents on the plant's large solvent tanks. The vents reduced solvent air emissions from the tanks by 30 to 75 percent [1].

In addition to proper storage, solvent leaks can be minimized through better material handling techniques. In the transfer of solvents, submerged filling of storage tanks can reduce solvent emissions by 50 percent over splash filling. The submerged filling technique minimizes the agitation and escape of aerosolized solvent. Vapor recovery systems should be used in conjunction with loading/unloading or equipment cleaning, whenever possible, to reduce solvent loss [12].

4.4.3.2 Preventive and Corrective Maintenance

A maintenance program, whether preventive, corrective, or a combination of both, can prove instrumental in cutting production costs stemming from expensive repairs, excessive waste disposal, and business interruptions. Proper maintenance can also prevent hazardous waste releases due to equipment failure and facility degradation.

An effective maintenance program carries back into the design phase. Designs should take into account access to process equipment components and accessories by maintenance equipment and personnel. Design considerations should include larger access doors, wider internal catwalks, accessible components, hopper access doors, and duct cleanout and inspection hatches. Specification of easily maintained equipment at the outset serves to reduce the cost of preventive and corrective maintenance during operation.

Most ongoing maintenance programs focus on ways to efficiently maintain production at an existing plant. Computers are increasingly being used in industry to facilitate the development of successful maintenance programs. The level of computer usage ranges from simple self-written programs to help, for example, in developing equipment testing schedules to sophisticated software modules, that can provide monitoring and control of materials and equipment over the entire facility. In practically all cases, it has been found that the use of computers has significantly increased the efficiency of a plant's overall maintenance program [16].

Preventive maintenance, targeted at minimizing equipment breakdown and malfunction, is a major part of an overall maintenance program. Losses due to breakdowns and malfunctions can account for three to four times the level of operating and maintenance costs [17]. Proper preventive maintenance increases the life of the equipment, decreases downtime, and reduces waste resulting from off-specification products.

Preventive maintenance is routine, recurring work required to keep a facility and its equipment in such a condition that they can be used at original or design capacity or efficiency. Scheduled preventive maintenance programs often entails cleaning, making minor adjustments, lubrication, testing, measuring, and replacing minor parts [18]. Any additional measures taken to prevent premature decompositon of process solutions (which causes the materials to be come unusable) also falls within the context of preventive maintenance.

A preventive maintenance program often can be started with one or two groups of critical equipment, or by plant area or building. Other equipment/facilities can be added to the program gradually. A typical preventive maintenance system requires five record-keeping documents [18]:

- Equipment data card. This card details equipment characteristics, location, and maintenance accessibility.
- Master preventive maintenance schedule. The schedule notes the frequency and time required for inspection. The best source of information to determine the frequency of inspection is the vendor submittals for each equipment.
- Deferred preventive maintenance report. This report assesses the applicability of the scheduling frequency or points out the equipment that may not belong in the preventive maintenance program.
- Equipment history card. The card reflects repair and replacement history of equipment.
- Equipment breakdown report. The report notes causes of breakdown and repair requirements. It also records by trade the time spent to correct the situations. This report is an excellent communication tool among the different groups involved in the plant's overall maintenance program.

Preventive maintenance is often a part of the overall maintenance program and is usually done by the plant's production crew. Preventive maintenance can be less expensive and more efficient in some cases if contracted out to a maintenance firm. Cost and efficiency advantages can be found in: 1) the increased time that plant personnel can spend on production operations; 2) the easy handling of fluctuating workloads by contract maintenance firms; 3) the avoided expenditure on crews, repairs, repair facilities, tools, and measurement instruments; and 4) the greater operational experience of contract maintenance personnel leading to more rapid identification and troubleshooting of equipment malfunctions and thereby to product improvement [17].

In addition to ensuring that preventive steps are taken, corrective maintenance should be adopted to correct a condition of unexpected failure. This involves identifying and correcting indirect factors that influence the equipment's maintenance requirements. A machine should operate predictably if it is performing the duty for which it was designed. If the duty demanded shifts to a different level from that of the design, the maintenance demands also will have to shift. In a process plant, where the maintenance department generally functions independent of the operations department, the shift in duty demands can go completely unrecognized. The corrective maintenance program brings all pertinent data, normally documented at different places, together into one document, to make the correlation obvious and available routinely [21].

Corrective maintenance goes hand in hand with process optimization and improvement of process efficiency. It calls for an overview of the design concepts, taking into consideration the operating conditions obtained and the maintenance demanded. Maintenance and operating data sheets should be designed on an individual basis for each piece of equipment and each process in the plant. They should delineate the difference between an operating condition and a maintenance requirement, and wave a red flag when the variance between the operating conditions and the normal or design levels exceeds a certain limit [21].

A final facet of corrective maintenance involves the ability to take prompt actions to prevent a catastrophic equipment failure through proper recognition of symptoms. Corrective actions can significantly reduce or even eliminate the generation of hazardous waste or catastrophic, uncontrolled releases of hazardous substances.

4.4.4 Wastestream Segregation

Hazardous waste that is hauled to off-site disposal facilities is often a mixture of two or more wastestream types. Wastestream segregation as a good operating measure may involve:

- Isolation of hazardous materials from nonhazardous materials,
- Isolation of hazardous waste by contaminant, and
- Isolation of liquid from solid waste.

Wastestream segregation can result in smaller waste haulage volumes and easier disposal of the hazardous waste generated while producing the same amount of product. In addition, segregation can often result in simplifying waste treatment or make it easier to recover and recycle materials.

When a nonhazardous material is mixed with a hazardous material, the entire mixture may be classified as hazardous. According to current RCRA regulations (40 CFR 261), " a solid waste is a hazardous waste if it is a mixture of a solid waste and a hazardous waste that is listed ..., unless the resultant mixture no longer exhibits any characteristic of hazardous waste identified ..., or if the generator can demonstrate that the mixture consists of wastewater, the discharge of which is subjected to regulation under ... the Clean Water Act". By separating hazardous from nonhazardous materials or not allowing them to mix in the first place, the quantity of waste requiring regulated disposal is thus reduced.

To simplify waste solvent handling and to make recycling feasible, the following procedures should be followed [22]:

- Keep solvents segregated. In the recycling process, it is much easier to separate a solvent from its impurities than to separate two solvents.

- Keep waste solvents as free from water and garbage as possible. Label the container clearly, keep the container closed and, if possible, sheltered from rain.

- Where feasible, use solvents in a "countercurrent" manner to minimize the need for new high purity material.

For example, if a similar or compatible type of paint is to be produced in the equipment, then the solvent waste can be used as thinner or makeup for the fresh paint. This has been widely practiced in paint manufacturing and printing operations. The following case studies serve to illustrate the methods as well as benefits resulting from the implementation of solvent segregation and reuse programs. Other case studies are discussed in Section 4.2.3.3.

ICI Americas, Inc. of Goldsboro, North Carolina, an agricultural chemical research and development firm, designates separate containers for hazardous and nonhazardous waste, thus preventing cross-contamination of the nonhazardous waste with the hazardous waste. In conjunction with this effort, a procedure for segregating chlorinated solvents from non-chlorinated solvents and a policy of returning unused chemicals to the distribution center was implemented. As a result, the overall volume of waste exiting ICI was reduced from 100 drums in 1981 to 60 drums in 1984. The product output of the firm nearly doubled in that period. Observing that disposal costs doubled as well (from $120/barrel to $266/barrel), the firm saved roughly $37,000 in 1984 alone [1].

In addition to making recycling feasible, solvent waste segregation can also increase the efficiency of the recycling operation, and thus reduce overall solvent waste generation. IBM Corporation has recently reported that by segregating chlorinated and non-chlorinated solvents, the yield of recycled solvent increased 15 to 20 percent [23].

For segregation to be cost effective, the savings resulting from reuse, recycling, resale, or lower disposal costs must outweigh the costs of the additional personnel allocations, and of the on-site equipment and storage facilities needed. For example, at Thiele-Engdahl, in Winston-Salem, North Carolina, solvent segregation and reuse was attempted. However, due to the large variety of products made, segregation proved to be too complicated. In addition, the high cost of raw materials (Thiele-Engdahl produces specialty inks for rotogravure printing) and the risks of contaminating an entire batch far outweighed the savings in virgin solvent cost [22].

4.4.5 Material Handling and Storage

Most processes involve the storage of raw materials, products, and wastes and the transfer of these items from one area of the plant to another. Proper material handling and storage ensures that raw materials reach the production process without spills, leaks, or other types of losses that could result in waste generation. Similarly, proper material handling ensures that products and wastes that result from the production process are transferred to off site locations without additional waste generation.

Proper storage of hazardous materials may include:

- o Adequately spacing rows of drums to allow for a visual inspection of each container for corrosion and leaks;
- o Maintaining distance between different types of chemicals to prevent cross-contamination;
- o Insulating electrical circuitry and checking it frequently for corrosion and potential sparking; and
- o Raising drums off the storage area floor to prevent corrosion through concrete "sweating".

In addition, using larger containers for chemical storage reduces the ratio of container surface area to volume, implying less clingage residual and container cleaning waste per unit of volume stored. Large containers (such as tote-bins or "mega-drums", see Figure 4.5) are preferred over 55-gallon drums, which themselves can become hazardous waste and are unsafe and inconvenient.

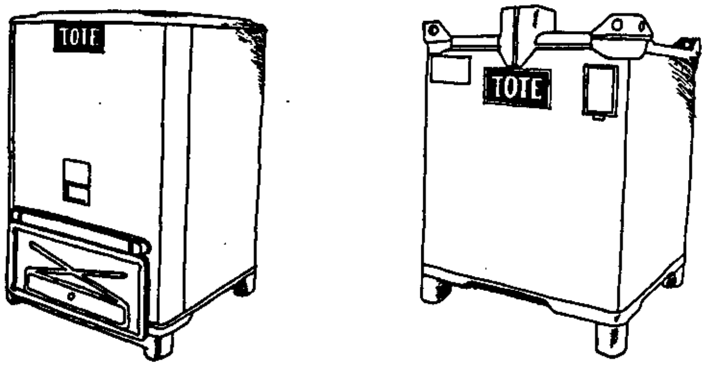
An innovative approach to material handling is illustrated by Ford Motor Company. In order to provide a more efficient method for adhesive storage and application, Ford's Utica, Michigan, trim plant developed a system utilizing returnable bulk supply and storage containers with collapsible plastic bag liners. The problem posed by the solvent-based adhesive was that its two components (a resin and isocyanate) were highly sensitive to moisture from the air and therefore could react prematurely, causing the materials to become unusable. In addition, once mixed, the component has a relatively short useful life (about 3 hours). The typical procedure was to mix batches of adhesive and scrap the unused compound when it became too thick and unsprayable. This approach, however, led to a considerable amount of waste. With the new system, the adhesive components are held in separate 300 gallon containers with polyethylene bag liners. The sealed and lined containers prevent the entry of moisture-laden air, dust, or other contaminants. The collapsible liners also prevent condensation inside the tank and the evaporation of solvent. An added benefit of the liner is that it eliminates the need for tank cleaning and thus reduces the associated cleaning wastes. The adhesive components are pumped from the containers to two surge tanks, then to a proportioner system and are mixed just before being sent to the spray guns. Overall, the system has provided substantial savings by reducing material handling requirements as well as raw material and waste disposal costs [24].

Material safety data sheets (e.g., Form OSHA 20) are prescribed for hazardous materials by the Occupational Safety and Health Administration (OSHA) of the Department of Labor. Although intended primarily as a safety precaution, the material safety data sheets (MSDS) can aid in reducing hazardous waste generation. These sheets contain the manufacturer's information on the chemical, physical, and toxicological properties of the hazardous substances being used. They also contain recommendations on the proper handling and storage procedures for these substances. Following these recommendations reduces the likelihood of waste creation due to spills or cross-contamination with other chemicals. In the event of a spill, a response crew can refer to the appropriate MSDS for instructions on how to clean up the chemical while producing the least amount of hazardous waste.

In addition to having MSDS, each substance should be stored and handled in containers that are clearly marked with information on contents, storage and handling recommendations, spill procedures, and requisite first aid for exposure. Some innovative products have recently been developed to aid in labeling. The Legitronec 2060 electronic labeling system, manufactured by Weber Marking Systems of Arlington Heights, Illinois, prints labels on an as-needed basis. These labels contain information on product identification, weight, lot number, health hazard warnings, first aid and spill procedures, and storage and handling instructions. The labels can contain Department of Transportation symbols when needed. The system is in use at Stephan Company of Northfield, Illinois, where 400 separate products are produced at four separate production facilities [25].

FIGURE 4.5

PORTABLE BULK STORAGE CONTAINERS



TOTE BIN

TOTE TANK

~~Courtesy of Hoover Universal.~~

Another labeling method rapidly coming into use is the automatic identification system using bar codes [26]. Bar coded labels can link containers and materials to a computer through the production, inventory, storage, and shipping stages. This improves the accuracy of material tracking and inventory accounting, thereby allowing work-in-process monitoring and preventing material from going astray on the plant site and/or becoming dated. Hazardous waste in the form of discarded chemicals and waste resulting from inefficient operations are reduced in this manner. When a new item is delivered, it is allocated a unique identification number. This number is fed into a computer along with any other pertinent data. A corresponding bar code is then attached to the top of the item's container. During inventory, bar codes are read by hand-held scanner. The entire system is manufactured by Symbol Technologies, Inc. of Bohesian, New York.

4.4.6 Summary

The applicability of good operating practice is determined at the level of the individual plant or company. Two plants producing the same product may have different process or organizational structures which make a particular measure more or less applicable. Nevertheless, certain process characteristics do appear to enhance the effectiveness and/or implementation of good operating practice.

The types of operation for which the implementation of good operating practice will prove to be most beneficial are batch or discrete processes. Batch processes are often performed in less automated plants, and the level of human involvement is relatively high. There is, therefore, a greater chance for human error in equipment operation, material handling, inventory control, and production scheduling.

Firms that use the same processing facilities for various products generally have more potential to implement good operating practice. In producing several products, scheduling, material handling, supervision and training, and material tracking are not only more difficult but also more important in terms of maintaining throughput, minimizing leaks and spills, and minimizing waste generation. There is generally more equipment cleaning as the equipment is prepared for the next product run. It is often possible, however, to segregate the cleaning wastes by contaminants to allow for reuse and therefore produce a subsequent reduction in waste generation.

Another factor which often influences the implementation of a waste reduction program based on good operating practice is the size of the individual company. Large generators, which generally have the necessary financial and personnel resources and which have been under regulation longer, have developed comprehensive environmental programs in an effort to reduce disposal costs and avoid fines stemming from non-compliance. While good operating practice is certainly practiced in these companies, their environmental efforts include examining and implementing extensive process changes to reduce waste.

Small generators, on the other hand, often lack the financial and personnel resources and only recently have come under regulation. Small firms cannot afford the expense of investigating various pollution abatement methods, may not have the expertise to do so, and most likely cannot withstand the losses from business interruption that implementation of these methods often requires. For small generators, good operating practice offers more promise for waste reduction. Many of these practices can be instituted quickly with little or no capital investment and require merely an examination of existing procedures. Implementation of good operating practices can significantly reduce solvent waste generation.

4.5 Solvent Air Emission Control

This section addresses the subject of solvent air emission control within the context of "end-of-pipe" technologies. There are cases when even the most intensive efforts to reduce emissions at the source cannot obviate the need for "end-of-pipe" controls required to meet the regulatory emissions limitations.

In cases where "end-of-pipe" controls are needed, it is imperative that the choice of control technology includes consideration of hazardous waste generation. In the current climate of increasing disposal costs and disposal restrictions coupled with strict liability for environmental impairment, it is unwise to control air emissions at the expense of creating a hazardous wastestream destined for a landfill without considering low, or zero waste control options. Hence, there is a need for evaluating source reduction <u>within</u> the domain of a control unit.

This section provides a brief overview of current commercially available technologies for solvent air emission control with a special emphasis on their waste generation characteristics. The technologies discussed include thermal and catalytic incineration, carbon adsorption, liquid absorption and condensation.

4.5.1 Incineration

Incineration of solvent-laden air streams is an established conventional technology. Two types of incineration are distinguished: thermal and catalytic. Thermal incineration, also called thermal or direct flame oxidation, involves oxidation of organics at essentially atmospheric pressures, and temperatures ranging from 850^{o} F to 1,800^{o} F with 1,400^{o} F being fairly typical. Destruction efficiencies ranging from 85 to nearly 100 percent (with a typical range of 90 to 95 percent) are achieved when residence times are kept within 0.3 to 1.0 second and gas velocities in the oxidation chamber range between 15 and 25 ft/sec.

To reduce fuel requirements, the incoming solvent-laden air is preheated against the hot flue gas using a heat exchanger (recuperator). Designs offering up to 85 percent thermal efficiency are commercially available. Additional heat recovery, employing a waste heat boiler or a secondary exchanger, is achievable in situations where low temperature heat can be used for process or space heating. Either natural gas or fuel oil can be used; currently, cost considerations favor fuel oil.

Catalytic incineration or oxidation of solvent-laden air streams takes place at temperatures ranging from 500^{o} F to 900^{o} F, considerably lower than thermal incineration. The lower combustion temperatures result in lower fuel consumption rates, again compared to a thermal oxidizer with an equivalent destruction efficiency. The catalysts usually involve various noble metals, such as palladium, platinum, ruthenium or rhodium, deposited on an alumina support formed into a monolithic block with a "honeycomb" structure. Catalytic incinerators can also be fitted with recuperators to increase energy efficiency. The disadvantages of catalytic oxidation include catalyst poisoning and catalyst replacement cost.

Schematics of both thermal and catalytic oxidizers are presented in Figures 4.6 and 4.7. Many vendors offer proven designs for both kinds of incinerators. Retrofit cases include conversion of existing oxidizers from a thermal to a catalytic process to increase fuel efficiency or conversion of existing boilers to use solvent-laden air as the combustion air. The only wastes associated with incineration, in general, are ash, soot, spent blower lubricant and recoverable spent catalyst. The principal environmental tradeoffs include increased carbon monoxide and nitrogen oxide air emissions. Nitrogen oxide emissions associated with catalytic oxidation are lower compared to direct flame oxidation as a result of lower combustion temperatures. The presence of halogenated solvents may require special materials of construction in addition to a scrubber to remove hydrochloric acid (HCL) or hydrofluoric acid (HF) from the exhaust flue gas.

Cost data are presented in Table 4.14 for derivation of order-of-magnitude equipment costs for thermal oxidizers. Comparative technical and economic data for thermal and catalytic systems are given in Tables 4.15 and 4.16. The estimates were obtained in 1985 and are based on budget equipment and installation costs derived by application of methods given by Vatavuk and Neveril [1]. Application-specific information should be requested from equipment vendors.

4.5.2 Carbon Adsorption

Removal of contaminants using activated carbon is a well established technology. Its current use dates back to the time when the early settlers used charred logs to purify the waterholes. Activated carbon impregnated with various salts of silver, chromium and copper was used in World War I to protect the soldiers against chlorine, phosgene, arsine and other gases. At the end of the war, there was an effort to find different uses for activated carbon; one of the first applications was the recovery of solvents that were previously lost to the atmosphere.

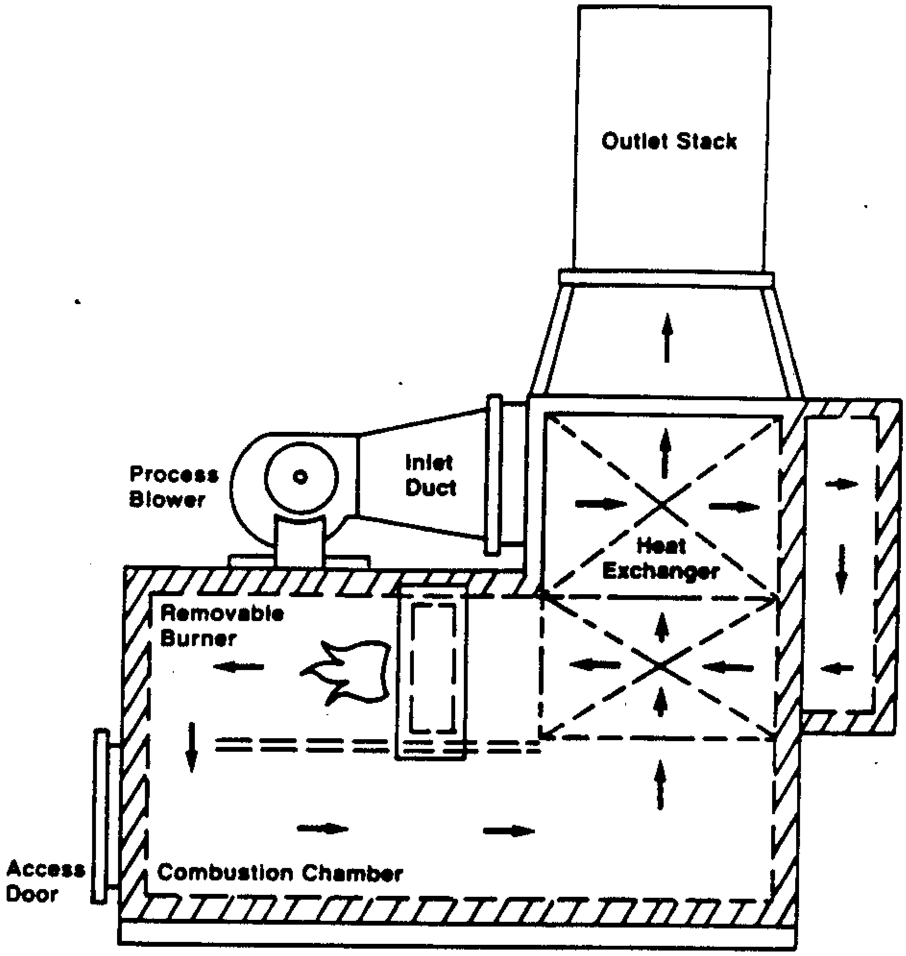
In 1919, the American Solvent Recovery Company was formed by "Doc" Barnebey, one of the developers of the gas mask. During the 1920's, almost every conceivable method of adsorption and regeneration was tried, tested and fought in the patent courts. Over the next 40 years, most of the systems built for solvent recovery used steam regeneration. For the last two decades the market for the carbon adsorption systems has been driven by progressively stringent regulatory air emission requirements.

The process of treating solvent contamination consists of three discrete sequential steps: adsorption, desorption and desorbed gas processing. The process is schematically represented in Figure 4.8 as a block flow diagram. As seen, each step can be accomplished using a variety of available options. Each option that appears in the diagram is commercially available; however, not every combination is practiced. The following sections provide a discussion of each step in the sequence along with descriptions of commercial systems.

<u>Adsorption</u> is the accumulation of molecules (adsorbate) at the interface between the fluid and solid phases, where the molecules are selectively

FIGURE 4.6

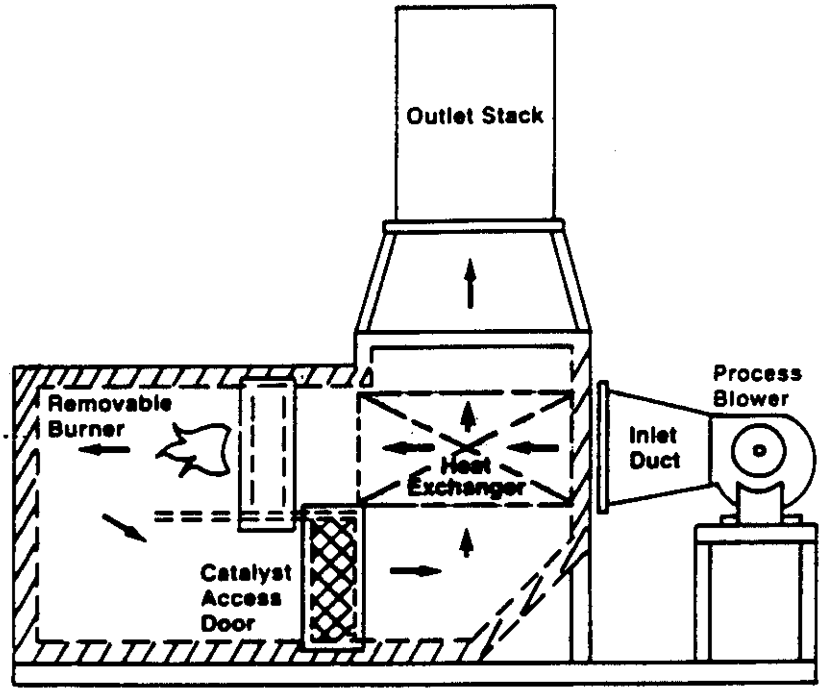
THERMAL OXIDIZER



Courtesy of Met-Pro Corp.

FIGURE 4.7

CATALYTIC OXIDIZER



Courtesy of Met-Pro Corp.

FIGURE 4.8

PROCESS OPTIONS FOR SOLVENT AIR EMISSION CONTROL VIA CARBON ADSORPTION

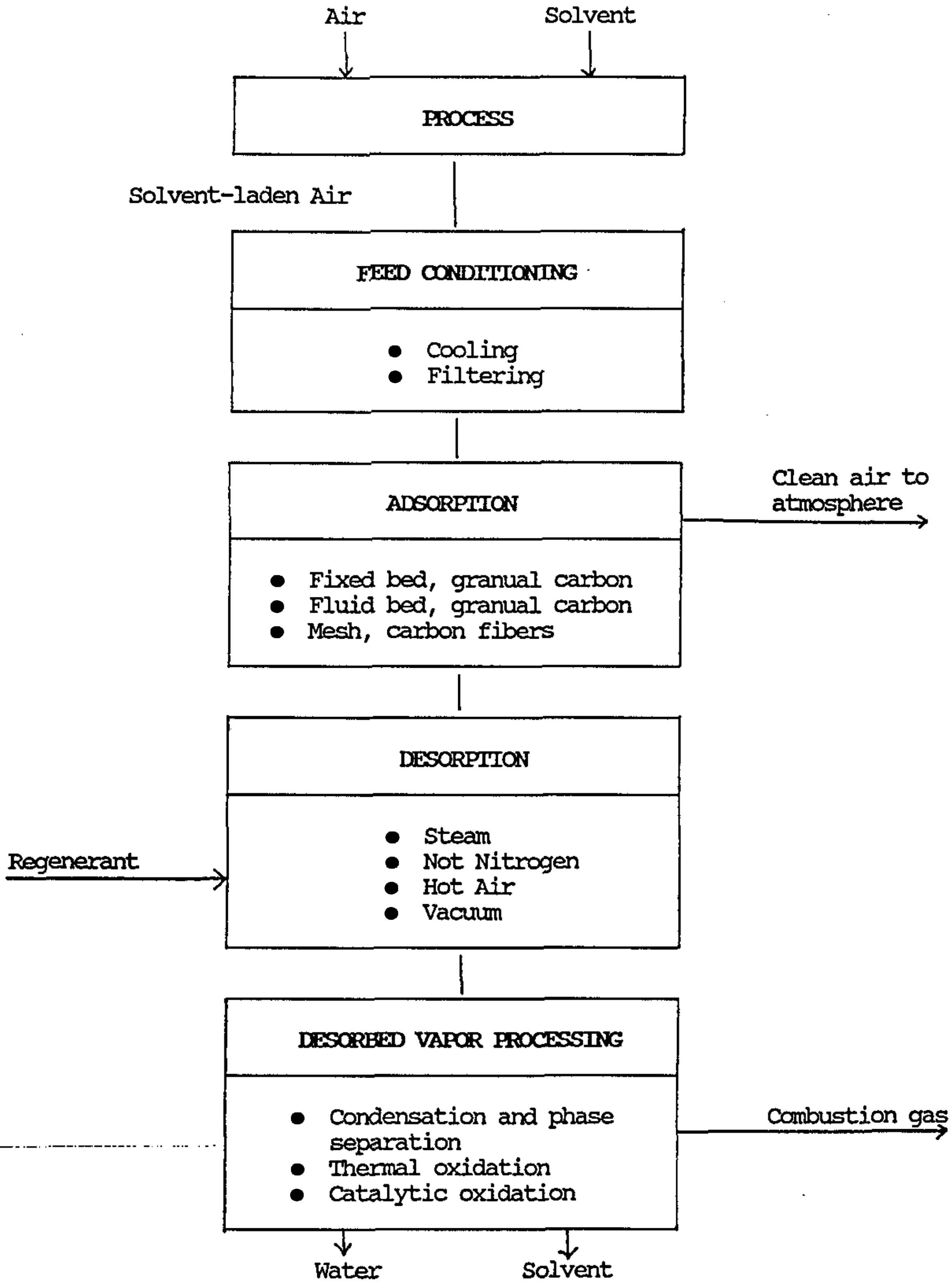


TABLE 4.14

ORDER-OF-MAGNITUDE COST DATA FOR THERMAL OXIDIZERS
(For Capacities Exceeding 10,000 SCFM)

Equipment Cost	No heat recovery - $7.50/SCFM 50% heat recovery - $15/SCFM 85% heat recovery - $30/SCFM
Fuel Cost - with no heat recovery	Natural gas fired - $10.50/hr per 1,000 SCFM Oil fired - $ 6.00/hr per 1,000 SCFM

SCFM - Standard Cubic Feet Per Minute

Source: D.R. Lee, consultant - private communications.

TABLE 4.15
COMPARATIVE COSTS FOR THERMAL AND CATALYTIC OXIDATION SYSTEMS

	Thermal Incineration	Catalytic Incineration W/Recuperator	Catalytic Incineration W/O Recuperator
CAPITAL COSTS (x $1000)			
Delivered Equipment Cost	287	335	195
Direct Installation Cost	136	136	92
Indirect Installation Cost	213	213	119
TOTAL CAPITAL COSTS	636	684	406
OPERATING COST (x $1000/yr)			
Fuel	87.4	50.2	286.3
Electricity	12.2	15.4	6.9
Water	-0-	-0-	-0-
Nitrogen	-0-	-0-	-0-
Total Utilities	99.6	65.6	293.2
Operating Labor	3.9	3.9	3.9
Maintenance Labor	4.7	4.7	4.7
Supervision	1.3	1.3	1.3
Catalyst/Carbon Replacement	-0-	8.4	8.4
Direct Operating Costs	109.5	83.9	311.5
Overhead	7.9	7.9	7.9
Taxes, Insurance & Admin.	25.3	27.1	11.8
Total Indirect Costs	33.2	35.0	19.7
TOTAL OPERATING COST	142.7	118.9	331.2

Note : Design Basis: 10,000 SCFM, 150 ppm of non-chlorinated solvents.
Refer to Table 4.16 for technical parameters.

TABLE 4.16
COMPARATIVE TECHNICAL PARAMETERS FOR THERMAL AND CATALYTIC OXIDATION SYSTEMS

Description	Thermal Incineration	Catalytic Incineration W/Recuperator	Catalytic Incineration W/O Recuperator
Destruction Efficiency, %	90	90	90
Combustion Temparature, F	1400	900	900
Recuperative Efficiency, %	80	80	-0-
Fuel, MM BTU/day	67.2	38.6	220.2
Electricity, KW	30	38	17
Nitrogen, SCFM	----	----	----
Boiler Feed Water, Mgal/day	----	----	----
Cooling Water, Mgal/day	----	----	----
Catalyst Replacement	----	$ 21,000/3 yrs	$ 21,000/3 yrs
Carbon Replacement	----	----	----
Plot Requirements, ft.	44 x 14	50 x 15	20 x 15
Purchased Cost, $1,000(FOB Shop)	257	300	185
Delivery, Weeks ARO (Dwgs)	4	6	6
Weeks ARO (Eqpt)	14	18	18

Note : Design Basis: 10,000 SCFM, 150 ppm of non-chlorinated solvents.

attached to the surface of the solid. Activated carbon is used extensively because of its low polarity. This results in low selectivity for water vapor in contrast to other adsorbents, such as alumina, zeolite or molecular sieves. Other advantages of activated carbon include a large internal surface area and relatively low cost.

The conventional adsorption step relies on passing solvent-laden air through a fixed bed of granular activated carbon. Adsorption of organics takes place with an associated release of heat (heat of adsorption), until the saturation capacity of carbon is reached or approached. At this point, the carbon inventory must be regenerated and the solvent-laden air stream rerouted to a standby bed of fresh carbon. Other, more recent designs, originated in Japan, rely on an adsorption process based on:

(a) A fluidized bed of special attrition-resident activated spherical carbon granules of uniform 0.7 mm particle size (Purasiv HR technology marketed by Union Carbide); and

(b) Mesh composed of carbon fibers (KF/KPR technology offered by Met-Pro).

In comparison to granular carbon, the adsorption rate on carbon fibers was reported to be extremely fast (up to 1000 times greater) owing to lower diffusional resistance in the absence of macropores. The saturation capacity is claimed to be 1.5 to 1.6 times higher [2].

<u>Desorption</u> relies on heating the carbon to release captured solvents. A carrier gas is provided as a heat transfer medium and as a diluent to lower the partial pressure of solvents in the gas phase, so as to increase the driving force and the rate of desorption. The desorption modes used in commercial applications include:

o steam regeneration,

o hot nitrogen regeneration,

o hot air regeneration, and

o vacuum regeneration.

Steam regeneration is practiced most frequently - over 90 percent of all carbon beds in the United States are steam-regenerated. Steam has the advantage of providing more than 40 times the available heat per unit weight compared to air or nitrogen, owing to its ability to release the heat upon condensation at the low operating pressures of the desorption process. Additionally, the formation of low boiling point azeotropes between certain high boiling organic solvents and water facilitates their efficient desorption at temperatures below those that would otherwise be required by hot air or nitrogen. Principal disadvantages of stream are the creation of a potentially troublesome regenerant vapor stream (discussed below) and the enhancement of corrosion due to the presence of compounds, such as hydrochloric acid or acetic acid, that form as a result of the decomposition of certain chlorinated hydrocarbons and esters of acetic acid that are catalyzed by metallic impurities present in most grades of granular carbon [2]. The potential for corrosion necessitates the application of expensive construction materials, such as Hasteloy C or titanium, for use with a solvent such as 1,1,1-trichloroethane.

Hot nitrogen regeneration is offered in conjunction with the fluid bed (Purasiv HR) process and is depicted in Figure 4.9. Its advantages include easy recovery of water soluble solvents. With the exception of atmospheric moisture, no water is introduced into the process. This often cancels the need for the expensive and cumbersome recovery or treatment steps. Hot nitrogen technology is well established - there are over 40 commercial installations in Japan and over a dozen in the United States.

Hot air regeneration is offered as part of the carbon fiber-based KPR technology depicted in Figure 4.10. The adsorption cylinder, made of carbon fiber spun into a honeycomb structure, is rotated through an incoming solvent-laden air stream. Following an extremely rapid adsorption process, the solvent-rich segment of the cylinder enters a desorption zone where hot air regenerates the carbon fibers at 250°F. Since the quantity of hot air used for regeneration is considerably smaller compared to the incoming solvent-laden air stream, the solvents can be concentrated up to 20 times their original level. The concentrated stream is then catalytically incinerated with a minimum thermal penalty. Because regeneration is performed in the presence of oxygen, care must be taken to control the explosive range and ignition point.

Vacuum regeneration is available commercially from vendors such as Met-Pro or McGill who offer skid mounted systems. Advantages include lower temperatures leading to less solvent breakdown. Disadvantages may include comparatively long desorption periods as a result of slow heat transfer, or presence of maintenance-intensive vacuum pumps. Vacuum regeneration has been applied commercially for recovery of isobutane [3].

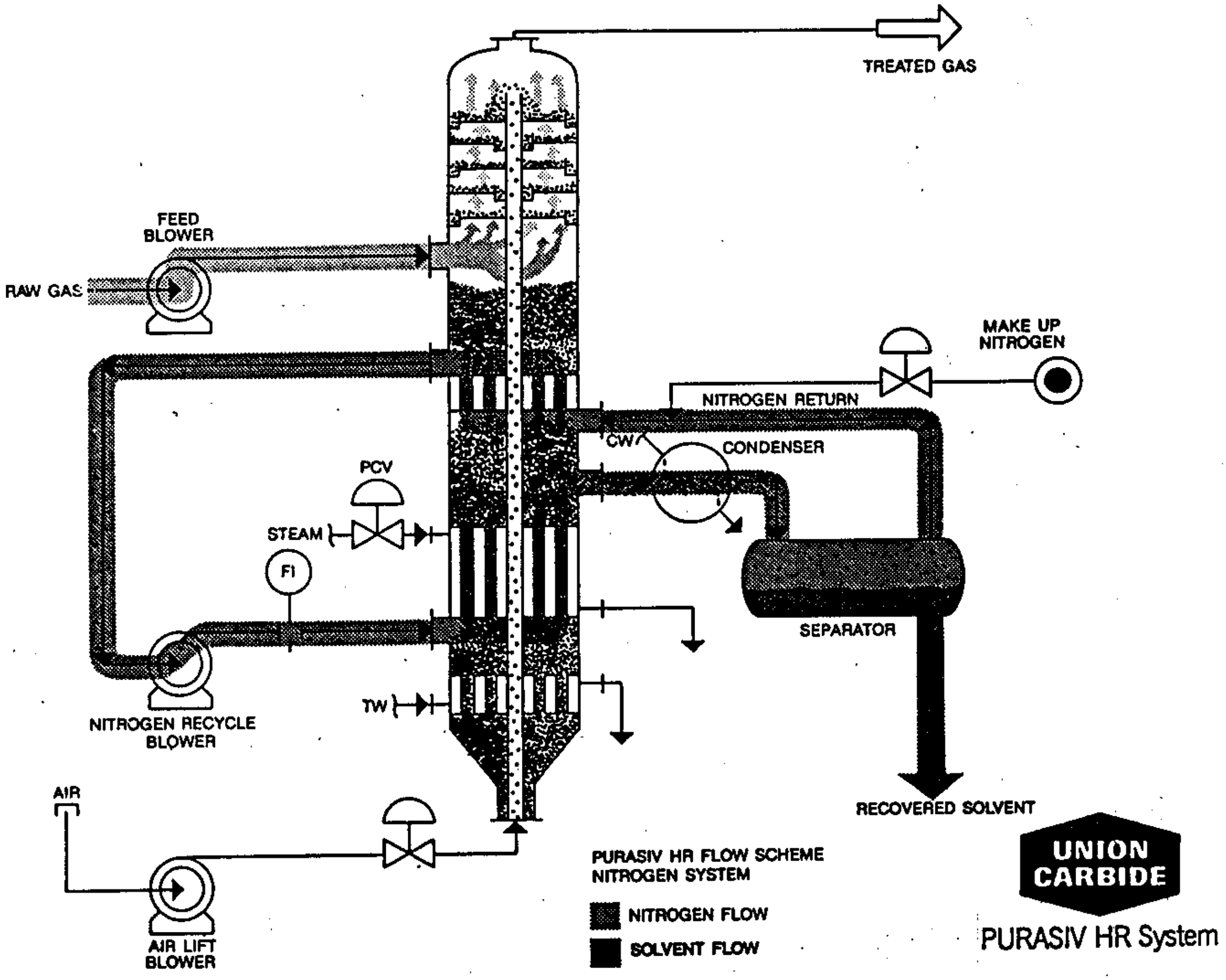
Regenerant vapor processing is a step following desorption and is usually accomplished through: (1) condensation followed by phase separation; and (2) direct incineration.

