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Best Demonstrated Final Available Technology (BDAT) Background Document for F001 - F005 Spent Solvents

Volume 1

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BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT)
BACKGROUND DOCUMENT FOR F001-F005 SPENT SOLVENTS

VOLUME 1

U.S. ENVIRONMENTAL PROTECTION AGENCY

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BDAT BACKGROUND DOCUMENT FOR
F001-F005 SPENT SOLVENT WASTES

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EXECUTIVE SUMMARY

The final rule for the Land Disposal Restrictions of F001-F005 Spent Solvent Wastes establishes technology-based treatment standards representative of Best Demonstrated Available Technology (BDAT). These standards will, to the extent possible, reflect well designed and operated treatment systems and account for variations in treatability due to waste matrix effects.

For the F001-F005 spent solvent rule, EPA identified two broad categories of wastes consisting of wastewater and non-wastewater. Within the wastewater treatability group, the Agency identified a separate treatability subgroup for methylene chloride wastewater generated at pharmaceutical plants.

The treatment standards are summarized in the following table. The technologies used as the basis for BDAT as well as the treatment data used to develop the specific performance levels are presented in Section 5 of this document.

The BDAT Background Document for F001-F005 Spent Solvents consists of three volumes. The first volume contains Sections 1 through 4. Section 1 summarizes the legal background and general approach to the development of BDAT; Section 2 characterizes the principal industries that generate wastes subject to this rule; Section 3 presents waste characterization data for F001-F005 spent solvents; and Section 4 discusses the technologies found to be demonstrated for treatment of F001-F005 spent solvents. The second volume consists of Section 5 as previously described. The third volume contains complete data sets for all data considered in the development of the treatment standards.

BDAT TREATMENT STANDARDS
(As Concentrations in the Treatment Residual Extract)

<u>Constituent</u>	<u>Wastewaters Containing Spent Solvents (mg/L)</u>	<u>Non-Wastewater Spent Solvent Wastes (mg/L)</u>
Acetone	0.05	0.59
n-Butyl alcohol	5.0	5.0
Carbon disulfide	1.05	4.81
Carbon tetrachloride	0.05	0.96
Chlorobenzene	0.15	0.05
Cresols (cresylic acid)	2.82	0.75
Cyclohexanone	0.125	0.75
1,2-Dichlorobenzene	0.65	0.125
Ethyl acetate	0.05	0.75
Ethylbenzene	0.05	0.053
Ethyl ether	0.05	0.75
Isobutanol	5.0	5.0
Methanol	0.25	0.75
Methylene chloride	0.20	0.96
Methylene chloride generated at pharmaceuticals plants	12.7	0.96
Methyl ethyl ketone	0.05	0.75
Methyl isobutyl ketone	0.05	0.33
Nitrobenzene	0.66	0.125
Pyridine	1.12	0.33
Tetrachloroethylene	0.079	0.05
Toluene	1.12	0.33
1,1,1-Trichloroethane	1.05	0.41
1,1,2-Trichloro-1,2,2- trifluoroethane	1.05	0.96
Trichloroethylene	0.062	0.091
Trichlorofluoromethane	0.05	0.96
Xylene	0.05	0.15

1. BACKGROUND AND GENERAL DESCRIPTION

1.1 Legal Background

This rulemaking sets the regulatory framework for implementing the land disposal restrictions and establishes treatment standards and associated effective dates for certain solvent- and dioxin-containing wastes. This action is responsive to amendments to the Resource Conservation and Recovery Act (RCRA), enacted through the Hazardous and Solid Waste Amendments of 1984 (HSWA). These amendments impose substantial new responsibilities on those who handle hazardous waste.

In particular, the amendments prohibit the continued land disposal of untreated hazardous wastes beyond specified dates, "unless the Administrator determines that the prohibition . . . is not required in order to protect human health and the environment for as long as the wastes remain hazardous . . ." (RCRA sections 3004(d)(1), (e)(1), (g)(5), 42 U.S.C. 6924(d)(1), (e)(1), (g)(5)). Congress established a separate schedule in section 3004(f) for making determinations regarding the disposal of dioxins and solvents in injection wells.