Condensation is, by far, the most conventional method of handling the solvent-rich vapor. It is commonly applied with steam, hot nitrogen or vacuum regeneration steps. The vapor is passed through a downflow-type condenser typically cooled with water (although air-cooled designs can also be employed). The condensate enters a vented receiver/separator vessel. If steam is used as a regenerant, the mixture of solvent and water is obtained upon condensation. Those solvents which are insoluble or only slightly soluble in water will separate from the water phase. However, in many cases, solvents are water-soluble to an appreciable entent (e.g., ethyl acetate, some ketones and alcohols). This significantly decreases their recyclability, since an energy-intensive distillation step may be required to remove water. Frequently, a rather complex azeotropic separation using entrainers is also required. Alternatives include extraction, membrane separation processes or molecular sieves. In any case, additional processing steps are necessary to recover solvent from water, often making the economics of recovery unattractive. The net result is the generation of an aqueous solvent wastestream that may pose a serious treatment or disposal problem.

The problem of water contamination/separation can be alleviated if nitrogen or, in some cases, a vacuum is used to regenerate the bed. Condensed solvent quality is high, since the water present is limited to the ambient air moisture co-adsorbed together with solvents - usually a small amount relative to the

FIGURE 4.9

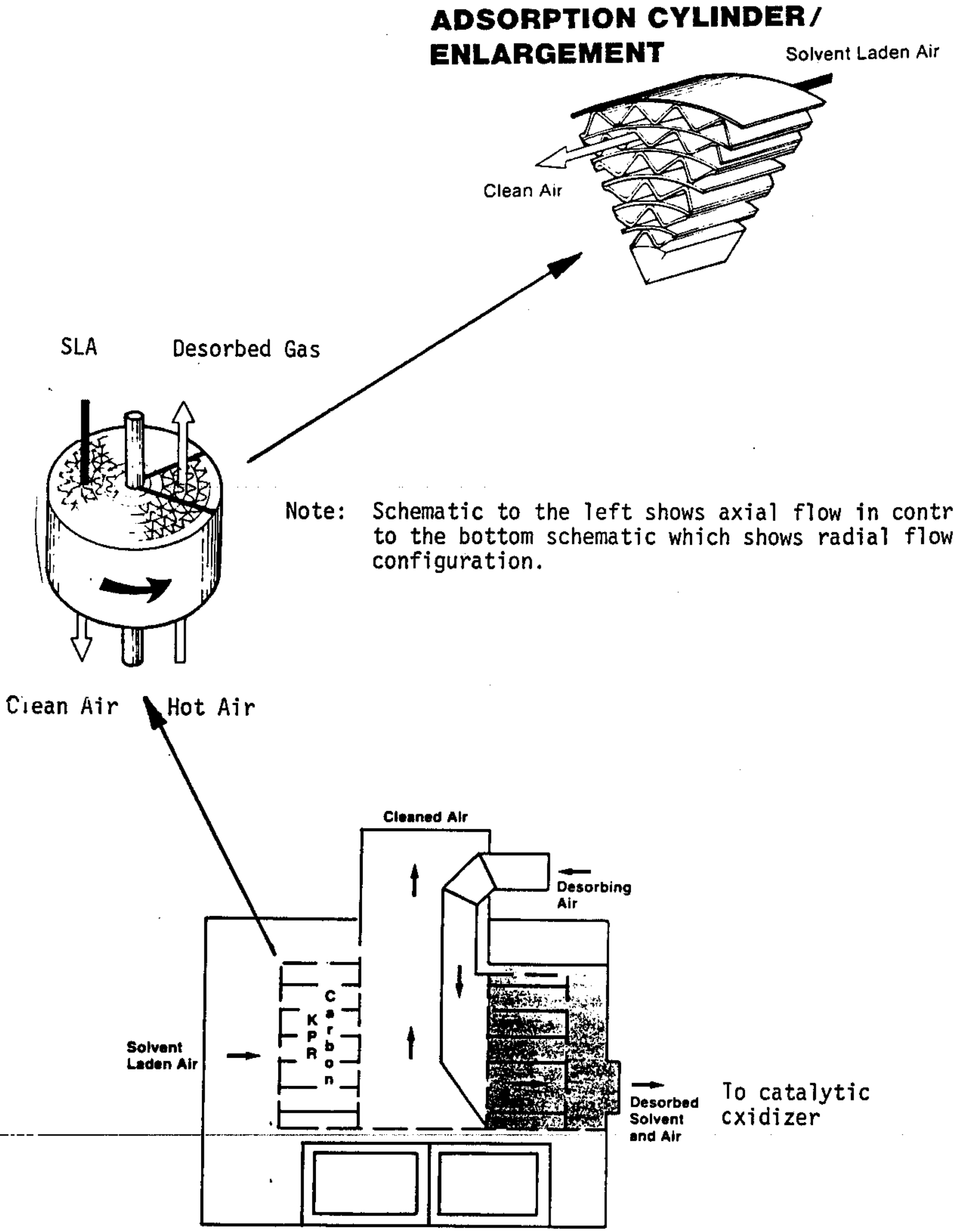
HOT NITROGEN DESORPTION - PURASIV HR$^{(R)}$ SYSTEM



Courtesy of Union Carbide Corporation.

FIGURE 4.10

HOT AIR DESORPTION - KPR SYSTEM



Note: Schematic to the left shows axial flow in contrast to the bottom schematic which shows radial flow configuration.

solvents. In such cases, dewatering can be accomplished relatively inexpensively through the use of dessicants, or may not be required at all.

Incineration of regenerant vapor offers an attractive alternative to condensation in cases where the economics do not justify solvent recovery. Thermal oxidation is practiced with steam-regenerable beds in the, so called, "hybrid system" depicted in Figure 4.11. Regenerant vapor from desorption is thermally oxidized using solvent-laden air as combustion air. A thermal oxidizer is coupled with a waste heat boiler which generates the steam used for desorption. Thus, the heating value of the solvents is utilized, greatly reducing the fuel costs. Such systems are marketed by Amcec Corporation and by Pullman Industries in cooperation with Vic Manufacturing Company and Combustion Engineering. The technology is well proven, but not well established, and only a few commercial installations exist.

Incineration is also practiced with the hot-air regenerated carbon fiber KPR system (Figure 4.10). The hot air stream, containing desorbed solvents at concentrations 10 to 20 times higher, is catalytically oxidized following heat exchange with the combustor exhaust. As in the hybrid systems, the solvents are destroyed and no solvent waste is generated. The KPR technology is well established in Japan; reportedly, there are about 30 operating systems. However, acceptance of this technology in the U.S. is still very low.

Incineration of regenerant gas is not well suited for halogenated solvents. A hybrid system which uses thermal oxidation may tolerate a small amount of chlorinated solvents present in the mixture with other solvents. A carbon fiber system which uses catalytic oxidation cannot tolerate any chlorinated solvents, except as a trace contaminant (5 ppm or less) on a periodic basis.

Comparative technical and economic parameters were derived for four carbon adsorption systems:

(a) a conventional steam regenerated carbon bed with regenerant vapor condensation followed by decantation;

(b) a nitrogen regenerated fluid bed (Purasiv HR system) followed by a condenser and separator;

(c) a hybrid system (steam regenerated conventional bed followed by a thermal oxidizer with waste heat boiler); and

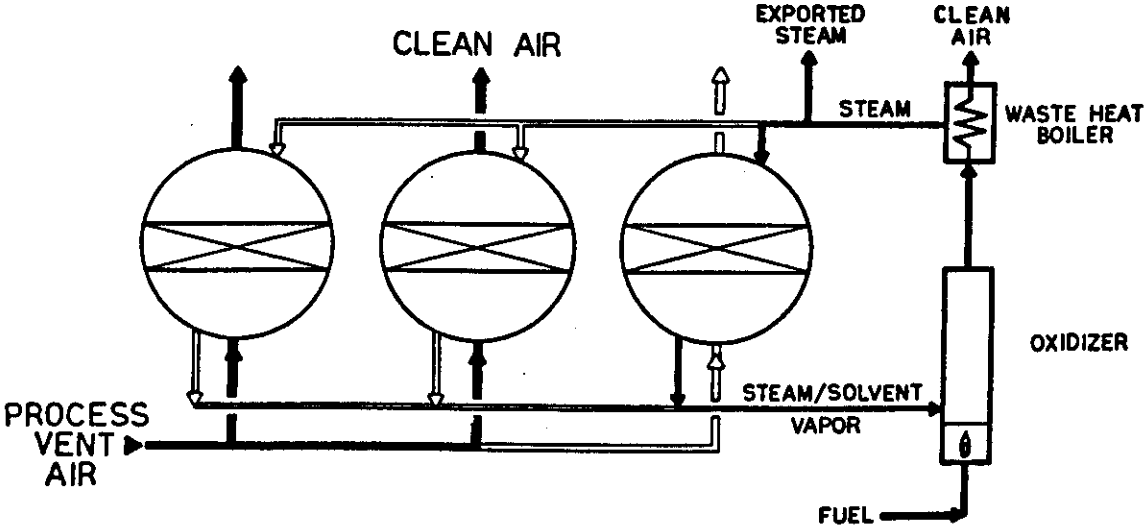
(d) a KPR system (carbon fiber with hot air regeneration followed by catalytic oxidizer with heat recuperation).

The systems were all designed for 10,000 SCFM of air containing 150 ppm of a mixture of isobutanol, various acetates and hydrocarbons. A compilation of technical and project parameters is given in Table 4.17. The economic parameters are given in Table 4.18. The estimates were derived in 1985 using equipment budget costs and installation costs obtained partially through methods presented by Vatavuk and Neveril [1].

Quick comparison of annualized total costs favors hybrid and KPR systems for the application. In this specific case, a very small quantity of solvents

FIGURE 4.11

SCHEMATIC OF THE HYBRID SYSTEM



Courtesy of AMCEC Corporation.

TABLE 4.17

COMPARISON OF TECHNICAL PARAMETERS BETWEEN FOUR CARBON ADSORPTION SYSTEMS

Description	Carbon Adsorption W/Steam Regen. and Condensation	Carbon Adsorption W/N2 Regen. and Condensation (Purasiv HR)	Carbon Adsorption W/Steam Regen. and Combustion (Hybrid System)	Carbon Adsorption W/Hot air Regen. and Cat. Oxidation (KPR System)
Organic Removal Efficiency, %	95	95	95	95
Combustion Temparature, F	N/A	N/A	1400	650
Recuperative Efficiency, %	-0-	N/A	-0-	-0-
Fuel, MM BTU/day	50.4	5.7	11.3	21.9
Electricity, KW	38	18	30	22
Nitrogen, SCFM	---	3	---	---
Boiler Feed Water, Mgal/day	4.8	---	1.44	---
Cooling Water, Mgal/day	123	53	---	---
Catalyst Replacement	---	---	---	$ 12,000/4 yrs
Carbon Replacement	$ 18,000/10 yrs	$ 15,000/yr	$ 18,000/10 yrs	$ 29,000/4 yrs
Plot Requirements	15 x 35	20 x 20	30 x 30	13 x 14
Purchased Cost, $1,000(FOB Shop)	180	480	332	285
Delivery, Weeks ARO (Dwgs)	4		4	6
ADA (Eqpt)	22	32 - 40	16	20
Installation time, wks	4		4	4
Startup Time, wks	4		2	2

Note : Based on 10,000 SCFM, 150 ppm of non-halogenated solvents.

TABLE 4.18

COMPARATIVE 1985 COSTS FOR FOUR CARBON ADSORPTION SYSTEMS

Parameters (in $1,000)	Carbon Adsorption W/Steam Regen. & Condensation	Carbon Adsorption W/N2 Regen. & Condensation (Purasiv HR)	Carbon Adsorption W/Steam Regen. & Combustion (Hybrid System)	Carbon Adsorption W/Hot Air Regen. & Combustion (KPR System)
CAPITAL COSTS (x $1000)				
Delivered Equipment Cost	195	495	350	300
Direct Installation Cost	148	135	141	104
Indirect Installation Cost	250	293	239	218
TOTAL CAPITAL COSTS	593	923	730	622
OPERATING COST (x $1000/yr)				
Fuel	65.5	7.4	14.7	28.5
Electricity	15.4	8.1	12.2	9.0
Water	5.7	1.4	0.7	-0-
Nitrogen	-0-	5.6	-0-	-0-
Total Utilities	86.6	22.5	27.6	37.5
Operating Labor	7.8	8.0	3.9	3.9
Maintenance Labor	6.3	12.7	8.0	4.7
Supervision	2.1	9.6	2.7	1.3
Catalyst/Carbon Replacement	5.9	15.0	5.9	15.9
Direct Operating Costs	108.7	67.8	48.1	63.3
Overhead	13.0	31.2	11.7	7.9
Taxes, Insurance & Admin.	23.7	36.9	29.2	24.9
Total Indirect Costs	36.7	68.1	40.9	32.8
TOTAL OPERATING COST	145.4	135.9	89.0	96.1
Recovered Solvent Value	-0-	(45)	-0-	-0-
Solvent Waste Disposal	18.7	-0-	-0-	-0-

Note : Based on 10,000 SCFM, 150 ppm of non-chlorinated solvents.
Refer to Table 4.17 for comparative technical parameters.

does not justify the otherwise attractive option of recovery provided by the Purasiv system.

It should be noted that the cost comparisons are not representative of a full range of conditions and applications. Competitive bidding conditions among various vendors may change the capital costs considerably. The comparisons are presented for illustration only and should be used with great caution.

Several problem areas have been encountered in carbon adsorption systems. Carbon adsorption units are not applicable where certain solvents are used. Also, the efficiency of the units depends on input stream characteristics including temperature, humidity, particulate loading, and solvent concentration. These and other problems are discussed in references 5 and 6.

4.5.3 Liquid Absorption

Removal of solvents from the air stream can sometimes be accomplished using liquid absorption. Typically, an air stream is contacted with a scrubbing solution in which the solvent contaminants are dissolved. The contacting typically takes place in a packed or trayed column through which the gas and liquid are passed in a counter-current flow.

The choice of a scrubbing solution is central to the success of the process. Water is a good scrubbing medium for acetone, alcohols and other water-soluble solvents. However, water scrubbing may result in the necessity for on-site treatment - most municipalities impose severe restrictions on the concentrations and quantities of solvents discharged to the sewer along with wastewater. The on-site pre-treatment may involve biological oxidation or other methods applicable to dilute aqueous wastes (See Chapter 6).

Hydrocarbon vapors can be scrubbed and subsequently recovered using high-boiling oil as a scrubbing medium. Ceilcote Corporation markets a scrubbing system which uses "SOL-VOL-X", a proprietary organic liquid.

4.5.4 Condensation

Condensation of vapors from the gas stream is technically the most straightforward and simple recovery method. If concentrations are high enough, the stream can be cooled using an indirect heat transfer with some refrigerant. In some cases, it may be desirable to raise the dew point by compression to higher pressures in order to avoid the use of refrigerant altogether and instead, rely on cooling water.

In case of dilute air streams containing solvents, the cost of cooling and/or compression is often prohibitively high, which explains the relative scarcity of condensation applications in this service. In order to make condensation economically feasible, solvent concentrations must be raised. This can be accomplished by enclosing the process or its part responsible for emissions. Automation may be necessary to limit the access by human operators to the environment with high concentrations of toxic fumes. In case of flammable solvents, air concentrations above 25 percent of the lower explosion limit may necessitate the use of an inert gas instead of air to purge the enclosure.

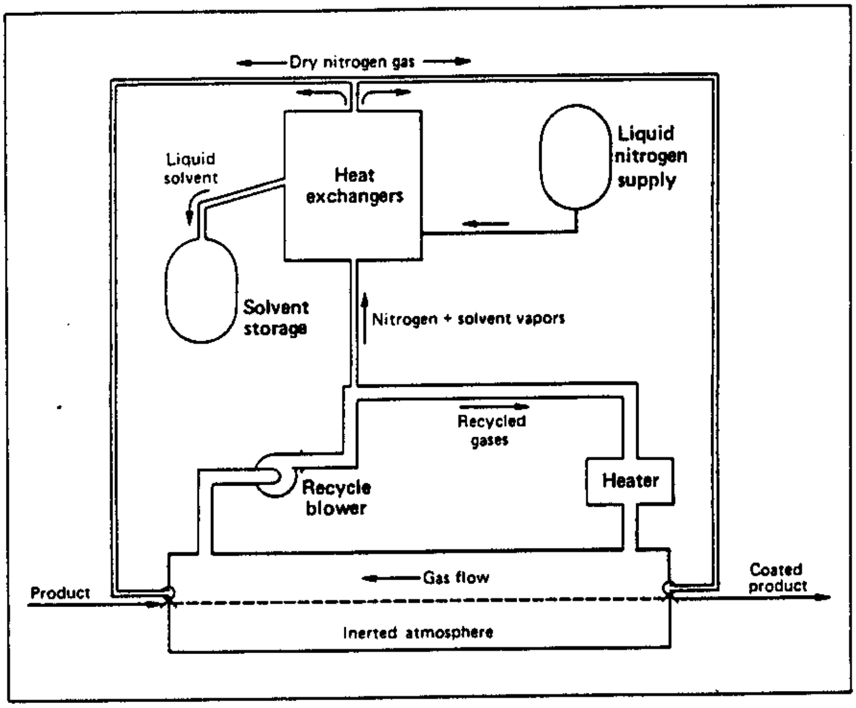
Airco Industrial Gases in Murray, New Jersey markets a system depicted in Figure 4.12 for use with coating operations. The system eliminates the need for heated air ventilation by switching to an inert nitrogen atmosphere. Savings of 40 percent in heating fuel costs and 99 percent recovery of evaporated solvent were claimed [4]. Care must be excercised in the design of the sealing systems for coating process enclosures, to minimize air infiltration and nitrogen loss.

4.5.5 Summary

Air emission control can be accomplished using a multitude of approaches differentiated not only by cost and technical parameters, but also by their potential to avoid generation of undesirable solvent wastes. Generally, when water-miscible solvents are present, use of steam to regenerate carbon beds can create dilute aqueous wastes which can pose a serious disposal problem. Such problems can be avoided if regenerant vapor is incinerated or nitrogen is used for regeneration when recovery of solvent is desired. The new carbon fiber technology appears to have technical merit and deserves close evaluation. Use of absorption for control of dilute air streams containing solvents appears limited. Removal of water-soluble solvents using water as a scrubbing medium results in a dilute aqueous stream which can pose disposal problems. A preferred control option is condensation of solvents out of a gas stream. The use of this option, however, requires installation of process enclosures, automation, and use of inert atmospheres to increase solvent concentration in the gas stream.

FIGURE 4.12

SOLVENT RECOVERY THROUGH CONDENSATION*



---

* The schematic depicts a nitrogen recirculation system involving an enclosed coating process.

Courtesy of Airco Industrial Gases, a division of Airco Inc.

REFERENCES FOR CHAPTER 4

References for Section 4.1

1. U.S. Environmental Protection Agency (USEPA), Office of Air Quality Planning and Standards. Organic Solvent Cleaners-Background Information for Proposed Standards, EPA-450-2-78-045a. Research Triangle Park, NC, 1979.

2. Bollinger, J.C. Control of Volatile Organic Emissions from Solvent Metal Cleaning. USEPA. Research Triangle Park, NC, 1977.

3. Pace Company Consultants and Engineers, Inc. Solvent Recovery in the United States 1980-1990, Houston, TX, 1983.

4. Mallarnee, W.M. "Paint and Varnish Removers." In. Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Vol. 16, pp 762-767, 1981.

5. GAF Corp. Acetylene Chemicals Division, Company Brochure. Irvine, CA, 1985.

6. Staebler, C.J. Jr. and B.F. Simpers. Reduced-Pollution Corrosion-Protection Systems, EPA-600/S2-83-003. USEPA. Industrial Environmental Research Laboratory. Cincinnati, OH, 1983.

7. Hansen, D. "Methylene Chloride Facing Regulation." Chemical and Engineering News. March 17, 1986.

8. Master Chemical Corp., Metalworking Fluids Division. Company Brochure. Perryburg, OH, 1985.

9. Higgins, T.E. Industrial Process Modifications to Reduce Generation of Hazardous Waste at DOD Facilities: Phase I Report. Prepared by CH2M Hill for the DOD Environmental Leadership Project Office. Washington, DC, 1985

10. Dan Straten Chemicals. Personal Communication with Eric Ruder, 1986.

11. J.S. Mannor Company. Personal Communication with Dave Bendl, 1986.

12. J. Hall Marketing Co. Personal Communication, 1986.

13. GCA Corp. Preliminary Analysis of Possible Substitutes for 1,1,1-Trichloroethane. USEPA. Washington, DC, 1983.

14. Anonymous. "Cyclonic Separator Saves Pretreatment Chemicals." Product Finish. March 1982.

15. Kohl, J., R. Moses, and B. Triplett. Managing and Recycling Solvents: North Carolina Practices, Facilities and Regulations. North Carolina University, Industrial Extension Service, School of Engineering. Raleigh, NC, 1984.

16. Huisingh, D., H. Hilger, S. Thesen, and L. Martin. Proven Profit from Pollution Prevention. The Institute for Local Self-Reliance. Washington, DC, 1985.

17. Anonymous. "Cryogenic Paint Stripping." Product Finish. December, 1982.

18. Pauli & Griffin Company, Aeronautical Products Division. The PRAM Series Plastic Reclaimable Abrasive Machines. Vacaville, CA, 1985.

19. Aerolyte Systems Company, Aerolyte Division of Clemco Industries. Dry Paint Stripping. Burlingame, CA, 1985.

20. Roberts, R.A. Plastic Material Blasting-PMB, Interim Report on Stripping Paint from the Second F-4E Prototype at Hill AFB, Utah, Hill Air Force Base, Ogden, Utah, 1985.

21. Forth, K. Assoc. ed. "Stripped Clean and Dry." Aviation Equipment Maintenance. October, 1985.

22. Greenwood, T.G. Hill Top Times. June 22, 1985.

23. Durney, L.J. ed. Electroplating Engineering Handbook, 4th. ed. Van Nostrand Reinhold Co., New York, NY, 1984.

24. Westinghouse Electric Corp. Personal Communication with W.G. Vaux, 1985.

25. Durney, L.J. "How to Improve your Paint Stripping." Product Finish. December 1982.

26. ASTM. Handbook of Vapor Degreasing, Special Technical Publication 310-A. American Society of Testing Materials. Philadelphia, PA, April 1976.

27. Smith, C. "Troubleshooting Vapor Degreasers." Product Finish. November, 1981.

28. Desoi, H.J. "Cyanide Destruction and Waste Reduction in the Electroplating Industry." Proceedings, New Jersey Source Reduction of Hazardous Waste Seminar, New Jersey Department of Environmental Protection, Division of Waste Management, 1984.

29. Traverse, L.J. "Source Reduction by Substitution and Reuse." Proceedings, Massachusetts Hazardous Waste Source Reduction Conference, Massachusetts Department of Environmental Management, Bureau of Solid Waste Disposal, MA, 1984.

References for Section 4.2

1. Fromm, C.H., S. Budaraju, and S. A. Cordery. "Minimization of Process Equipment Cleaning Waste." Conference proceedings HAZTECH International, Denver, Colorado, August 13-15, 1986. pp. 291-307.

2. Loucks, C.M. "Boosting Capacities with Chemicals." Chemical Engineering. May 1973, pp. 79-84.

3. Wilkinson, S. "Lean Times for Farm Chemical Distributors." Chemical Business. January 1986, pp 42-45.

4. Ryan, C.W. Hazardous Waste Source Reduction Potential in the Paint Manufacturing Industry. Boston: Massachussetts Department of Environmental Management, June 29, 1984.

5. Morris, A. "A Tank Cleaning System for the Small Paint Plant." Journal of Coatings Technology. September 1979.

6. Campbell, M.E., and W.M. Glenn. Profit from Pollution Prevention. Pollution Probe Foundation. Ontario, Canada, 1982.

7. Weismantel, G., and S. Guggilam, "Mixing and Size Reduction". Chemical Engineering. June, 1984, pp. 71-109.

8. Personal Communication with Dr. G.J. Hollod, Sr. Environmental Engineer, Petrochemical Dept., E. I. du Pont de Nemours & Co., Wilmington, DE, 1985.

9. National Paint and Coatings Association. Personal Communication with R.J. Nelson, Associate Director, Environmental Affairs Technical Division, Washington, D.C., 1985.

10. Major Paint Co. Personal Communication with J.A. Guerra, Operations Manager, Torrance, CA, 1986.

11. U.S. Environmental Protection Agency. Development Document for Effluent Limitations Guidelines and Standards for the Paint Formulating Point Source Category. Washington, D.C. December, 1979.

12. Kohl, J., P. Moses, and B. Triplett. Managing and Recycling Solvents, North Carolina Practices, Facilities, and Regulations. North Carolina State University. Raleigh, NC, December 1984.

13. 3M Corporation. Ideas - A Compendium of 3M Success Stores. (Company brochure), St. Paul, MN.

14. PPG Industries Inc.. "Waste Reduction: The Untold Story." Proceedings, League of Women Voters of Massachusetts Conference. Woods Hole, MA, June 1985.

15. Sprayings Systems Co. "Advertisement." In: Chemical Processing, Feb. 1985, p. 159.

16. Laborde, L., and A. Gaines. "Hydroblasting Avoids Hazards, Reduces Downtime to Clean Acid Flash Cooler." Chemical Processing. March 1986, p. 61.

17. Kennedy, J.P. "Computerized Process Control in the Manufacturing Process." Journal of Coatings Technology. Nov. 1983, pp. 51-56.

18. Huisingh, D., H. Hilger, S. Thesen, and L. Martin. Proven Profit from Pollution Prevention. The Institute for Local Self-Reliance. Washington, D.C., 1985.

<u>References for Section 4.3</u>

1. Hughes, T.H., K.E. Brooks, B.W. Norris, B.M. Wilson, B.N. Roche. <u>A Descriptive Survey of Related Organic Solvents</u>. University of Alabama, Tusculoosa, Alabama, August, 1985.

2. Layman, P.L. "Paints and Coatings: the Global Challenge." <u>Chemical and Engineering News</u>. September 30, 1985, pp. 27-68.

3. Campbell, M.E. and W.M. Glenn. <u>Profit from Pollution Prevention</u>. The Pollution Probe Foundation. Toronto, Canada, 1982.

4. Zink, J. "Coating Processes." In: <u>Kirk-Othmer Encyclopedia of Chemical Technology</u>, Vol. 6, 3rd ed., pp. 386-426. John Wiley and Sons. New York, 1979.

5. Brewer, G. <u>Calculations of Painting Wasteloads Associated with Metal Finishing</u>. USEPA. Cincinnati, Ohio, 1980.

6. Powder Coatings Institute. <u>Information Brochure</u>. Washington, D.C., 1983.

7. European Committee of Paint, Printing Ink, and Artists' Colours Manufacturers' Association. "Results of the Experimental Toxicological Studies and Thermosetting Powders." Brussels, Belgium, 1984.

8. Cole, G.E. "VOC Emission Reductions and other Benefits Achieved by Major Powder Coating Operations." Paper No. 84-38.1 presented at the Air Pollution Control Association, June 25, 1984.

9. Church, F.L. "Powder Coatings Blitz Keeps on Rolling Along." <u>Modern Metals</u>, Nov. 1984. pp. 28-35.

10. Kohl, J., P. Moses, and B. Triplett. <u>Managing and Recycling Solvents: North Carolina Practices, Facilities, and Regulations</u>, North Carolina State University, Raleigh, North Carolina, 1984.

11. Huisingh, D., H. Hilger, S. Thesen, and L. Martin. <u>Proven Profit from Pollution Prevention</u>. The Institute for Local Self-Reliance. Washington, D.C., 1985.

12. State of California, Department of Health Services. "Alternative Technology for Recycling and Treatment of Hazardous Waste." 3rd Biannual Report. Sacramento, CA, 1986.

13. Perry, R.H, and A.A. Nishimura. "Magnetic Tape." In: <u>Kirk-Othmer Encyclopedia of Chemical Technology</u>, 3rd Col., Vol. 14, pp. 732-753. John Wiley and Sons. New York, 1982.

14. "News Briefs." <u>Chemical Marketing Reporter</u>. Aug. 21, 1978, p. 21.

15. DiNunzio, J. "Chlorinated Solvents for Low VOC Coatings." <u>Modern Paint and Coatings</u>. June, 1983, p. 50.

16. "Computer-controlled Incinerator Handles Load/Flow Fluctuations to Destroy Eight Solvent Types." <u>Chemical Processing</u>. May, 1986, p. 102.

17. Scharfenberger, J.A. Automated Electrostatic Equipment for the Wood Industry.

18. Yotti, B.A. Assessment of Coating Transfer Efficiency and Waste Stream Analysis. Minnesota Technical Assistance Program, Minnesota Waste Management Board. Minnesota, 1985.

19. Kohl, J., J. Pearson, and P. Wright. Managing and Recycling Solvents in the Furniture Industry. North Carolina State University, Raleigh, NC, 1986.

20. Lenckus, D. "Increasing Productivity." Finishing Wood and Wood Products Magazine. May, 1982, pp. 44-66.

21. Durney, L.J. "How to Improve Your Paint Stripping." Product Finishing. Dec. 1982, pp. 52-53.

22. Sandberg, J. Final Report on the Internship Served at Gage Tool Company. Minnesota Technical Assistance Program, Minnesota Waste Management Board, Minnesota, 1985.

23. Kenson, R.E. "Recovery and Reuse of Solvents from VOC Air Emissions." Environmental Progress. Aug. 1985, pp. 161-165.

24. Isooka, Y., Y. Imamura, and Y. Sakamoto. "Recovery and Reuse of Organic Solvent Solutions." Metal Finishing. June, 1984, pp. 113-118.

25. Reay, W.H. "Solvent Recovery in the Paint Industry." Paint & Resins. March/April, 1982, pp. 41-44.

26. Roembke, R., J. Mode, and A.E. Hodel. "Thin-film Evaporator Recovers Solvents Continuously." Chemical Processing. Nov. 1985, pp. 28-29.

27. Leitert, F.C., and A.E. Hodel. "Vacuum, Agitated, Thin-Film Evaporator Strips High-Boiling Solvents from Heat-Sensitive Products." Chemical Processing. Mid-Nov., 1985, pp. 122-123.

References for Section 4.4

1. Huisingh, D., H. Hilger, S. Thesen and L. Martin. Proven Profit from Pollution Prevention. The Institute for Local Self-Reliance. Washington, D.C., 1985.

2. State of North Carolina, North Carolina Pollution Prevention Program. Environmental Auditing. 1985.

3. Baumer, R.A. "Making Environmental Audits." Chemical Engineering. November 1, 1982, p. 101.

4. National Agricultural Chemicals Association. Good Warehousing Practices for Agricultural Chemicals. 1981.

5. National Agricultural Chemicals Association. Good Workplace Practices for the Handling and Storage of Pesticides. 1981.

6. Lenchkus, D. "Increasing Productivity." Finishing Wood and Wood Products Magazine, Vol. 87, No. 4.

7. Stus, T. "On Writing Operating Instructions." Chemical Engineering. Vol. 91, No. 24, 1984. p. 105.

8. Giltenan, E. "Keeping Chemical Records on Track." Chemical Business. Vol. 6, No. 11, 1984, p. 47.

9. Hickman, W.E., and Moore, W.D. "Managing the Maintenance Dollar." Chemical Engineering. April 14, 1986, p. 68.

10. Kohl, J., Pearson, J., and P. Wright. Managing and Recycling Solvents in the Furniture Industry" (Draft Report). North Carolina State University. Raleigh, North Carolina, 1985.

11. Higgins, T.E. Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. DOD Environmental Leadership Project Office. Washington, D.C., 1985.

12. Campbell, M.E., and W.M. Glenn. Profit from Pollution Prevention: A Guide to Industrial Waste Reduction and Recycling. The Pollution Probe Foundation, Toronto, Canada, 1982.

13. Kletz, T.A. "Minimize Your Product Spillage." Hydroc. Process., Vol. 61, No. 3, 1982, p. 207.

14. Sarokin, D. "Reducing Hazardous Wastes at the Source: Case Studies of Organic Chemical Plant in New Jersey." Paper Presented at Source Reduction of Hazardous Waste Conference, Rutgers University, August 22, 1985.

15. Shields, E.J. "Prevention and Control of Chemical Spill Incidents." Pollution Engineering. Vol. 12, No. 4, 1980, p. 52.

16. Katzel, J. "Putting Personal Computers to Work in the Plant." Plant Engineering. April 24, 1986, p. 40.

17. Rimberg, D. "Minimizing Maintenance Makes Money." Pollution Engineering. Vol. 12, No. 3, 1980, p. 46.

18. Singh, J.B., and R.M., Allen. "Establishing a Preventive Maintenance Program." Plant Engineering. Feb. 27, 1986, p. 46.

19. Durney, L.J. "How to Improve Your Paint Stripping." Product Finishing. December, 1982.

20. Payne, H.F. Organic Coating Technology. Wiley, New York, 1961.

21. Parker, N.H. "Corrective Maintenance and Performance Optimization." Chemical Engineering. April 16, 1984, p. 93.

22. Kohl, J., P. Moses, and B. Triplett. Managing and Recycling Solvents: North Carolina Practices, Facilities, and Regulations. North Carolina State University. Raleigh, North Carolina, 1984.

23. IBM Corporation. Waste Reduction: The Untold Story. Conference Proceedings, League of Women Voters of Massachusetts. Woods Hole, Mass., June 19-21, 1985.

24. Dunn, R.L. "Bulk Tanks Help Solve Sticking Storage and Application Problems." Plant Engineering. April 24, 1986, p. 60.

25. Bobrowicz, D., and J. Powers. "Electronic Labeling System Keeps Tab on 400-plus Products." Chemical Processing. Vol. 48, No. 2, 1985, p. 90.

26. Powers, J. "Automatic Identification Guides CPI Plants to Higher Efficiency." Chemical Processing. Vol. 48, No. 2, 1985. p. 84.

27. Symbol Technologies, Inc. "J & B Labeling System Makes Problems Rare." Ind. Main. Plant Oper. Vol. 47, No. 7, July, 1986, p. 25.

References for Section 4.5

1. Vatavuk, W. and R. Neveril. "Estimating Costs for Air Pollution Systems." Chemical Engineering. Oct. 30, 1980.

2. Anonymous. "Activated Carbon Fiber Aids in Solvent Recovery." Chemical Engineering. Aug. 24, 1984, pp. 63-64.

3. Anonymous. "Solid Bed Adsorption System Regenerated with Vacuum." Chemical Processing. November, 1982, p. 128.

4. Anonymous. "Solvent Recycling System Saves Costs and Cleans Air." Chemical Engineering, March 10, 1980, pp. 91-92.

5. KVB, Inc. Airborne Toxic Materials Study for Sacramento County, July 1985.

6. "Solvent Vapor Recovery and VOC Emission Control," Pollution Engineering, June 1986.

CHAPTER 5

RECYCLING

There are a number of recycling options available to solvent waste generators. This chapter discusses current recycling practices used in California, and the uses and limitations of technologies commonly applied to solvent wastes. Section 5.1 presents an overview of the basic principles and technologies used in solvent recycling. Section 5.2 categorizes industrial solvent wastes according to the extent that they are or are not recycled. Section 5.3 provides a discussion of recycling options including: the advantages and disadvantages of on-site recycling; off-site recycling options; and California waste exchange operations. Separation techniques applicable to solvent recycling are described in Section 5.4. Finally, Section 5.5 presents specifications of small packaged distillation equipment.

5.1 General Discussion

The goal of recycling is to recover solvent of a purity similar to the virgin solvent for reuse in the same process, or of sufficient purity to be used in another process application. Recycling also includes combustion for energy recovery, where 60 percent or more of the original heating value of the waste solvent is recovered. Typically, of the heat energy recovered, 75 percent is exported for use in applications other than the combustion unit itself [1]. Combustion is covered separately in Chapter 6.

Solvents can be recovered either on site or off site. The decision to recycle on site or off site generally depends on the capital and operating costs, and availability of in-house expertise. If volumes of waste are small or in-house expertise is minimal, companies are more likely to ship waste off site for recycling. The issue of liability, however, may discourage companies from recycling their waste off site. Generators can be held liable for the costs for future cleanups at disposal sites. It is difficult for small firms that do not have the ability to audit recycling vendors to choose a reliable recycler and minimize potential liability costs associated with cleanups.

The decision to recover solvents from a process on site is typically based on economics for reuse of the substance. Solvent recycling may be incorporated into the process design as an integral part of the initial installation or as an added completely separate process at the end-of-the-pipe. Recycling back to the generating process is favored for solvents used in large volumes in one or more processes. Facilities that use several different solvents in low volume applications, may find the economics of solvent recovery unfavorable [2].

On-site, closed loop solvent recycling systems have in common an initial step or steps to separate the product from the recycled stream, and at least one additional purification step to separate the spent solvent from solid, liquid, or gaseous contaminants. The technology used in the first step of the purification process generally dictates the sequence of technologies used later. Some well known examples of industrial processes in which on-site recovery and recycling are employed are:

- o recovery, by adsorption, of mixed solvents in fabric coating;
- o recovery of acetone from cellulose acetate spinning using water scrubbing and absorption and subsequent recycling within the process;

- recovery of diluent in solvent refining of oil using vaporization and recompression;
- liquid-liquid extraction (water-washing) for recovery of methyl ethyl ketone in an azeotropic process for producing toluene;
- recovery of hexane in vegetable oil extraction;
- recovery of furfural in butadiene purification;
- batch recovery, by evaporation and condensation, of perchloroethylene in dry cleaning; and
- distillation for recovery of mixed solvents (ethyl alcohol and triethylamine) in antibiotic manufacture [2].

Each of the recovery operations listed above involves similar technologies employed in varying sequences and under process-specific reaction conditions. Volatility, solubility, thermal stability, corrosion, purity requirements, capacity, steam and water conditions, worker exposure, and economics must all be considered in the design of the recovery system [2]. Each on-site recovery system is unique. Standardization is usually not possible even within closely related industrial facilities. Advantages and disadvantages of on-site recycling is discussed in more detail in Section 5.3.

The availability of off-site commercial recycling facilities and commercial operations that set up mobile or fixed treatment/recycling units on the generator's property offers additional options for recovery of solvents whenever on-site recovery is not selected. The Congressional Budget Office investigated the economics of on-site and off-site alternatives for management of hazardous wastes including solvents [3]. Of the technologies identified, the analysis indicated a lower unit cost break-even point for off-site as opposed to on-site management of solvent wastes using separation technologies such as steam stripping and solvent extraction ($26 and $83 per metric ton, respectively - 1983 dollars). Although this analysis was not verified for California, the results suggest that off-site recycling of solvent wastes may be more economical than on-site management for specific technologies (exclusive of potential liability costs associated with future clean-up actions at disposal sites.)

The technologies used by commercial recyclers are similar to those employed on site. The recycling technology most commonly employed by commercial recycling facilities is distillation. Solvent extraction and incineration for heat recovery are also available in California. Commercial recycling facilities accept most halogenated and non-halogenated solvent waste. The handling charge varies based upon the quantity, type, and composition of the waste. Solvent wastestreams segregated by the generator are more recyclable than mixed solvent waste.

An alternative to on-site recycling is the transfer of solvent wastes from the generator to another company that can use the waste, either in treated or untreated form. These transfers are facilitated by waste exchanges that provide confidential information and assistance to generators and potential users/recyclers. Relatively pure uniform wastes are more easily recycled through the waste exchange system than mixed waste. For example, halogenated solvent wastes generated by the semiconductor industry are not suitable for closed-loop recycling. They are easily purified by distillation to a sufficient purity for applications such as paint formulation or equipment degreasing operations [3, cited in 4].

Certain technologies used in closed-loop or commercial recycling are also applicable to treatment of solvent-containing wastewasters discharged to municipal systems. Air stripping, for example, is appropriate for removing volatile organic solvents present at low concentrations in wastewater, or for treating higher concentrations of solvents prior to biological treatment [5]. Treatment technologies are discussed in more detail in Chapter 6.