Wastes treated in accordance with treatment standards set by EPA under section 3004(m) of RCRA, are not subject to the prohibitions and may be land disposed. The statute requires EPA to set "levels or methods of treatment, if any, which substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized" (RCRA section 3004(m)(1), 42 U.S.C. 6924(m)(1)).

Land disposal prohibitions are effective immediately upon promulgation unless the Agency sets another effective date based on the earliest date that adequate alternative treatment, recovery, or disposal capacity which is protective of human health and the environment will be available (RCRA sections 3004(h) (1) and (2), 42 U.S.C. 6924(h) (1) and (2)). However, these effective date variances may not exceed 2 years beyond the applicable statutory deadline. In addition, two 1-year case-by-case extensions of the effective date may be granted under certain circumstances.

For the purposes of the land disposal restrictions program, the legislation specifically defines land disposal to include, but not be limited to, any placement of hazardous waste in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome or salt bed formation, or underground mine or cave (RCRA section 3004(k), 42 U.S.C. 6924(k)).

Congress also has prohibited the storage of any hazardous waste that is subject to a prohibition from one or more methods of land disposal unless "such storage is solely for the purpose of the accumulation of such quantities of hazardous waste as are necessary to facilitate proper recovery, treatment or disposal" (RCRA section 3004(j), 42 U.S.C. 6924(j)).

There also is a statutory exemption from the land disposal restrictions for the treatment of wastes in a surface impoundment, provided that the impoundments meet minimum technological requirements (with limited exceptions) and that treatment residues that do not meet the treatment standard(s) are removed within 1 year of the entry of the waste into the impoundment (RCRA section 3005(j)(11)(A)(B), 42 U.S.C. 6925(j)(11)(A)(B)).

The legislation sets forth a series of deadlines for Agency action. At certain deadlines, further land disposal of a particular group of hazardous wastes is prohibited if the Agency has not set treatment standards under section 3004(m) for such wastes or determined, based on a case-specific petition, that there will be no migration of hazardous constituents from the unit for as long as the wastes remain hazardous. Other deadlines cause conditional restrictions on land disposal to take effect if treatment standards have not been promulgated or if a petition has not been granted. In any case where EPA does not set a treatment standard for a waste by the statutory date, it is not precluded from later promulgating a treatment standard for that waste. Similarly, where EPA has set a treatment standard, it is not precluded from revising that standard after the statutory date through rulemaking procedures.

The above discussion is meant to serve as a summary of the legal background of the final rule. See the preamble to the final rule for a detailed discussion.

1.2 EPA's Approach to Developing BDAT

This section establishes the framework under which treatment standards based on the Best Demonstrated Available Technology (BDAT) will be developed in accordance with 3004(m). Development of waste treatability groups is discussed in subsection 1.2.1. Determination of "Demonstrated" treatment technologies is discussed in subsection 1.2.2. Determination of "Available" treatment technologies is discussed in subsection 1.2.3. Collection and analysis of performance data is discussed in subsection 1.2.4. Identification of "Best" demonstrated available treatment is discussed in subsection 1.2.5.

1.2.1 Waste Treatability Groups

Fundamental to waste treatment is the concept that the type of treatment technology used and the level of treatment achieved depend on the physical and chemical characteristics of the waste. The Agency will establish broad "waste treatability groups" based on similar physical and chemical properties (e.g., metal-bearing sludges or wastes containing cyanides; etc.) in order to account for differences in types of treatment used and effectiveness of treatment on different wastes. Because it may not be possible to fully account for the full range of chemical and physical characteristics of a waste with these broad groups, EPA recognizes that treatability groups could require further subdivision to more fully account for these effects. However, further subdivision must be reasonably limited by the availability of sufficient time and resources necessary to conduct the various analyses required in the proposed standard setting process.