5.2 Characterization and Recycling Patterns of Solvent Wastes

The pattern of recycling has both industry-specific and wastestream-specific components. Some major industries recycle a substantially larger fraction of the wastes they generate than other industries. Within an industry some wastes are more likely to be recycled than others (e.g., solvents more than pesticides), and the patterns of on-site and off-site recycling vary with the size of the industry and the waste stream generated.

Wastestreams that may be recycled directly without prior treatment are those that can be used as ingredients or feedstocks in a production process. Recycled wastes must have the functional properties of the virgin material to be reusable. Wastestreams that are typically high in impurities or that are not amenable for direct reuse must be processed to recover the materials of value. Some production processes result in unwanted byproducts that are rarely, if ever, used in any subsequent manufacturing or processing operations. For example, the residues from waste solvent distillation processes are concentrates of the same nonvolatile contaminants or impurities present in the original wastestream. These impurities are generally unwanted since there is no use for them in any production process except for heat recovery in boilers or incinerators.

Table 5.1 presents a summary of the recyclability of solvents and solvent wastes. Of the materials that are commonly recycled, the table describes whether the solvents are commonly recycled via waste exchanges or internal closed-loop processes. The information on wastes recycled via waste exchanges was obtained from the quarterly publication entitled "California Waste Exchange," published by the California Department of Health Services [6]. Internal closed-loop refers to on-site distillation processes. Still bottoms from the distillation of the solvents are used for heat recovery, with the exception of chlorinated still bottoms. This waste can generally be used as feedstock to make carbon tetrachloride.

5.3 Recycling Options

5.3.1 On-site Recycling

Due to the costs associated with the purchase of virgin solvents and subsequent disposal of solvent waste, recycling is often performed as an integral part of a manufacturing process. The reduced volume of waste generated results in lower disposal costs and liability associated with disposal.

TABLE 5.1

RECYCLING PATTERNS FOR SOLVENTS AND SOLVENT WASTE

Solvent	Commonly recycled	Not commonly recycled	Commonly recycled via waste exchange	Commonly recycled in internal closed-loop processes
Tetrachloroethylene	o	-	o	o
Trichloroethylene	o	-	o	o
Methylene chloride	o	-	o	o
1,1,1 Trichloroethane	o	-	o	o
Carbon Tetrachloride (not used)	o	-	o	-
Chloro fluoromethanes and ethanes	o	-	o	o
Chlorobenzene (not used)	o	-	-	o
Xylene[a]	o	-	o	-
Acetone[a]	o	-	o	o
Ethyl acetate[a]	o	-	-	-
Ethyl benzene[a]	o	-	-	-
Benzene[a]	o	-	o	o
Ethyl ether[a]	-	o	-	-

TABLE 5.1 (CONTINUED)

RECYCLING PATTERNS FOR SOLVENTS AND SOLVENT WASTE

Solvent	Commonly recycled	Not commonly recycled	Commonly recycled via waste exchange	Commonly recycled in internal closed-loop processes
Methyl isobutyl ketone[a]	-	-	-	-
Butanol[a]	o	-	o	-
Cyclohexane[a]	o	-	-	-
Methanol[a]	o	-	-	o
Cresols[a]	-	o	-	-
Nitrobenzene[a]	o	-	-	o
Toluene[a]	o	-	o	o
Methyl ethyl ketone[a]	o	-	-	o
Isobutanol[a]	o	-	-	-
Pyridine[a]	o	-	-	-

[a] High BTU content.

Once the decision to recycle has been made, the next choice is between recycling on site or off site. Advantages of recycling on site include:

- less waste leaving the facility;
- owner's control of reclaimed solvent's purity;
- reduced liability and cost of transporting waste off site;
- reduced reporting (manifesting); and
- possible lower unit cost of reclaimed solvent.

Disadvantages of on-site recycling must also be considered. These include:

- capital outlay for recycling equipment;
- liabilities for worker health, fires, explosions, leaks, spills, and other risks as a result of improper equipment operation;
- possible need for operator training; and
- additional operating costs.

A limited survey of California facilities that have installed small distillation units was conducted. The reasons given for installing the unit are listed below in the order corresponding to the descending response frequency:

- favorable economics for recovery (e.g. reduced solvent purchase demand);
- reduction in disposal costs;
- reduction in reporting (manifesting); and
- lower liability.

In most cases, more than a single reason was given. The reported operational difficulties include:

- loss of solvent during distillation process;
- low solvent recovery efficiency;
- installation problems; and
- maintenance problems.

The primary problem reported by companies was difficulty obtaining the necessary permits to operate the equipment. The payback period was reported to vary between one to two years. Most companies reported that land disposal was their prior solvent waste management method.

In summary, the decision to procure, install, and operate an on-site solvent recovery system must be based on a thorough analysis of the technical and economic feasibility of the system. This analysis must also take into consideration a balance between the ease and safety of operating the equipment and the level of operator's expertise.

5.3.2 Off-site Recycling

Off-site commercial recycling services are well suited to small quantity generators (SQG's). This is because SQG's do not generate sufficient volume of waste solvent to justify on-site recycling. The off-site services are also used by generators who prefer to avoid the technical, economic, and managerial demands of on-site recycling. However, off-site recycling has the disadvantage of potentially high transportation and liability costs. Another concern to generators that recycle solvent wastes off site is the liability associated with disposal of still bottoms.

Commercial recycling facilities are privately owned companies that offer a variety of services ranging from operating a waste treatment/recycling unit on the generator's property to accepting and recycling batches of solvent waste at a central facility. Some recyclers accept both halogenated and non-halogenated solvents, others specialize in one or the other. Used oil recyclers often accept only non-halogenated wastes. The Reclamar Company specializes in perchloroethylene recycling for the dry cleaning industry [21]. The recycler may charge the generator by volume of waste accepted and later credit the generator's account for the value of saleable solvent recovered from the batch of waste. Other recyclers charge a straight fee or accept waste at no charge based on the type and volume of waste received. The value of a solvent waste to a commercial recycler depends on the type, market value, purity (quality), and quantity of waste generated; how often the waste is produced; and the distance between the generating facility and the recycling facility.

A commonly practiced arrangement between generator and recycler is batch tolling. In a batch tolling arrangement, the commercial recycler accepts solvent waste from a generator, distills or otherwise reclaims the solvent, and resells the recovered product to the original generator for reuse. Batch tolling is attractive if the price of reclaimed solvent is less than the equivalent grade of virgin solvent.

Safety Kleen Inc. (Reedly, CA) provides a batch-tolling service for degreasing solvents, and leases the process equipment and solvents as one system. Safety Kleen's mobile units provide fully-contained degreasing systems to automobile repair shops. Safety Kleen periodically replaces the spent solvent with fresh solvent. The spent solvent is then recycled at a central facility. This arrangement is popular with small quantity generators. Another advantage of the toll system is that each generator's solvents can be recycled separately. This separation reduces the chances of the recycled solvent being contaminated with substances foreign to the process of the generator.

The technologies most widely practiced by commercial recycling facilities are distillation and incineration for heat recovery. Recent surveys in 1982 (Southern California only) and 1983 analyzed the capacity of off-site recycling facilities in California for handling halogenated organic wastes [21, 22]. Current capacity data are available from DHS permit records (see Table 5.2).

5.3.2.1 Distribution and Capacity of Recycling Facilities

The information available from the DHS permit data indicates that most commercial recyclers are located near the industrial centers for solvent waste generation; namely Los Angeles and Santa Clara counties (see Tables 5.2 and 5.3). As indicated in Tables 5.2 and 5.3, the maximum solvent recycling capacity in California is approximately 140,000 tons. Annual throughput for 1985 was approximately 175,000 tons or 53 percent of capacity.

5.3.2.2 Recommendations for Improving Recyclability of Solvent Waste

Representatives of commercial recycling facilities interviewed in a 1986 telephone survey (conducted as part of this study) were asked for recommendations on ways that generators can improve the recyclability of solvent wastes destined for off-site recycling. The following recommendations were suggested:

1. Segregate solvent wastes. Segregation of solvents was the most frequent suggestion to improve the recyclability of wastes. Specific recommendations were to separate:
    - chlorinated from nonchlorinated solvent wastes;
    - aliphatic from aromatic solvent wastes;
    - Freon from methylene chloride; and
    - water waste from flammables.
2. Keep water out of the waste solvents. Drums should be covered to prevent contamination with water.
3. Minimize solids. Solids concentration should be kept at a minimum to allow for efficient solvent reclamation.
4. Control solvent concentration. Maintain solvent concentration at ≥ 40 percent.
5. Label waste. Keep a chemical identification label on each waste container. Record the exact composition and method by which the solvent waste was generated.

5.3.2.3 Selection of a Commercial Waste Management Facility

The following factors should be considered before choosing a commercial recycling or treatment service [21]:

1. Permits held by the facility.
2. Types of solvent wastes managed.
3. Ability to meet solvent purity specifications if the solvent is to be returned to the generator.

TABLE 5.2

SOLVENT WASTE RECYCLING AND TREATMENT FACILITIES IN CALIFORNIA

Name Address	Telephone No. Contact	Permit* Service	Facility Design Capacity**
Acto-Kleen P.O. Box 278 Pico Rivera, CA 90660	(213) 723-5111 (714) 944-3330 Shelden Eisenman	ISD Hauler, Seller	Not Applicable
Baron-Blakeslee, Inc. 3596 California Street San Diego, CA 92101	(619) 295-0041 David L. Thompson	ISD Hauler, Processor, Seller	100-120 gal/hr
Baron-Blakeslee, Inc. 8333 Enterprise Drive Newark, CA 94560	(415) 794-6511 Mike Nissen	Permit Hauler, Processor, Seller	180 gal/hr
Bayday Chemical 2096-B Walsh Avenue Santa Clara, CA 95050	(408) 727-8634 Thomas Taylor	ISD Hauler, Processor, Seller	400 tons/year
Demenno/Kerdoon 2000 North Alameda Compton, CA 90222	(213) 537-7100 Cathy Demenno	ISD Processor	Not Available
Detrex Chemical Industries, Inc. Gold Shield Solvent Division 3027 Fruitland Avenue Los Angeles, CA 90058	(213) 588-9214 Darrel W. Craft	Permit Hauler, Processor	350 gal/hr
General Portland Inc./SYSTECH 23505 Crenshaw Boulevard Room 201 Torrance, CA 90505	(213) 325-2800 Michael Zimmer	Permit Processor	1,200 gal/hr 24,000 tons/yr

TABLE 5.2 (Continued)

SOLVENT WASTE RECYCLING AND TREATMENT FACILITIES IN CALIFORNIA

Name Address	Telephone No. Contact	Permit* Service	Facility Design Capacity**
Holchem/Service Chemical 1341 East Maywood Santa Ana, CA 92706	(714) 546-5890 Elmer Dudash (714) 538-4554 Chaz Hilton	ISD Processor	1,500 gal/day
IT Corporation-Vine Hill Facility 4575 Pacheco Boulevard Martinez, CA 94553	(415) 372-9100 John Ettl	ISD Hauler, Processor	Not Available
McKesson Chemical Company 5353 Jillson Street Commerce, CA 90040	(213) 269-9531 Ben Whittle	Permit Hauler, Seller	Not Applicable
Nelco Oil Refining Corporation 600 West 12th Street National City, CA 92050	(619) 474-7511 Steve Humphrey	ISD Processor	72 tons/yr
Oil and Solvent Process Company 1704 West First Street Azusa, CA 91702	(818) 334-5117 Ken O'Morrow	Permit Hauler, Processor, Seller	24,000 tons/yr
Omega Chemical Company 12504 East Whittier Boulevard Whittier, CA 90602	(213) 689-0991 Dennis R. O'Meara	ISD Hauler, Processor, Seller	5,600 tons/yr
Orange County Chemical Co. 425 Ancleason Drive Escondido, CA 92025	(619) 489-0798 Richard Gallade	ISD Hauler, Seller	Not Applicable
Orange County Chemical Co. 1230 East-Saint Gertrude Place Santa Ana, CA 92707	(714) 546-9901 Jim Gallade	ISD Hauler, Seller, Processor	520 tons/yr

TABLE 5.2 (Continued)

SOLVENT WASTE RECYCLING AND TREATMENT FACILITIES IN CALIFORNIA

Name Address	Telephone No. Contact	Permit* Service	Facility Design Capacity**
Plastic Materials, Inc. 3033 West Mission Road Alhambra, CA 91803	(818) 289-7979 Jean Greco Todd Greco	ISD Hauler, Seller, Processor	1,000 gal/day
Reclamar 131 North Marine Avenue Wilmington, CA 90744	(213) 835-3103 Paul DeVries	Permit Hauler, Processor	5,000 tons/yr
Rho-Chem Corporation 425 Iris Avenue Inglewood, CA 90301	(213) 776-6233 Dick Gustafson	Permit Hauler, Processor	200-300 gal/hr
Romic Chemical Corporation 2081 Bay Road East Palo Alto, CA 94303	(415) 324-1638 Peter Schneider	Permit Hauler, Processor	31,000 tons/yr
Safety Kleen 1000 South I Street Reedly, CA	(209) 638-3010	Permit Hauler, Processor	16,000 tons/yr
Solvent Services, Inc. 1021 Berryessa Road San Jose, CA 95133	(408) 286-6446 Tom Dinette	Permit Hauler, Processor, Seller	22,000 tons/yr
Van Waters and Rogers 2256 Junction Avenue San Jose, CA 95131	(408) 435-8700 Ron Haydel	Permit Hauler, Seller	Not Applicable
Van Waters and Rogers 1363 South Bonny Beach Place Los Angeles, CA 90023	(213) 265-8123 Kirk Steinseifer	ISD Hauler, Seller	Not Applicable

* Permit information correct as of August 29, 1986. ISD - Interim Status Document.

** Due to storage and operating limitations, hourly or daily capacities cannot be used to provide meaningful annual capacities

TABLE 5.3

SOLVENTS RECYCLED AND TECHNOLOGIES FOR COMMERCIAL FACILITIES IN CALIFORNIA

Name Address	Solvents Recycled	Recycling Technologies	Solvents Handled 1985 (tons)
Acto-Kleen P.O. Box 278 Pico Rivera, CA 90660	Perchloroethylene, 1,1,1-trichloroethylene, methylene chloride, trichloroethylene, fluorocarbons	Stores solvents for transfer to other facilities for processing	21
Baron-Blakeslee, Inc. 3596 California Street San Diego, CA 92101	Chlorinated and fluorinated solvents	Pot distillation	57
Baron-Blakeslee, Inc. 8333 Enterprise Drive Newark, CA 94560	Chlorinated and fluorinated solvents	Single plate distillation	163
Bayday Chemical 2096-B Walsh Avenue Santa Clara, CA 95050	Chlorinated and fluorinated solvents	Distillation, electric	182
Demenno/Kerdoon 2000 North Alameda Compton, CA 90222	Petroleum solvents, gasoline, jet fuels, and napthas with a flashpoint greater than 100^{o}F.	Filtration/sedimentation, decant/de-emulsify/air flotation, vacuum distillation, flash distillation, steam stripping, boiler, chemical dehydration	1,048
Detrex Chemical Industries, Inc. Gold Shield Solvent Division 3027 Fruitland Avenue Los Angeles, CA 90058	Chlorinated and fluorinated solvents	Single plate distillation	86
General Portland Inc./SYSTECH 23505 Crenshaw Boulevard Room 201 Torrance, CA 90505	Energy recovery from ignitable wastes (organic). Volume approx. 1000 gallons. Chlorine content five percent or less. Waste must be pumpable. Solvents, still bottoms, paint, adhesive, resin, ink waste, etc.	Incineration	15,909

TABLE 5.3 (Continued)

SOLVENTS RECYCLED AND TECHNOLOGIES FOR COMMERCIAL FACILITIES IN CALIFORNIA

Name Address	Solvents Recycled	Recycling Technologies	Solvents Handled 1985 (tons)
Holchem/Service Chemical 1341 East Maywood Santa Ana, CA 92706	Chlorinated and fluorinated solvents	Not Available	64
IT Corporation-Vine Hill Facility 4575 Pacheco Boulevard Martinez, CA 94553	Energy recovery from non-halogenated solvents	Incineration	436
McKesson Chemical Company 5353 Jillson Street Commerce, CA 90040	Chlorinated and fluorinated solvents	Stores solvents for transfer to other facilities for processing	50
Nelco Oil Refining Corporation 600 West 12th Street National City, CA 92050	Energy recovery from oxygenated and hydrocarbon solvents	Incineration	2
Oil and Solvent Process Company 1704 West First Street Azusa, CA 91702	Aliphatic and aromatic hydrocarbons, Freons, chlorinated hydrocarbons, lacquer wash thinner, all types of chemical solvents. Bend for incineration at another facility.	Pot distillation, film evaporation	16,126
Omega Chemical Company 12504 East Whittier Boulevard Whittier, CA 90602	All types of refrigerants, lithium bromide, halogenated and oxygenated solvents, tetrahydrofuren, dimethylfermamide, Freons, paint wastes, lacquer thinners, dry cleaning solvents	Film evaporation	905
Orange County Chemical Co. 425 Ancleason Drive Escondido, CA 92025	Chlorinated and fluorinated solvents	Stores solvents for transfer to other facilities for processing	6
Orange County Chemical Co. 1230 East-Saint Gertrude Place Santa Ana, CA 92707	Chlorinated and fluorinated solvents	Filtration, flash distillation	66

TABLE 5.3 (Continued)

SOLVENTS RECYCLED AND TECHNOLOGIES FOR COMMERCIAL FACILITIES IN CALIFORNIA

Name Address	Solvents Recycled	Recycling Technologies	Solvents Handled 1985 (tons)
Plastic Materials, Inc. 3033 West Mission Road Alhambra, CA 91803	Ketones, chlorinated solvents	Distillation	220
Reclamar 131 North Marine Avenue Wilmington, CA 90744	Drycleaning wastes containing perchloroethylene	Not Available	250
Rho-Chem Corporation 425 Iris Avenue Inglewood, CA 90301	1,1,1-Trichloroethane, perchloroethane, methylene chloride, trichlorotrifuoroethane, alcohols, ketones, aromatics, lacquer thinner and paint thinners. Also blend for incineration at another facility.	Film evaporation	1,928
Romic Chemical Corporation 2081 Bay Road East Palo Alto, CA 94303	Aliphatic, aromatic, chlorinated, fluorinated substances; alcohols; esters, trichloroethane, methylene chloride, lacquers, paint thinners, Freons, ketones, tetrahydrofuran, methylpyrrolidone. Water wastestreams containing lower concentrations of solvents like acetone, MEK, IPA. Also blend for incineration at another facility.	Fractional distillation	18,845
Safety Kleen 1000 South I Street Reedly, CA	Hydrocarbon solvents, methylene chloride	Solvent exchange service with automobile repair shops.	14,982
Solvent Services, Inc. 1021 Berryessa Road San Jose, CA 95133	All halogenated and non-halogenated solvents. Also blend for incineration at another facility.	Distillation, gravimetric separation	3,215

TABLE 5.3 (Continued)

SOLVENTS RECYCLED AND TECHNOLOGIES FOR COMMERCIAL FACILITIES IN CALIFORNIA

Name Address	Solvents Recycled	Recycling Technologies	Solvents Handled 1985 (tons)
Van Waters and Rogers 2256 Junction Avenue San Jose, CA 95131	1,1,1-trichloroethane and Freons	Stores solvents for transfer to other facilities for processing	183
Van Waters and Rogers 1363 South Bonny Beach Place Los Angeles, CA 90023	1,1,1-trichloroethane and Freons	Stores solvents for transfer to other facilities for processing	195

4. Availability of registered trucks to transport the solvent wastes.

5. Distance to the recycling facility and associated transportation costs.

6. Available laboratory facilities and analytical procedures.

7. Record keeping practices.

8. Availability of custom recycling services (e.g., vendor-owned recycling units that can be operated on the generator's property).

9. Expertise on in-plant waste management strategies and process controls.

10. Insurance for recycling/treatment/disposal operations.

11. Disposal procedures for still bottoms and solvents that cannot be recycled.

12. State regulatory agency's compliance records on the facility.

13. Current customers' comments on the facility.

14. Facility's financial stability.

These factors can be readily checked by visiting the recycling facility, and by phoning regulatory agencies and references provided by the facility.

5.3.3 Other Off-site Recycling Alternatives

5.3.3.1. Waste Exchanges

An alternative to on-site or off-site recycling, is shipping wastes to companies that use the materials in their operations. Recipient companies either use the waste untreated or subject it to a minimal amount of treatment before reuse. The success of such waste transfer operations depends on: (1) the supply and demand for a specific waste; and (2) a mechanism by which interested parties can make contact and negotiate an agreement. Such a mechanism is provided by waste exchanges. Waste exchanges are private or government-funded organizations that facilitate recycling transactions by identifying the supply and demand for various wastes.

There are two types of waste exchanges: information exchanges and material exchanges. <u>Information exchanges</u> act as clearing houses for information on waste demand and supply. <u>Material exchanges</u> take temporary physical possession of the waste and may initiate or actively participate in the actual transfer of wastes to users. Supplementing the activities of these two types of waste exchanges are waste brokers. Brokers are individuals or firms which, for a fee, locate processors, sellers, or companies to use the recyclable materials. The broker does not take physical possession of the material.

In California, an information exchange is operated by the California Waste Exchange (CWE)[6]. It is a program administered by the Toxic Substances Control Division of DHS. CWE publishes a directory of industrial recyclers and a quarterly newsletter and catalog. The newsletter documents recent developments in the area of hazardous wastes (i.e., laws, regulations, technology). The catalog lists wastes requested and wastes available. Through this service, industries locate parties interested in receiving their wastes. The parties in the catalog are identified only by a box number, a procedure much the same as that used in classified ads. This system ensures a degree of confidentiality. Some companies fear that an analysis of their wastes could reveal proprietary information about their manufacturing process.

Wastes currently recycled through waste exchanges include acids, alkalis, other inorganic chemicals, organics and solvents, and metals and metal sludges. Of these wastes, solvents and metal wastes are most frequently listed by waste exchanges. These materials have a high recovery value. Of the total wastes listed via exchanges, approximately 20 to 30 percent are exchanged [23,24,25,26]. Table 5.4 indicates the solvents most commonly recycled by the CWE.

5.3.3.2 Cooperative Arrangements

Companies may make cooperative arrangements with each other to facilitate recycling in ways other than the commercial batch-tolling agreements discussed above. These usually involve arrangements between plants located near and even at some distance from each other.

One example of a cooperative off-site recycling arrangement is the Neighborhood Cleaners Association (NCA). NCA delivers waste recycling kits to participating member establishments and, on a periodic basis, arranges for pickup of the accumulated wastes by a commercial recycling facility. Spent solvent (perchloroethylene) is recovered by distillation, cartridges are shredded, and any usable parts are recycled. Oily wastes that cannot be recovered are incinerated. According to World Information Systems, the average cost for an NCA establishment participating in this program is $600 to $700 per year [28]. NCA is located at 116 E. 27th Street, New York, New York 10016; telephone (212) 684-0945.

5.4 Separation Techniques for Solvent Recovery

A summary of techniques that can be used to purify or concentrate solvents is presented in Table 5.5. Dilute aqueous streams containing small concentrations of solvent are usually treated for disposal to a sewer or a body of water. Solvent recovery is a secondary consideration because of the small quantities of solvent that can be recovered. If recovery is planned, solvent-rich residuals from wastewater treatment (such as carbon adsorption or steam stripping) usually require additional processing such as drying or azeotropic distillation. Concentrated solvent wastes are more frequently recycled. The techniques applicable to the concentrated wastes are discussed below.

5.4.1 Distillation

Distillation is the oldest and most popular solvent recovery technique. It relies on the difference in volatility between the solvent and the impurities present in the mixture. There are two primary types of distillation: batch and continuous. A batch process, also known as differential, Raleigh, or pot distillation, consists of placing a fixed amount of solvent waste inside a

TABLE 5.4

SOLVENTS COMMONLY RECYCLED VIA CALIFORNIA WASTE EXCHANGE

1,1,1 trichloroethane
tetrachloroethylene
trichlorotrifluoroethane
methylene chloride
lacquer thinner
mixed solvents (oxygenated and aromatic hydrocarbons)
napthas
xylenes
toluene
methyl ethyl ketone
acetone
isopropyl alcohol
methyl alcohol
benzene
mineral spirits

TABLE 5.5

SOLVENT SEPARATION TECHNIQUES

TECHNIQUE	USUAL APPLICATION Concentrated Solvent Waste	Dilute Aqueous Waste
Distillation	X	
Evaporation	X	
Solvent Extraction	X	X
Supercritical Extraction *		X
Freeze Crystallization *		X
Air Stripping		X
Steam Stripping	X	X
Carbon Adsorption		X
Sedimentation	X	X
Decantation	X	X
Filtration	X	X
Membrane Separation *	X	X
Centrifugation	X	
Dissolved Air Flotation		X

* - Novel technology or application [7,8,9]

heated evaporation chamber and applying heat with simultaneous withdrawal and condensation of the overhead vapor. As solvent is depleted from the batch inside the pot, the mixture boiling temperature and the partial pressure of high boiling impurities rise. The process is terminated when the impurity level in distillate becomes prohibitive, when the temperature exceeds the limit set by thermal stability of waste constituents and/or materials of construction, or when the viscosity of the residual is increased beyond the range allowing for efficient heat transfer or flowability.

In solvent recycling, batch distillation most commonly uses a single equilibrium stage (i.e., there is no refluxed packed or trayed column present). Refluxed multistaged batch distillation is sometimes used for fractionation; however, the applications are rare. The disadvantages include the lack of stripping action present in continuous columns. Single stage batch distillation can usually produce acceptable purity (greater than 95 percent), especially if the process is carried out slowly and the components' vapor pressures differ widely.

Continuous multistage distillation, often called fractional distillation, is commonly applied when the following requirements are present:

- high degree of distillate purity;
- volatility differences are small; and
- amounts are large.

Distillation is carried out in a column equipped with trays or packing to facilitate maximum contact between liquid and vapor phases. Feed is introduced continuously at the optimum location in the column and part of the condensed distillate (reflux) is introduced at the top. Downward moving liquid is contacted with the upward moving vapor. The vapor is progressively enriched with more volatile components. High boilers are concentrated in the liquid, mostly below the feed in the stripping section of the column, and are eventually withdrawn in a continuous or semi-continuous fashion. The heat is delivered to the bottom part of the column through a reboiler, usually a shell-and-tube exchanger, a coil, or a tube bundle insert. Most of this heat is removed in the condenser at the top of the column.

Intermediate draw-offs enable a number of solvents to be recovered from a mixture (in a batch process, fractionation can be accomplished through routing the distillate to separate receivers at different times during the period of operation). An example of fractionation is the Westinghouse Electric plant in Raleigh, North Carolina where perchloroethylene and Freon are separated from degreasing operation waste [10].

One of the principal concerns in solvent waste distillation process is fouling of column internals and heat transfer surfaces on the process side of the reboiler. Fouling is usually caused by thermal degradation or polymerization of compounds present in the bottoms, such as oils, resins, greases, and fats. Thermal degradation is also undesirable because of formation of volatile byproducts that can contaminate the recovered solvent or cause emission hazards. When high boiling solvents are recovered, it is desirable to keep the bottoms temperature down to avoid degradation. This is done either by conducting distillation under vacuum or by injecting steam directly into the bottom of the column (steam distillation, also known as steam stripping or wet distillation). Steam provides the necessary heat input, and serves as an inert diluent that lowers the partial pressure (and thus the temperature) of the organic high boilers in the mixture. Steam distillation is useful when water is not miscible with solvent and does not enter into undesirable reactions. Direct steam injection can also be applied in batch distillations. The disadvantages include water saturation of recovered solvent, possible need for additional azeotropic distillation, water disposal, corrosion, and foaming.

Another concern is impediment of heat transfer into highly viscous bottoms stream. Solvent concentration in the column bottoms is usually maintained at a level that provides adequate fluidity for efficient boiling and free drainage. When high distillate yield is required, or when the volume of the bottoms stream is excessive, special evaporator designs (such as agitated film or drum dryer) are employed for secondary recovery of solvents from the highly viscous bottom streams.

In at least one case, drainability of the bottom stream is not a consideration. In design of their commercial pot distillation system, Recyclene Products, Inc. uses disposable plastic liners for the boiling chamber. The liners are removed after each cycle. A similar principle is used in applications involving removable pans or where drum containers are used directly as a boiling chamber. Appendix D contains information on small stills suitable for on-site recycling.

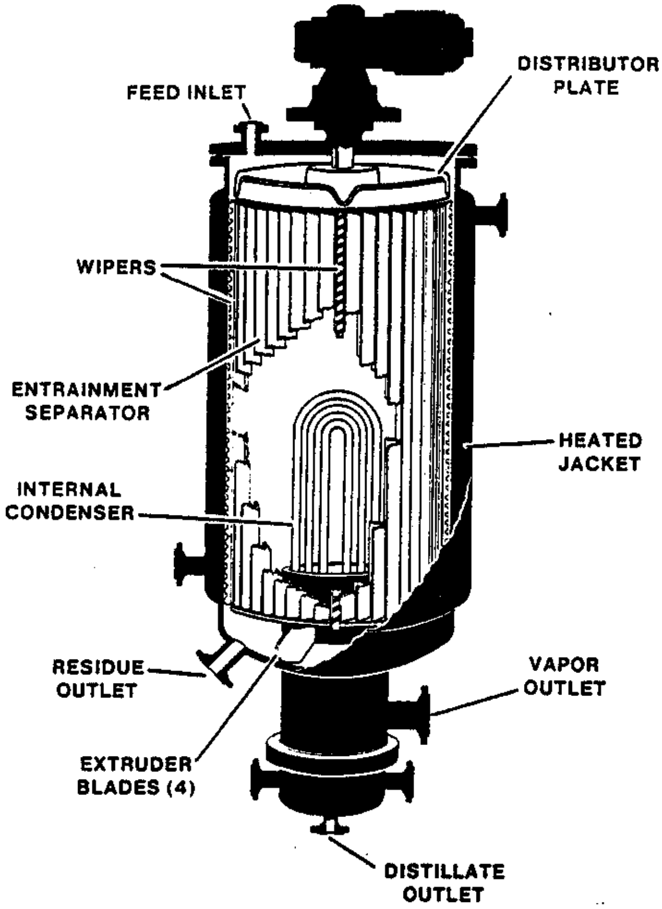
5.4.2 Evaporation

Evaporation is a process often used on solvent bearing sludges or bottoms from distillation units. In a turbulent film evaporator, also called a scraped- or wiped-film evaporator, a set of rotating blades spreads the waste in a thin film against the heated wall of the cylindrical vessel. The sludge is continually moved against the heated wall of the unit using rotor tip velocities of up to 40 ft/sec. A high degree of heat transfer is maintained. Heavy solids and sludges eventually make their way to the bottom of the vessel and are collected. Solvent vapors exit the top of the unit where they are collected, condensed, and further treated if required. Figure 5.1 shows a schematic of a wiped film evaporator. Film evaporation can be used to reclaim solvent from heat sensitive viscous wastes including solvent/resin mixtures. It is best suited for low-boiling solvents without abrasive solids.

Drying operations may involve the use of a drum dryer, also referred to as double drum dryer or scraped-drum dryer. In this unit, viscous waste is fed continually between two horizontal cylindrical drums. The drums are heated internally and counter-rotated. The feed liquid is deposited on the hot drums' surface and solvent is vaporized. The nonvolatile components form a dry film. The vapors are condensed and recovered. Solids are scraped off the drum surface and collected. Figure 5.2 depicts the drum dryer's schematic. Drum drying can handle extremely viscous pumpable sludges that contain up to 90 percent solids and can recover nearly all the solvent for reuse.

FIGURE 5.1

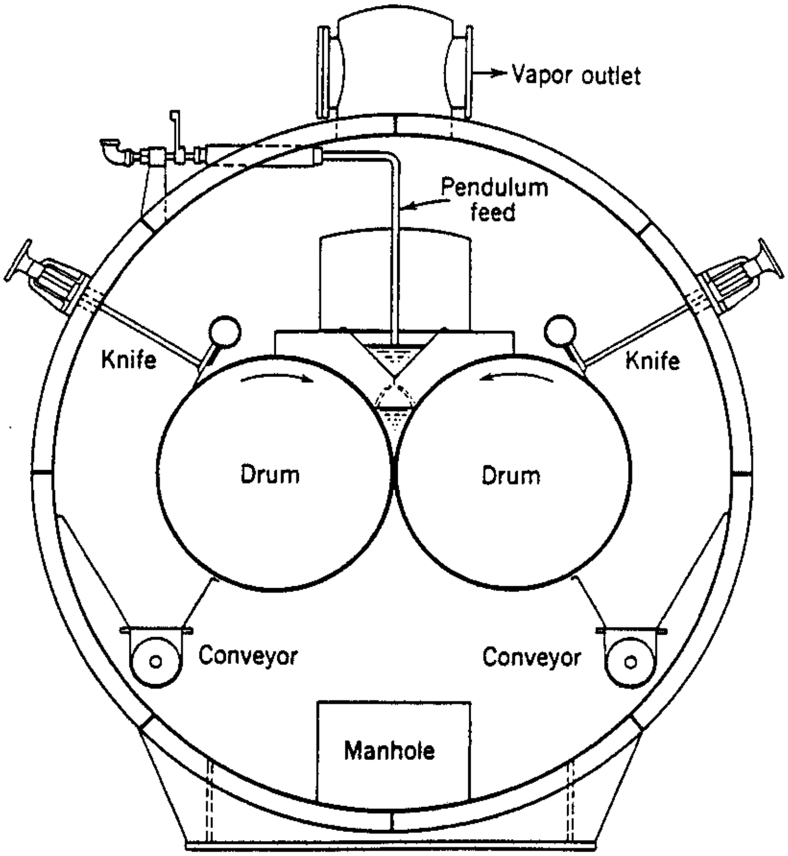
WIPED FILM EVAPORATOR



Courtesy of the Pfaudler Company.

FIGURE 5.2

DOUBLE-DRUM DRYER



Courtesy of Blaw-Knox Company, Buflovak Equipment Division.

Other drying equipment applications for solvent recovery include a vacuum rotary dryer capable of handling solvent slurries as well as pastes and filter cakes. Recovery efficiencies are in the range of 90 to 95 percent [11]. The selection of evaporators for large scale applications is discussed in reference 12. Table 5.6 contains some information on evaporation units suitable for solvent recovery.

5.4.3 Sedimentation

Sedimentation is a process in which particles suspended in a liquid are settled out by gravity. The liquid with suspended solids is introduced into settling tanks. After sufficient settling time, the clarified liquid is drawn off from the solids resting on the bottom of the vessel. The solids are removed and usually treated prior to disposal. Sedimentation is a widely employed separation technique for removing solids suspended in organic solvents and as a preliminary purification or pre-filtration step. Capital and operation/maintenance costs tend to be low because of the simplicity of the equipment required and low energy input. A disadvantage of sedimentation is that finely dispersed colloidal particles tend to stay suspended in solution making separation efficiency quite low. Settling times for these particles can be quite long, and large volumes or multiple tanks may be necessary to provide quantity through-put. Significant air emissions of volatile organic components may result if sedimentation is performed in large open tanks or holding ponds. Sedimentation is used in the paint formulation industry to handle equipment cleaning wastes [10].

5.4.4 Decantation

Decantation is a gravity separation technique used to separate immiscible liquids of different densities. The unstable mixture of immiscible liquids is slowly fed into a decant tank where it is continuously separated, coalesced, and withdrawn. Dust and dirt particles can interfere with the process of coalesence. They are sometimes filtered out before decantation. Depending on composition, these particles must be treated and disposed of. Decantation is often used to remove insoluble oils from spent solvents in the dry cleaning and petroleum refining industries. Because the nonaqueous layer removed by decantation is often saturated with water, further processing to dry the recovered liquid is often necessary.

Decant tanks are simple in design and relatively compact. The main factors in designing a decanter are the droplet size of the discontinuous phase, and the volume fraction of the discontinuous fluid. More complex units, used mainly by the petroleum refining industry to separate oil-water mixtures, are the API and titlted-plate separators.

5.4.5 Centrifugation

Centrifugation is a technique used to separate a liquid or solids from another liquid with a similar density. The technique relies on the application of centrifugal force to achieve separation. In sedimentation-type centrifugation, a wastestream is introduced into the spinning centrifuge. Due to the centrifugal force exerted on the mixture, the slightly denser solids are

TABLE 5.6 MANUFACTURERS OF EVAPORATION EQUIPMENT

	Blaw-Knox Food&Chemical Equipment Co. 750 E.Perry St. Buffalo,NY 14211		Cherry-Burrell P.O.Box 35600 Louisville,KY 40232	UIC Inc. P.O.Box 863 Joliet,IL 60434		
Technical Description	Roto-Vak	Drum Dryer	Model#04-020	Model#5034-10	Model#5034-01	Model#5036-10
Mode of Operation	Mechanically agitated thin-film evaporation	Drum drying	Mechanically agitated thin-film evaporation	Rotary Evaporation	Rotary Evaporation	Rotary Evaporation
Feed Throughput, Lb/hr.		60-80		2.6 gal.	2.6 gal.	2.6 gal.
Characteristics of Residues	About 50% solvent content	About 99% solids				
Equipment Features	2 sq ft Heat transfer area,Heat Flux of 20-50,000 Btu/hr-sq ft, Counter-current/cocurrent	9.4 sq ft Heat transfer area	1.4 sq ft Heat transfer area,vacuum operation	1.5 KW heater	2.5 KW heater	Explosion proof heating unit
Material of Construction	SS 316L	SS 304L	SS 316	Glass	Glass	Glass
Equipment Dimensions, In		60x36x62	27x16x56			
Weight, Lbs		3,600	175			
Type of Cooling				Water	Water	Water
Type of Heating	Steam/Heat transfer fluid	Steam	Steam/Heat transfer fluid	Electric	Electric	Steam
Control Features						
Options		Vacuum operation,Vapor condenser				
F.O.B. Cost, $	27,000	110,000		7,500	8,200	9,800
Maintenance Costs, $/yr.	500	300-1,000				
Delivery Time, Wks.	16	26				
Payment Terms	20% at time of order,60% ten weeks later,balance on shipment	20% at time of order,30% 8 weeks later,30% 16 weeks later,balance on shipment				
Solvents Recovered	Alcohols,Ketones,Esters, Glycols,Chlorinated solvents					

forced against the inner wall of the unit. Usually, the solids are removed by the continuous displacement of the entering fluid or by a screw conveyor inside the unit. In filtration-type centrifugation the inner wall of the unit is actually a filter. The solvent is forced through the filter and the solids are retained. Inside the unit, the solids are periodically removed by mechanical blades that scrape the filter surface as the unit rotates [13]. Treatment of the residual solids depends on the composition of the wastestream.

Like filtration or gravity separation, centrifugation is used as a preliminary purification step before other recycling operations. Crystalline solids, for example, are often separated from spent dry cleaning solutions before distillation. For wastestreams that contain less than one percent sedimentable solids, tubular-bowl centrifuges can be used. A modification of the tubular-bowl model is the multichamber centrifuge. The multichamber centrifuge can achieve a better degree of separation. The disk centrifuge uses a stack of truncated cones to achieve centrifugal forces ranging from 4,000 to 14,000 times the force of gravity. This equipment is generally used for cream separation in the dairy industry. Improved efficiency can be obtained by using nozzle-discharge centrifuges, self-opening centrifuges, continuous decantor centrifuges, screen bowl decantors, and knife-discharge clarifiers. Available filter-type centrifuges include variable-speed or constant-speed units and a wide variety of basket designs [13]. Reference 14 provides more information on centrifuges.