The legislative history to Section 3004(m) supports this general approach by providing that treatment determinations do not have to be made only by waste code and by authorizing EPA to establish "generic" treatment standards for similar wastes (Volume 130 Congressional Record S9179 (daily edition July 25, 1984)). EPA believes grouping and subgrouping wastes by industry or manufacturing process may be used to account for waste matrix effects on treatment performance (i.e., similar manufacturing operations appear to generate waste with similar treatability characteristics). For example, in this rulemaking, EPA has sufficient data to form a separate treatability subgroup for wastewaters containing spent methylene chloride generated by the pharmaceutical industry.

However, while the Agency believes that industry-specific analyses will generally account for waste matrix effects, some wastes (e.g., spill contaminated soils) are not amenable to categorization by industry because the wastes are generated independent of routine manufacturing operation. Therefore, EPA also may establish additional treatability groups for wastes from unknown or miscellaneous sources.

1.2.2 Determination of "Demonstrated" Treatment Technologies

To be considered a "demonstrated" treatment technology, a full scale facility first must be known to be in operation for the waste or a waste judged to be similar. EPA will not, during this first step of its methodology, examine data to see if the data from the treatment facilities represent a well-designed and operated system. This factor is more appropriately taken into account later when evaluating the performance of the treatment operations. If no full scale treatment operations are known to exist for a waste or wastes with similar

treatability characteristics, the Agency will be unable to identify any "demonstrated" treatment technologies for the waste and, accordingly, the waste will be completely prohibited from continued placement in RCRA land disposal units (unless handled in accordance with the exemption and variance provisions of the rule). The Agency is, however, committed to establishing new treatment standards as soon as new or improved treatment processes become demonstrated as full scale operations.

Pilot- and bench-scale operations will not be considered in identifying "demonstrated" treatment technologies for a waste. EPA believes that this approach will ensure that currently used technologies will be considered. This approach is consistent with legislative history providing that "[t]he requisite levels of [sic] methods of treatment established by the Agency should be the best that has been demonstrated to be achievable" and not a "BAT-type process which contemplates technology-forcing standards." (Vol. 130 Cong. Rec. S9178 (daily ed., July 25, 1984). In certain circumstances data from such operations may be used by the Agency in evaluating the performance of demonstrated full scale treatment operations for certain wastes. A more detailed discussion of the circumstances that would prompt the use of data from pilot- or bench-scale operations in assessing treatment performance, as well as the manner in which such data will be used, is presented below in subsection 1.2.4.

1.2.3 Determination of "Available" Treatment Technologies

EPA will use the following criteria for "available" treatment technologies: 1) the technology does not present a greater total risk than land disposal; 2) if the technology is a proprietary or patented process, whether it can be purchased or licensed from the proprietor; and 3) the technology provides substantial treatment.

EPA will not set treatment standards based on a technology that does not meet the above criteria. Thus, the decision to classify a technology as "unavailable" may have a direct impact on the treatment standard. If the best technology is unavailable, the treatment standard would have to be based upon the next best treatment technology that was determined to be available. To the extent that the resulting treatment standards are less stringent, greater concentrations of hazardous constituents in the treatment residuals could be placed in land disposal units.

There also may be circumstances where EPA concludes that for a given waste none of the demonstrated treatment technologies are "available" for purposes of establishing the 3004(m) treatment performance standards. Subsequently, these wastes will be prohibited from continued placement in or on the land unless managed in accordance with the exemption and

variance provisions. The Agency is, however, committed to establishing new treatment standards as soon as new or improved treatment processes become "available".

(1) Treatment technologies that present greater total risks than land disposal methods. EPA will evaluate the risks associated with treatment technologies relative to land disposal methods. Based on a comparative risk assessment, those technologies that are found to present greater total risks than land disposal of the untreated waste will be excluded (*i.e.*, considered "unavailable") as a basis for establishing treatment standards.

If all demonstrated treatment technologies are determined to present greater risks than land disposal for the waste treatability group, the Agency will not be able to identify any "available" treatment technologies and, accordingly, will not set a treatment standard for that group. As a result of such a determination, the waste will be prohibited from land disposal (unless managed in accordance with the exemptions and variance provisions) unless a new or improved technology emerges that is determined not to pose greater total risks than direct land disposal. Treatment technologies identified as riskier than land disposal and, therefore, classified as unavailable for purposes of establishing standards may still, however, be used by facilities in complying with treatment standards expressed as performance levels. EPA is committed to developing sufficient regulatory controls or prohibitions over the design and operation of these technologies to ensure that their use in complying with the treatment standards do not result in increased risks to human health and the environment.

(2) Proprietary or patented processes. If the demonstrated treatment technology is a proprietary or patented process that is not generally available, EPA will not consider the technology in its determination of the treatment standards. EPA will consider proprietary or patented processes available if it determines that the treatment method can be purchased or licensed from the proprietor or is commercially available treatment. The services of the commercial facility offering this technology often can be purchased, although the technology itself cannot.

Treatment technologies classified as proprietary are unavailable for the purposes of establishing the treatment standards but may still be used by facilities in complying with treatment standards expressed as performance levels.

(3) Substantial treatment. In order to be considered "available", a demonstrated treatment technology must "substantially diminish the

toxicity" of the waste or "substantially reduce the likelihood of migration of hazardous constituents" from the waste in accordance with section 3004(m). By requiring that substantial treatment be achieved in order to set a treatment standard, the statute ensures that all wastes are adequately treated before being placed in or on the land, and that the Agency does not require a treatment method that provides little or no environmental benefit. Treatment will always be deemed substantial if it results in nondetectable levels of the hazardous constituents of concern in the TCLP extract. EPA will evaluate whether a treatment technology provides substantial treatment on a case-by-case basis when the treatment technology does not achieve nondetectable constituent concentrations in the residual. This approach is necessary due to the difficulty in establishing a meaningful guideline that can be applied broadly to the many wastes and technologies that will be considered. EPA will consider the following factors in an effort to evaluate whether a technology provides substantial treatment on a case-by-case basis:

- (a) Number and types of constituent treated;
- (b) Performance (concentration of the constituents in the treatment residuals); and
- (c) Percent of constituents removed.

If none of the demonstrated treatment technologies achieve substantial treatment of a waste, the Agency cannot establish treatment standards for the constituents of concern in that waste.

1.2.4 Collection and Analysis of Performance Data

(1) Collection of performance data. Once the demonstrated available treatment technologies have been determined for a waste treatability group, the Agency will collect data representing treatment performance and information on the design and operation of the treatment system. In developing technology-based standards, treatment performance is evaluated using the TCLP. The Agency, in future land disposal restrictions rulemakings, may consider using a total waste analysis on the constituents of concern as the basis for determining treatment standards.

Wherever possible, the Agency will evaluate treatment technologies using full scale systems. If performance data from properly designed and operated full scale treatment methods for a particular waste or waste judged to be similar are not available, EPA may use data from pilot-scale operations. Similarly, where pilot-scale data cannot be obtained EPA may use data from bench-scale treatment operations. Whenever bench- and pilot-scale data are used, EPA will explain the use of such data in the

preamble or background document and will request comments on the use of such data. When data on treatment performance for a particular waste or similar wastes are judged by EPA to be insufficient, EPA will generate data and information through sampling and analysis regarding the design and operational parameters and performance of the demonstrated available treatment technologies.

The Agency recognizes that in some instances all wastes represented by a particular waste code may not be included in the studies. EPA, therefore, recognizes the possibility that unique waste matrices may not be considered in establishing the treatment standard. EPA is providing the opportunity for interested parties to petition the Agency for variances to the treatment standards based on a demonstration that the promulgated treatment standards for a particular waste cannot be attained. In essence, the variance process allows the applicant to present information which, if properly considered when the treatment standard was originally developed, would have required EPA to create a separate treatability subgroup for the waste.