5.4.6 Filtration

Filtration is a process that separates suspended particles from a liquid by using a porous filter medium. Several types of filtration can be used, and the design and operation of each type varies widely. Basic operational steps entail forcing the mixture of solids and liquid through a filter medium using gravity or pressure. As the mixture flows through the filter, particles larger than the pore openings of the filtration media cannot pass through and are trapped. The filter medium may be either cleaned or discarded when it becomes clogged.

Some of the process-related factors important to the proper selection of filtration equipment are particle size distribution, viscosity, production throughput, process condition, performance requirements, and permissible materials of construction. Equipment-related factors include type of operation (batch or continuous), driving force, production rate, separation effectiveness, washing capability, dependability, material of construction, and cost. Based on generalized guidelines, such as the ones given by Van Note and Weems proper selection can usually be made [13]. Reference 15 provides detailed information on the types of equipment available from various manufacturers.

Cost for filtration equipment may vary widely because of the wide array of equipment available. When using a washable filter, environmental concerns usually center around increasing the volume of waste by addition of backwash fluid, treatment and disposal of the solids, and the escape of volatile components into the atmosphere which can occur if the unit must be opened for cleaning. Disposable cartridges or bag filters avoid the problem of waste quantity increasing due to backwash, however, at the expense of extending this quantity by their own mass. Disposable filters are widely used by the dry cleaning industry for removing soil from spent perchloroethylene.

As a simplified form of filtration, strainers are often employed to remove large or coarse particles from liquid. Equipment includes stationary or moving screens, perforated plates, metal mesh baskets, belts, or chains.

5.4.7 Membrane Separation

Membrane separation (includes ultrafiltration and reverse osmosis) is a process in which solute molecules with molecular weight exceeding 500, or particles with diameter not exceeding 0.5 microns can be separated from a wastestream using semi-permeable membranes as the filtering media. The membranes are highly efficient filters because the pore openings are submicron in size. Pore size can range from 0.0005 to 0.0025 microns in the case of reverse osmosis and up to 0.0025 to 0.01 microns for ultrafiltration. Pressure is applied to one side of the membrane so water and low molecular weight compounds in the wastestream flow through the pores. The large organic molecules and colloidal particles build up on the other side. Compared to reverse osmosis, ultrafiltration uses a membrane with much larger pore sizes. Hence, it is less susceptible to pore blockage or membrane degradation and better suited for most solvent recovery applications. More information on ultrafiltration can be found in references 9 and 16.

There are three primary ultrafiltration device configurations: tubular, spiral wound, and hollow fiber. The tubular device is often used for small-flow, high value applications. Because of the tubular construction, mechanical cleaning can be done easily. The tubular device is the unit of choice for cases involving severe fouling. The spiral-wound design is often used for high volume applications. The spiral-wound configuration is more vulnerable to fouling and mechanical cleaning is difficult to perform. The hollow fiber design consists of a membrane wound into a hollow cylinder with the inside diameter varying from 500 to 1,100 microns. The choice of diameter size depends on whether the application is high-fouling or low-fouling. Capital costs for ultrafiltration systems range from medium to high. The operating/maintenance costs are medium. Current commercial applications of ultrafiltration include paint recycling from the electrodeposition painting process, concentration of metal cutting and machine oil-water emulsion, and recovery of polyvinyl alcohol from textile wastes [4,17,18,19].

Applications of ultrafiltration to recover organic solvents are described in reference 27. These applications include revovery of cleaning solvent in automotive painting processes, recovery of paint solvents from roll coating operations, and recovery of cleaning solvent from printing operations.

5.4.8 Solvent Extraction

Solvent extraction is a process in which the separation of components is achieved by contacting the wastestream with a liquid that acts as a solvent to one component but is relatively immiscible with the other component. A basic single stage operation consists of mixing the wastestream and solvent together and then allowing the mixture to separate into phases in a holding tank. Several solvent extraction units are operated in counter-current fashion to increase removal efficiency. Separation of the recovered solvent and the extraction solvent usually requires the use of a distillation system.

Though not as popular as stripping or carbon adsorption processes due to higher costs, extraction is widely used to recover valuable solvents. Extraction can achieve 98 percent recovery. Extraction is a proven method for removing phenol, acetic acid, salicylic (and other hydroxy aromatic) acids, and petroleum oils from aqueous solutions. It is also used to recover methylene chloride from isopropyl alcohol, Freon from organic wastestreams containing oil and alcohol, and a mix of chlorinated hydrocarbon from alcohol or acetone. Many valuable organics present in moderate to high concentrations in aqueous or organic solutions can potentially be extracted (e.g. phenols, acids, alcohols, amines, glycols, tetrahydrofuran, and dimethylformamide). The major limitation to solvent extraction is the difficulty in finding a suitable solvent low in cost, high in extraction efficiency, and easily separable from the extracted substance.

5.5 Small Packaged Distillation Equipment

Most small distillation systems are designed as single stage batch stills, ranging from 0.8 to 1,000 gallons batch capacity. Some batch still manufacturers provide an option for semi-continuous, constant feed rate operation. In this mode, the bottoms are not removed continuously. They are accumulated until the end of the batch. Applications of semi-continuous mode for single stage distillation appear limited to direct steam injection (DCI's DYNA-1G system) probably due to built-in deficiencies of the indirect heat transfer mode in this situation. Continuous multistage refluxed distillation systems are usually custom designed based on standardized components and are available from a smaller number of suppliers. These units range from 1 to 1,440 gallons per hour capacity based on the feedrate.

There are many factors and options to consider when specifying solvent recovery distillation equipment. These are summarized in a datasheet (Figure 5.3). It is intended to guide the buyer through the major available options and choices. The datasheet reflects the information obtained from the survey of manufacturers. Key features of distillation equipment selection are discussed below.

<u>Stream characteristics</u> lists the attributes (quantities, compositions and properties) of feed, distillate, and bottom streams. Stripping stream and water phase are also included. An hourly mass flowrate (lbs/hr) should be entered based on the desired maximum still throughput and not as an averaged value.

<u>Choice of pressure</u> is a function of the vapor pressure dependence on temperature for a particular solvent, available cooling water temperature, and the impurities' volatility or thermal stability. To provide the largest thermodynamic driving force for separation (relative volatility), the pressure should be kept as low as possible. For most solvents, atmospheric pressure is sufficient. For high boiling species (boiling points above 400° F), a vacuum is often required. When a vacuum is used, air leaks into the equipment must be avoided to minimize the risk of fire, explosion, or premature corrosion or fouling. Particular attention must be paid to the gaskets, seals, and packing types used.

FIGURE 5.3

SOLVENT RECOVERY STILL DATA SHEET

OLVENT RECOVERY STILL DATASHEET	PROJECT NO. SPEC. NO.
ervice	Item(s) Tag No.
or	By Date Rev. No.
ite	Approval by Date
lanufacturer	Size and Model
	Serial No.
ench/Pilot Test Required Yes ☐ No ☐	No. Units Required

STREAM CHARACTERISTICS

Attribute	Feed		Distillate		Bottoms
	Dirty Solvent	Stripping Stream	Solvent Phase	Water Phase	
Flowrate, lb/hr					
Component, weight %					
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
Temp., °F					
Pressure, psig					
Density, lb/cu. ft					
Viscosity, cP					
Thermal Cond.,Btu/hr-ft-°F					
Latent Heat, Btu/lb					
Spec. Heat, Btu/lb-°F					
Boiling Range, °F					
Toxic (Y/N)					
Corrosive (Y/N)					
Ignitable (Y/N)					
Max. Stable Temp.,°F					
Steam Degradable (Y/N)					
Other					

FIGURE 5.3 (CONTINUED)

SOLVENT RECOVERY STILL DATA SHEET

CAPACITY AND OPERATION REQUIREMENTS

Dirty Solvent Load : Lb/Shift Shift/Day Days/Week

Mode Of Operation : Batch (Rayleigh) ☐ Continuous ☐ Other(Explain) ☐

Still Capacity : Lb/Hr Feed ☐ Product ☐

Turndown Ratio :

No. Of Stages : Theoretical Actual ΔP, In.WC.

Trays ☐ Type Spacing ΔP, In.WC.

Packing ☐ Type HETP, Inches ΔP, In.WC.

Reflux Ratio Design Range

HEATING MODE

Direct Steam Inj. ☐ Shell & Tube Reboiler ☐

Insert Tube Bundle ☐ Jacket ☐ Coil ☐

Electric ☐ Other (Explain) ☐

AVAILABLE UTILITIES / CONSUMPTION RATES

Steam : Sat. ☐ Pressure Level(s), PSIG : Flow, Lb/Hr

Supht. ☐ Press.,PSIG/Temp. °F : Flow, Lb/Hr

Vacuum : mm Hg Abs. Flow, ACFM

Plant Air, PSIG , SCFM Instr. Air, PSIG , SCFM

Cooling Water : Temp. In/Out, °F GPM

Electric Power : Volts Phase Hz KW

Heating/Cooling Media :

SPACE / INSTALLATION / TEST REQUIREMENTS

Length Height Width

Weight, Lbs Empty Operating

Stationary ☐ Moveable ☐

Foundations Required Yes ☐ No ☐

Field Assembly Required Yes ☐ No ☐ No. of Delivered Modules

Estimated Assembly Labor, Mhrs

Insulation Shop ☐ Field ☐

Painting Shop ☐ Field ☐

Performance Test Witnessed ☐ Nonwitnessed ☐

Hydrostatic Test Witnessed ☐ Nonwitnessed ☐

Shop Inspection Yes ☐ No ☐

FIGURE 5.3 (CONTINUED)

SOLVENT RECOVERY STILL DATA SHEET

INSTRUMENTATION

Piping and Instrumentation Diagram Provided Yes ☐ No ☐

Conceptual Control Schematic Provided Yes ☐ No ☐

Instrumentation Requirements Mfg Standard Acceptable ☐

Custom Requirements ☐

Automatic Control Options :

Feed Flowrate ☐ Bottoms Flowrate ☐ Condenser Temp. : Inlet ☐ Outlet ☐

Reboiler/Still Liquid Level ☐ Receiver Liquid Level ☐

Still Pressure ☐ Reflux Ratio ☐

Monitoring Options (A - Alarm ; I - Indicator; R - Recorder ; M - Multiplex)

	Liq. Level	Pressure	Temp.	Flow	Composit.
Solvent Feed					
Steam Feed					
Reboiler/Still					
Receiver					
Separator					
Condenser Inlet					
Condenser Outlet					
Clg. Wtr. Inlet					
Clg. Wtr. Outlet					
Bottoms					
Feed Tank					
Bottoms Tank					

Control Panel Local ☐ Remote ☐

SAFETY FEATURES

Automatic Unit Shutdown Due To :

CW Failure ☐ Low Level ☐ Other ☐

Bottoms Temperature ☐ Pressure ☐ Feed Interrupt ☐

Overpressure Protection :

Rupture Disk(s) ☐ Relief Valve(s) ☐ Other ☐

Explosion - Proof Electricals Yes ☐ No ☐

Grounding Protection ☐

FIGURE 5.3 (CONTINUED)

SOLVENT RECOVERY STILL DATA SHEET

EQUIPMENT TO BE SUPPLIED

FEED	1. Feed Transfer Pump ☐ 2. Feed Tank ☐ Gravity Flow ☐
	3. Feed Charge Pump ☐ 4. Filter(s) ☐ 5. Strainer(s) ☐
	6. Feed Preheater ☐
STILL	7. Boiling Chamber ☐ 8. Column ☐
	9. Column Internals ☐ 10. Reflux Head ☐
DISTILLATE	11. Condenser ☐ 12. Receiver ☐ 13.Coalescer/Separator ☐
	14. Reflux Pump ☐ 15. Product Pump ☐ 16. Product Tank ☐
BOTTOMS	17. Reboiler ☐ Type :
	18. Bottoms Pump ☐ 19. Bottoms Tank ☐
	Removal Mode : 19. Pan ☐ 20. Liner Bag ☐ 21. Gravity Flow ☐
AUXILIARY EQUIPMENT	22. Chiller ☐ 23. Cooling Tower ☐ 24. Boiler ☐
	25. Vacuum Generator ☐

COMPONENT DESIGN PARAMETERS

PARAMETER	Package Component Number (from above)									
Pump GPM/TDH, ft.										
Tank Capacity, gal.										
Dimensions /Size										
Duty, BTU/ hr										
Heat Transfer Area, sq. ft.										
TEMA Type										
Mat'l. of Construction										
Shell										
Tube										
Impeller										
Casing										
Liner										
Gaskets										
Corrosion Allowance										
Design P/T (PSIG/^{o}F)										
Design Code										

Operating temperature is determined by the operating pressure. The capacity and operation requirements are based on the waste generation rate, stream characteristics, product purity requirements, and plant operation schedules. The mode of operation is batch or continuous depending on the same considerations. The solvent waste may be allowed to accumulate for a period of time before distillation to recover pure solvent in periodic campaigns. This storage period may not exceed 90 days, or the facility is considered to be a hazardous waste storage facility requiring a RCRA permit from EPA. The plant schedule of operation determines the frequency of operation of the unit. For low feed rates, batch operation is chosen, unless the product purity constraints and the stream characteristics require the use of a continuous operation. When continuous distillation is chosen, the reflux ratio and the number of theoretical stages is determined by the relative volatilities of the species and the specified product purity. A detailed description of the design and operation principles of distillation columns can be found in many standard texts, such as Perry's Chemical Engineer's Handbook [13], or Handbook of Separation Techniques for Chemical Engineers [20].

The choice of the heating mode is determined by the available utilities, preference of the operator, and the characteristics of the bottom stream. If the bottoms are very viscous, better heat transfer can be obtained by using direct steam injection. Direct stream injection can be used only if the product is not steam degradable and if water is a tolerable impurity in the recovered solvent. The aqueous wastestream that is generated by this process may need treatment before disposal to the sewer.

Space/installation/test requirements should include the consideration of whether the equipment should be weather-proof and also whether a performance test is required. Space constraints, if any, are also specified here. Close attention must be paid to the location of the installed still in the facility. A well ventillated, easily accessible area away from possible sources of sparking or fires, but in proximity to feed sources is preferable. A check with the local fire marshall and industrial insurance company together with an examination of codes such as the Uniform Building Code, NFPA and OSHA is recommended.

The automatic operation control options consist of flow, level, temperature, or pressure regulation. The heat input rate can be fixed or controlled in a modulating or on-off fashion, by bottoms or vapor temperature, or bottoms liquid level. Heat input can be independently interrupted by a low liquid level, high temperature condition in the pot, or loss of cooling water to the condenser. Low liquid level shutdown can prevent severe fouling of unsubmerged heating surfaces. Cooling water flow can be modulated by the condensed distillate temperature controller. When stringent product purity requirements exist, or when the operation is continuous, a higher level of control sophistication is required.

Safety features such as explosion proof electricals and grounding protection are required when flammable solvents, such as acetone, are handled. Relief valves of rupture disks are necessary to prevent equipment failure in the event of overpressure. Overpressure can occur due to blocked vapor outlets, or external fire. If cooling water supply fails, the vapors will not be condensed, resulting in sustained vapor emission - an extremely hazardous condition. This is prevented by reliable automatic interruption of the heat supply in the event of cooling water failure.

Feed conditioning such as filtering or preheating is useful for energy conservation. For feed containing suspended solids, filtering prior to distillation prevents fouling of the heat transfer surfaces. Feed preheating with the available waste heat from bottoms or condenser may result in energy savings.

The bottoms removal mode is important from an equipment cleaning viewpoint. The use of still pans or bags facilitates the removal of the bottoms for easy disposal. Mechanical cleaning of the equipment in the absence of such devices may damage the heat transfer surfaces.

The material of construction is determined by the corrosivity of the feed/product at process conditions, and the expected equipment lifetime. Carbon steel, austenitic stainless steels and polymeric linings are typical construction materials offered by manufacturers. If chlorinated solvents are used, austenitic steel may not be suitable. Traces of hydrochloric acid present in the solvent can cause chloride stress corrosion. The proper material can be chosen after testing or through consultation with the material or equipment suppliers.

Information on existing commercial packaged systems for small scale solvent recovery was solicited from 48 U.S. equipment manufacturers. The data collected are summarized in Appendix D.

REFERENCES FOR CHAPTER 5

1. "Empirical Analysis of U.S. Hazardous Waste Generation, Management, and Regulatory Costs, Draft Report." Washington, D.C.: U.S. Congressional Budget Office, September 1985.

2. Cooper, C.M. "Solvent Recovery." In Kirk-Othmer Encyclopedia of Chemical Technology, Volume 21, pp. 355-76, 1983.

3. De Renzo, D.J., editor. Unit Operations for Treatment of Hazardous Industrial Wastes, Park Ridge, New Jersey: Noyes Data Corporation, 1978.

4. Schwartz, S. I., et al. Managing the Electronics Industry's Hazardous Wastes: Technology and Economics of Alternatives to Land Disposal, Sacramento: California Department of Health Services and Golden Empire Health Planning Center, 1985.

5. U.S. Environmental Protection Agency. Analysis of Treatment and Recycling Technologies for Solvents and Determination of Best Available Demonstrated Technologies (BDAT), 1986.

6. California Waste Exchange, Vol. 1, No. 1., Sacramento: Department of Health Services, 1986.

7. Basta, N. "Supercritical Fluids: Still Seeking Acceptance." Chemical Engineering, Feb. 4, 1985.

8. Neuman, E., P. Daley, and O. Winter. "Freeze Crystallization for Concentration of Hazardous Waste." Paper presented at the Engineering Foundation Conference, Henniker, NH, June 17, 1986.

9. Applegate, L.E. "Membrane Separation Processes." Chemical Engineering, June 11, 1984.

10. Kohl, J., P. Moses, and B. Triplett. Managing and Recycling Solvents: North Carolina Practices, Facilities, and Regulations, Raleigh: North Carolina State University, 1984.

11. Anonymous. "Vacuum Rotary Dryer Recovers Solvent." Chemical Processing, Nov. 1982, p. 36.

12. Mehra, D.K. "Selecting Evaporators." Chemical Engineering, Feb. 3, 1986, pp. 56-72.

13. Perry, R.H., D.W. Green, and J.O. Maloney. Perry's Chemical Engineers Handbook, 6th. ed., New York: McGraw Hill Book Co, 1984.

14. West, J. "Disc-bowl Centrifuges." Chemical Engineering, Jan. 7, 1985, pp. 69-73.

15. Hodel, A.E., and F.M. Bonady. "Guide to Filtration." Chemical Processing, Jan. 1986, pp. 52-74.

16. Gooding, C.H. "Reverse Osmosis and Ultrafiltration Solve Deparating Problems." Chemical Engineering, Jan. 7, 1985, pp. 56-62.

17. Sotdderd, S.K., G.A. Davis, and H.M. Freeman, Alternatives to the Land Disposal of Hazardous Wastes - An Assessment for California, Sacramento: State of California, Governor's Office of Appropriate Technology, 1981.

18. Corey, D.L. "Hazardous Waste Recycling Technologies." 1985.

19. California Department of Health Services. Third Biennial Report on Alternative Technologies, Sacramento: State of California, Department of Health Services, 1986.

20. Schweitzer, P.A. Handbook of Separation Techniques for Chemical Engineers, New York: McGraw-Hill Book Co., 1979.

21. Radimsky, J., K. Wilhelm, R. Boggs, M.R. Eriksson, R.E. Marx, and R. Piacentini. Recycling and/or Treatment Capacity for Hazardous Wastes Containing Halogenated Organic Compounds, 1984 Draft Report. Sacramento: State of California Department of Health Services, 1984.

22. SCS Engineers. "Hazardous Waste Management Plan for Small Quantity Generators." Final report to the Southern California Association of Governments, Los Angeles, California, 1985.

23. Industrial Material Exchange. Assessment Report, Springfield, Ill: Illinois Environmental Protection Agency, 1985.

24. Banning W., S. Hoefer. An Assessment of the Effectiveness of the Northeast Industrial Waste Exhcange in 1983, Syracuse, New York: Northeast Industrial Waste Exchange, November 1983.

25. Banning W. An Assessment of the Effectiveness of the Northeast Industrial Waste Exchange in 1984, Syracuse, New York: Northeast Industrial Waste Exchange, 1984.

26. Piedmont Waste Exchange. Annual Report. Charlotte, North Carolina.

27. Issoka, Y., Y. Imamura, Y. Sakamoto. "Recovery and Reuse of Organic Solvent Solutions," Metal Finishing, June 1984, pp. 113-118

28. World Information Systems. Hazardous Materials Intelligence Report, Cambridge, MA: World Information Systems, May 24, 1985, p.5.

CHAPTER 6

TREATMENT AND PRETREATMENT

This chapter presents major aspects of treatment and pretreatment of solvent waste. Treatment refers to processes or techniques that destroy the waste and yield wastestreams that pose little or no environmental risk. In this chapter, the terms treatment and pretreatment are used interchangeably. In a strict sense, however, pretreatment is applied to wastestreams to make them more suitable for either recycling or final treatment (e.g., in publicly owned treatment works). Section 6.1 provides a discussion of reasons for treating solvent waste and the types of waste commonly treated. Section 6.2 follows with a discussion of the various types of equipment or processes used to treat or destroy solvent waste.

6.1 Overview of Treatment

Increasing costs for land disposal and the associated liabilities, can make treatment a viable option. Waste treatment systems are often costly and the decision to rely on treatment should only be made after considering all available source reduction and recycling options.

Aqueous wastes containing solvents are often treated onsite to reduce their toxicity and chemical or physical properties. For facilities producing large volumes of wastewater with very low solvent concentrations, the most common treatment systems either involve biological degradation or stripping the wastewater with air or steam. Stripping may be followed by treatment or recovery to control air emissions. Recycling by steam stripping is favored because it produces a more concentrated solvent wastestream than air stripping. Biological treatment in large aerated open tanks can result in air emissions and the cost for emission control can be prohibitive.

Concentrated solvent wastes may be incinerated. Like most treatment systems, an incinerator must be specifically tailored to the type of waste. Chlorinated solvents form hydrochloric acid upon burning. Therefore special acid resistant construction materials and a flue gas acid scrubber may be required. Reference 13 provides information on the importance of reviewing the charactistics of a particular incinerator design in conjunction with the wastes being treated.

Models are available to evaluate treatment processes. Such models are useful in estimating design parameters, sizing the equipment, and process optimization. A good discussion of such models is in reference 20.

Several innovative arrangements for treatment of waste are available for facilities that do not have the necessary capital or technical staff to build and operate a system. Companies that market transportable incineration systems include: Ensco Environmental Services in Little Rock, Arkansas; Shirco Infrared Systems in Dallas, Texas; and Huber Corporation in Borger, Texas. G.A. Technologies (GAT), San Diego, California; and Modar Incorporated in Natick, Massachusetts, market a transportable supercritical water system. Another option for treating waste onsite is to lease land to another company or joint-venture that then builds and operates the treatment system. Waste Tech Services Inc. in Denver, Colorado and GAT in San Diego, California are examples of companies that offer this service.

Off-site treatment can typically be justified in cases where generation volumes are small, periodic in nature, and where off-site treatment capacity is available. In California, one off-site hazardous waste incinerator is currently in operation - General Portland, Inc. in Lebec, operates a cement kiln that is permitted to burn hazardous waste. Allowable wastes are limited to a maximum of five weight percent chlorine and a minimum heating value of 10,000 British Thermal Units (BTU) per pound. Arrangements for use of cement kilns can be made through Systech Corporation, Lebec, California. Systech also uses General Portland's facility in Fredonia, Kansas. GAT in San Diego and Stauffer Chemical Company in Dominguez and in Martinez are in the process of seeking federal and state permits to burn hazardous waste from off-site facilities.

6.2 Treatment Technologies

Treatment technologies involve the removal of solvents from wastewater streams by physical means, the destruction of solvents in wastewater by chemical or biological means, and the destruction of solvent waste by thermal techniques. Many treatment technologies can be used in combination with recycling technologies (distillation of waste solvent followed by incineration of the remaining solids).

Only technologies involving the destruction of waste solvent are covered in this section. In this context, solvent incineration followed by heat recovery has been classified as a treatment technology, although EPA regulations allow for its classification as a recycling technology (see Chapter 5). The solvent waste treatment technologies that are discussed below include:

Chemical Treatment
- Wet Air Oxidation
- Chemical Oxidation
- Supercritical Water Oxidation

Biological Treatment
- Activated Sludge
- Aerated Lagoon
- Trickling Filter
- Anaerobic Systems

Thermal Treatment
- Boilers
- Rotary Kilns
- Liquid Injection
- Fluidized Bed
- Fixed Hearth
- Multiple Hearth
- Infrared
- Oxygen Injection
- Plasma Arc

Chemical treatment technologies rely on liquid-phase oxidation of organic material using various oxidizers. Biological technologies rely on micro-organisms to use the organic material as a source of food. These technologies are well proven for many types of solvents. Thermal methods are generally well established except infrared, oxygen injection, and plasma arc. Reference 17 provides the names and addresses of manufacturers that produce most of the equipment or systems discussed in this section.

6.2.1 Wet Air Oxidation

Wet air oxidation treats aqueous wastestreams containing organics through contact with air at 350 to 700 degrees Fahrenheit and pressure up to 2,000 pounds per square inch. The organics are oxidized in an exothermic process by oxygen in the air. After treatment, the pressure is released and the wet air exiting the vessel is passed through a carbon adsorption column to recover any remaining organics. Wet air oxidation is used for handling wastes that are too dilute to incinerate and that are not biologically degradable. The organic concentration of the wastestreams typically handled ranges from 10,000 to 100,000 milligrams per liter.

Wet air oxidation is used mainly for treating wastewaters that contain easily oxidized nonhalogenated solvents. Typically, eighty percent of the organics present are fully oxidized. The remainder is oxidized partially - additional bio-oxidation step may be necessary. Depending on the composition and volatility of the remaining organics, much of the organic content is stripped out when the pressure is released. Some halogenated solvents can be treated by employing catalysts such as bromides, nitrites, and copper. The effect of these catalysts on subsequent waste treatment processes is unclear. More information on wet air oxidation can be obtained in reference 14 or from Zimpro, Inc. in Rothschild, Wisconsin.

6.2.2 Chemical Oxidation

Chemical oxidation commonly uses oxidants such as potassium permanganate, ozone, or hydrogen peroxide to break down or oxidize organic materials contained in wastewater. Other chemical oxidants include chlorine, chlorine dioxide, perchlorates, persulfates, or nitric acid. Wastes are treated in a batch reactor or a well mixed continuous reactor, followed by a settling or separation step. This step is required to remove insoluble oxidized materials (such as metal oxides) that precipitate during treatment.

This treatment technique is effective on aqueous wastes containing less than one percent oxidizable material. Reduction by 70 to 95 percent of ethylbenzene, chlorobenzene, and 1,2-dichlorobenzene was reported for a wastestream containing other toxic pollutants [1]. A U.S. Air Force facility (AFP 3 in Tulsa, Oklahoma) is currently designing an on-site system to pretreat wastewater containing methylene chloride paint stripper. Hydrogen peroxide, in the presence of an iron catalyst, is used to batch treat the waste. The pretreated waste can then be discharged to the plant's general industrial waste treatment system [2]. Chemical oxidation is often used in conjunction with UV irradiation which, in case of hydrogen peroxide, catalyzes its decomposition into hydroxyl radicals (powerful oxidants) [18].

When a wastestream contains a large amount of easily oxidizable material (such as phenols, aldehydes, and aromatic amines), all of the oxidant may be consumed before the less reactive materials (such as halogenated hydrocarbons, alkenes, or benzenes) are oxidized. In addition, violent reactions can occur if the concentration of easily oxidized material is too great. Therefore, chemical oxidation might not be a suitable treatment process if the composition of the waste varies with time or contains a wide variety of different pollutants. Chemical oxidation can be used as a pretreatment step for industrial wastewaters. The technology is offered by a number of vendors (Huber, Peroxidation Systems, Ultrox). Chemical oxidation can be combined with biological treatment for more effective pollutant removal.

6.2.3 Supercritical Water Oxidation

Supercritical water oxidation treatment is similar to the wet air oxidation process. The process begins by mixing oxygen into the wastewater and then using heat to raise the temperature and pressure of the waste above the supercritical point of water. Under these conditions, water acts as an excellent solvent for organics and aids in the decomposition of these wastes. During treatment, superheated steam and innocuous gases are produced. They can be used as a process steam or to produce electricity. The Modar Company of Natick, Massachusetts designed and built a system that achieved better than 99.999 percent destruction efficiency when treating highly chlorinated compounds. The company currently offers a skid-mounted design that can process 30,000 gallons of wastewater per day at 5 percent organic loading.

6.2.4 Activated Sludge

Activated sludge treatment is a two-step process. The process starts with bio-oxidation of organic waste by sludge in an aeration tank or basin for two to twenty-four hours, followed by clarification of the wastewater. Part of the sludge recovered during clarification is recycled to the aeration tank while the remainder is dewatered before disposal. Conditions in the system must be maintained within the environmental tolerances of the microorganisms for the process to function properly. Toxic effects due to variations in the types of waste being processed must be avoided. Sudden or extreme variations in the waste content can disrupt or destroy the microorganisms.

Activated sludge treatment may be used to treat dilute solvent-bearing wastes that contain less than one percent suspended solids. The process is frequently used for solvent-laden wastes from organic chemical manufacuturing, petroleum refining, paint and ink formulation, and gum and wood chemicals. Wastestreams containing halogenated organics, oils, grease, heavy metals, or viscous materials are usually not suitable for this treatment. Disadvantages associated with activated sludge treatment include the requirement to dispose of large quantities of sludge produced in the process and the potential need for air emission control. More information on the activated sludge process is contained in reference 15.

6.2.5 Aerated Lagoons

Aerated lagoons are shallow biological treatment basins maintained in an aerobic state by mechanical agitation. Instead of using microbial cultures especially selected for degrading one or more specific pollutants, lagoons contain a wide variety of naturally occuring bacteria and algae. An important disadvantage of aerated lagoons is that significant air emissions may occur due to volatilization of low-boiling solvent wastes. Current regulations require that lagoons meet the same standards as holding ponds (i.e., liners must be installed and groundwater monitored) thus raising the cost for building, permitting and maintaining a system. More information on aerated lagoons is contained in reference 15.

6.2.6 Trickling Filter

Trickling filters are similar to activated sludge systems except that their design allows higher biological degradation rates. By filling the aeration basin with rocks or artificial media to a depth ranging from three to fifteen feet, the surface area available for microbial growth is significantly increased. To provide for even distribution of the waste over the rocks or media, rotary distribution arms or fixed sprays are used. Upflowing air is introduced into the system by an underdrain which also conveys effluent to the clarifier. Retention times for treatment may be as short as one hour.

The trickling filter system is suitable for treatment or pretreatment of dilute aqueous wastes that contain less than one percent suspended solids. Degradation of the organics may not be complete because of the short retention time. Extreme fluctuations in wastewater flow or hydraulic loading are not tolerated by the system, because they remove bacteria from the surface of the media. Use of the trickling filter for the degradation of toluene has been reported [1]. More information on trickling filters is provided in reference 15.

6.2.7 Anaerobic Treatment

Anaerobic treatment is conducted in a closed vessel without agitation at temperatures ranging from 31 to 60 degrees Centigrade. Anaerobic bacteria digest simple organic and nitrogen-containing compounds by a series of oxidation-reduction reactions that do not require oxygen. During digestion, large quantities of methane gas are produced. The gas can be used as a source of fuel. Retention times can be as long as two weeks or more.

Anerobic treatment offers several advantages over aerobic treatment. Anaerobic treatment requires only about ten percent as much nutrient in the wastestream, produces one-tenth the sludge requiring disposal, and produces methane gas [3]. The process is also suitable for wastewater containing higher suspended solids content than activated sludge (five to seven percent versus less than one percent). More information on the anaerobic sludge process is available in references 3 and 15.

6.2.8 Boilers

Boilers can be used to destroy solvent waste by using the waste as a supplement to fossil fuel. It was reported that 4,934 industrial boilers in the United States burn waste-derived fuel [1]. The process usually consists of blending the waste material with fuel and injecting the mixture into the modified boiler burner. Care must be taken to assure that the heating value of the resulting fuel mixture is adequate to maintain proper combustion and that the composition of the waste remains fairly constant over time. Stratification of waste in storage tanks is quite common and can lead to a too-lean or too-rich fuel mixture being injected into the burner [12]. When this happens, incomplete combustion can occur.

Another concern is that the solvent waste/fuel mixture must be free of solids or ash. Solids can lead to plugging of the burner nozzles or a build-up of deposits inside the unit. In addition, solids can cause an increase in particulate emissions and require the use of air pollution control equipment. Depending on their compositions, both the captured flue dust and the ash removed from the system may require encapsulation before land disposal. Excess chlorine in the waste can cause severe corrosion of refractory and metal parts. Therefore, it is best to limit chlorine content to 3 percent or less. If chlorine is present, hydrochloric acid scrubbers may have to be installed.

At present, EPA allows hazardous wastes having a heating value greater than 3,000 BTUs per pound to be burned as supplementary fuel in on-site boilers. Toluene, xylene, acetone, ethanol, butanol, isopropyl alcohol, naphtha, methyl ethyl ketone, and esters are burned for heat recovery at the Burlington Furniture Company in Lexington, North Carolina [6]. Spent lacquer thinner is burned at the Bowling Company in Mt. Oliver, North Carolina. Nashua Corporation, in Nashua, New Hampshire, reported on their efforts to convert their existing boiler system to one that could incinerate solvent waste containing iron oxide particles [7]. Recommended modifications include redesign of the burner and installation of a settling tank and filter press to remove solid particles (this was favored over the installation of dust collection equipment on the boiler). The payback period for the system exceeds five years, but the project was justified based on the elimination of risk associated with off-site disposal.

Solvent-laden air streams may be incinerated. Methyl ethyl ketone vapors are burned at the Rexham Corporation in Matthews, North Carolina [6]. At the 3M Company in Minneapolis, Minnesota, solvent-laden air (predominantly heptanes) is burned to reduce the overall amount of fuel required for their boiler [4].

6.2.9 Rotary Kilns

Rotary kilns consist of a cylindrical, refractory-lined chamber tilted several degrees off the horizon. Rotation of the chamber mixes the waste and combustion air. The tilt induces the solids to flow towards the outlet where they are continuously removed. Gaseous combustion products pass through an afterburner (sometimes a liquid injection system) and then through scrubbers. Residence times range from seconds for gases to hours for solids. Temperatures typically reach 3000 degrees Fahrenheit. Waste handling capacity ranges from one to eight tons per hour for conventionally sized units. Figure 6.1 presents a process flow diagram for a typical rotary kiln incineration system [10].

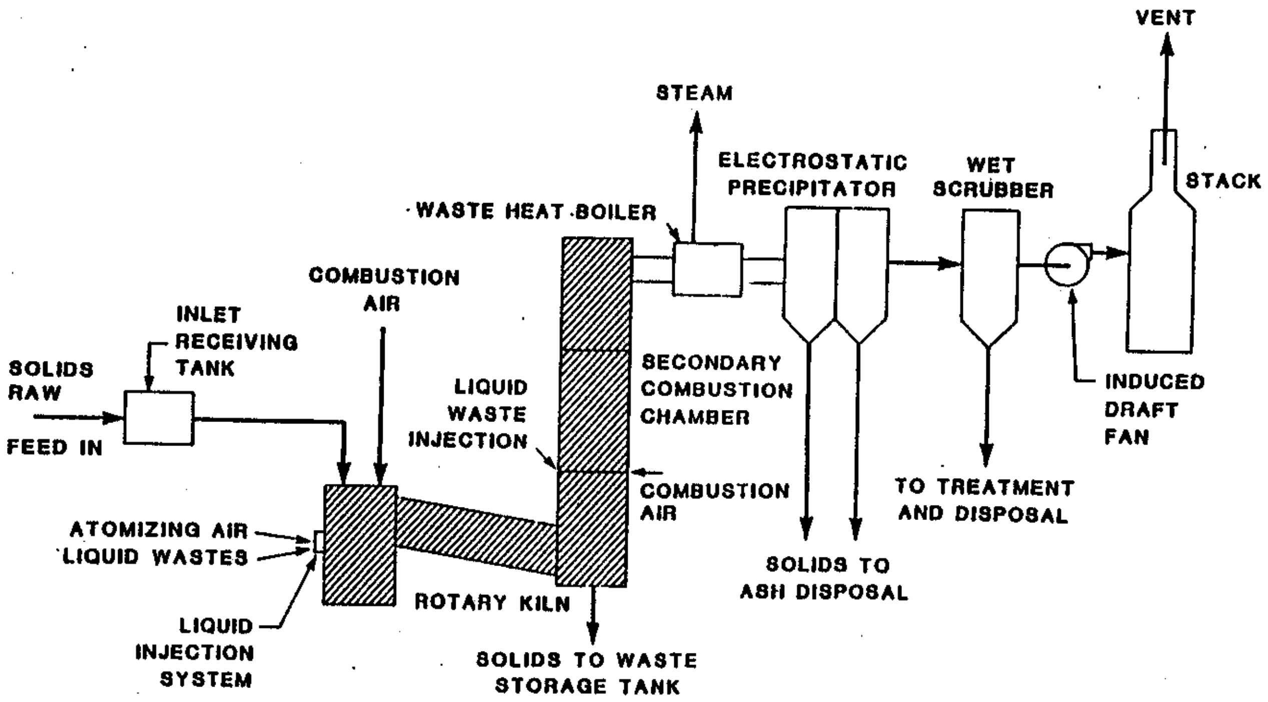
Rotary kilns can efficiently burn viscous still bottoms, waste solvents, and solid material. The wide flexibility of the feed mechanism design allows the unit to process liquids and solids independently or in combination. Air pollution control equipment is a must because airborne particles may be carried out of the kiln before complete combustion can occur. Rotary kilns are not recommended for any wastes that contain heavy metals or have a high inorganic content.

6.2.10 Liquid Injection

Liquid injection incinerators consist of a refractory-lined combustion chamber and a series of nozzles. The nozzles atomize the waste and fuel as

FIGURE 6.1

ROTARY KILN INCINERATOR



Reprinted from "Supplemental Report on the Technical Assesment of Treatment Alternatives for Waste Solvents", ENGINEERING-SCIENCE INC., prepared for Office of Solid Waste, EPA, Sept. 1984.

they are injected into the chamber. Viscous wastes are blended with more free flowing wastes before injection to improve the ease of pumping and the combustion properties of the waste. Viscous wastes are difficult to pump, but usually have high heats of combustion. Free flowing wastes are easy to pump but can have very low heats of combustion. Combustion residence times typically vary from 0.5 to 2.0 seconds and the temperatures range from 1200 to 2400 degrees Fahrenheit. Figure 6.2 presents a process flow diagram for a typical liquid injection incineration system [10].

Liquid injection systems can incinerate a wide variety of liquid wastes including phenols, PCB's, still and reactor bottoms, solvents, and polymer wastes. Usually an incinerator is geared to handle a specific wastestream to maintain a high thermal destruction efficiency. Many units are designed with electrostatic precipitators and scrubbers. This design allows chlorinated solvents to be handled. Units have been designed to process up to 10 tons of waste per hour. Listed below are several companies located in California that are currently operating liquid injection incinerators [19]. Also included, is the name of the manufacturer and the types of waste being burned.