(2) Treatment design and operation. The Agency will not establish treatment standards using performance data that are determined not to be representative of a well designed and operated treatment system. The effectiveness of a particular treatment technology will depend, to a significant extent, on how well the system is designed and operated. EPA will explain the parameters considered in the determination of proper design and operation with each rulemaking, because the parameters that comprise a well designed and operated system will vary for each technology. However, by way of example, some of the critical design and operating parameters for steam stripping include the number of equilibrium stages in the column, the temperature at which the unit is designed to operate, and how well the design temperature is controlled. In evaluating performance data from a steam stripping operation, the Agency would examine the design specifications (e.g., the basis for selecting the number of stages and design temperature) for the treatment unit in order to determine the extent to which the hazardous constituents could be expected to volatilize. After the design specifications are established, the Agency would collect data (e.g., hourly readings of the column temperature) throughout the operation of the treatment process demonstrating that the unit was operating according to design specifications. If the data collected varies considerably from the design requirements, it could form the basis of a determination that the treatment was improperly operated. If the temperature data show, for example, that for significant periods of time the temperature varied considerably from the design requirements, the Agency would not use this data to determine the levels of performance achievable by BDAT.

Ideally, for all treatment data, EPA will have associated design and operating data. However, when treatment performance data are limited, EPA may use treatment performance data for which there are few or no associated design and operating data. In these instances, EPA will use engineering judgment based on a comparison of constituent concentrations before and after treatment to determine whether the data reflect a well designed and operated treatment system. The Agency will also use a statistical outlier analysis to confirm the engineering analysis. An outlier in a data set is an observation that is significantly different from the trend in the data. (Refer to Section 5.4.2 for further discussion of the outlier analysis.) The Agency believes this approach is reasonable in view of statutory time constraints.

1.2.5 Identification of "Best" Demonstrated Available Treatment

After deleting data representing treatment from systems that are not well designed or operated, EPA will calculate average performance values for each specific waste treated with a particular technology.

In cases where the Agency has data on treatment of the same or similar wastes using more than one technology, we will perform an analysis of variance test to determine if one of the technologies performs significantly better. In cases where a particular treatment technology performs better, the treatment standard will be based on the best technology. If one of the technologies does not perform significantly better, we will average the performance values and multiply this value by the highest variability factor associated with any of the accepted technologies to derive the treatment standard.

Where the Agency has data from the treatment of different wastes containing the same constituent of concern but achieving significantly different levels of performance, the Agency will establish a separate treatability group in cases where the data and information on the waste are sufficient to do so. Within any treatability group, however, the Agency will use the highest treatment value reflecting well designed and operated treatment to establish BDAT. EPA believes that this approach ensures that the treatment standard can be achieved by all facilities within a treatability group.

1.2.6 Variance from the Treatment Standard

The Agency recognizes that there may exist unique wastes that cannot be treated to the level specified as the treatment standard. In such cases, generators or owners/operators may submit a petition to the Administrator requesting a variance from the treatment standard. A particular waste may be significantly different from the wastes considered in establishing treatability groups because the waste contains

a more complex matrix which makes it more difficult to treat. For example, complex mixtures may be formed when a restricted waste is mixed with other waste streams by spills or other forms of inadvertent mixing. As a result, the treatability of the restricted waste may be altered such that it cannot meet the applicable treatment standard.

Variance petitions must demonstrate that the treatment standard established for a given waste cannot be met. This demonstration can be made by showing that attempts to treat the waste by available technologies were not successful, or through appropriate analyses of the waste which demonstrate that the waste cannot be treated to the specified levels. Variances will not be granted based on a showing that adequate BDAT treatment capacity is unavailable. (Such demonstrations can be made according to the provisions in §268.5 for case-by-case extensions of the effective date.) The Agency will consider granting generic petitions provided that representative data are submitted to support a variance for each facility covered by the petition.