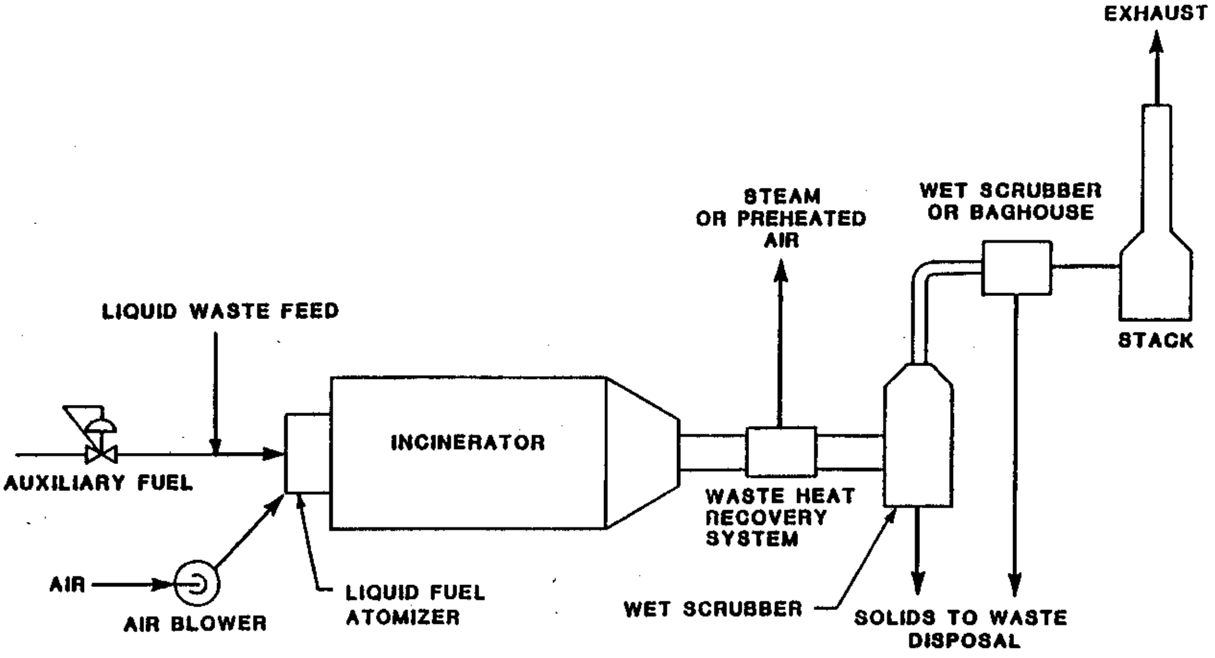
COMPANY	MANUFACTURER	WASTE TYPES
Alpha Resin Perris, Ca.	Hirt Combustion	Aldehyde vapor and aq. phenol liquid
Ashland Chemical Los Angeles, Ca.	Hirt Combustion	Resin rinse water
Cargill Lynwood, Ca.	Hirt Combustion	Resin rinse water
Chevron - Ortho Richmond, Ca.	Thorpe Custom	90 % HC in water
IT Vine Hill Martinez, Ca.	Trane Thermal	Organic liquids/ vapors including chlorinated HC
Koppers Chemicals Oxnard, Ca.	Hirt Combustion	5 % glycols in water and vapor
PPG Industries Torrance, Ca.	Hirt Combustion	Alcohol and ketone vapors only
Shell Martinez, Ca.	Alcorn	1 % HC liquid and 2 % organic sludge

6.2.11 Fluidized Bed

Fluidized bed incinerators consist of a refractory-lined vessel containing an inert granular material. Combustion air is blown through the granular material. The combustion gases rise upward through the bed maintaining particles in suspension. The gas in excess of the flow required for incipient fluidization (minimum particle separation) passes through the bed in the form

FIGURE 6.2

LIQUID INJECTION INCINERATOR



Reprinted from "Supplemental Report on the Technical Assesment of Treatment Alternatives for Waste Solvents", ENGINEERING-SCIENCE INC., prepared for Office of Solid Waste, EPA, Sept. 1984.

of bubbles. Mixing occurs as bubbles move through the liquid-like suspended particle (emulsion) phase. An auxilary heater is used to supply heat to the bed to maintain the desired operating temperature. Waste enters the reactor and undergoes thermal oxidation under the high turbulence and uniform temperature conditions of the fluidized bed. Solid combustible material remains in the bed until the particles become so small and light that they are carried out of the reactor with the flue gas. These particles are then removed in the air pollution control equipment, along with fines that are emitted due to bed material attrition. Lime or limestone is often added to the bed material to neutralize any acidic gases that may form. Figure 6.3 presents a process flow diagram for a typical fluidized bed incineration system [10].

Common applications for fluidized bed incinerators are in the petroleum, power generation, paper, and sewage disposal industries. In recent years, the circulating fluid bed design has been extensively tested for hazardous waste destruction. In this design, the combustion gas velocities are higher than in conventional, stationary fluid beds. This results in considerable entrainment of bed particles into the moving stream of gas. The particles are de-entrained in a cyclone and routed back to the bed. Based on pilot scale tests, better than 99.999+ percent destruction efficiency is obtained with chlorinated organic wastes [16]. Advantages over the conventional design include lower capital and operating costs, higher thermal efficiencies, and better response to upsets. This technology is available commercially from GAT in San Diego, California.

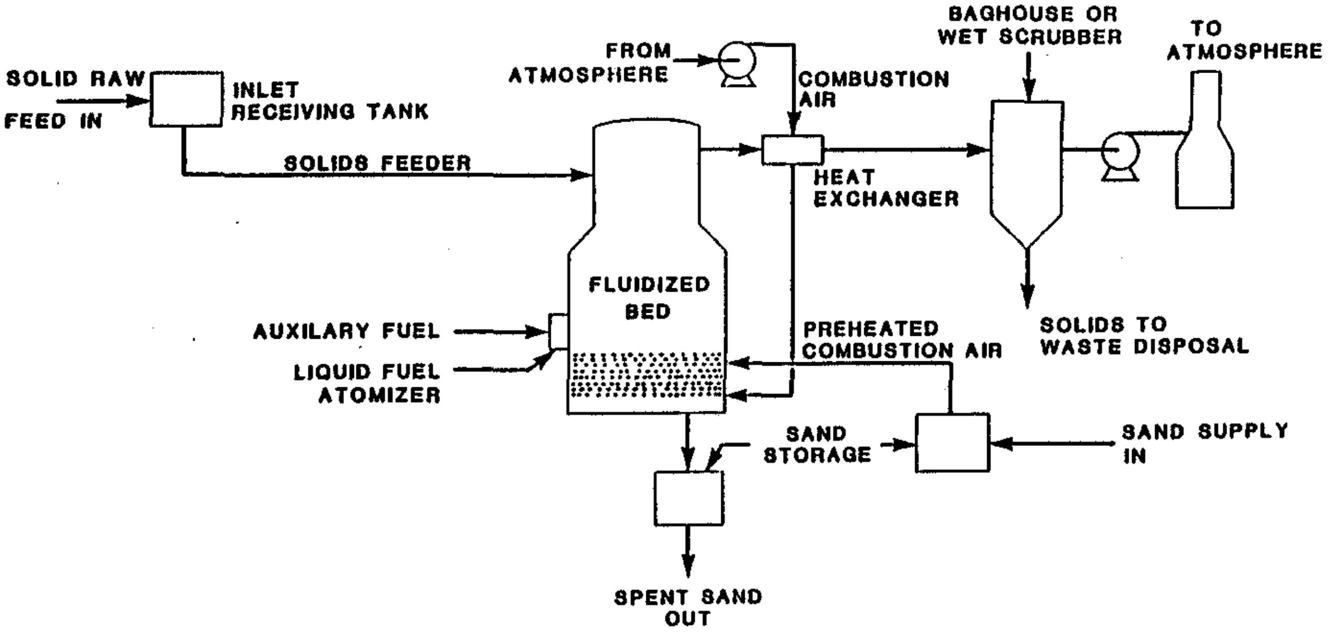
6.2.12 Fixed Hearth Incineration

Fixed hearth incineration systems usually consist of a single steel shell lined with a refractory material. The overall design of the unit is simple and the units are seldom custom designed. Incineration of the waste takes place in stages in the primary and secondary combustion chambers. The first chamber operates in a starved air mode and at temperatures ranging from 600 to 1,600 degrees Fahrenheit. Vortex-type burners are used to inject liquid wastes into the primary chamber. Solid wastes are fed onto grates located above the chamber. Gaseous combustion products travel upward into the secondary chamber where more air is added to ensure complete combustion. Solid combustion products (ash) fall through the grate and are discharged from below the unit. To ensure complete incineration, the secondary combustion chamber operates at a temperature range of 1,200 to 1,800 degrees Fahrenheit. Figure 6.4 presents a process flow diagram for a typical fixed hearth incineration system [10].

Mixed wastes, including waste solvents and combustible solids, can be handled by the fixed hearth incinerator. Based on available designs, most units are designed to process feed rates of less than one ton per hour. Most units are designed without any air pollution control equipment. Fixed hearth incinerators have only limited ability to destroy more stable compounds such as chlorinated solvents. Their use tends to be limited to nonhalogenated solvents. Listed below are several companies located in California that are currently operating a fixed hearth incinerator. Also included is the name of the manufacturer and the types of waste being burned [19].

FIGURE 6.3

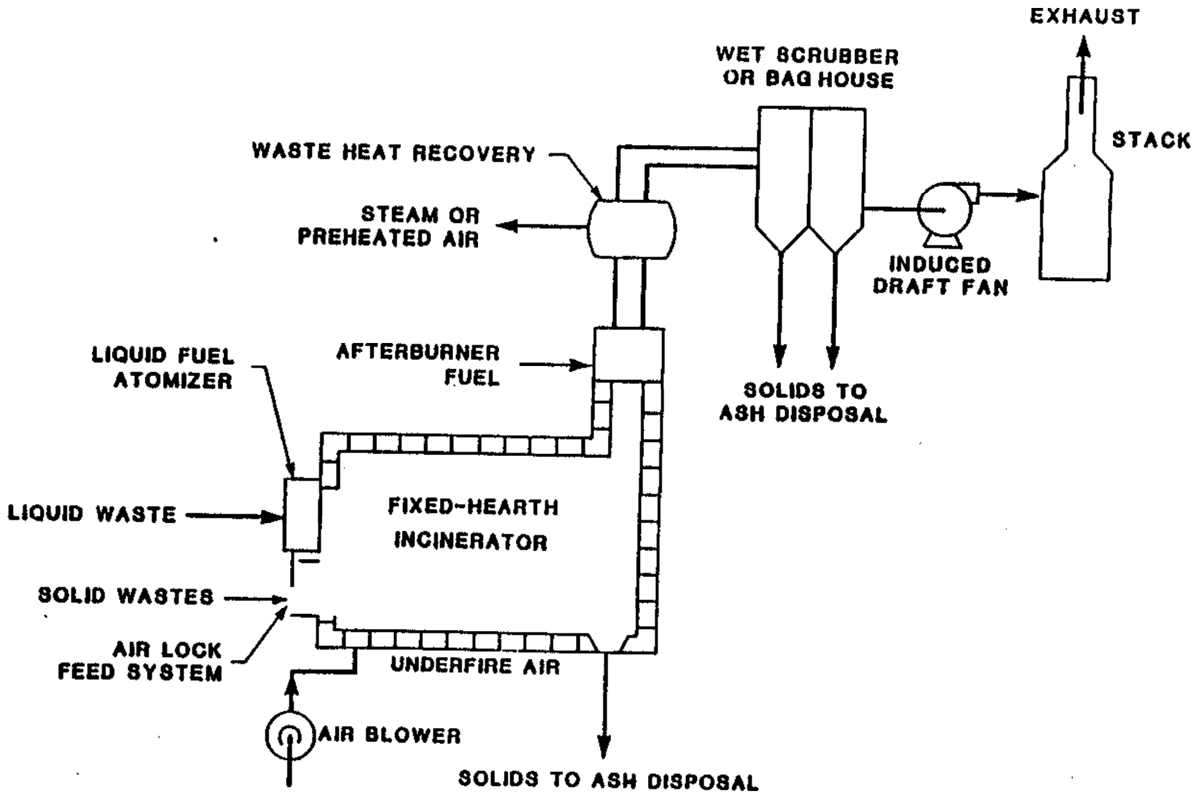
FLUIDIZED BED INCINERATOR



Reprinted from "Supplemental Report on the Technical Assessment of Treatment Alternatives for Waste Solvents", ENGINEERING INC., prepared for Office of Solid Waste, EPA, Sept. 1984.

FIGURE 6.4

FIXED-HEARTH INCINERATOR



Reprinted from "Supplemental Report on the Technical Assessment of Treatment Alternatives for Waste Solvents", ENGINEERING INC., prepared for Office of Solid Waste, EPA, Sept. 1984.

COMPANY	MANUFACTURER	WASTE TYPES
American Environmental Sacramento, Ca.	Therm Tech Corp.	Infectious waste
Rohm & Haas Redwood City, Ca.	North American	Vinyl chloride vapor only
Lawrence Livermore Laboratory Livermore, Ca.	Environmental Control Products	Liquid solvents and solid pathologicals

6.2.13 Multiple Hearth Incineration

Multiple hearth incineration systems usually consist of a steel shell lined with refractory material, several refractory hearths situated one above the other, a central shaft that rotates, a series of rabble arms with plows for each hearth, fuel burners mounted on the walls, an ash removal system, and a waste feeding system. Waste enters as a sludge at the top and is pushed across the various levels by the rabble arms. As the waste passes to the hearths below, it is incinerated and broken down. Finally, it is discharged as ash at the bottom and disposed. During the process, waste grease and tar may be injected through side ports to improve combustion. Figure 6.5 presents a process flow diagram for a typical multiple hearth incineration system [10].

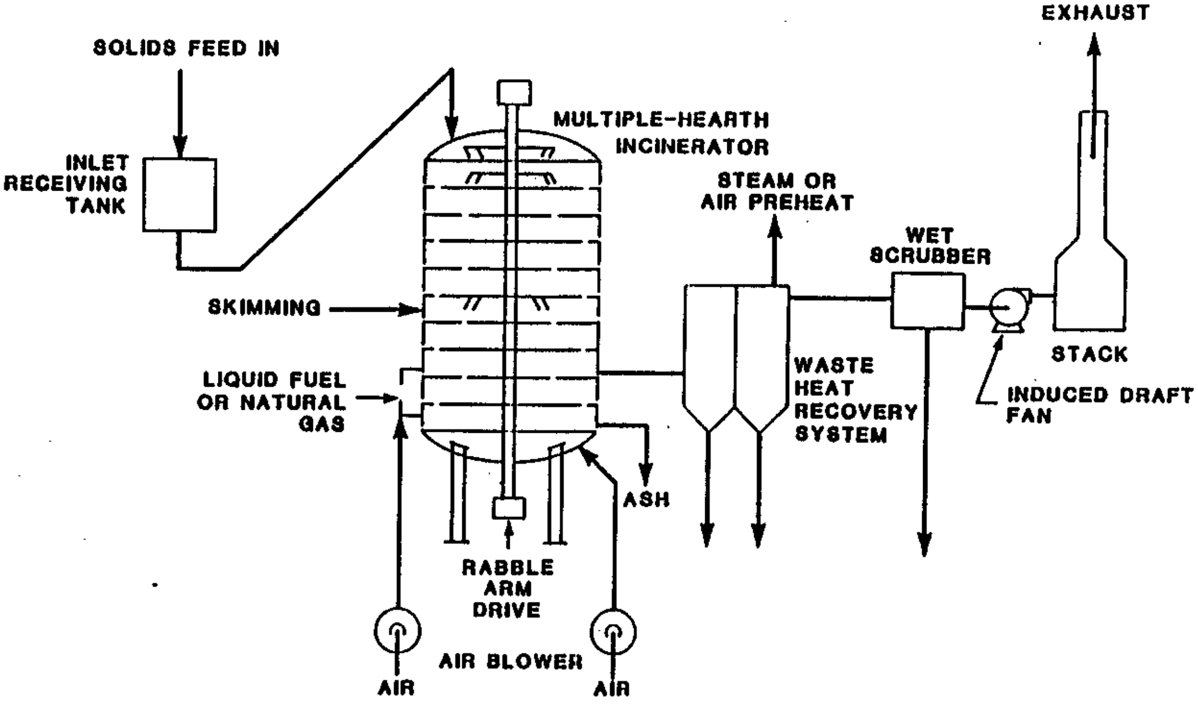
Multiple hearth incinerators have been used to dispose of sewage, industrial sludges, tars, solids, gases, and liquid combustable wastes. Highly contaminated solvents and residues from solvent reclamation can be blended together and used as fuel. Principle advantages of the unit are: residence times are extremely long (leads to efficient destruction of less volatile material); large quantities of water can be evaporated (hence, dilute streams can be handled); fuel efficiency is high; and a wide variety of wastes can be handled. Disadvantages include potential hot and cold spots inside the unit. This can lead to incomplete combustion and can subject moving parts to combustion gases, thereby, increasing maintenance costs. Multiple hearth incineration is not well-suited for wastes containing fusible ash, wastes requiring high temperatures for destruction, or irregular bulky solids [8,10].

6.2.14 Infrared Incineration

Infrared incineration is a relatively new technology for pyrolysis and subsequent oxidation of hazardous wastes. In a typical system, a woven metal conveyor belt transports the waste under the infrared heating elements. The elements are equally spaced and can be located along the entire length of the unit. At the end of the unit, ash falls into a collection hopper for disposal. The off-gases are sent to a burner for complete combustion. Advantages of this system include controlled residence time by varying belt speed, controlled temperature by varying electrical input to the heating units, and high thermal efficiency. Other advantages include a wide turndown range, versatility, rapid start-up and shut-down, and continuous or intermittent operation. Portable or fixed systems, designed to handle loads of 10 pounds per hour up to 100 tons per day, are available from Shirco Infrared Systems in Dallas, Texas.

FIGURE 6.5

MULTIPLE-HEARTH INCINERATOR



Reprinted from "Supplemental Report on the Technical Assessment of Treatment Alternatives for Waste Solvents", ENGINEERING-SCIENCE Inc., prepared for Office of Solid Waste, EPA, Sept. 1984.

6.2.15 Oxygen Incineration

Oxygen incineration uses pure oxygen instead of air to achieve a higher destruction rate. In the past, use of oxygen injection was plagued by problems associated with improper mixing of fuel and oxygen, and excessive temperatures. Union Carbide designed the Linde "A" Burner System, an oxygen injection burner that solves both of these problems [11]. Advantages of this technique include greater throughput for retrofitted incinerators; more effective and less costly gas cleaning (oxygen produces less flue gas, which means that existing scrubber systems would be oversized); lower fuel consumption due to less loss of heat in the flue gas; and higher levels of destruction efficiency. These advantages are offset by the costs to purchase, store, and handle liquid oxygen on-site. Oxygen incineration is claimed to be cost competitive with conventional air incineration.

6.2.16 Plasma Arc Incineration

Plasma arc incineration utilizes a plasma generator to pyrolize hazardous waste. By passing an intense electrical current through air at low pressure, a thermal plasma is created with temperatures ranging from 10,000 to 20,000 degrees Centigrade. Upon being injected into the plasma, the waste molecules quickly disintegrate into individual atoms. After leaving the unit and cooling, these atoms recombine to form hydrogen, carbon monoxide, nitrogen, hydrogen chloride, and particulate carbon. The exhaust is scrubbed with caustic to remove hydrogen chloride and particulate carbon, and is flared to convert the hydrogen and carbon monoxide to water and carbon dioxide. A portable demonstration unit, built by Pyrolysis Systems Inc. using a Westinghouse Plasma Systems plasma torch, has achieved 99.9999+ percent destruction efficiency on MEK/MeOH solutions containing either 43 percent by weight carbon tetrachloride or 14 percent by weight polychlorinated biphenyls [12].

6.3 Summary

Many treatment options for solvent-bearing waste are currently available. For environmental and cost reasons, the waste volume destined for treatment should first be minimized through source reduction and recycling alternatives.

REFERENCES FOR CHAPTER 6

1. USEPA. "Background Document for Solvents to support 40 CFR 268, Land Disposal Restrictions," Vol. II, Analysis of Treatment and Recycling Technologies for Solvents and Determination of Best Available Demonstrated Technologies (BDAT), Revised, Washington, D.C.: USEPA, 1986.

2. Hazelwood, D.L., B.J Burgher, and C. Alford. "Waste Minimization at Air Force GOCO Facilities." National Conference on Hazardous Wastes and Hazardous Materials, Atlanta, Georgia, March 4-6, 1986.

3. Parkin, G.F. and R.E. Speece. "Anaerobic Biological Waste Treatment." Chemical Engineering Progress, December 1984.

4. Porter, J.W. et al. "Background Document for Solvents to Support 40 CFR, Part 268; Land Disposal Restrictions," Vol. II, February 1986.

5. Bateman, G.E., S.J. Zoss, and G.A. Hohenstein. "Organic Solvent Recovery: A Cost Savings and Energy Conservation Approach to Recovering Waste Streams." Industrial Waste, November-December 1982, pp. 8-10.

6. Kohl, J., P. Moses, and B. Triplett. Managing and Recycling Solvents: North Carolina Practices, Facilities, and Regulations, 1984. Raleigh: North Carolina State University, Industrial Extension Service, 1984.

7. Driessen, A.W. and B.W. Doyle. "Design of a Specific System for Waste Solvent Combustion." Paper presented to the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota, June 22-27, 1986.

8. California Governor's Office of Appropriate Technology, Toxic Waste Assessment Group. Alternatives to the Land Disposal of Hazardous Wastes - An Assessment for California, Sacramento: Governor's Office of Appropriate Technology, 1981.

9. Schwartz, S.I. et al. Managing the Electronic Industry's Hazardous Waste: Technology and Economics of Alternatives to Land Disposal, Davis: University of California, Division of Environmental Studies, 1985.

10. Engineering Science,Inc. Final Report: Supplemental Report on the Technology Assessment of Treatment Alternatives for Waste Solvents, Washington, D.C.: USEPA, Office of Solid Waste, Waste Treatment Branch, 1985.

11. Union Carbide, Inc. Materials distributed at the Engineering Foundation Conference on Alternative Technologies for Hazardous Waste Management, Henniker, New Hampshire, June 15-20, 1986.

12. Barton, T.G. et al. "Plasma Arc Destruction of Hazardous Waste." Paper presented at the Engineering Foundation Conference on Alternative Technologies for Hazardous Wastes, Henniker, New Hampshire, June 15-20, 1986.

13. Santoleri, J.J. "Design and Operating Problems of Hazardous Waste Incinerators." Environmental Progress, Vol. 4, No. 4, November 1985.

14. Dietrich, M.J., T.L. Randall, and P.J. Canney. "Wet Air Oxidation of Hazardous Organics in Wastewater." Environmental Progress, Vol. 4, No. 3. August 1985.

15. Eckenfelder, W., J. Patoczka, and A. Watkin. "Wastewater Treatment." Chemical Engineering, September 2, 1985.

16. Rickman, W., N. Holder,and D. Young. "Circulating Bed Incineration of Hazardous Wastes." Chemical Engineering Progress, March 1985.

17. "Chemical Engineering Equipment Buyers Guide, 1986", a McGraw-Hill publication.

18. Hager, D.G., and C.E. Smith. The UV-Hydrogen Peroxide Process: An Emerging Technology for Groundwater Treatment, presented at Hazmat West 85, Long Beach, CA: December, 1985.

19. California Department of Health Services, Alternative Technology for Recycling and Treatment of Hazardous Waste, 3rd Biennial Report, Sacramento, CA: 1986.

20. "Techniques for Treating Hazardous Wastes to Remove Volatile Organic Compounds", Journal of the Air Pollution Control Association, August 1985.

CHAPTER 7

REGULATORY PERSPECTIVE

Several types of regulations and statutes govern the management of solvents and solvent waste. These include hazardous waste, air pollution, water pollution, occupational health, and transportation regulations. Waste managers should be familiar with each set of requirements. This chapter presents a general overview of the state and federal hazardous waste regulatory programs. Other regulations and statutes generally applicable to waste disposal and generation practices are also presented.

The specific requirements for a facility handling hazardous waste depend on the location of the facility, type and amount of emissions and effluents, and the nature of the activities at the facility. Table 7.1 provides a summary of regulations and permit requirements for solvent waste generation, minimization, and disposal practices.

This chapter provides only a summary of the relevant regulations. Persons involved in regulated activities should become familiar with the regulations and statutes. If needed, additional help can be obtained from the agencies listed in Table 7.2.

7.1 Federal Waste Minimization Requirements

The federal hazardous and solid waste law is known as the Resource Conservation and Recovery Act (RCRA). The regulations implementing RCRA can be found in Title 40 of the Code of Federal Regulations. In 1984, Congress passed a sweeping set of amendments to RCRA known as the Hazardous and Solid Waste Amendments of 1984 (HSWA). These will have significant implications for waste minimization.

In general, California and other states administer the federal hazardous waste laws and regulations in cooperation with EPA. At the time of this writing, EPA is in the process of transferring responsibility for the hazardous waste programs to the California Department of Health Services and the California Water Resources Control Board. California has its own hazardous waste laws and regulations which add detail to, and often extend, the federal requirements.

7.1.1 Manifest Certification and Biennial Report

Almost all hazardous waste shipments must be accompanied by a manifest. The HSWA require that the manifest include a waste minimization certification. The generator must certify "that I have a program in place to reduce the volume and toxicity of waste generated to the degree I have determined to be economically practicable." This language appears as Item 16 on the EPA uniform hazardous waste manifest. The generator must also certify that he or she has chosen the safest method of treatment or disposal.

TABLE 7.1

SUMMARY OF GENERAL REGULATORY REQUIREMENTS

ACTIVITY	REQUIREMENT	AGENCY
	Hazardous Waste	
Waste Generation	Shipments of waste must be accompanied by a manifest; agency must be notified.	DHS
	Prepare biennial report concerning the volume of waste generated.	DHS/EPA
	If wastes are temporarily stored on site, the generator must comply with handling procedures, personnel requirements, etc.	DHS, county hazardous material regulators
	Generators disposing of "recyclable wastes" may be asked to provide justification for not recycling.	DHS
Process Modification; Material Substitution	If the new process involves treatment of a hazardous waste, a treatment, storage and disposal (TSD) permit may be necessary.	DHS
	Process must comply with fire codes and occupational health requirements.	Local fire department, Cal/OSHA
On-site Treatment	In general, a treatment, storage and disposal permit is required. DHS may grant variances for activities adequately regulated by other agencies.	DHS
On-site Recycling	Same as above; however, some on-site recycling activities are categorically exempt from permit requirements.	DHS
Off-site Recycling	Commercial recycling activities require a TSD permit.	DHS
	Commercial recyclers must submit an annual report.	DHS
	Some resource recovery facilities are eligible for Series 'A', 'B', or 'C' resource recovery permits in lieu of a TSD permit.	DHS

TABLE 7.1 (continued)

SUMMARY OF GENERAL REGULATORY REQUIREMENTS

ACTIVITY	REQUIREMENT	AGENCY
	Hazardous Waste	
Disposal	In California, several classes of hazardous waste are restricted from land disposal.	DHS
	A national land disposal restriction program is being implemented.	EPA
	Disposal facilities must have a TSD permit and comply with technical and financial regulations.	DHS
	Air Pollution	
Industrial	All devices emitting air pollutants must be permitted or exempted.	Local APCD/AQMD
	If changes in equipment or procedures result in an increase of any pollutant above a specified level, a permit is required.	Local APCD/AQMD
	If certain designated toxic air contaminants are emitted, the generator must comply with rules established under the toxic air contaminant program.	Local APCD/AQMD
	If there is an increase in an "attainment pollutant" by a significant amount (generally 25 to 40 tons/yr), a PSD permit may be necessary.	EPA Region IX
	Water Pollution	
Industrial	Discharge of industrial waste to sewer requires a sewer permit.	Local sewer agency
	Discharge of waste to land requires a discharge permit.	Regional Water Quality Control Board
	Discharge of waste to public waters requires an NPDES permit.	Regional Water Quality Control Board

TABLE 7.2

GENERAL INFORMATION SOURCES

Agency	Telephone Number
1. U.S. EPA RCRA Hotline	800-424-9346 800-231-3075
2. Department of Health Services, Toxics Division, Regional Offices	
Berkeley	415-540-2043
Los Angeles	213-620-2380
Sacramento	916-739-3145
3. Air Quality Management Districts *	
Bay Area Air Quality Management District	415-771-6000
South Coast Air Quality Management District	818-572-6212 or 818-572-6153
4. Regional Water Quality Control Boards **	
Los Angeles Region	213-620-4460
Oakland Region	415-464-1255
Palm Desert Region	619-346-7491
Sacramento Region	916-445-0270
San Diego Region	619-265-5114
San Luis Obispo Region	805-549-3147
Santa Ana Region	714-782-4130

TABLE 7.2 (Continued)

GENERAL INFORMATION SOURCES

Agency	Number
4. Regional Water Quality Control Boards (Continued)	
Santa Rosa Region	707-576-2220
South Lake Tahoe Region	916-544-3481
5. Office of Permit Assistance	916-322-4245

---

* Please see Appendix E for a listing of other air pollution control districts.
**Refer to Table 7.5 for additional information.

Generators are required to submit a report, at least once every two years, describing their efforts to minimize waste generation. The biennial report must include: (1) a description of the efforts undertaken during the year to reduce the volume and toxicity of waste actually produced for that year, and (2) a description of the changes in volume and toxicity achieved in the past year compared with previous years.

7.1.2 TSD Permit Certification

Hazardous waste treatment, storage, and disposal (TSD) permits issued on or after September 1, 1985 require that the permittee annually certify that a waste minimization program is in place. The program must "reduce the volume and toxicity of hazardous waste that (the permittee) generates to the degree determined by the permittee to be economically practicable, and the proposed method of treatment, storage, or disposal is that practicable method currently available to the permittee which minimizes the present and future threat to human health and the environment." Determinations of "economically practicable" and "practicable method currently available" are to be made by the generator. In response to inquiries, EPA has affirmed that participation in waste exchange programs and recycling in general qualifies as waste minimization.

7.1.3 EPA's Definition of Solid Waste

EPA published a revised version of the definition of solid waste in the January 4, 1985, Federal Register. The revised definition introduces new tests by which a substance may be deemed to be: (1) a solid waste, and (2) legitimately recycled. The previous definition exempted from regulation certain wastes that are recycled in any manner. The current definition now asserts that RCRA jurisdiction is determined by the type of material and the method of recycling.

7.1.4 Land Disposal Restrictions

The HSWA create a comprehensive national land disposal restriction program. Under the federal program, restricted wastes must be treated before disposal. At the time of this writing, EPA is preparing regulations that will specify minimum treatment standards. Congress included in HSWA an implementation schedule of land disposal restrictions for specific groups of hazardous wastes. Solvent wastes are among the first wastes to be subject to the land disposal restrictions. Congress also included a 'hammer provision'; the disposal bans take effect even if EPA does not issue regulations. EPA does, however, have the perogative to delay implementation of any phase of the program for up to two years. EPA can also issue individual exemptions of up to four years for companies making a good faith effort to acquire treatment technology in compliance with the land disposal restrictions.

A wide variety of solvent wastes are to be restricted from land disposal beginning November 8, 1986. The solvent wastes included in this phase of the restriction program are listed in Table 7.3. Other solvent wastes are scheduled to be restricted later in the program.

The federal land disposal restriction ban does not affect deep well injection of hazardous wastes until 1988.

TABLE 7.3

SOLVENT-CONTAINING HAZARDOUS WASTES FOR WHICH LAND DISPOSAL RESTRICTIONS WERE PROPOSED BY EPA[a]

Waste code	Description
F001	The following spent halogenated solvents used in degreasing: tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; spent solvent mixtures/blends used in degreasing containing, before use, a total of 10 percent or more (by volume) of one or more of the above halogen solvents or those solvents listed in F002, F004, and F005; and still bottom from the recovery of these spent solvents and spent solvent mixtures.
F002	The following spent halogenated solvents: tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, and trichlorofluoromethane; all spent solvent mixture/blends containing before a total of 10 percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F001, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F003	The following spent nonhalogenated solvents: xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, methyl isobutyl ketone, n-butyl alcoho cyclohexanone, and methanol; all spent solvent mixtures/blends containing solely the above spent nonhalogenated solvents; and all spent solvent mixtures/blends containing, before use, one or more of the above nonhalogen solvents, and a total of 10 percent or more (by volume) of one or more of t solvents listed in F001, F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F004	The following spent nonhalogenated solvents: cresols and cresylic acid and nitrobenzene; all spent solvent mixtures/blends containing, before use, a total of 10 percent or more (by volume) of one or more of the above nonhalogenated solvents or those solvents listed in F001, F002, and F005; a still bottoms from the recovery of these spent solvents and spent solvent mixtures.

TABLE 7.3 (continued)

SOLVENT-CONTAINING HAZARDOUS WASTES FOR WHICH LAND DISPOSAL RESTRICTIONS WERE PROPOSED BY EPA[a]

Waste code	Description
F005	The following spent nonhalogenated solvents: toluene, methyl ethyl ketone, carbon disulfide, isobutanol, and pyridine; all spent solvent mixtures/blends containing, before use, a total of 10 percent or more (by volume) of one or more of the above nonhalogenated solvents or those solvents listed in F001, F002, and F004; and still bottoms from the recovery of these spent solvents and solvent mixtures.

---

[a] January 14, 1986 at 51 FR 1763; 40 CFR 268.30(b).

7.1.5 Other Requirements

The HSWA also establish a large number of minimum standards for disposal technologies. These provisions may lead to further increases in the price of disposal and provide additional incentives for alternative waste reduction technologies.

7.2 California Hazardous Waste Reduction Regulations

California's Hazardous Waste Control Law is promulgated in Division 20 of the Health and Safety Code, beginning with Section 25100. This law prescribes the regulation of hazardous waste by DHS. It contains many of the state's standards for hazardous waste management. The detailed regulations, written by the Department of Health Services, are in the California Administrative Code, Title 22, Division 4, Chapter 30. The regulations are available from the State of California; DOCUMENTS SECTION; P.O. Box 1015; North Highlands, CA 95660. The law can be purchased from legal publishers and may also be found at law libraries.

7.2.1 Fees for Land Disposal of Hazardous Waste

In 1986, a new series of fees for hazardous waste management was established in California. Three classes of fees apply: facility fees, disposal fees, and generator fees. This system was designed in part to provide hazardous waste generators with incentives for choosing treatment instead of land disposal.

7.2.2 California's Land Disposal Restriction Program

Following a 1981 executive order from the Governor, California established the nation's first hazardous waste land disposal restriction program. The regulations implementing the law can be found in Article 15 of Chapter 30, Division 4, Title 22 of the California Administrative Code. DHS established a schedule by which they would restrict specified wastes from land disposal. No wastes were restricted until the Department made a finding that adequate treatment and recycling capacity existed. The wastes that have been restricted from land disposal in California are listed below. The numbers in parentheses give the concentration at or above which wastes are not allowed to be land disposed.

<u>Liquid Hazardous Wastes Restricted from Land Disposal</u>

1. Free cyanides (1,000 ppm)

2. Toxic metal wastes:

Arsenic	(500 ppm)	Cadmium	(100 ppm)
Chromium	(500 ppm)	Lead	(500 ppm)
Mercury	(20 ppm)	Nickel	(134 ppm)
Selenium	(100 ppm)	Thallium	(130 ppm)

3. Polychlorinated biphenyls (PCBs) (50 ppm)

4. Acid waste (below pH 2.0)

5. Wastes containing halogenated organics (1,000 ppm)

A land disposal ban for solid hazardous wastes containing halogenated organic compounds was scheduled to go into effect July 1, 1985. This restriction was postponed until July 8, 1987 due to the lack of available treatment capacity in the state.

Under the California restriction program, land disposal includes landfills, surface impoundments, and land treatment. To qualify, the impoundment has to be cleaned annually. When the land ban was first implemented, restricted wastes could be treated in a surface impoundment. However, the Toxic Pits Cleanup Act of 1984 eliminated this practice. In 1986, only one commercial facility, Chemical Waste Management, Kettleman Hills, received a variance extending the use of surface impoundments for treatment until 1987.

SB 509 was signed into law in 1985. This bill mandates that after January 1, 1988, hazardous wastes containing greater than 3,000 BTU must be incinerated or treated. After January 1, 1990, the requirement will apply to wastes containing specified percentages of volatile organic compounds. The percentages are to be established by DHS.

The California land disposal restriction program will be expanded in concert with the federal program.

7.2.3 Letters of Inquiry Regarding Disposal of Recyclable Waste

California's hazardous waste regulations (Sections 66763 and 66796) require that a generator of wastestreams listed as recyclable (see Table 7.4) by DHS attempt to recycle those wastes. DHS staff routinely check shipment manifests to determine if any of the specified wastes are being disposed of on land. If so, the Department contacts the generator and inquires why the wastes are not being recycled. The regulations stipulate that the generator must respond in thirty days or less. The generator's justification must include a summary of efforts made to find a use for the waste, and technological and economic reasons for not having recycled the waste. The justification must address:

- Available amount and storability of the waste;
- Properties of the waste which might affect its recyclability;
- Concentration or recoverability of the chemical components and other factors which may determine the feasibility of recycling;
- Processing required in recycling the waste, and the availability and cost of suitable processing technology and facilities; and

TABLE 7.4

LIST OF RECYCLABLE WASTES

- Commercial chemical products including unused laboratory grade products.
- Solvents, used or contaminated including:
  - Halogenated solvents such as trichloroethane, perchloroethylene, methylene dichloride, chloroform, carbon tetrachloride, and Freons (R);
  - Oxygenated solvents, such as acetone, methyl ethyl ketone, methanol, ethanol, butanol, and ethyl acetate; and
  - Hydrocarbon solvents, such as hexanes, Stoddard, benzene, toluene, xylenes, and paint thinner.
- Used or unused petroleum products, including motor oils, hydraulic fluids, cutting lubricants, and fortified weed oils.
- Pickling liquor.
- Unspent acids, such as hydrochloric, hydrofluoric, nitric, phosphoric, and sulfuric, in concentrations exceeding 15%.
- Unspent alkalis, including hydroxides, carbonates of sodium, potassium, calcium, and acetylene sludge.
- Unrinsed empty containers of iron or steel used for pesticides or other hazardous chemicals:
  - Pesticide containers; and
  - Hazardous chemical containers.

- o Marketability of the waste as such or as its reclaimed components, the distance from the waste source to point of use or reclamation, the costs of handling and transport, and market prices for the waste components.

The program has been quite successful. Many generators have begun to consider recycling as a result of these letters.

7.2.4 New Rules for Recycling

In 1985, two significant legal changes were made for hazardous waste recycling in California. AB 2166 changed the statutory definitions of waste and recyclable material. The new law regulates recyclable materials as hazardous wastes. AB 2166 brought California law into conformance with the federal statute and clarifies the regulation of recyclable hazardous wastes. The new law does provide exemptions for specified materials and processes. Companies uncertain whether their recycling activities are regulated should consult Health and Safety Code, Section 25143.2. Further clarification can be obtained from the regional offices of the DHS Toxic Substances Control Division (Table 7.2).

In 1985, to facilitate recycling, DHS developed a series of resource recovery facility permits which complement the hazardous waste facility permits. The hazardous waste facility permit is required for companies which treat or dispose of hazardous wastes. The associated requirements include comprehensive insurance coverage, ground water monitoring, and elaborate reporting and record maintenance requirements. The Series 'A' permit, the most stringent, has essentially the same requirements as a hazardous waste facility permit. The Series 'B' and Series 'C' permits have less elaborate requirements and are acceptable for recyclers handling less hazardous wastes in specified manners. This variety of permits expedites recycling while assuring that hazardous wastes are handled with appropriate caution.

7.3 Air Quality Regulations

7.3.1 Federal Requirements

The federal air quality permit program is administered by EPA. The program establishes health-based ambient air quality standards (AAQS) for major air pollutants. The program is concerned primarily with those pollutants for which the national ambient air quality standards (NAAQS) are being attained. These pollutants are called "attainment" pollutants. Permits are required for new or modified sources of air pollution if one or more attainment pollutants are emitted in amounts above specified levels. Thus, a company adding a piece of equipment to their facility would need a federal air permit if an attainment pollutant were emitted in amounts greater than specified "significant levels" defined in the regulations. The permit is called a "prevention of significant deterioration" (PSD) permit. Several California air pollution control districts (APCDs) have recently received authorization from EPA to administer the PSD program in their districts.

Most solvent treatment equipment discussed in the Guide emit volatile organic compounds (VOCs). VOCs are precursors to the pollutant ozone. Ozone is a non-attainment pollutant in many areas of California; therefore, a PSD permit would most likely not be necessary for most solvent treatment applications.

A pollutant is defined as a "non-attainment" pollutant if the NAAQS are being violated for that pollutant. Non-attainment pollutants come under the jurisdiction of California's air quality regulations discussed below.

7.3.2 California Requirements

California has also set air quality standards for major air pollutants. Some of these standards are more stringent than the NAAQS. For a proposed facility to receive an air quality permit in California, the applicant must show that the project will not interfere with achieving or maintaining the state and national AAQS.

Permits are required for any piece of equipment or process that emits air contaminants unless it is specifically exempted. A more vigorous permitting process is applied to major sources, as defined by APCD and EPA regulations.

Sources that plan to locate in an area that is nonattainment for an AAQS must apply for New Source Review (NSR) permit. This program is administered by the local APCDs with oversight by the California Air Resources Board (ARB). NSR requirements vary by APCD but follow some general guidelines. The APCD in which a facility is to be located should be contacted early in the planning stage to determine the specific requirements. A list of California APCDs with mailing addresses and telephone numbers is in Appendix E.

One major component of the NSR program requires proposed facilities emitting non-attainment pollutants, or their precursors as defined in APCD regulations, to apply best available control technology (BACT). NSR also requires emission offsets if the projected emissions are above the APCD "trigger" levels. The APCDs "discount" the offsets to cause a net improvement in air quality.

The purpose of the offsets is to not only negate the new facility impact on an AAQD violation, but to actually improve the ambient concentration and progress toward attaining AAQS. Also, facility emissions must sometimes be analyzed by atmospheric dispersion modelling to determine impacts on attaining state and national AAQS.

New facility projects must also comply with California's toxic air contaminant program. Under this program, the ARB identifies toxic air contaminants. The ARB and APCD develop control programs for the contaminants. The APCDs will administer the control programs.

Some common industrial solvents have already been identified as toxic air contaminants. These solvents include benzene, ethylene dibromide, and ethylene dichloride. More solvents are currently being identified.

Control programs developed for toxic air contaminants will probably be applied at emission levels much lower than the typical 150 lb/day trigger level for the NSR program. In addition, siting decisions for sources of toxic air contaminants may involve risk assessment based on atmospheric dispersion modelling.

7.4 Federal and California Water Quality Guidelines

This overview is limited to the regulations that pertain to the management of solvent wastes.

7.4.1 Regulatory Agencies

Through authority established by the Clean Water Act and the Safe Drinking Water Act, EPA administers water quality control programs for wastewater disposed to surface waters, municipal sewers, and injection wells. In California, surface water disposal is regulated by the National Pollutant Discharge Elimination System (NPDES) program. Administration of the program has been delegated to the state. The state also recently applied for delegation of the Pretreatment Program which regulates the discharge of industrial wastewaters into municipal sewer systems. The Underground Injection Control (UIC) program, which regulates wastewater disposal in injection wells, is administered by EPA, with the exception of oil production-related injection wells, which are regulated by the California Department of Conservation, Division of Oil and Gas.

Through authority provided by the Porter-Cologne Water Quality Control Act and other state legislation, nine Regional Water Quality Control Boards administer water quality control programs in their geographic areas. Regional Water Quality Control Boards possess the authority to regulate discharges to surface waters, land (including surface impoundments), municipal sewers, and injection wells. Statewide oversight is provided by the State Water Resources Control Board.

The Regional Water Quality Control Boards adopt waste discharge requirements to protect the waters of the state for the use and enjoyment of the people of California. Any questions regarding wastewater discharge regulations should be directed to the nearest office of the California Regional Water Quality Control Boards (Table 7.5).

Additional discussion on the requirements for the disposal options is provided below.

7.4.2 Surface Waters

Under the Clean Water Act and NPDES regulations, EPA issues technology-based effluent limitations on wastewater discharges to surface waters based on industrial category. California incorporated these guidelines in the regulations implemented by the Regional Water Quality Control Boards. The guidelines and standards are based on chemical use minimization or substitution, and water use reduction to reduce pollutant discharges. The Regional Water Quality Control Boards may adopt more stringent limitations to

TABLE 7.5

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARDS

NORTH COAST REGION (1)
1000 Coddingtown Center
Santa Rosa, California 95401
(707) 576-2220

SAN FRANCISCO BAY REGION (2)
1111 Jackson Street, Room 6040
Oakland, California 94607
(415) 464-1255

CENTRAL COAST REGION (3)
1102-A Laurel Lane
San Luis Obispo, California 93401
(805) 549-3147

LOS ANGELES REGION (4)
107 South Broadway, Room 4027
Los Angeles, California 90012
(213) 620-4460

CENTRAL VALLEY REGION (5)
3201 S Street
Sacramento, California 95816
(916) 445-0270

Fresno Branch Office
3614 E. Ashlan Ave.
Fresno, California 93726
(209) 445-5116

Redding Branch Office
100 East Cypress Avenue
Redding, California 96002
(916) 225-2045

LAHONTAN REGION (6)
2092 Lake Tahoe Boulevard
P.O. Box 9428
South Lake Tahoe, California 95731
(916) 544-3481

Victorville Branch Office
15371 Bonanza Road
Victorville, California 92392
(519) 245-6583

COLORADO RIVER BASIN REGION (7)
73-271 Highway 111, Suite 21
Palm Desert, California 92260
(619) 346-7491

SANTA ANA REGION (8)
6809 Indiana Avenue, Suite 200
Riverside, California 92506
(714) 684-9330

SAN DIEGO REGION (9)
6154 Mission Gorge Road, Suite 205
San Diego, California 92120
(619) 255-5114

protect the water quality of specific receiving waters. The specific limitations for any facility are incorporated into an NPDES permit issued by the Regional Water Quality Control Boards.

Generally, the limitations are expressed in terms of constituent limits placed on the wastestream. Two limits apply: a 1-day maximum, and a monthly average.

There are some industries for which constituents subject to regulation include many solvents. These industries are electroplating, metal finishing, coil coating, paint formulating, ink formulating, electrical and electronic components, and copper and aluminum forming. The term "total toxic organics" is defined separately for each industrial category. Typical solvents in this group include 1,1,2-trichloroethane, pyrene, tetrachloroethylene, toluene, trichloroethylene, ethylbenzene, and benzene.

7.4.3 Above-Ground Storage Tanks

The Regional Water Quality Control Boards also possess the authority to require industries to develop Best Management Practice (BMP) plans to prevent or mitigate water pollution from sources ancillary to industrial manufacturing or treatment processes. BMP plans may contain provisions for good housekeeping, employee training, preventive maintenance, security, and physical improvements such as alarms or containment structures around storage tanks.

7.4.4 Land

For facilities disposing of wastewater to land, the Regional Water Quality Control Boards develop effluent limitations which are incorporated into water discharge requirements. These limitations are developed in accordance with California Administrative Code, Title 23, Chapter 3, Subchapter 15, <u>Discharge of Waste to Land</u>.

Industries that store, treat, or dispose of liquid hazardous wastes in surface impoundments are also subject to the provisions of the Toxic Pits Cleanup Act of 1984.

7.4.5. Municipal Sewer

Industries that discharge wastewater into a municipal sewer system are generally regulated by the municipality. In addition, certain industries may be subject to technology-based pretreatment standards developed by EPA. The bases for the pretreatment standards are similar to those used for surface water disposal.

In some of the larger municipalities in California, EPA requires that local pretreatment programs incorporating federal pretreatment standards be adopted. For smaller communities that do not have EPA-approved pretreatment programs, EPA may regulate directly the industries subject to federal pretreatment standards.

In September 1985, the State Water Resources Control Board applied for delegation of the Pretreatment Program in California. If delegation is authorized, then the State Board and Regional Boards will be responsible for administering the Pretreatment Program.

7.4.6 Injection Wells

Industries that dispose wastewater to injection wells are regulated by the Underground Injection Control (UIC) Program administered by EPA. Specific injection well operators are issued UIC permits by EPA. In addition, the Regional Boards have the option of issuing waste discharge requirements to injection well owners and operators.

7.4.7 Underground Storage Tanks

Recently passed federal and state legislation protects the waters of the state from discharges of hazardous substances from underground storage tanks. State regulations establish tank construction, monitoring, closure, and reporting requirements. Counties are required to implement the regulations. In some cases, cities can assume the responsibilities within their boundaries.

7.5 Federal and California Occupational Safety and Health Administration (OSHA) Regulations

The federal and California OSHA regulations pertain to administrative responsibilities including standards-setting, recordkeeping, activities of advisory committees, access to employee medical records, duties of employers, enforcement actions, accreditation of testing laboratories, on-site consultations, and examination and copying of documents.

Under the Occupational Safety and Health Act of 1970, employers are required to keep and make available to the Labor Secretary and to the Secretary of Health and Human Services records on certain employer activities. These records include reports of work-related deaths, injuries, and illnesses. Minor injuries requiring only first-aid treatment need not be recorded, but a record must be made if it involves medical treatment, loss of consciousness, restriction of work or motion, or transfer to another job.

Employers are also required to maintain accurate records of employee exposures to potentially toxic materials or harmful physical agents under Section 6(b)(7) of the OSHA Act, and to promptly advise employees of any excessive exposure and of the corrective action being undertaken.

In general, OSHA requires that worker exposure standards to specific toxic substances be established. Associated with these standards are requirements for recordkeeping as mentioned above.

Those employers in industries which use hazardous materials must identify the hazards of such materials and record this information on a Material Safety Data Sheet, OSHA Form No. 20, or a similar form. The Data Sheet can be useful as a fact sheet on the properties and potential hazards of a chemical. The pertinent information required includes: the chemical name of the material; physical data; fire and explosion hazard data; reactivity data; spill, leak, and clean-up procedures; special protection; and handling information.

The Federal Right-To-Know Regulation of 1986 requires that employees be trained in the safe use of potentially hazardous substances. The regulation also requires that all hazardous substances be properly labelled and a Data Sheet on that substance be available to each employee.

Standards for toxic and hazardous substances are implemented on an air contaminant basis as well as a handling basis. Air contaminant levels are defined in 29 CFR 1910.1000 on an 8-hour average basis.

Handling standards are procedures that companies must follow for a specific chemical. These procedures include appropriate protective equipment, respirators, personal monitoring, environmental monitoring, and appropriate signs, information and training. Table 7.6 presents a list of substances for which handling standards are in effect.

In California, Cal/OSHA has the authority to enforce health and safety regulations. The nearest Cal/OSHA enforcement unit should be contacted for details on any health or safety issues.

TABLE 7.6

LIST OF SUBSTANCES FOR WHICH HANDLING STANDARDS ARE IN EFFECT UNDER OHSA

Asbestos
4-Nitrobiphenyl
alpha-Naphthylamine
Methyl chloromethyl ether
3,3'-Dichlorobenzidine (and its salts)
bis-Chloromethyl ether
beta-Naphthylamine
Benzidine
4-Aminodiphenyl
Ethyleneimine
beta-Propiolactone
2-Acetylaminofluorene
4-Dimethylaminioazobenzene
N-Nitrosodimethylamine
Vinyl Chloride
Inorganic Arsenic
Lead
Benzene
Coke oven emissions
Cotton Dust
1,2-dibromo-3-chloropropane
Acrylonitrile
Exposure to cotton dust in cotton gins

REFERENCES FOR CHAPTER 7

1. Environ Corporation. Documentation for the Development of Toxicity and Volume Scores for the Purpose of Scheduling Hazardous Waste, Report prepared for U.S. Environmental Protection Agency (U.S. EPA), Office of Solid Waste, EPA-68-01-6861. Washington, D.C.: U.S. EPA, 1985.

GLOSSARY OF TERMS

Recycled:	A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1(b)(7)).
Reclaimed:	A material is "reclaimed" if it is processed to recover a usable product or if it is regenerated. Examples are recovery of lead values from spent batteries and regeneration of spent solvents (40 CFR 261.1(b)(4)).
Reduction of total volume or quantity:	The reduction in the total amount of hazardous waste generated, treated, stored, or disposed of as defined by volume, weight, mass, or some other appropriate measure.
Reduction of toxicity:	The reduction or elimination of the toxicity of a hazardous waste by (1) altering the toxic constituent(s) of the waste to less toxic or nontoxic form(s) or (2) lowering the concentration of toxic constituent(s) in the waste by means other than dilution.
Product substitution:	The replacement of any product intended for an intermediate or final use with another product intended and suitable for the same intermediate or final use.
Source control:	Any activity or treatment classifiable under source reduction with the notable exception of product substitution.
Source reduction:	Any activity or treatment that reduces or eliminates the generation of a hazardous waste within a process.
Treatment:	The destruction or degradation of wastes to yield less toxic residuals without generating reusable material.
Used or reused:	A material is "used or reused" if it is either (1) employed as an ingredient (including use as an intermediate) in an industrial process to make a product (for example, distillation bottoms from one process used as feedstock in another process). However, a material will not satisfy this condition if distinct components of the material are recovered as

	separate end products (as when metals are recovered from metal-containing secondary materials) or (2) employed in a particular function or application as an effective substitute for a commercial product (for example, spent pickle liquor used as phosphorous precipitant and sludge conditioner in wastewater treatment) (40 CFR 261.1(b)(45)).
Waste minimization:	The reduction, to the extent feasible, of hazardous waste that is generated or subsequently treated, stored, or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste, or (2) the reduction of toxicity of hazardous waste, or both, so long as such reduction is consistent with the goal of minimizing present and future threats to human health and the environment.

GLOSSARY OF ABBREVIATIONS

AAQS	Ambient Air Quality Standards
APCD	Air Pollution Control Districts
ARB	California Air Resources Board
BACT	Best Available Control Technology
BMP	Best Management Practices
CWE	California Waste Exchange
DHS	California Department of Health Services
EPA	United State Environmental Protection Agency
HSWA	Hazardous and Solid Waste Amendments
ISD	Interim Status Document
MSDS	Material Safety Data Sheet
NAAQS	National Ambient Air Quality Standards
NCA	Neighborhood Cleaners Association
NPDES	National Pollutant Discharge Elimination System
NSR	New Source Review
OEM	Original Equipment Manufacture
OSHA	Occupational Safety and Health Administration
PSD	Prevention of Significant Deterioration
RCRA	Resource Conservation and Recovery Act
SIC	Standard Industrial Classification
SPCC	Spill Prevention Control and Countermeasures
SQG	Small Quantity Generator
TSD	Treatment, Storage and Disposal
UIC	Underground Injection Control
VOC	Volatile Organic Compounds

APPENDIX A

MAJOR SOLVENT USER INDUSTRIES

SIC Population Within California Counties, Distributed by Company Size

INTRODUCTION

In order to identify solvent waste reduction alternatives of industrial importance in California, major solvent-user industries were identified.

The data presented here provide a geographical distribution of major solvent user industries and are derived from the County Business Patterns (1983) for California (compiled by the U.S. Department of Commerce, Bureau of the Census). The data are sorted primarily by selected 4-digit Standard Industrial Classification codes (SICs), and secondarily by county. Table 1 provides a description of the SICs listed in the printout.

METHODOLOGY

The group of facilities listed in Table 1 was derived from a search of the 1984 California manifest data for hazardous wastes disposed offsite. These manifests were examined to screen for high volume generators of solvent wastes. This was done on the assumption that solvent-user industries could be identified by the type of wastes they generate; high volume solvent waste generators must also be high volume solvent users.

For screening purposes, the definition of "high volume generator" was limited to facilities with 50,000 tons or more of solvent waste generated in the reporting period (January 1, 1984 to December 31, 1984). SICs codes were assigned to individual generator facilities from the manifest records and the waste volumes reported were summed for all facilities within an SIC category. Those SICs with the highest total volume of waste generated (all greater than 1 million gallons in 1984) were selected as probable high volume solvent-user industries.

The list of SICs compiled from the manifest data does not necessarily account for high volume solvent-user industries that consume or dispose of most of their solvents onsite, or for small quantity users. Therefore, the list of SICs identified from the manifest records was checked against references describing industries commonly known to use organic solvents as part of manufacturing, fabrication, or maintenance processes. (i.e., the Kirk-Othmer Encyclopedia of Chemical Technology, Volume 21, pp. 377-401, and U.S. EPA, Background Document for Solvents to Support 40 CFR Part 268 Land Disposal Restrictions, Volume II. see bibliography for Section 2.1 of the report for more information).

Information sources for point source category VOC emissions that are indicative of industrial solvent use also were consulted. Small quantity solvent-user/generator industries were identified from a study of small quantity generators in Southern California[1]. There is no unique SIC group that applies to solvent reclamation facilities per se. Rather, the current SIC system defines a category for Business Services under SIC 73. Within this category is the sub-category 7399, which is defined as Business Services, Not Elsewhere Classified. This category consists of approximately 120 variety of services (e.g., bondsmen, drafting services, and interior decorating). Specifically included in this listing is "solvents recovery service on a contract basis". Although this SIC group is appropriate for inclusion in our data bases, the distribution of facilities listed in Appendix A may be somewhat misleading. It is impossible for the Bureau of Census data base to differentiate the services within SIC 7399. Thus, the number of facilities listed in the various California counties include those that are not solvent recycling firms as well as those that are.

TABLE 1

LIST OF SIC CODES

SIC Code	Description
2834	Pharmaceutical manufacture
2850	Manufacture of paints, varnishes, lacquers, enamels and allied products
2865	Cyclic (coal tar) crudes, and cyclic intermediate dyes and organic pigments
2869	Industrial organic chemicals manufacture
2879	Pesticides and agricultural chemicals
2893	Manufacture of printing ink, gravure ink, screen process ink, and lithographic ink
2899	Chemicals and chemical preparations, not elsewhere classified
3582	Rug cleaning
3674	Semiconductors and related devices
3679	Electronics components and accessories
3711	Manufacture of motor vehicles and passenger car bodies
3721	Aircraft manufacture
5510	Motor vehicle dealers
7215	Coin operated dry cleaners
7216	Dry cleaning except rugs
7399	Solvent reclamation facilities
7538	General automotive repair shops
291	Petroleum refining

---

1 - SCS Engineers, "Hazardous Waste Management Plan for Small Quantity Generators, Final Report", submitted to the Southern California Association of Governments, Los Angeles, CA, 1985.

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE
IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group: 1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
** SIC CODE: 2834																		
ALAMEDA	E	0	0	0	3	0	1	0	1	0	0	1	0	0	0	0	0	0
CONTRA COSTA	B	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0	0
FRESNO	D	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
LOS ANGELES		3323	17067	69438	35	6	4	3	7	7	3	3	2	0	0	0	0	0
ORANGE		3844	25679	106500	17	4	1	2	4	2	0	2	0	2	1	1	0	0
RIVERSIDE	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
SAN DIEGO	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
SAN LUIS OBISPO	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
SAN MATEO	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
SANTA CLARA		1156	7167	31665	10	2	2	1	1	1	1	1	1	0	0	0	0	0
SONOMA	D	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0
TUOLUMNE	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 2850																		
ALAMEDA		644	3806	16835	22	4	5	5	4	1	3	0	0	0	0	0	0	0
CONTRA COSTA		23	126	607	4	2	1	1	0	0	0	0	0	0	0	0	0	0
FRESNO	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
HUMBOLDT	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
KERN	A	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0
LOS ANGELES		3672	18019	81280	101	21	23	15	25	9	7	0	1	0	0	0	0	0
MARIN	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
ORANGE		784	4246	18460	20	5	2	7	1	3	1	1	0	0	0	0	0	0
RIVERSIDE	D	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
SACRAMENTO	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO		272	1045	4474	7	1	0	3	0	3	0	0	0	0	0	0	0	0
SAN DIEGO	C	0	0	0	3	0	0	0	2	1	0	0	0	0	0	0	0	0
SAN FRANCISCO		289	1764	7508	10	1	2	5	1	0	1	0	0	0	0	0	0	0
SAN JOAQUIN	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
SAN MATEO		537	3544	15692	9	2	2	0	2	1	2	0	0	0	0	0	0	0
SANTA BARBARA	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
SANTA CLARA		165	868	3708	10	2	3	1	4	0	0	0	0	0	0	0	0	0
SANTA CRUZ	A	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0
SHASTA	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SOLANO	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 2865																		
ALAMEDA	D	0	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0	0
CONTRA COSTA	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
LOS ANGELES	B	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
ORANGE	C	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
SAN BERNARDINO	B	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0
** SIC CODE: 2869																		
CONTRA COSTA	F	0	0	0	5	1	0	0	0	2	1	1	0	0	0	0	0	0
FRESNO	D	0	0	0	7	5	1	1	0	0	0	0	0	0	0	0	0	0
IMPERIAL	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
KERN	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE
IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	>1000	1000-1499	1500-2499	2500-4999	>5000
LOS ANGELES	E	0	0	0	19		2	5	2	8	2	0	0	0	0	0	0	0	0
ORANGE	G	0	0	0	5		2	0	0	0	2	0	0	0	1	1	0	0	0
RIVERSIDE	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
SAN DIEGO	F	0	0	0	4		0	1	0	1	0	0	2	0	0	0	0	0	0
SAN FRANCISCO	B	0	0	0	2		1	0	0	0	1	0	0	0	0	0	0	0	0
SAN LUIS OBISPO	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
SAN MATEO	B	0	0	0	2		0	0	1	1	0	0	0	0	0	0	0	0	0
SANTA CLARA	E	0	0	0	4		1	0	1	0	1	1	0	0	0	0	0	0	0
STANISLAUS	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
VENTURA	B	0	0	0	1		0	0	0	1	0	0	0	0	0	0	0	0	0
YOLO	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 2879																			
ALAMEDA	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA	E	0	0	0	2		0	0	0	0	0	1	1	0	0	0	0	0	0
EL DORADO	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
FRESNO	C	0	0	0	5		1	2	0	0	1	1	0	0	0	0	0	0	0
HUMBOLDT	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
KERN	D	0	0	0	1		0	0	0	1	0	0	0	0	0	0	0	0	0
LOS ANGELES		396	1717	7247	13		3	2	1	4	3	0	0	0	0	0	0	0	0
MARIN	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
MONTEREY	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
ORANGE		5	9	56	3		3	0	0	0	0	0	0	0	0	0	0	0	0
RIVERSIDE	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
SAN DIEGO	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
SAN FRANCISCO	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
SAN MATEO	B	0	0	0	1		0	0	0	1	0	0	0	0	0	0	0	0	0
SANTA CLARA	C	0	0	0	3		0	0	1	1	0	1	0	0	0	0	0	0	0
TULARE	B	0	0	0	3		1	1	1	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 2893																			
ALAMEDA		207	1534	6254	9		3	0	4	1	0	1	0	0	0	0	0	0	0
AMADOR	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA	A	0	0	0	3		2	0	1	0	0	0	0	0	0	0	0	0	0
KERN	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
LOS ANGELES	F	0	0	0	33		7	5	8	11	2	0	0	0	0	0	0	0	0
ORANGE	B	0	0	0	3		1	0	1	0	1	0	0	0	0	0	0	0	0
SAN DIEGO	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
SAN FRANCISCO	B	0	0	0	1		0	0	0	1	0	0	0	0	0	0	0	0	0
YOLO	C	0	0	0	2		0	1	0	0	0	1	0	0	0	0	0	0	0
** SIC CODE: 2899																			
ALAMEDA		633	3813	16565	17		6	4	2	2	1	1	1	0	0	0	0	0	0
CONTRA COSTA	C	0	0	0	8		6	1	0	0	0	1	0	0	0	0	0	0	0
FRESNO	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
GLENN	A	0	0	0	2		0	2	0	0	0	0	0	0	0	0	0	0	0
KERN	B	0	0	0	4		0	2	2	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group: 1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	>1000	1000-1499	1500-2499	2500-4999	>5000
LOS ANGELES		1636	7265	31082	66	21	12	13	9	7	4	0	0	0	0	0	0	0
MARIN	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
NAPA	B	0	0	0	2	0	1	0	0	1	0	0	0	0	0	0	0	0
NEVADA	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
ORANGE		229	1180	4492	21	9	5	4	1	2	0	0	0	0	0	0	0	0
RIVERSIDE	C	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
SACRAMENTO		19	57	253	4	3	0	1	0	0	0	0	0	0	0	0	0	0
SAN BENITO	B	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0
SAN BERNARDINO		199	633	2409	8	2	1	2	2	1	0	0	0	0	0	0	0	0
SAN DIEGO		249	1306	5806	10	3	0	1	5	0	1	0	0	0	0	0	0	0
SAN FRANCISCO	A	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
SAN JOAQUIN	C	0	0	0	3	1	0	0	1	1	0	0	0	0	0	0	0	0
SAN MATEO		41	223	1342	7	2	4	1	0	0	0	0	0	0	0	0	0	0
SANTA BARBARA		44	223	829	4	0	2	1	1	0	0	0	0	0	0	0	0	0
SANTA CLARA	B	0	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0	0
SOLANO	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
TULARE	B	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0
VENTURA	A	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 3582																		
LOS ANGELES	B	0	0	0	5	2	0	1	2	0	0	0	0	0	0	0	0	0
ORANGE	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
SACRAMENTO	A	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0
SAN FRANCISCO	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
SANTA CRUZ	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 3674																		
ALAMEDA	F	0	0	0	7	2	1	2	1	0	0	0	1	0	0	0	0	0
AMADOR	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
KINGS	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
LOS ANGELES		3742	18481	82394	42	11	6	5	9	2	5	1	3	0	0	0	0	0
MARIN	E	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
ORANGE		5288	31510	135565	25	4	1	7	3	1	3	3	1	2	1	1	0	0
SAN BENITO	A	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO	B	0	0	0	3	1	1	1	0	0	0	0	0	0	0	0	0	0
SAN DIEGO		3090	16355	66172	21	5	3	3	3	1	3	1	1	1	1	0	0	0
SAN JOAQUIN	E	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
SAN LUIS OBISPO	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SAN MATEO		48	258	1088	6	3	2	0	1	0	0	0	0	0	0	0	0	0
SANTA BARBARA	A	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0
SANTA CLARA		39589	248358	1173727	127	34	15	11	13	11	17	9	7	10	5	1	2	2
SANTA CRUZ	B	0	0	0	3	1	0	2	0	0	0	0	0	0	0	0	0	0
SONOMA	E	0	0	0	3	1	0	0	0	1	0	1	0	0	0	0	0	0
TULARE	B	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0
VENTURA	F	0	0	0	10	2	1	2	2	1	0	2	0	0	0	0	0	0