Petitioners should submit at least one copy to:

The Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

An additional copy marked "Treatability Variance" should be submitted to:

Chief, Waste Treatment Branch
Office of Solid Waste (WH-565)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Petitions containing confidential information should be sent with only the inner envelope marked "Treatability Variance" and "Confidential Business Information," and the contents marked in accordance with the requirements of 40 CFR Part 2 (41 FR 36902, September 1, 1976, amended by 43 FR 40000).

The petition should contain the following information:

- (1) The petitioner's name and address;
- (2) A statement of the petitioner's interest in the proposed action;

(3) Name, address, and EPA identification number of the facility generating the waste, and the name and telephone number of the plant contact;

(4) The process(es) and feed materials generating the waste and an assessment of whether such process(es) or feed materials may produce a waste that is not covered by the demonstration;

(5) A description of the waste sufficient for comparison with the wastes considered by the Agency in developing BDAT, and an estimate of the average and maximum monthly and annual quantities of waste covered by the demonstration; (Note: The petitioner should consult the appropriate BDAT background document for determining the characteristics of the wastes considered in developing treatment standards.)

(6) If the waste has been treated, provide a description of the system used for treating the waste, including the process design, operating conditions and an explanation of the reasons the treatment standards are not achievable or are based on inappropriate technology for treating the waste; (Note: The petitioner should refer to the appropriate BDAT background document as guidance for determining the design and operating parameters that the Agency used in developing treatment standards.)

(7) A description of the alternative treatment systems examined by the petitioner (if any), a description of the treatment system deemed appropriate by the petitioner for the waste in question, and, as appropriate, the concentrations in the treatment residual or extract of the treatment residual (using the TCLP) that can be achieved by applying such treatment to the waste;

(8) The dates of the sampling and testing;

(9) A description of the methodologies and equipment used to obtain representative samples;

(10) A description of the sample handling and preparation techniques, including techniques used for extraction, containerization, and preservation of the samples; and

(11) A description of the tests performed (including results).

After receiving a petition for a variance, the Administrator may request any additional information or waste samples which he may require to evaluate and process the petition.

Additionally, all petitioners must certify that the information provided to the Agency is accurate under §268.4(b).

In determining whether a variance would be granted, the Agency will first look at the design and operation of the treatment system being used. If EPA determines that the technology and operation are consistent with BDAT, the Agency will evaluate the waste to determine if the waste matrix and/or physical parameters are such that BDAT properly reflects treatment of the waste.

In cases where more than one technology is applicable to a waste, the petitioner would have to demonstrate that the treatment standard cannot be met using any of the technologies, or that none of the technologies is appropriate for treatment of the waste. After the Agency has made a determination on the petition, the Agency's findings will be published in the FEDERAL REGISTER, followed by a 30-day period for public comment. After review of the public comments, EPA will publish its final determination in the FEDERAL REGISTER as an amendment to the treatment standards in Part 268 Subpart D.

2. INDUSTRIES AFFECTED

2.1 Introduction

A list of industries which use listed F001-F005 solvents is presented in Section 2.3. Spent solvent wastes included in the F001-F005 hazardous waste testing are presented in Section 2.2. A discussion of how spent solvent wastes are generated in industry is presented in Section 2.4. Geographical data for industries generating spent solvent waste are presented in Section 2.5 by state and by EPA region.