07/23/86

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE
IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
** SIC CODE: 3679																			
ALAMEDA	G	0	0	0	32		5	4	9	9	3	1	1	0	0	0	0	0	0
BUTTE	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA		614	3046	12256	8		3	1	0	1	2	0	1	0	0	0	0	0	0
EL DORADO	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
FRESNO	A	0	0	0	3		1	1	1	0	0	0	0	0	0	0	0	0	0
KERN	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
LAKE	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
LOS ANGELES		14038	70912	286932	279		76	49	41	53	19	29	10	1	1	0	1	0	0
MARIN	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
MENDOCINO	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
NEVADA		54	171	937	4		2	1	0	1	0	0	0	0	0	0	0	0	0
ORANGE		7155	30545	139510	162		48	24	31	40	25	10	2	2	0	0	0	0	0
PLACER	B	0	0	0	3		1	0	1	1	0	0	0	0	0	0	0	0	0
RIVERSIDE	E	0	0	0	7		1	1	2	2	0	0	1	0	0	0	0	0	0
SACRAMENTO		210	1549	4625	11		5	1	2	1	2	0	0	0	0	0	0	0	0
SAN BENITO	D	0	0	0	2		0	1	1	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO	E	0	0	0	23		10	6	3	2	2	0	0	0	0	0	0	0	0
SAN DIEGO		5255	26274	98502	72		19	15	9	10	12	2	2	2	1	1	0	0	0
SAN FRANCISCO	G	0	0	0	8		1	3	0	1	0	1	2	0	0	0	0	0	0
SAN JOAQUIN	F	0	0	0	8		2	2	0	0	2	0	2	0	0	0	0	0	0
SAN LUIS OBISPO	G	0	0	0	13		2	2	0	3	0	4	2	0	0	0	0	0	0
SAN MATEO	F	0	0	0	37		12	10	5	7	1	2	0	0	0	0	0	0	0
SANTA BARBARA		631	2743	12253	16		5	3	1	3	2	2	0	0	0	0	0	0	0
SANTA CLARA	J	0	0	0	251		58	33	45	58	28	14	10	3	2	2	0	0	0
SANTA CRUZ	F	0	0	0	19		6	3	0	5	3	1	1	0	0	0	0	0	0
SHASTA	A	0	0	0	2		1	0	1	0	0	0	0	0	0	0	0	0	0
SISKIYOU	A	0	0	0	1		0	1	0	0	0	0	0	0	0	0	0	0	0
SOLANO	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
SONOMA	B	0	0	0	3		1	0	1	1	0	0	0	0	0	0	0	0	0
STANISLAUS	A	0	0	0	2		0	1	1	0	0	0	0	0	0	0	0	0	0
TULARE	F	0	0	0	5		0	0	2	2	0	0	0	1	0	0	0	0	0
VENTURA		2325	11085	47979	31		10	4	4	4	5	2	1	0	1	1	0	0	0
YOLO	B	0	0	0	2		1	0	0	1	0	0	0	0	0	0	0	0	0
** SIC CODE: 3711																			
ALAMEDA	F	0	0	0	3		1	0	0	1	0	0	0	1	0	0	0	0	0
LOS ANGELES	H	0	0	0	12		4	3	1	1	0	1	1	0	1	0	0	1	0
ORANGE	D	0	0	0	7		3	2	2	0	0	0	0	0	0	0	0	0	0
RIVERSIDE	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
SACRAMENTO	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO	B	0	0	0	2		0	0	1	1	0	0	0	0	0	0	0	0	0
SAN DIEGO	A	0	0	0	3		3	0	0	0	0	0	0	0	0	0	0	0	0
SANTA CLARA	A	0	0	0	2		1	0	1	0	0	0	0	0	0	0	0	0	0
STANISLAUS	B	0	0	0	1		0	0	0	0	1	0	0	0	0	0	0	0	0
VENTURA	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE
IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
## SIC CODE: 3721																			
KERN	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
KINGS	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
LOS ANGELES		55299	426283	1785956	17		3	2	1	3	0	2	0	0	6	0	2	1	3
MONTEREY	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
ORANGE	B	0	0	0	1		0	0	0	0	1	0	0	0	0	0	0	0	0
RIVERSIDE	C	0	0	0	3		2	0	0	0	0	1	0	0	0	0	0	0	0
SACRAMENTO	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
SAN BENITO	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO	G	0	0	0	3		0	2	0	0	0	0	0	0	1	1	0	0	0
SAN DIEGO	G	0	0	0	3		2	0	0	0	0	0	0	0	1	1	0	0	0
SANTA BARBARA	F	0	0	0	2		0	0	0	0	0	1	0	1	0	0	0	0	0
SANTA CRUZ	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
TULARE	C	0	0	0	1		0	0	0	0	0	1	0	0	0	0	0	0	0
VENTURA	C	0	0	0	1		0	0	0	0	0	1	0	0	0	0	0	0	0
## SIC CODE: 5510																			
ALAMEDA		3480	21883	97281	95		16	5	9	39	23	3	0	0	0	0	0	0	0
AMADOR	B	0	0	0	2		1	0	0	1	0	0	0	0	0	0	0	0	0
BUTTE		458	1928	8854	18		2	0	4	10	2	0	0	0	0	0	0	0	0
CALAVERSA	B	0	0	0	2		0	0	2	0	0	0	0	0	0	0	0	0	0
COLUSA	B	0	0	0	2		0	1	1	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA		1777	11264	49566	57		11	2	6	27	11	0	0	0	0	0	0	0	0
DEL NORTE		37	123	550	4		1	1	2	0	0	0	0	0	0	0	0	0	0
EL DORADO		169	712	3052	10		0	0	9	1	0	0	0	0	0	0	0	0	0
FRESNO		1549	8226	35958	52		8	3	13	16	11	1	0	0	0	0	0	0	0
GLENN	B	0	0	0	3		1	0	1	1	0	0	0	0	0	0	0	0	0
HUMBOLDT		326	1537	6323	17		2	2	5	8	0	0	0	0	0	0	0	0	0
IMPERIAL		242	1299	5150	11		3	0	1	6	1	0	0	0	0	0	0	0	0
INYO		95	371	1515	5		0	0	2	3	0	0	0	0	0	0	0	0	0
KERN		1222	6093	25925	35		7	3	7	10	6	2	0	0	0	0	0	0	0
KINGS		148	613	2678	5		0	0	3	1	1	0	0	0	0	0	0	0	0
LAKE		68	255	1323	7		1	2	4	0	0	0	0	0	0	0	0	0	0
LASSEN	B	0	0	0	3		1	0	1	1	0	0	0	0	0	0	0	0	0
LOS ANGELES		24573	139387	601739	520		69	18	40	176	177	39	1	0	0	0	0	0	0
MADERA		74	215	1142	5		1	0	2	2	0	0	0	0	0	0	0	0	0
MARIN		785	4812	21559	28		3	0	6	16	3	0	0	0	0	0	0	0	0
MENDOCINO		170	674	3252	12		1	4	2	5	0	0	0	0	0	0	0	0	0
MERCED		387	1900	7402	18		1	3	3	10	1	0	0	0	0	0	0	0	0
MODOC	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
MONTEREY		867	4843	21793	31		6	0	5	14	6	0	0	0	0	0	0	0	0
NAPA		271	1218	5884	12		1	1	3	7	0	0	0	0	0	0	0	0	0
NEVADA		91	396	1668	4		0	0	1	3	0	0	0	0	0	0	0	0	0
ORANGE		7202	43012	187404	156		27	7	13	45	46	18	0	0	0	0	0	0	0
PLACER		560	3088	14315	20		3	1	3	10	3	0	0	0	0	0	0	0	0
PLUMAS	B	0	0	0	3		1	0	1	1	0	0	0	0	0	0	0	0	0
RIVERSIDE		2505	12201	53536	65		4	1	9	33	15	3	0	0	0	0	0	0	0
SACRAMENTO		2788	16944	77938	51		9	1	1	15	17	8	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE
IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
SAN BENITO		84	358	1587	4		0	0	2	2	0	0	0	0	0	0	0	0	0
SAN BERNARDINO		2290	11114	48057	71		9	3	13	29	16	1	0	0	0	0	0	0	0
SAN DIEGO		7045	34836	152184	157		34	3	10	47	47	16	0	0	0	0	0	0	0
SAN FRANCISCO		1473	10575	45651	36		5	1	6	9	14	1	0	0	0	0	0	0	0
SAN JOAQUIN		1065	4881	21889	38		6	4	9	15	2	2	0	0	0	0	0	0	0
SAN LUIS OBISPO		408	1950	8917	18		3	0	3	11	1	0	0	0	0	0	0	0	0
SAN MATEO		2404	14097	61157	60		6	3	8	28	13	1	1	0	0	0	0	0	0
SANTA BARBARA		994	5034	21348	35		10	0	5	14	6	0	0	0	0	0	0	0	0
SANTA CLARA		4135	29297	126697	93		17	3	2	31	34	6	0	0	0	0	0	0	0
SANTA CRUZ		522	3039	13129	19		1	1	2	15	0	0	0	0	0	0	0	0	0
SHASTA		306	1428	6674	12		2	2	2	4	2	0	0	0	0	0	0	0	0
SIERRA	B	0	0	0	1		0	0	0	1	0	0	0	0	0	0	0	0	0
SISKIYOU		52	203	895	5		1	2	1	1	0	0	0	0	0	0	0	0	0
SOLANO		628	3969	16841	24		1	1	6	15	1	0	0	0	0	0	0	0	0
SONOMA		961	5203	23505	36		4	4	7	16	5	0	0	0	0	0	0	0	0
STANISLAUS		810	3622	15534	27		3	0	5	15	4	0	0	0	0	0	0	0	0
SUTTER		147	886	2873	4		0	0	1	1	2	0	0	0	0	0	0	0	0
TEHAMA		94	390	1776	5		0	0	3	2	0	0	0	0	0	0	0	0	0
TULARE		680	3173	12646	34		10	1	7	15	1	0	0	0	0	0	0	0	0
TUOLUMNE		57	225	996	5		2	1	1	1	0	0	0	0	0	0	0	0	0
VENTURA		1787	10493	48200	46		7	1	2	23	11	2	0	0	0	0	0	0	0
YOLO		280	1388	6619	16		4	1	4	7	0	0	0	0	0	0	0	0	0
YUBA	B	0	0	0	2		0	0	0	1	1	0	0	0	0	0	0	0	0
** SIC CODE: 7215																			
ALAMEDA		137	468	1726	34		28	4	1	0	1	0	0	0	0	0	0	0	0
BUTTE	A	0	0	0	7		7	0	0	0	0	0	0	0	0	0	0	0	0
COLUSA	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA		36	74	301	11		9	1	1	0	0	0	0	0	0	0	0	0	0
EL DORADO	A	0	0	0	3		3	0	0	0	0	0	0	0	0	0	0	0	0
FRESNO		45	113	446	9		5	2	2	0	0	0	0	0	0	0	0	0	0
HUMBOLDT		35	103	445	9		6	2	1	0	0	0	0	0	0	0	0	0	0
IMPERIAL		5	3	19	4		4	0	0	0	0	0	0	0	0	0	0	0	0
INYO	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
KERN		29	42	179	12		11	1	0	0	0	0	0	0	0	0	0	0	0
KINGS	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
LOS ANGELES		1014	3505	13738	210		175	18	11	3	2	0	1	0	0	0	0	0	0
MADERA	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
MARIN		21	27	134	10		9	1	0	0	0	0	0	0	0	0	0	0	0
MENDOCINO	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
MERCED	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
MONO	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
MONTEREY		80	108	483	16		12	1	3	0	0	0	0	0	0	0	0	0	0
NAPA	A	0	0	0	3		3	0	0	0	0	0	0	0	0	0	0	0	0
NEVADA	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
ORANGE		223	604	2470	45		30	6	7	2	0	0	0	0	0	0	0	0	0
RIVERSIDE		57	75	331	19		14	5	0	0	0	0	0	0	0	0	0	0	0
SACRAMENTO		98	585	1831	20		15	1	3	1	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group: 1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
SAN BERNARDINO		83	256	950	18	14	1	2	1	0	0	0	0	0	0	0	0	0
SAN DIEGO		189	554	2277	51	43	5	0	3	0	0	0	0	0	0	0	0	0
SAN FRANCISCO		156	469	2017	43	37	4	1	0	1	0	0	0	0	0	0	0	0
SAN JOAQUIN		72	91	352	13	11	1	0	1	0	0	0	0	0	0	0	0	0
SAN LUIS OBISPO		15	20	73	5	4	1	0	0	0	0	0	0	0	0	0	0	0
SAN MATEO		58	202	759	20	16	4	0	0	0	0	0	0	0	0	0	0	0
SANTA BARBARA		54	114	479	15	12	2	1	0	0	0	0	0	0	0	0	0	0
SANTA CLARA		113	270	1356	25	17	5	2	1	0	0	0	0	0	0	0	0	0
SANTA CRUZ		34	38	183	8	5	2	1	0	0	0	0	0	0	0	0	0	0
SHASTA	A	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
SISKIYOU	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SOLANO	A	0	0	0	5	4	1	0	0	0	0	0	0	0	0	0	0	0
SONOMA		16	22	73	7	6	1	0	0	0	0	0	0	0	0	0	0	0
STANISLAUS		20	17	76	9	8	1	0	0	0	0	0	0	0	0	0	0	0
SUTTER	A	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0
TEHAMA	A	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	0
TULARE	A	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
TUOLUMNE	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
VENTURA		42	72	351	20	18	2	0	0	0	0	0	0	0	0	0	0	0
YOLO	A	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
YUBA	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 7216																		
ALAMEDA		550	1485	6132	106	60	34	8	4	0	0	0	0	0	0	0	0	0
AMADOR	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
BUTTE		59	118	480	9	6	1	1	1	0	0	0	0	0	0	0	0	0
CALAVERSA	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
COLUSA	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA		328	856	3743	66	37	22	7	0	0	0	0	0	0	0	0	0	0
DEL NORTE	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
EL DORADO		34	50	207	8	5	2	1	0	0	0	0	0	0	0	0	0	0
FRESNO	E	0	0	0	50	19	22	6	3	0	0	0	0	0	0	0	0	0
GLENN	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
HUMBOLDT		24	43	166	4	2	1	1	0	0	0	0	0	0	0	0	0	0
IMPERIAL		16	27	108	3	1	2	0	0	0	0	0	0	0	0	0	0	0
INYO	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
KERN		261	605	2380	24	9	11	2	1	0	1	0	0	0	0	0	0	0
KINGS		31	62	255	5	2	2	1	0	0	0	0	0	0	0	0	0	0
LAKE	A	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0
LOS ANGELES		4911	11014	45810	745	420	176	110	36	2	0	1	0	0	0	0	0	0
MADERA	A	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0	0	0
MARIN		189	480	2248	26	10	8	7	1	0	0	0	0	0	0	0	0	0
MARIPOSA	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
MENDOCINO		17	23	105	3	0	3	0	0	0	0	0	0	0	0	0	0	0
MERCED		45	68	281	11	7	3	1	0	0	0	0	0	0	0	0	0	0
MONTEREY		214	472	2095	23	8	8	5	2	0	0	0	0	0	0	0	0	0
NAPA		41	93	394	4	1	1	1	1	0	0	0	0	0	0	0	0	0
NEVADA		22	39	154	3	1	1	1	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
ORANGE		1246	2413	10017	220		135	54	20	9	2	0	0	0	0	0	0	0	0
PLACER		74	152	601	12		7	3	1	1	0	0	0	0	0	0	0	0	0
RIVERSIDE		296	627	2463	43		19	15	6	3	0	0	0	0	0	0	0	0	0
SACRAMENTO		532	1265	4948	63		35	18	7	2	0	1	0	0	0	0	0	0	0
SAN BENITO	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO		366	669	2859	58		29	21	7	0	1	0	0	0	0	0	0	0	0
SAN DIEGO		1187	2207	9178	158		70	51	26	10	1	0	0	0	0	0	0	0	0
SAN FRANCISCO		346	773	3174	62		37	11	13	1	0	0	0	0	0	0	0	0	0
SAN JOAQUIN		167	371	1547	22		8	9	4	1	0	0	0	0	0	0	0	0	0
SAN LUIS OBISPO		45	79	335	10		6	2	2	0	0	0	0	0	0	0	0	0	0
SAN MATEO		452	1074	4864	72		33	24	13	2	0	0	0	0	0	0	0	0	0
SANTA BARBARA		191	411	1716	28		11	9	7	1	0	0	0	0	0	0	0	0	0
SANTA CLARA		563	1311	5243	126		78	36	12	0	0	0	0	0	0	0	0	0	0
SANTA CRUZ		107	204	793	14		9	3	0	2	0	0	0	0	0	0	0	0	0
SHASTA	B	0	0	0	9		4	5	0	0	0	0	0	0	0	0	0	0	0
SOLANO		83	184	736	15		6	8	1	0	0	0	0	0	0	0	0	0	0
SONOMA		145	293	1243	24		9	11	4	0	0	0	0	0	0	0	0	0	0
STANISLAUS		128	235	955	20		8	8	4	0	0	0	0	0	0	0	0	0	0
SUTTER		15	34	120	4		3	1	0	0	0	0	0	0	0	0	0	0	0
TEHAMA	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
TULARE		55	95	370	12		5	6	1	0	0	0	0	0	0	0	0	0	0
TUOLUMNE	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
VENTURA		240	424	1889	45		26	12	6	1	0	0	0	0	0	0	0	0	0
YOLO		42	91	379	8		4	3	1	0	0	0	0	0	0	0	0	0	0
YUBA	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
## SIC CODE: 7399																			
ALAMEDA		2240	6549	28070	196		110	33	26	17	6	4	0	0	0	0	0	0	0
AMADOR	A	0	0	0	2		0	2	0	0	0	0	0	0	0	0	0	0	0
BUTTE		80	121	498	20		13	5	2	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA		649	1918	8363	108		68	19	13	7	1	0	0	0	0	0	0	0	0
DEL NORTE	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
EL DORADO		29	59	253	6		4	0	2	0	0	0	0	0	0	0	0	0	0
FRESNO		679	1677	6877	91		52	18	13	8	0	0	0	0	0	0	0	0	0
GLENN	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
HUMBOLDT		64	149	647	8		4	1	2	1	0	0	0	0	0	0	0	0	0
IMPERIAL		22	48	203	11		10	1	0	0	0	0	0	0	0	0	0	0	0
INYO		8	21	79	3		2	1	0	0	0	0	0	0	0	0	0	0	0
KERN		321	1119	4674	51		34	6	9	1	1	0	0	0	0	0	0	0	0
KINGS		11	19	94	4		3	1	0	0	0	0	0	0	0	0	0	0	0
LAKE		4	7	39	4		4	0	0	0	0	0	0	0	0	0	0	0	0
LASSEN	A	0	0	0	1		0	0	1	0	0	0	0	0	0	0	0	0	0
LOS ANGELES		20874	80520	327537	1832		975	333	286	173	43	13	8	1	0	0	0	0	0
MADERA	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
MARIN		375	1247	5166	65		46	7	5	6	1	0	0	0	0	0	0	0	0
MARIPOSA	A	0	0	0	1		1	0	0	0	0	0	0	0	0	0	0	0	0
MENDOCINO		38	38	184	5		3	0	2	0	0	0	0	0	0	0	0	0	0
MERCED		61	96	621	10		6	2	1	1	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	)1000	1000-1499	1500-2499	2500-4999	)5000
MONO	A	0	0	0	6		6	0	0	0	0	0	0	0	0	0	0	0	0
MONTEREY		180	435	2155	31		18	4	9	0	0	0	0	0	0	0	0	0	0
NAPA		121	265	1153	14		5	5	2	2	0	0	0	0	0	0	0	0	0
NEVADA		42	90	274	8		4	3	1	0	0	0	0	0	0	0	0	0	0
ORANGE		4798	17205	75480	450		265	71	68	32	7	6	0	1	0	0	0	0	0
PLACER		88	186	827	24		18	3	3	0	0	0	0	0	0	0	0	0	0
RIVERSIDE		1253	3458	15302	104		64	20	12	5	2	0	0	1	0	0	0	0	0
SACRAMENTO		1424	3692	16162	134		63	33	18	15	4	1	0	0	0	0	0	0	0
SAN BENITO	A	0	0	0	2		2	0	0	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO		673	2247	8925	106		64	21	15	5	1	0	0	0	0	0	0	0	0
SAN DIEGO		2495	8278	35471	342		207	64	40	26	4	1	0	0	0	0	0	0	0
SAN FRANCISCO		3007	10757	46085	247		136	42	31	24	7	7	0	0	0	0	0	0	0
SAN JOAQUIN		327	849	3731	45		21	15	6	2	1	0	0	0	0	0	0	0	0
SAN LUIS OBISPO		127	319	1500	17		7	7	1	2	0	0	0	0	0	0	0	0	0
SAN MATEO		1506	5450	22980	123		76	21	5	13	4	4	0	0	0	0	0	0	0
SANTA BARBARA		563	1884	8634	61		28	13	10	10	0	0	0	0	0	0	0	0	0
SANTA CLARA		2953	11437	48703	265		148	43	37	23	10	3	1	0	0	0	0	0	0
SANTA CRUZ		175	454	1789	24		14	4	2	4	0	0	0	0	0	0	0	0	0
SHASTA		40	42	241	13		11	0	2	0	0	0	0	0	0	0	0	0	0
SOLANO		273	924	3646	22		12	2	5	1	1	1	0	0	0	0	0	0	0
SONOMA		243	554	2434	47		32	8	5	2	0	0	0	0	0	0	0	0	0
STANISLAUS		203	696	3347	39		26	7	4	2	0	0	0	0	0	0	0	0	0
SUTTER		53	101	416	9		2	6	1	0	0	0	0	0	0	0	0	0	0
TEHAMA	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
TULARE		104	270	1126	26		17	6	3	0	0	0	0	0	0	0	0	0	0
TUOLUMNE	B	0	0	0	4		2	0	2	0	0	0	0	0	0	0	0	0	0
VENTURA		687	2363	11519	75		45	11	9	8	1	1	0	0	0	0	0	0	0
YOLO		79	185	919	15		11	3	0	1	0	0	0	0	0	0	0	0	0
YUBA		9	18	71	4		4	0	0	0	0	0	0	0	0	0	0	0	0
** SIC CODE: 7538																			
ALAMEDA		1155	6687	21668	290		214	54	16	5	1	0	0	0	0	0	0	0	0
AMADOR		6	16	92	6		6	0	0	0	0	0	0	0	0	0	0	0	0
BUTTE		90	258	1153	39		36	2	1	0	0	0	0	0	0	0	0	0	0
CALAVERSA		13	26	136	8		7	1	0	0	0	0	0	0	0	0	0	0	0
COLUSA	A	0	0	0	3		2	1	0	0	0	0	0	0	0	0	0	0	0
CONTRA COSTA		433	1639	7120	133		109	18	5	1	0	0	0	0	0	0	0	0	0
DEL NORTE	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
EL DORADO		40	100	497	25		23	2	0	0	0	0	0	0	0	0	0	0	0
FRESNO		504	1760	7697	138		103	23	10	2	0	0	0	0	0	0	0	0	0
GLENN		3	3	8	3		3	0	0	0	0	0	0	0	0	0	0	0	0
HUMBOLDT		78	278	1470	34		31	2	1	0	0	0	0	0	0	0	0	0	0
IMPERIAL		58	177	759	23		19	4	0	0	0	0	0	0	0	0	0	0	0
INYO		12	42	177	4		3	1	0	0	0	0	0	0	0	0	0	0	0
KERN		426	1540	6851	113		84	21	6	2	0	0	0	0	0	0	0	0	0
KINGS		59	248	974	21		19	1	0	1	0	0	0	0	0	0	0	0	0
LAKE		22	39	194	11		9	2	0	0	0	0	0	0	0	0	0	0	0
LASSEN		4	3	50	5		5	0	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group:	1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	>1000	1000-1499	1500-2499	2500-4999	>5000
LOS ANGELES		6214	22263	95826	1736		1295	336	82	21	2	0	0	0	0	0	0	0	0
MADERA		45	102	566	14		10	3	1	0	0	0	0	0	0	0	0	0	0
MARIN		283	1256	5600	81		59	17	5	0	0	0	0	0	0	0	0	0	0
MARIPOSA	B	0	0	0	5		3	1	1	0	0	0	0	0	0	0	0	0	0
MENDOCINO		60	183	880	20		15	5	0	0	0	0	0	0	0	0	0	0	0
MERCED		76	209	766	28		24	3	1	0	0	0	0	0	0	0	0	0	0
MODOC	A	0	0	0	3		3	0	0	0	0	0	0	0	0	0	0	0	0
MONO	A	0	0	0	3		3	0	0	0	0	0	0	0	0	0	0	0	0
MONTEREY		198	750	3332	60		46	8	6	0	0	0	0	0	0	0	0	0	0
NAPA		65	251	1096	21		16	5	0	0	0	0	0	0	0	0	0	0	0
NEVADA		29	83	417	16		15	1	0	0	0	0	0	0	0	0	0	0	0
ORANGE		1666	6594	28837	459		332	102	20	4	1	0	0	0	0	0	0	0	0
PLACER		77	209	1042	30		27	3	0	0	0	0	0	0	0	0	0	0	0
PLUMAS		4	9	70	4		4	0	0	0	0	0	0	0	0	0	0	0	0
RIVERSIDE		487	1555	6734	151		120	24	5	2	0	0	0	0	0	0	0	0	0
SACRAMENTO		763	2492	11039	214		155	43	13	3	0	0	0	0	0	0	0	0	0
SAN BENITO	A	0	0	0	2		1	1	0	0	0	0	0	0	0	0	0	0	0
SAN BERNARDINO		693	2180	9802	232		184	34	13	1	0	0	0	0	0	0	0	0	0
SAN DIEGO		1621	5442	23275	475		361	92	18	4	0	0	0	0	0	0	0	0	0
SAN FRANCISCO		622	2837	12034	156		111	30	13	2	0	0	0	0	0	0	0	0	0
SAN JOAQUIN		360	1208	5453	108		87	17	1	3	0	0	0	0	0	0	0	0	0
SAN LUIS OBISPO		128	448	2077	48		38	6	4	0	0	0	0	0	0	0	0	0	0
SAN MATEO		532	2567	10938	158		124	27	5	2	0	0	0	0	0	0	0	0	0
SANTA BARBARA		279	1012	4464	101		79	18	4	0	0	0	0	0	0	0	0	0	0
SANTA CLARA		1037	4390	19182	324		250	52	21	1	0	0	0	0	0	0	0	0	0
SANTA CRUZ		168	561	2468	57		47	9	1	0	0	0	0	0	0	0	0	0	0
SHASTA		86	265	1319	41		36	5	0	0	0	0	0	0	0	0	0	0	0
SISKIYOU		14	33	151	8		8	0	0	0	0	0	0	0	0	0	0	0	0
SOLANO		131	446	1943	47		36	9	2	0	0	0	0	0	0	0	0	0	0
SONOMA		303	913	4074	111		89	19	2	1	0	0	0	0	0	0	0	0	0
STANISLAUS		261	839	4053	78		57	16	5	0	0	0	0	0	0	0	0	0	0
SUTTER	B	0	0	0	11		11	0	0	0	0	0	0	0	0	0	0	0	0
TEHAMA		63	244	1182	13		8	3	1	1	0	0	0	0	0	0	0	0	0
TRINITY	A	0	0	0	4		4	0	0	0	0	0	0	0	0	0	0	0	0
TULARE		133	372	1645	58		51	7	0	0	0	0	0	0	0	0	0	0	0
TUOLUMNE		22	67	310	10		9	1	0	0	0	0	0	0	0	0	0	0	0
VENTURA		267	963	3935	94		80	10	4	0	0	0	0	0	0	0	0	0	0
YOLO		231	973	4450	42		24	13	3	2	0	0	0	0	0	0	0	0	0
YUBA	A	0	0	0	7		7	0	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF INDUSTRIES BY SIC AND SIZE
IN CALIFORNIA:

County	Data Suppressed	# Mid-March Employees	1st Qtr Payroll	Total Annual Payroll	Total # of Establistments	Total # of Establisments Employee Size Group: 1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	>1000	1000-1499	1500-2499	2500-4999	>5000
** SIC CODE: 2910																		
CONTRA COSTA		4627	39741	164213	6	1	0	0	0	1	0	0	3	1	0	1	0	0
KERN		1281	10988	42023	12	1	2	2	2	1	2	2	0	0	0	0	0	0
KINGS	F	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
LOS ANGELES		7354	60859	255793	22	3	1	1	3	1	4	3	4	2	2	0	0	0
ORANGE	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SACRAMENTO	A	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
SAN DIEGO	A	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SAN LUIS OBISPO	B	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
SAN MATEO		33	195	808	3	0	2	1	0	0	0	0	0	0	0	0	0	0
SANTA BARBARA	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
SANTA CLARA	D	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
SOLANO	E	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
VENTURA	B	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0

APPENDIX B

RULE 442. USAGE OF SOLVENTS

(Adopted May 7, 1976) (Amended Sept. 2, 1977) (Amended March 3, 1978)
(Amended July 6, 1979) (Amended March 5, 1982)

(a) A person shall not discharge organic materials into the atmosphere from equipment in which organic solvents or materials containing organic solvents are used, unless such emissions have been reduced by at least 85 percent or to the following:

(1) Organic materials that come into contact with flame or are baked, heat cured or heat polymerized, are limited to 1.4 kilograms (3.1 pounds) per hour not to exceed 6.5 kilograms (14.3 pounds) per day.

(2) Organic materials emitted into the atmosphere from the use of photochemically reactive solvents are limited to 3.6 kilograms (7.9 pounds) per hour, not to exceed 18 kilograms (39.6 pounds) per day, except as provided in subsection (a)(1). All organic materials emitted for a drying period of 12 hours following their application shall be included in this limit.

(3) Through and including November 30, 1980, organic materials emitted into the atmosphere from the use of non-photochemically reactive solvents are limited to 180 kilograms (396 pounds) per hour not to exceed 1,350 kilograms (2,970 pounds) per day, except as provided in subsection (a)(1). All organic materials emitted for drying period of 12 hours following their application shall be included in this limit.

(4) On and after December 1, 1980, organic materials emitted into the atmosphere from the use of non-photochemically reactive solvents are limited to 36.8 kilograms (81 pounds) per hour not to exceed 272 kilograms (600 pounds) per day, effective December 1, 1980. All organic materials emitted for a drying period of 12 hours following their application shall be included in this limit.

(5) The provisions of subsection (a)(4) shall not apply to:

(A) Coating application to aerospace subassemblies or assemblies prior to March 3, 1983, provided the emissions of organic materials from the use of non-photochemically reactive solvents is limited to 100 kilograms (220 pounds) per hour not to exceed 600 kilograms (1,320 pounds) per day, effective December 1, 1980.

(B) Use of undertread cementers in tire manufacturing processes prior to March 3, 1983, provided the emission of organic materials from the use of undertread cementers is limited to 180 kilograms (396 pounds) per hour not to exceed 1,350 kilograms (2,970 pounds) per day effective December 1, 1980.

(C) Any primer or topcoat application line of a motor vehicle or motor vehicle component production line for a light or medium-duty vehicle (as defined in Section 1900, Title 13, California Administrative Code) prior to March 3, 1983, provided the emissions of organic materials from the use of non-photochemically reactive solvents is limited to 180 kilograms (396 pounds) per hour not to exceed 1,350 kilograms (2,970 pounds) per day.

(6) A person operating equipment which is subject to the provisions of subsection (a)(4) shall comply with the following increments of progress:

(A) Submit by September 1, 1978, to the Executive Officer a control plan which describes the steps that will be taken to achieve compliance with the provisions of this rule.

(B) By December 1, 1978, negotiate and sign all necessary contracts for emission control systems or issue orders for the purchase of component parts to accomplish emission control.

(C) By June 1, 1979, initiate construction or installation of emission control equipment.

(D) By June 1, 1980, complete construction or installation of emission control equipment.

(E) By December 1, 1980, assure final compliance with the provisions of subsection (a)(4) of this rule.

(b) Equipment designed for processing in a continuous web, strip or wire which emit organic materials shall be collectively subject to the limitations stated in subsection (a)(1).

(c) Emissions of organic materials into the atmosphere required to be controlled by subsection (a) shall be reduced by:

(1) Incineration, provided that 90 percent or more of the carbon in the organic material being incinerated is oxidized to non-organic materials, or

(2) Incineration, provided that the concentration of organic material following incineration is less than 60 ppm, calculated as carbon and with dilution, or

(3) Adsorption, or

(4) Processing in a manner determined by the Air Pollution Control Officer to be not less effective than (1) or (3) above.

(d) A person shall not use any organic solvent containing a total of four percent or more by volume of the materials described in Rule 102 under PHOTOCHEMICALLY REACTIVE SOLVENT for the commercial cleaning of garments and fabrics unless the emission of organic materials into the atmosphere has been reduced at least 90 percent by weight.

(e) A person shall not use photochemically reactive solvent to thin, reduce or dilute industrial and commercial metal surface coatings unless the emission of organic materials into the atmosphere has been reduced at least 85 percent by weight.

(f) A person shall not use photochemically reactive solvent in industrial and commercial surface cleaning or degreasing operations unless the emission of organic materials into the atmosphere has been reduced at least 85 percent by weight.

(g) A person shall not during any one day dispose of a total of more than 5 liters (1.3 gallons) of any photochemically reactive solvent, or of any material containing more than 5 liters (1.3 gallons) of any photochemically reactive solvents by any means which will permit the evaporation of such solvents into the atmosphere.

(h) The provisions of this rule shall not apply to:

(1) The manufacture of organic solvents, or the transport or storage of organic solvents, or the transport or storage of materials containing organic solvents.

(2) The use of equipment for which other requirements are specified by Rules 461, 462, 463, or 464 or which are exempt from air pollution control requirements by said rules.

(3) The spraying or other employment of organic solvents as insecticides, pesticides, or herbicides.

(4) The use of water reducible materials, provided that:

(A) The volatile content of such material is not photochemically reactive and consists of at least 80 percent water by volume, and

(B) The organic solvent or any material containing organic solvent does not come into contact with flame.

(5) The use of high solid materials, provided that:

(A) The volatile content of such materials is not photochemically reactive and does not exceed 20 percent by volume of said material, and

(B) More than 50 percent by volume of such volatile material is evaporated before entering a chamber heated above ambient application temperature, and

(C) The organic solvent or any material containing organic solvent does not come into contact with flame.

(6) The use of ultra high solid materials, provided that:

(A) The volatile content of such material is not photochemically reactive and does not exceed 5 percent by volume of said material and

(B) The organic solvent or any material containing organic solvent does not come into contact with flame.

(7) The use of equipment which complies with the emission limits and/or solvent coating formulation requirements specified in source specific rules of Regulation XI.

(8) The use of 1,1,1-trichloroethane, methylene chloride, and trichlorotrifluoroethane.

RULE 1122. SOLVENT CLEANERS (DEGREASERS)

(Adopted March 2, 1979) (Amended June 1, 1979)
(Amended February 1, 1980) (Amended July 8, 1983)

(a) Definitions

For the purpose of this rule, the following definitions shall apply:

(1) Cold Cleaner is any batch loaded, non-boiling solvent degreaser.

(2) Conveyorized Degreaser is any degreaser which uses an integral continuous, mechanical system for moving materials or parts to be cleaned into and out of a solvent liquid or vapor cleaning zone.

(3) Drag-out is that solvent carried out of a degreaser along with a part being removed from the degreaser. The solvent may exist as a liquid coating the part of a liquid entrapped in irregular surfaces and cavities within or on the part.

(4) Degreaser is any liquid container and ancillary equipment designed to clean and remove soils from surfaces using non-aqueous solvents.

(5) Freeboard Height

(A) For cold cleaning tanks, freeboard height is the distance from the top of the solvent to the top of the tank.

(B) For vapor degreasing tanks, freeboard height is the distance from the solvent vapor-air interface to the top of the tank.

(6) Freeboard Ratio is the freeboard height divided by the smaller of the length or width of the degreaser.

(7) Open-Top Vapor Degreaser is any batch loaded, boiling solvent degreaser.

(8) Solvent is any non-aqueous organic liquid used to clean and remove soils from surfaces in a degreasing operation. These solvents are principally derived from petroleum and include petroleum distillates, chlorinated hydrocarbons, ketones, and alcohols. They are used along with or in blends to remove water insoluble soils for cleaning purposes and to prepare parts for painting, plating, repair, inspection, assembly, heat treatment, or machining.

(9) Solvent Cleaning (degreasing) means those processes using non-aqueous solvents to clean and remove soils, oils, dirt, and greases from surfaces by dissolving or dispersing them with organic compounds which do not adhere to the surface being cleaned.

(10) Volatile Organic Compound (VOC) is any volatile compound which contains the element carbon; excluding carbon monoxide, carbon dioxide, carbonic acid, carbonates and metallic carbides; and excluding methane, 1,1,1-trichloroethane, methylene chloride, tri-fluoromethane and chlorinated-fluorinated hydrocarbons.

(11) Wipe Cleaning is that method of cleaning which utilizes a material such as a rag wetted with a solvent, coupled with a physical rubbing process to remove contaminants from surfaces.

(12) High-Vapor Cutoff Thermostat is a combination safety switch consisting of a temperature sensor located above the design vapor level of an open-top degreaser or conveyorized degreaser, and a response switch that shuts off heat to the sump. High vapor thermostats must have manual reset capabilities only.

(13) Refrigerated Condenser is a control device consisting of primary coils which carry a refrigerant to condense solvent vapor from the degreaser bath.

(14) Refrigerated Freeboard Chiller is a control device which is mounted above the water jacket or primary condenser coils, consisting of secondary coils which carry a refrigerant to provide a chilled air blanket above the solvent vapor to reduce emissions from the degreaser bath.

(15) Remote Reservoir Cold Cleaner is any device in which liquid solvent is pumped through a sink-like work area which drains back into an enclosed container while parts are being cleaned.

(b) Equipment Requirements

A person who uses solvent containing VOC, as defined in subsection (a)(10), to clean or degrease surfaces shall use a device for such operations which includes all of the following equipment:

(1) A container for the solvent. The articles being cleaned are either immersed in the solvent or suspended above the solvent for brushing or flushing.

(2) An apparatus or cover for the solvent tank which prevents solvent evaporation when not processing in the degreaser. The cover shall be closed or in place on the tank at all times except while processing work through the degreaser.

(3) A facility for draining cleaned parts that allows the drained solvent or drag-out to be returned to the solvent container.

(4) For cold solvent cleaning, one of the following control devices:

(A) A freeboard such that the freeboard ratio is equal to or greater than 0.75.

(B) A water cover if the solvent is insoluble in and heavier than water, or

(C) Any other system of equivalent control approved by the Executive Officer.

(5) For open-top vapor degreasing or conveyorized degreasing all the following:

(A) high vapor cutoff thermostat with manual reset; and

(B) a freeboard such that the freeboard ratio is greater than or equal to 0.75, or if exclusively perchloroethylene is used, a control device consisting of either a refrigerated chiller, water jacket, or condensing coils.

(6) For vapor degreasers or conveyorized degreasers having an open solvent surface area of more than 1.0 square meters (10.8 square feet), one of the following or a combination of the following control devices approved by the Executive Officer:

(A) refrigerated freeboard chiller, designed such that the refrigerant temperature at the degreaser outlet does not exceed 40 F.

(B) a carbon adsorption system having a capture efficiency of 90 percent in terms of organic input to the bed; or

(C) an operating or control technique which achieves an efficiency equivalent to any of the above.

(7) For conveyorized degreasers, all of the following control measures:

(A) A hood or enclosure with a delivery system or ductwork to collect degreaser emissions, exhaust to a carbon adsorber, or equivalent control method approved by the Executive Officer.

(B) Either a drying tunnel, which is an extension from the exit of the conveyorized degreaser to allow more time for the cleaned parts to dry completely with resulting emissions captured by the main control enclosure, or other means such as a rotating (tumbling) basket, sufficient to prevent cleaned parts from carrying solvents liquid out of the degreaser, and

(C) Entrances and exits shall silhouette work so that the average clearance between each part and the edge of the degreaser opening is either less than 10 cm or less than 10% of the width of the opening.

(c) Operating Requirements

A person who uses solvent containing VOC as defined in subsection (a)(10), to clean or degrease surfaces shall conform to the following operating requirements:

(1) Solvent shall not leak from any portion of the degreasing equipment.

(2) Solvent including waste solvent shall not be stored or disposed of in such a manner as will cause or allow its evaporation into the atmosphere.

(3) After distillation recovery of waste solvent, residues shall not contain more than 20% volatile organic compound.

(4) A device designed to function as a anti-evaportion cover for a degreaser shall not be displaced or removed for more than five consecutive minutes unless processing work in the degreaser or performing maintenance on the degreaser.

(5) For cold cleaning, cleaned parts shall be drained until dripping ceases.

(6) Solvent flow cleaning shall consist only of a liquid stream, rather than a fine, atomized, or shower-type spray, and such operation shall not cause liquid solvent to splash outside of the solvent container. Alternatively, emissions from the solvent flow cleaning operation must be reduced by at least 85 percent before being vented to the atmosphere.

(7) Solvent agitation, where necessary, shall be achieved only by pump recirculation, or by means of a mixer, or with ultrasonics. Air agitation of the solvent bath shall be used only under the following conditions:

  (A) The air flow into the air agitation cleaner may not exceed two pounds per square inch gauge.

  (B) The top or cover must remain closed while the air agitation system is in operation.

(8) For an open-top degreaser equipped with a lip exhaust, the exhaust shall be turned off when the degreaser is covered.

(9) The vertical speed of a powered hoise or conveyor, if one is used, shall not be more than 3.4m/min (11.2 ft/min) when lowering and raising parts.

(10) For vapor degreasers, the following measures:

  (A) During start up, the primary condenser and the refrigerated freeboard chiller, if one is used, shall be turned on either simulaneously or before the sump heater. During shutdown, the sump heater shall be turned off, either simultaneously or before the condenser water and refrigerated freeboard chiller are turned off. The degreaser must be covered whenever the primary condenser is turned off.

  (B) Solvent flow cleaning shall be done within the vapor region.

  (C) The work load shall be degreased in the vapor zone until condensation ceases.

(11) For remote reservoir cold cleaner, the following measures:

  (A) The cover for the drainage tank must be closed at all times except when the tank is being cleaned or repaired.

(B) The work area shall not be exposed to drafts greater than 40 meters per minute (131 ft/min).

(d) Exemptions

The provisions of this rule shall not apply to equipment using only the following cleaning materials or methods:

(1) Emulsion cleaners having a solvent content, as used, of 2 percent or less by volume.

(2) Wipe cleaning.

(3) Cold solvent cleaning is exempt from the provisions of paragraph (b)(4) if the vapor pressure of the volatile organic compounds is equal to or less than 33 mm Hg or 0.6 psia at 38° C. The freeboard ratio must then still be 0.5 or greater.

(4) Conveyorized degreasers with less than 2.0 square meters (21.6 square feet) of air/vapor interface are exempt from the provisions of paragraph (b)(7)(A).

(5) Vapor degreasers or conveyorized degreasers that are equipped with refrigerated condensers are exempt from the provisions of paragraph (b)(6), provided that the refrigerant temperature at the degreaser outlet is 55° F or less.

(6) Vapor degreasers or conveyorized degreasers using exclusively perchloroethylene are exempt from the provisions of paragraph (b)(6).

(7) Solvent cleaning using exclusively perchloroethylene to clean non-metal surfaces.

(e) Effective Dates

(1) The owner or operator of any solvent cleaning or degreasing facility subject to this rule for which a Permit to Construct is issued on or after July 8, 1983 shall comply with the provisions of this rule at the time of installation.

(2) The owner or operator of any existing solvent cleaning or degreasing facility which was issued a Permit to Construct prior to July 8, 1983 shall comply with the provisions of this rule 9 months after the amended date.

(f) Additional Requirements

Notwithstanding the provisions of Rule 442(h)(7), the owner or operator of any solvent metal cleaning or degreasing facility shall comply with the provisions of Rule 442(f).

RULE 102. PHOTOCHEMICALLY REACTIVE SOLVENT

(Amended September 2, 1977)

PHOTOCHEMICALLY REACTIVE SOLVENT means any solvent with an aggregate or more than 20 percent of its total volume composed of the chemical compounds classified below or which exceeds any of the following individual percentage composition limitations, referred to the total volume of solvent;

(a) A combination of hydrocarbons, alcohols, aldehydes, ethers, esters or ketones having an olefinic or chloolefinic type of unsaturation except perchloroethylene: 5 percent;

(b) A combination of aromatic compounds with eight or more carbon atoms to the moelcule except ethylbenzene, methyl benzoate and phenyl acetate: 8 percent;

(b) A combination of ethylbenzene, ketones having branched hydrocarbon structures, trichloroethylene or toluene: 20 percent.

Whenever any organic solvent or any constituent of an organic solvent may be classified from its chemical structure into more than one of the above groups of organic compounds, it shall be considered as a member of the most reactive chemical group, that is, that group having the least allowable percent of the total volume of solvents.

APPENDIX C

ADDITIONAL SOURCES OF INFORMATION

Trade Associations

Halogenated Cleaning Solvents Association
c/o SOCMA, 1075 Central Park Ave.,
Scarsdale, NY 10583

Reclaim Managers Association
Tektronix, Inc.,
Delivery Station 68-000
Beaverton, OR 97077

National Association of Recycling Industries
330 Madison Ave.,
New York, NY 10017
(212)867-7330

National Paints and Coatings Association
1500 Rhode Island Ave., N.W.,
Washington, DC 20005
(202)462-6272

National Association of Solvent Recyclers
1406 Third National Building,
Dayton, OH 45402
(513)223-0419

National Association of Printers and Lithographers
780 Palisade Ave.,
Teaneck, NJ 07666
(201)342-0700

National Association of Printing Ink Manufacturers
550 Mamaroneck Ave.,
Harrison, NY 10528
(914)698-1004

National Agricultural Chemicals Association
1155 15th. Street, N.W.,
Washington, DC 20005

Federation of Societies for Coatings Technology
Suite 830, 1315 Walnut St.,
Philadelphia, PA 19107
(215)545-1506

Chemical Coaters Association
Box 241
Wheaton, IL 60187
(312)668-0949

International Brotherhood of Painters and Allied Trades
1750 New York Ave.,N.W.,
Washington, DC 20006
(202)637-0700

The Powder Coating Institute
44 Husted Lane
Greenwich, CT 06830
(203)622-1093

Journals

Canadian Printer and Publisher
Maclean Hunter Ltd.,
481 University Ave.,
Toronto, Ontario, M5W 1A7

Editor & Publisher
Editor & Publishing Co., Inc.,
575 Lexington Ave.,
New York, NY 10022

Journal of Coatings Technology
Federation of Societies for Coatings Technology
Suite 830, 1315 S. Walnut St.,
Philadelphia, PA 19107

American Paint & Coatings Journal
American Paint Journal Co.,
2911 Washington Ave.,
St. Louis, MO 63103

Journal of Coatings Technology
Federation of Societies for Coatings Technologies
Suite 830, 1315 S. Walnut St.,
Philadelphia, PA 19107

Industrial Finishing
Hitchcock Publishing Co.,
Hitchcock Bldg.,
Wheaton, IL 60187

The Painters and Allied Trades Journal
International Brotherhood of Painters and Allied Trades
1750 New York Ave.,N.W.,
Washington, DC 20006

Coatings Magazine
86 Wilson St.,
Oakville, Ontario
Canada L6K 3G5

Products Finishing Magazine
Gardner Publications,Inc.,
6600 Clough Pike,
Cincinnati, OH 45244

APPENDIX D

SMALL PACKAGED DISTILLATION EQUIPMENT

The tables in this appendix present data on existing commercial packaged systems for small scale solvent recovery. The data were solicited from 48 U.S. equipment manufacturers.

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS

	Acra Electric Corp. 3801 N.25th Ave. Schiller Park,IL 60176	Artisan Industries 73 Pond Street Waltham,MA 02154	Baeuerle & Morris,Inc. 282 South Gulph Road King of Prussia,PA 19406	Baron-Blakeslee,Inc. 2001 N.Janice Ave. Melrose Park,IL 60160		
Technical Description	Model # SD-15	Model	Model	Model#NRS-60	Model#NRS-120	Model#NRS-180
Solvent Boiling Range, F						
Feed Capacity, Gal	5	5-1440 GPH		60	120	180
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %	85					
Operating Time, Hr	1.5					
Cold Start Heat-up Time, Hr	1.84					
Distillation Rate, GPH				45-60	90-120	135-180
Utilities				Steam 100Lb/hr	Steam 190Lb/hr	Steam 280Lb/hr
Voltage, V	115/230			230/460	230/460	
Phase				3	3	3
Power Rating, KW	3.66			27	54	81
Cooling Water Consumption, GPH	73 Gal.			200	415	620
Material of Construction				SS	SS	SS
Equipment Dimensions, In	21 dia,27 ht.			64x44x81	69x54x86	86x64x90
Weight, Lbs	85			900	1260	1590
Type of Cooling	Water			Water	Water	Water
Type of Heating				Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat					
Options				Liquid level control	Liquid level control	Liquid level control
F.O.B. Cost, $	775	Few Thousand-1,400,000	15,000-150,000			
Delivery Time, Wks.						
Payment Terms	Net Cash 30 Days					
Solvents Recovered	TCE,1,1,1-TCE,PCE etc.			TCE,1,1,1-TCE,PCE	TCE,1,1,1-TCE,PCE	TCE,1,1,1-TCE,PCE

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Baron-Blakeslee, Inc. 2001 W.Janice Ave. Melrose Park, IL 60160					
Technical Description	Model#NRS-300	Model#HRS-60	Model#HRS-120	Model#HRS-180	Model#HRS-300	Model#MRW-20
Solvent Boiling Range, F						
Feed Capacity, Gal	300	70	95	150	240	30
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	225-300	45-60	90-120	135-180	225-300	20
Utilities	Steam 465Lb/hr.	Steam 125Lb/hr.	Steam 225LB/hr.	Steam 350Lb/hr	Steam 500Lb/hr	
Voltage, V		230/460	230/460	460		230
Phase		3	3	3		3
Power Rating, KW		30	54	90		7.5
Cooling Water Consumption, GPH	1020	225-300	375-500	600-750	900-1200	150
Material of Construction	SS	SS	SS	SS	SS	Heavy Gauge SS
Equipment Dimensions, In	98x74x93	60x43x81	66x50x86	75x54x91	87x65x96	47x36x71
Weight, Lbs	2200	800	1140	1450	2000	610
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features						
Options	Liquid level control	Liquid level control	Liquid level control	Liquid level control	Liquid level control	Liquid level control
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	TCE,1,1,1-TCE,PCE	TCE,1,1,1-TCE,PCE	TCE,1,1,1-TCE,PCE	TCE,1,1,1-TCE,PCE	TCE,1,1,1-TCE,PCE	Chlorofluorocarbons

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Baron-Blakeslee,Inc. 2001 N.Janice Ave. Melrose Park,IL 60160				
Technical Description	Model#MRW-60	Model#MRW-120	Model#MRR-10	Model#MRR-20	Model#MRR-60
Solvent Boiling Range, F					
Feed Capacity, Gal	70	95	8	30	65
Maximum Degree of Contamination, %					
Typical Purity of Product, %					
Typical Yield, %					
Operating Time, Hr					
Cold Start Heat-up Time, Hr					
Distillation Rate, GPH	60	120	10	20	60
Utilities					
Voltage, V	230	230	230	230	230
Phase	3	3	1	3	3
Power Rating, KW	18	36	3/3.5	9	21/24
Cooling Water Consumption, GPH	350	750			
Material of Construction	Heavy Gauge SS	Heavy Gauge SS	Heavy gauge SS	Heavy Gauge SS	Heavy Gauge SS
Equipment Dimensions, In	56x43x81	66x50x86	35x30x61	40x43x73	75x52x97
Weight, Lbs	800	1140	600	1250	2000
Type of Cooling	Water	Water	Refrigeration	Refrigeration	Refrigeration
Type of Heating	Electric	Electric	Electric	Electric	Electric
Control Features					
Options	Filtration	Filtration	Filtration *Level control*	Filtration *Level control*	Filtration *Level control*
F.O.B. Cost, $					
Delivery Time, Wks.					
Payment Terms					
Solvents Recovered	Chlorofluorocarbons	Chlorofluorocarbons	Chlorofluorocarbons	Chlorofluorocarbons	Chlorofluorocarbons

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Branson Cleaning Equipment Co. Parrot Drive,P.O.Box 768 Shelton,CT 06484					
Technical Description	Model#S110W	Model#S111W	Model#S120W	Model#S121W	Model#S130W	Model#S131W
Solvent Boiling Range, F						
Feed Capacity, Gal	22	22	22	22	70	70
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	7.8	9.3-14.9	16.1	21.3-31.3	26.7	37.1-54.7
Utilities	Steam 10.5Lb/hr.	Steam 14.5Lb/hr.	Steam 21Lb/hr.	Steam 29Lb/hr.	Steam 35.5Lb/hr.	Steam 50.5Lb/hr.
Voltage, V	230	230	230	230	230	230
Phase	1	1	3	3	3	3
Power Rating, KW	3	4	6	8	10	14
Cooling Water Consumption, GPH	114	18-96	240	42-210	396	72-366
Material of Construction	SS 304L	SS 304L	SS 304L	SS 304L	SS 304L	SS 304L
Equipment Dimensions, In	25.5x22x51	25.5x22x51	25.5x22x51	25.5x22x51	38x30x63	38x30x63
Weight, lbs	240	240	250	250	450	450
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Electric/Steam	Electric/Steam	Electric/Steam	Electric/Steam	Electric/Steam	Electric/Steam
Control Features	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control
Options	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes
F.O.B. Cost, $	3,000					
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	Freon TMC	1,1,1-TCE,Freon TF	Freon TMC	1,1,1-TCE,Freon TF	Freon TMC	1,1,1-TCE,Freon TF

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Branson Cleaning Equipment Co. Parrot Drive,P.O.Box 768 Shelton,CT 06484					
Technical Description	Model#S140W	Model#S141W	Model#S110R	Model#S111R	Model#S120R	Model#S121R
Solvent Boiling Range, F						
Feed Capacity, Gal	70	70	22	22	22	22
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	48.9	66.9-95.8	7.8	9.3-14.9	16.1	21.3-31.3
Utilities	Steam 65Lb/hr.	Steam 86Lb/hr.	Steam 10.5Lb/hr.	Steam 14.5Lb/hr.	Steam 21Lb/hr.	Steam 29Lb/hr.
Voltage, V	230	230	230	230	230	230
Phase	3	1	1	1	3	3
Power Rating, KW	18	24	3	4	6	8
Cooling Water Consumption, GPH	720	132-636				
Material of Construction	SS 304L	SS 304L	SS 304L	SS 304L	SS 304L	SS 304L
Equipment Dimensions, In	38x30x63	38x30x63	25.5x42x51.5	25.5x42x51.5	25.5x60x51.5	25.5x60x51.5
Weight, Lbs	500	500	450	475	500	450
Type of Cooling	Water	Water	Refrigeration	Refrigeration	Refrigeration	Refrigeration
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control
Options	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant drier for azeotropes
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	Freon TMC	1,1,1-TCE,Freon TF	Freon TMC	1,1,1-TCE,Freon TF	Freon TMC	1,1,1-TCE,Freon TF

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Branson Cleaning Equipment Parrot Drive,P.O.Box 768 Shelton,CT 06484			Crest Ultrasonics Corp. Scotch Rd,Mercer County Airport Trenton,NJ 08628		
Technical Description	Model#S130R	Model#S131R	Model#S140R	Model#CRS-10L	Model#CRS-10H	Model#CRS-10U
Solvent Boiling Range, F						
Feed Capacity, Gal	70	70	70	12	12	12
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	26.7	37.1-54.7	48.9	10	10	10
Utilities	Steam 35.5Lb/hr.	Steam 50.5Lb/hr.	Steam 65Lb/hr.	Steam 11Lb/hr.	Steam 18Lb/hr.	Steam 18Lb/hr.
Voltage, V	230	230	230	240	240	240
Phase	3	3	3	1	1	1
Power Rating, KW	10	14	18	3	5	5
Cooling Water Consumption, GPH				45	45	120
Material of Construction	SS 304L	SS 304L	SS 304L	SS	SS	SS
Equipment Dimensions, In	38x68x63.5	38x77x63.5	38x77x63.5	28x24x56	28x24x56	28x24x56
Weight, Lbs	900	1000	1000			
Type of Cooling	Refrigeration	Refrigeration	Refrigeration	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat	Thermostat	Thermostat
Options	Solvent transfer pump, Solvent inlet strainer, Desiccant direr for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant direr for azeotropes	Solvent transfer pump, Solvent inlet strainer, Desiccant direr for azeotropes	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage
F.O.B. Cost, $			11,000			
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	Freon TMC	1,1,1-TCE,Freon TF	Freon TMC	CFC-113 and its alcohol azeotropes	1,1,1-TCE,TCE,PCE	CFC-113,Its alcohol azeotropes,1,1,1-TCE, TCE,PCE,Methylene Chloride and its azeotropes

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Crest Ultrasonics Corp. Scotch Rd,Mercer County Airport Trenton,NJ 08628					
Technical Description	Model#CRS-20L	Model#CRS-20H	Model#CRS-20U	Model#CRS-40L	Model#CRS-40H	Model#CRS-40U
Solvent Boiling Range, F						
Feed Capacity, Gal	12	16	16	28	28	47
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	20	20	20	40	40	40
Utilities	Steam 22Lb/hr.	Steam 36Lb/hr.	Steam 36Lb/hr.	Steam 43Lb/hr.	Steam 65Lb/hr.	Steam 65Lb/hr.
Voltage, V	240	240	240	240	240	240
Phase	3	3	3	3	3	3
Power Rating, KW	6	10	10	12	18	18
Cooling Water Consumption, GPH	90	90	240	180	180	480
Material of Construction	SS	SS	SS	SS	SS	SS
Equipment Dimensions, In	28x24x56	32x26x64	32x26x64	38x26x70	38x26x70	38x38x70
Weight, Lbs						
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat	Thermostat	Thermostat	Thermostat	Thermostat	Thermostat
Options	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	Same as CRS-10L	Same as CRS-10H	Same as CRS-10U	Same as CRS-10L	Same as CRS-10H	Same as CRS-10U

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Crest Ultrasonics Corp. Scotch Rd,Mercer County Airport Trenton,NJ 08628			DCI Corporation 5752 W.79th.St. Indianapolis,IN 46268	Detrex Chemical Industries,Inc. P.O.Box 501 Detroit,MI 48232	
Technical Description	Model#CRS-80L	Model#CRS-80H	Model#CRS-80U	Model#D1-DG-15	Model#FC-6-EW	Model#FC-15-EW
Solvent Boiling Range, F						
Feed Capacity, Gal	47	47	75		52	52
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH				15	7-25	25-62
Utilities	Steam 86Lb/hr.	Steam 130Lb/hr.	Steam 130Lb/hr.			Steam 54Lb/hr.
Voltage, V	240	240	240	110	230/460	230/460
Phase	3	3	3		3	3
Power Rating, KW	24	36	36		6	15
Cooling Water Consumption, GPH	360	360	960	600	23-246	78-615
Material of Construction	SS	SS	SS	Carbon steel	SS	SS
Equipment Dimensions, In	38x38x70	38x38x70	56x38x70	57.5x43x49	34x34x66	34x34x66
Weight, Lbs					510	530
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Direct steam	Electric	Electric
Control Features	Thermostat	Thermostat	Thermostat	Automatic	Automatic	Automatic
Options	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	Refrigerated cooling, Non-standard voltage	SS construction,Indirect steam heating	Steam heating	Steam heating
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	Same as CRS-10L	Same as CRS-10H	Same as CRS-10U	Chlorinated,Aliphatics, Aromatic,Fluorocarbon	TCE,1,1,1-TCE,Freon TF	TCE,1,1,1-TCE,Freon TF

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Detrex Chemical Industries,Inc. P.O.Box 501 Detroit,MI 48232					
Technical Description	Model#FC-30-EW	Model#FC-54-EW	Model#FC-6-ER	Model#FC-15-ER	Model#FC-24-ER	Model#FC-65-SW
Solvent Boiling Range, F						
Feed Capacity, Gal	170	170	52	52	170	170
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	55-124	118-159	7-25	25-62	40-49	122-200
Utilities	Steam 108Lb/hr.	Steam 194Lb/hr.				Steam 108/225/234Lb/hr.
Voltage, V	230/460	230/460	230/460	230/460	230/460	
Phase	3	3	3	3	3	
Power Rating, KW	30	54	6	25	24	
Cooling Water Consumption, GPH	170-1229	367-430				477-1217
Material of Construction	SS	SS	SS	SS	SS	SS
Equipment Dimensions, In	58x46x88	82x34x69	82x34x69	82x34x69	118x46x88	58x46x88
Weight, Lbs	815	845	850	1500	1900	815
Type of Cooling	Water	Water	Refrigeration	Refrigeration	Refrigeration	Water
Type of Heating	Electric	Electric	Electric	Electric	Electric	Steam
Control Features	Automatic	Automatic	Automatic	Automatic	Automatic	Automatic
Options	Steam heating	Steam heating				
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	TCE,1,1,1-TCE,Freon TF	TCE,1,1,1-TCE,Freon TF	TCE,1,1,1-TCE,Freon TF	TCE,1,1,1-TCE,Freon TF	TCE,1,1,1-TCE,Freon TF	TCE,1,1,1-TCE,Freon TF

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS

	Finish Engineering Co. 921 Greengarden Road Erie,PA 16501				Garden Machinery Corp. 700 W.Summit Ave. Charlotte,NC 28233	
Technical Description	Model#LS-Jr	Model#LS-15	Model#LS-55	Model#LS-55ST	Model#50	Model#100
Solvent Boiling Range, F ,	100-320	100-320	100-320	100-320		
Feed Capacity, Gal	3-5	15	55	55		
Maximum Degree of Contamination, %						
Typical Purity of Product, %		99	99	99		
Typical Yield, %		80-95	80-95	80-95		
Operating Time, Hr	8					
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH					50-60	100-125
Utilities						
Voltage, V	110/220		220	440		
Phase	1		1	3		
Power Rating, KW	0.5	1.65	6.2	15/30		
Cooling Water Consumption, GPH	7.5-15	15-30	60-90	120-240		
Material of Construction	SS					
Equipment Dimensions, In	27x20x19	44x30x36	56x34x60	56x34x66	25x29x71	42x30x85
Weight, Lbs	150	425	875	660	730	1025
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Electric	Electric	Electric	Steam	Steam	Steam
Control Features	Thermostat	Thermostat	Thermostat	Thermostat		
Options	Explosion-proof Electricals	Vacuum attachment,Flow switch interlock	Vacuum attachment,Flow switch interlock	Vacuum attachment,Boiler		
F.O.B. Cost, $	2,995	5,625	13,950	22,825	4,950	7,050
Delivery Time, Wks.	2-4	2-4	2-4	2-4		
Payment Terms	Net 30 days	Net 30 days	Net 30 days			
Solvents Recovered	Alcohols,Aromatics, Ketones,Chlorinated solvents,Aliphatics	Alcohols,Aromatics, Ketones,Chlorinated solvents,Aliphatics	Alcohols,Aromatics, Ketones,Chlorinated solvents,Aliphatics	Hazardous waste solvents	Petroleum solvents&oils	Petroleum solvents&oils

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS

	Garden Machinery Corp. 700 N.Summit Ave. Charlotte,NC 28233			Hoyt Corporation Westport,MA 02790		Interel Corporation P.O.Box 4676 Engelwood ,CO 80155
Technical Description	Model#200	Model#300	Model#500	Model#EP8	Model#EP20	Model
Solvent Boiling Range, F				below 330	below 330	
Feed Capacity, Gal						
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %				below 98		
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	200-225	300-350	500-600	4-8	below 20	7.5
Utilities				Air 2 SCFM	Air 2 SCFM	
Voltage, V				220	220	
Phase				1	1	
Power Rating, KW				5		
Cooling Water Consumption, GPH				120	120	
Material of Construction				SS	SS	
Equipment Dimensions, In	51x39x95	66x66x101	75x71x101	30x30x92		
Weight, Lbs	3,000	3,600	4500	775		
Type of Cooling	Water	Water	Water	Water	Water	
Type of Heating	Steam	Steam	Steam	Thermal oil	Thermal oil	
Control Features				Programmable controls	Programmable controls	
Options						SS condenser,Explosion proof electricals
F.O.B. Cost, $	10,300	11,465	13,345	14,500	26,945	8,950
Delivery Time, Wks.				6-8	10-12	
Payment Terms				10% with order,balance on shipment	10% with order,balance on shipment	
Solvents Recovered	Petroleum solvents&oils	Petroleum solvents&oils	Petroleum solvents&oils	Hazardous waste solvents		Chlorinated,Petroleum

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Interel Corporation P.O.Box 4676 Engelwood ,CO 80155		Kontes Scientific Glassware/Instruments Spruce Street,P.O.Box 729 Vineland,NJ 08360		O-I/Schott Process Systems Inc. 1640 S.W.Blvd.,P.O.Box T Vineland, NJ 08360	
Technical Description	Model	Model	Model#K-547100	Model#K-547700	Model	Model
Solvent Boiling Range, F						
Feed Capacity, Gal			0.8	5.8	13.2	26.4
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %				95		
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	7.5	15		2.5		
Utilities						
Voltage, V			115	115		
Phase						
Power Rating, KW			0.5	3		
Cooling Water Consumption, GPH						
Material of Construction			Glass	Glass	Glass lined steel	Glass lined steel
Equipment Dimensions, In			12x16x31	6ft2x6ft		
Weight, Lbs			40			
Type of Cooling			Water	Water	Water	Water
Type of Heating			Electric	Electric	Steam	Steam
Control Features			Thermostat	Thermostat		
Options	SS condenser,Explosion proof electricals,vacuum attachment,Automatic controls	SS condenser,Explosion proof electricals,vacuum attachment,Automatic controls		Vacuum pump		
F.O.B. Cost, $	8,560	11,850	1,961	2,723		
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	Chlorinated,Petroleum	Chlorinated,Petroleum				

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	O-I/Schott Process Systems Inc. 1640 S.W.Blvd.,P.O.Box T Vineland, NJ 08360		Philips Manufacturing Co. 7343 N.Clark St. Chicago,IL 60626			
Technical Description	Model	Model	Model#RS-1	Model#RS-3	Model#RS-5	Model#RS-15
Solvent Boiling Range, F						
Feed Capacity, Gal	66	132.1				
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH			2-5	4-10	6-12	13-28
Utilities						
Voltage, V						
Phase						
Power Rating, KW			1.2	2.4	3	6.75
Cooling Water Consumption, GPH			10-49	20-98	25-123	55-278
Material of Construction	Glass lined steel	Glass lined steel				
Equipment Dimensions, In			24x18x36	26x21x49	28x24x62	32x30x68
Weight, Lbs						
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam	Steam	Electric	Electric	Electric	Electric
Control Features			Thermostat	Thermostat	Thermostat	Thermostat
Options			Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Philips Manufacturing Co. 7343 N.Clark St. Chicago,IL 60626					
Technical Description	Model#RS-20	Model#RS-25	Model#RS-40	Model#RS-50	Model#RS-60	Model#RS-10
Solvent Boiling Range, F						
Feed Capacity, Gal						15
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	17-37	23-49	41-86	52-111	58-123	5-10
Utilities						Steam 26Lb/hr.
Voltage, V						
Phase						
Power Rating, KW	9	12	21	27	30	4
Cooling Water Consumption, GPH	74-370	98-493	172-863	221-1109	246-1233	50
Material of Construction						
Equipment Dimensions, In	36x32x70	39x34x78	45x38x81	48x40x84	51x42x87	30x30x60
Weight, Lbs						500
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat	Thermostat	Thermostat	Thermostat	Thermostat	Thermostat
Options	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Philips Manufacturing Co. 7343 N.Clark St. Chicago,IL 60626					
Technical Description	Model#RS-30	Model#RS-75	Model#RS-100	Model#RS-125	Model#RS-175	Model#RS-250
Solvent Boiling Range, F						
Feed Capacity, Gal	50	100		125	175	250
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	5-10	60-75	100-210	90-125	163-345	245-517
Utilities	Steam 71Lb/hr.	Steam 163Lb/hr. Air 175Cuft/hr.		Steam 297Lb/hr. Air 307Cuft/hr.		
Voltage, V						
Phase						
Power Rating, KW	15	36	51	63	84	126
Cooling Water Consumption, GPH	125	295	418-2096	520-2589	688-3453	1033-5178
Material of Construction						
Equipment Dimensions, In	45x45x72	50x60x72	57x52x100	65x78x84	68x60x110	66x63x117
Weight, Lbs	650	950		1250		
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control
Options	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Philips Manufacturing Co. 7343 N.Clark St. Chicago,IL 60626					
Technical Description	Model#RS-300	Model#RS-350	Model#RS-400	Model#RS-500	Model#RS-700	Model#RS-1000
Solvent Boiling Range, F						
Feed Capacity, Gal						
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	286-604	327-690	409-863	491-1035	696-1,467	996-2,100
Utilities						
Voltage, V						
Phase						
Power Rating, KW	147	168	210	252	357	511
Cooling Water Consumption, GPH	1,205-6,042	1,377-6,906	1,722-8,632	2,066-10,359	2,928-14,675	4,191-21,006
Material of Construction						
Equipment Dimensions, In	74x66x124	83x70x132	102x72x132	110x90x135	118x95x140	126x100x144
Weight, Lbs						
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric	Steam/Electric
Control Features	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control	Thermostat,Level control
Options	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment	Refrigeration,Vacuum attachment
F.O.B. Cost, $						
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Progressive Recovery Inc. P.O.Box 521 Trumbull,CT 06611					
Technical Description	Model#SC-Jr	Model#SC-25	Model#SC-50	Model#SC-100	Model#SC-200	Model#SC-300
Solvent Boiling Range, F	below 400					
Feed Capacity, Gal	5	15	35	35	60	70
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr	2		2	1	1	1
Distillation Rate, GPH	1-2	2-4	5-8	8-12	15-20	20-30
Utilities						
Voltage, V	115/220					
Phase	1					
Power Rating, KW	1.2	3.7	4.5	9	18	27
Cooling Water Consumption, GPH			18	36	72	90
Material of Construction	SS		SS	SS	SS	SS
Equipment Dimensions, In	45x20x36		25ft2x60	25ft2x60	36ft2x62	36ft2x62
Weight, Lbs	350		700	750	1,000	1,200
Type of Cooling	Air Cooled	Water	Water	Water	Water	Water
Type of Heating	Thermal oil	Thermal oil	Thermal oil	Thermal oil	Thermal oil	Thermal oil
Control Features						
Options	Vacuum attachment	Vacuum attachment,Air cooling	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill
F.O.B. Cost, $	4,795	6,495	9,645	11,895	17,195	24,595
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered	MEK,Toluene,Xylene, TCE,Freon etc	MEK,Toluene,Xylene, TCE,Freon etc	MEK,Toluene,Xylene, TCE,Freon etc	MEK,Toluene,Xylene, TCE,Freon etc	MEK,Toluene,Xylene, TCE,Freon etc	MEK,Toluene,Xylene, TCE,Freon etc

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Progressive Recovery Inc. P.O.Box 521 Trumbull,CT 06611					
Technical Description	Model#SC-400	Model#SC-500	Model#LSR-8.5	Model#LSR-8.5E	Model#LSR-20	Model#LSR-20E
Solvent Boiling Range, F						
Feed Capacity, Gal	120	120	55	55	80	80
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr	1	1	1	2	1	2
Distillation Rate, GPH	30-35	35-40	10-15	8-12	30-35	25-30
Utilities						
Voltage, V						
Phase						
Power Rating, KW	32	36		20		44
Cooling Water Consumption, GPH	126	144	120	60	180	120
Material of Construction	SS	SS	SS	SS	SS	SS
Equipment Dimensions, In	50ft2x64	50ft2x64	25ft2x130	25ft2x130	60ft2x136	60ft2x136
Weight, Lbs	1,600	1,750	3,600	3,600	4,300	4,800
Type of Cooling	Water	Water	Water	Water	Water	Water
Type of Heating	Thermal oil	Thermal oil	Steam	Electric	Steam	Electric
Control Features			Microprocessor Controlled	Microprocessor Controlled	Microprocessor Controlled	Microprocessor Controlled
Options	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill	Vacuum attachment,Auto-fill
F.O.B. Cost, $	28,995	36,195	44,965	44,965	75,965	80,965
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Progressive Recovery Inc. P.O.Box 521 Trumbull,CT 06611			Unique Industries Inc. 11544 Sheldon St. Sun Valley,CA 91353		
Technical Description	Model#LSR-40	Model#LSR-80	Model#LSR-120	Model#1100-10W	Model#1100-10RW	Model#1100-10RA
Solvent Boiling Range, F						
Feed Capacity, Gal	210	465	710	25	25	25
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr	1.5	1.5	2			
Distillation Rate, GPH	60-100	140-180	250-300	12	12	12
Utilities						
Voltage, V				240	240	240
Phase				3	3	3
Power Rating, KW				4.5	4.5	4.5
Cooling Water Consumption, GPH	360	720	1,560	186		
Material of Construction	SS	SS	SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS
Equipment Dimensions, In	70ft2x154	100ft2x178	120ft2x209	38x56x59	38x56x59	38x56x59
Weight, Lbs	6,200	7,900	10,800			
Type of Cooling	Water	Water	Water	Water	Refrigeration	Refrigeration,Air cooled
Type of Heating	Steam	Steam	Steam	Electric	Electric	Electric
Control Features	Microprocessor Controlled	Microprocessor Controlled	Microprocessor Controlled	Level control	Level control	Level control
Options	Vacuum attachment	Vacuum attachment	Vacuum attachment	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage
F.O.B. Cost, $	95,300	110,000	129,965	5,270	8,250	8,600
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered				Chlorinared,Fluorinated	Chlorinared,Fluorinated	Chlorinared,Fluorinated

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Unique Industries Inc. 11544 Sheldon St. Sun Valley,CA 91353					
Technical Description	Model#1100-20W	Model#1100-20RW	Model#1100-20RA	Model#1100-30W	Model#1100-30RW	Model#1100-30RA
Solvent Boiling Range, F						
Feed Capacity, Gal	25	25	25	31	31	31
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	21	21	21	41	41	41
Utilities						
Voltage, V	240	240	240	240	240	240
Phase	3	3	3	3	3	3
Power Rating, KW	7.5	7.5	7.5	15	15	15
Cooling Water Consumption, GPH	312			600		
Material of Construction	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS
Equipment Dimensions, In	37x70x62	37x70x62	37x70x62	41x87x62	41x87x62	41x87x62
Weight, Lbs						
Type of Cooling	Water	Refrigeration	Refrigeration,Air cooled	Water	Refrigeration	Refrigeration,Air cooled
Type of Heating	Electric	Electric	Electric	Electric	Electric	Electric
Control Features	Level control	Level control	Level control	Level control	Level control	Level control
Options	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage
F.O.B. Cost, $	7,500	10,500	10,750	8,500	12,500	12,750
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Unique Industries Inc. 11544 Sheldon St. Sun Valley,CA 91353					
Technical Description	Model#1100-30ERSW	Model#1100-30ERSWDM	Model#1100-60W	Model#1100-60RW	Model#1100-60RA	Model#1100-60ERSW
Solvent Boiling Range, F						
Feed Capacity, Gal	31	31	56	56	56	56
Maximum Degree of Contamination, %						
Typical Purity of Product, %						
Typical Yield, %						
Operating Time, Hr						
Cold Start Heat-up Time, Hr						
Distillation Rate, GPH	41	41		69	69	69
Utilities						
Voltage, V	240	240	480	480	480	480
Phase	3	3	3	3	3	3
Power Rating, KW	15	15	27	27	27	27
Cooling Water Consumption, GPH						
Material of Construction	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS	Heavy Gauge SS
Equipment Dimensions, In	41x87x62	41x87x62	49x103x66	49x103x66	49x103x66	49x103x66
Weight, Lbs						
Type of Cooling	Refrigeration	Refrigeration	Water	Refrigeration	Refrigeration	Refrigeration
Type of Heating	Electric	Electric	Electric	Electric	Electric	Electric
Control Features	Level control	Level control	Level control	Level control	Level control	Level control
Options	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage	Steam heating,Other voltage
F.O.B. Cost, $	14,500	15,995	9,500	14,500	14,995	16,500
Delivery Time, Wks.						
Payment Terms						
Solvents Recovered						

SURVEY OF SOLVENT RECOVERY STILL MANUFACTURERS (Continued)

	Unique Industries Inc. 11544 Sheldon St. Sun Valley,CA 91353	Recyclene Products, Inc. 405 Eccles Avenue S.San Francisco, CA 94080			
Technical Description	Model#1100-60ERSWDM	Model#RX-35	Model#RS-35	Model#RS-20	Model#RX-14
Solvent Boiling Range, F		below 400	below 400	below 400	below 300
Feed Capacity, Gal	56	35	35	20	14
Maximum Degree of Contamination, %		30	30	30	30
Typical Purity of Product, %		99	99	99	99
Typical Yield, %		95	95	95	95
Operating Time, Hr					
Cold Start Heat-up Time, Hr		1.5	1.5	1.5	1.5
Distillation Rate, GPH	69	10-37	5-18	4-12	96
Utilities					
Voltage, V	480	240	240	240	120
Phase	3				
Power Rating, KW	27	9.9	5	3.3	1
Cooling Water Consumption, GPH		75	75	40	20
Material of Construction	Heavy Gauge SS	SS	SS	SS	SS
Equipment Dimensions, In	49x103x66	51x52x51	51x52x51	44x31x44	40x26x38
Weight, Lbs		872	804	440	275
Type of Cooling	Refrigeration	Water	Water	Water	Water
Type of Heating	Electric	Heat transfer fluid	Heat transfer fluid	Heat transfer fluid	Heat transfer fluid
Control Features	Level control	Thermostat	Thermostat	Thermostat	Thermostat
Options	Steam heating,Other voltage	Auto-fill	Auto-fill	Auto-fill	Auto-fill
F.O.B. Cost, $	17,995	12,000-16,000	12,000-16,000	11,000	6,500
Delivery Time, Wks.					
Payment Terms					
Solvents Recovered					

APPENDIX E

AIR POLLUTION CONTROL DISTRICTS IN CALIFORNIA

AMADOR COUNTY APCD
(Mountain Counties Air Basin)

108 Court Street
Jackson, CA 95642

Street Address:
810 Court Street
Jackson, CA

APCO - Dr. James B. McClenahan

Address all mail to:
Deputy APCO - Roxanne Jacques
(209) 223-6406

BAY AREA AQMD
(San Francisco Bay Area Air Basin)

939 Ellis Street
San Francisco, CA 94109

APCO - Milton Feldstein
Deputy APCO - Peter Hess
Enforcement - Hulan Brinkley
Administrative Services Director - Thomas F. Bell, Jr.
Legal - John Powell
Permits - Daniel Goalwin
Planning & Research - Lewis Robinson
Technical Services - Dario Levaggi
(415) 771-6000 (all District staff)

BUTTE COUNTY APCD
(Sacramento Valley Air Basin)

P.O. Box 1229
Oroville, CA 95965

Street Address:
316 Nelson Avenue
Oroville, CA

APCO - Joe E. Bandy
(916) 534-4383
Deputy APCO - Craig Gilmore

CALAVERAS COUNTY APCD
(Mountain Counties Air Basin)

Government Center
San Andreas, CA 95249

Street Address:
891 Mountain Ranch Road
San Andreas, CA

CALAVERAS COUNTY APCD (Cont.)

APCO - Robert Marshall, M.D.
(209) 754-4251
Deputy APCO - Margaret Blood
(209) 754-3849

COLUSA COUNTY APCD
(Sacramento Valley Air Basin)

P.O. Box 1029
Colusa, CA 95932

Street Address:
100 Sunrise Blvd., Suite F
Colusa, CA 95932

APCO - Wilber C. Disney, Jr.
(916) 458-5891

EL DORADO COUNTY APCD
(Lake Tahoe & Mountain Counties Air Basins)

360 Fair Lane
Placerville, CA 95667

APCO - Vernon C. Peterson
(916) 626-2407

FRESNO COUNTY APCD
(San Joaquin Valley Air Basin)

P.O. Box 11867
Fresno, CA 93775

Street Address:
1221 Fulton Mall
Fresno, CA

Address all mail to:
Louis Dooley
Asst. APCO

APCO - Donald R. Rowe
Director of Health
Program Manager - Bob Dowell
Engineering - Bill Roddy
Planning - Stew Wilson
(209) 445-3239 (all District staf

GLENN COUNTY APCD
(Sacramento Valley Air Basin)

P.O. Box 351
Willows, CA 95988

Street Address:
720 North Colusa Street
Willows, CA

APCO - Ed Romano
Technical - Joe McIntyre
(916) 934-4651

GREAT BASIN UNIFIED APCD
(Great Basin Valleys Air Basin)

157 Short Street, Suite 6
Bishop, CA 93514

APCO - Ms. Ellen Hardebeck
Deputy APCO - Bill Cox, Jr.
(619) 872-8211

IMPERIAL COUNTY APCD
(Southeast Desert Air Basin)

150 S. 9th Street
El Centro, CA 92243-2801

APCO - Claude M. Finnell
Chief Deputy APCO - Phillip Shafer
Engineer - Harry S. Dillon
(619) 339-4314

KERN COUNTY APCD
(San Joaquin Valley & Southeast Desert Air Basins)

1601 "H" Street, Suite 150
Bakersfield, CA 93301-5199

APCO - Leon M Hebertson, M.D.
(805) 861-3655
Chief Air Sanitation Officer -
Citron Toy
Asst. Chief Air Sanitation Officer -
Clifton Calderwood
Manager of Engineering -
Thomas Paxson
Manager of Enforcement -
Creighton Smith
Manager of Technical Services -
Henry Mayrsohn
(805) 861-3682 (all District staff)

KINGS COUNTY APCD
(San Joaquin Valley Air Basin)

330 Campus Drive
Hanford, CA 93230

APCO - Sheldon R. Minkin, D.O.
(209) 584-1401 Ext. 2605
Assistant APCO - Dennis Otani
(209) 584-1411 Ext. 2625
Supervising Sanitarian -
Keith Winkler
(209) 584-1411 Ext. 2626

LAKE COUNTY AQMD
(Lake County Air Basin)

883 Lakeport Blvd.
Lakeport, CA 95453

Air Pollution Control Director -
Robert L. Reynolds
(707) 263-2391

LASSEN COUNTY APCD
(Northeast Plateau Air Basin)

175 Russell Avenue
Susanville, CA 96130

APCO - Fredric L. (Les) Evans
(916) 257-8311 Ext. 110

MADERA COUNTY APCD
(San Joaquin Valley Air Basin)

135 West Yosemite Avenue
Madera, CA 93637

APCO - Dave Fishel
Assistant APCO -
Willard (Bill) Sturk
(209) 675-7823/24/25

MARIPOSA COUNTY APCD
(Mountain Counties Air Basin)

P.O. Box 5
Mariposa, CA 95338

Street Address:
Health Dept. Building
Hwy. 49 at 140 North
Mariposa, CA

APCO - Avery E. Sturm, M.D.
(209) 966-3689
Consultant - John Thomson
(209) 966-3060

MENDOCINO COUNTY APCD
(North Coast Air Basin)

Courthouse
Ukiah, CA 95482

Address all mail to:
Deputy Director -
Mr. Robert F. Swan
(707) 463-4391

Street Address:
890 North Bush
Ukiah, CA

APCO - Craig M. McMillan, M.D.
(707) 463-4465

MERCED COUNTY APCD
(San Joaquin Valley Air Basin)

Address all mail to:
Jeff Palsgaard, Asst. APCO
Environmental Health
P.O. Box 471
Merced, CA 95341

Attention: Roland Brooks,
Air Pollution Control Manager

Street Address:
210 East 15th Street
Merced, CA

APCO - Richard Welch, M.D.
Engineering - Richard Wachs
Program Manager - Roland Brooks
(209) 385-7391

MODOC COUNTY APCD
(Northeast Plateau Air Basin)

202 West 4th Street
Alturas, CA 96101

APCO - Clinton B. Greenbank
(916) 233-2225
Smoke Technician - John E. Kelley
(916) 667-2713

MONTEREY BAY UNIFIED APCD
(North Central Coast Air Basin)

1164 Monroe Street, Suite 10
Salinas, CA 93906-3596

APCO - Lawrence D. Odle
(408) 443-1135

NEVADA COUNTY APCD
(Mountain Counties Air Basin)

10433 Willow Valley Road
Nevada City, CA 95959

APCO - Jerry J. Zarriello, M.D.
(916) 265-1452
Assistant APCO - Ron E. Earles
(916) 265-1452

NORTH COAST UNIFIED AQMD
(North Coast Air Basin)

5630 South Broadway
Eureka, CA 95501

APCO - Charles Sassenrath
Engineering - Bob Clark
(707) 443-3093

NORTHERN SONOMA COUNTY APCD
(North Coast Air Basin)

118 North Street
Healdsburg, CA 95448

APCO - Michael W. Tolmasoff
(707) 433-5911

PLACER COUNTY APCD
(Lake Tahoe & Mountain Counties
Air Basins)

DeWitt Center
11484 B Avenue
Auburn, CA 95603

Street Address:
11582 B Avenue (Bldg. 117A)
Auburn, CA 95603

APCO - Kenneth F. Selover
(916) 823-4443

PLUMAS COUNTY APCD
(Mountain Counties Air Basin)

P.O. Box 480
Quincy, CA 95971

Street Address:
Highway 70
Courthouse Annex
Quincy, CA

APCO - Mike Murray
(916) 283-1256

SACRAMENTO COUNTY APCD
(Sacramento Valley Air Basin)

9323 Tech Center Drive, Suite 800
Sacramento, CA 95826

APCO - Norman D. Covell
Enforcement - Eric Munz
Engineering/Air Monitoring -
Bruce Nixon
APC Specialist - Gary Glissmeyer
(916) 366-2107 (all District staff)

SAN BERNARDINO COUNTY APCD
(Southeast Desert Air Basin)

15505 Civic Drive
Victorville, CA 92392

Executive Officer -
Walter R. Mook
Asst. Executive Officer -
Oscar Hellrich
A.Q. Specialist -
Chuck Fryxell
(619) 243-8147 (all District staff)

SAN DIEGO COUNTY APCD
(San Diego Air Basin)

9150 Chesapeake Drive
San Diego, CA 92123-1095

APCO - Richard J. Sommerville
(619) 565-5900
APCO Secretary - Vicky Hamill
(619) 565-5960
Deputy Director - Richard Smith
(619) 565-3930
Deputy Director - Paul Sidhu
(619) 565-3940
Fiscal - Nancy Egbert
(619) 565-5909
Enforcement - Allen Danzig
(619) 565-3909
Technical Services - Stella Willcox
(619) 565-3947
Public Information - Lynn Eldred
(619) 565-5903
General Information
(619) 565-5901

SAN JOAQUIN COUNTY APCD
(San Joaquin Valley Air Basin)

P.O. Box 2009
Stockton, CA 95201

Street Address:
1601 East Hazelton Avenue
Stockton, CA

APCO - Jogi Khanna, M.D.
(209) 466-6781
Assoc. AP Engr. - Lakhmir Grewal
(209) 462-8526

SAN LUIS OBISPO COUNTY APCD
(South Central Coast Air Basin)

2156 Sierra Way, Suite B
San Luis Obispo, CA 93401

APCO - George Rowland, M.D.
Director - Robert W. Carr
(805) 549-5912

Revised 6/86

SANTA BARBARA COUNTY APCD
(South Central Coast Air Basin)

Santa Barbara APCD
Health Care Service
315 Camino del Remedio
Santa Barbara, CA 93110

APCO - Lawrence Hart, M.D., M.P.H.
(805) 964-8848 Ext. 399

Director - John B. English
(805) 964-8111
(805) 964-8658 (message recorder)

Santa Barbara APCD
5540 Ekwill Street, Suite B
Santa Barbara, CA 93111

SHASTA COUNTY APCD
(Northeast Plateau & Sacramento Valley Air Basins)

1855 Placer Street
Redding, CA 96001

APCO - Richard Booth
(916) 225-5156
(916) 225-5674

Burn Day Information:
(916) 244-1308

SIERRA COUNTY APCD
(Mountain Counties Air Basin)

P.O. Box 530
Downieville, CA 95936

APCO - Tim Beals
(916) 289-3251
Basin Engr. - Mr. Earl Withycombe
(916) 289-3274 (Courthouse)
(916) 862-1233 (Home)

SISKIYOU COUNTY APCD
(Northeast Plateau Air Basin)

525 South Foothill Drive
Yreka, CA 96097

APCO - Edmond W. Hale
(916) 842-3531, Ext. 280
Technical - Kenneth L. Corbin
(916) 842-3906

SOUTH COAST AQMD
(South Coast Air Basin)

9150 Flair Drive
El Monte, CA 91731

Chief Deputy Executive Officer - James M. Lents, Ph.D.
(818) 572-6402
Deputy Executive Officer/Media Liaison - Jim Birakos
(818) 572-6280
Administration - Jay Peters
(818) 572-6340
Atmospheric Measurement - Bill Bope
(818) 572-6396
Enforcement - Ed Camarena
(818) 572-6296
Engineering - Sandy Weiss
(818) 572-6431
Fiscal - Gary Burton
(818) 572-6337
Laboratory Services - Margil Wadley
(818) 572-6452
Planning - Jo Anne Aplet
(818) 572-6377
Public Advisor - Eugene Calafato
(818) 572-6416
Rule Development - Larry Bowen
(818) 572-6445

STANISLAUS COUNTY APCD
(San Joaquin Valley Air Basin)

1716 Morgan Road
Modesto, CA 95351

APCO - Gordon M. Dewers

Address All Mail To:
Deputy APCO - Wayne Morgan
(209) 571-6908
ATSS 482-6908

SUTTER COUNTY APCD
(Sacramento Valley Air Basin)

142 Garden Highway
Yuba City, CA 95991

APCO - Alfred C. Perrin, Jr.
Asst. APCO -
Lourie (Lou) G. Gaschke
(916) 741-7500

TEHAMA COUNTY APCD
(Sacramento Valley Air Basin)

P.O. Box 38
Red Bluff, CA 96080

Street Address:
1760 Walnut Street
Red Bluff, CA

APCO - Donald R. Hill
Asst. APCO - Dave Sale
(916) 527-4504

TULARE COUNTY APCD
(San Joaquin Valley Air Basin)

Health Building
County Civic Center
Visalia, CA 93291

APCO - Ronald W. Probasco
(209) 733-6438

Address all mail to:
Asst. APCO - Donald A. Johnson
(209) 733-6441

TUOLUMNE COUNTY APCD
(Mountain Counties Air Basin)

2 South Green Street
Sonora, CA 95370

Street Address:
22365 South Airport
Columbia, CA 95310

APCO - Gerald A. Benincasa
(209) 533-5693

VENTURA COUNTY APCD
(South Central Coast Air Basin)

800 South Victoria Avenue
Ventura, CA 93009

Telecopier - (805) 654-2842

APCO - Richard H. Baldwin
(805) 654-2667
Air Monitoring -
(805) 654-2809
Enforcement - Neil Moyer
(805) 654-2665
Engineering/Permits - Dick Johnson
(805) 654-2808
Fiscal - Pat Donald
(805) 654-2429
Planning - Scott Johnson
(805) 654-2798
Rules -
(805) 654-2666

ATSS - 8-723———

YOLO-SOLANO APCD
(Sacramento Valley Air Basin)

P.O. Box 1006
Woodland, CA 95695

Street Address:
323 First Street, #5
Woodland, CA

APCO - James A. Koslow
(916) 666-8146 or 8147

YUBA COUNTY APCD
(Sacramento Valley Air Basin)

938 14th Street
Marysville, CA 95901

APCO - Earnie E. Vickrey
Technical - Dave McBride
(916) 741-6484