2.2 Classification of Waste as F001-F005 Spent Solvents

The classification of a waste as an F001-F005 spent solvent waste is based upon two criteria: the concentration of solvent in the virgin solvent mixture and the manner in which the solvent is used. The virgin solvent must have been comprised of any solvent mixture or blend which contains at least, in total, 10 percent by volume of one or more listed solvents. Also, the solvent must have been used for its "solvent" properties. Still bottoms from operations performed to recover listed solvent constituents are also classified as spent solvents. A solvent is considered "spent" when it has been used and is no longer fit for use without being regenerated, reclaimed, or otherwise reprocessed. Commercial chemical products, off-specification commercial chemical products, and manufacturing intermediates are not considered to be spent solvents under the F001-F005 hazardous waste listings. These residuals are regulated by the solvent-associated "P" and "U" hazardous waste listings that will be the subject of later standards. Also excluded from the listing are solvents used as reactants or ingredients in the formulation of commercial chemical products, solvents which are impurities in feed streams, and manufacturing process wastes which are contaminated with solvents.

The compounds included in hazardous waste codes F001-F005 are listed in Table 2-1. Wastes designated F001, F002, and F004 are listed based on their toxicity. Wastes designated as F003 are listed for ignitability, and wastes designated as F005 are listed for both ignitability and toxicity.

2.3 Industries Which Use Listed Solvents

A list of industries known by EPA to use solvents included in the F001-F005 hazardous waste listings is presented in Tables 2-2 and 2-3. However, there may be other industries and other solvent uses which have not been identified by EPA at this time and hence are not included in

Table 2-1. Constituents of Listed
Hazardous Spent Solvent Wastes

F001

Tetrachloroethylene
Trichloroethylene
Methylene chloride
1,1,1-Trichloroethane
Carbon tetrachloride
Chlorinated fluorocarbons

F002

Tetrachloroethylene
Methylene chloride
Trichloroethylene
1,1,1-Trichloroethane
Chlorobenzene
1,1,2-Trichloro-1,2,2-trifluoroethane
1,2-Dichlorobenzene
Trichlorofluoromethane

F003

Xylene
Acetone
Ethyl acetate
Ethylbenzene
Ethyl ether
Methyl isobutyl ketone
n-Butyl alcohol
Cyclohexanone
Methanol

F004

Cresols
Cresylic acid
Nitrobenzene

F005

Toluene
Methyl ethyl ketone
Carbon disulfide
Isobutanol
Pyridine

Table 2-2. Industries Using Solvents Listed as F001-F005

Industry	Solvents	How Solvents are Used
Furniture Manufacturing	n-Butyl alcohol Cyclohexanone Ethyl acetate Methyl ethyl ketone, Methylene chloride, 1,1,1-Trichloroethane, Xylene, Toluene	Solvent in metal furniture coatings Solvent in wood coatings Wood and metal furniture coatings Solvent in furniture coating
Plastics and Resins Manufacturing	Toluene, Acetone, Chlorobenzene, Xylene, Methanol Methanol, Acetone, Xylene, Toluene, Ethyl acetate Carbon tetrachloride Ethyl acetate Methyl ethyl ketone Methylene chloride 1,2-Dichlorobenzene	Solvent for paints and lacquers Solvent used in the production of alkyd resins Solvent in resins Solvent for plastics Purification solvent for epoxy resin manufacture Acrylic coatings solvent Vinyl coatings solvent Solvent used in plastics forming Solvent in paint removers
Fiber Manufacturing	Methanol, Acetone, Ethyl acetate, Methyl ethyl ketone Methanol Methylene chloride	Spinning solvent for cellulose acetate Process solvent in fabrics solvents Solvent in manufacture of Nylon 6,6 Solvent in synthetic fibers manufacture
Pharmaceutical Manufacturing	Acetone, Carbon tetrachloride, n-Butyl alcohol, Chlorobenzene, Cyclohexanone, Ethyl ether, Tetrachloroethylene, Methanol, Methyl ethyl ketone, 1,2-Dichlorobenzene, Toluene, 1,1,1-Trichloroethane, Xylene, Ethylbenzene, Isobutanol, Ethyl acetate Methyl isobutyl ketone, methylene chloride Pyridine Acetone, Ethyl ether	Solvent in the manufacture of pharmaceuticals Solvent for pharmaceuticals Solvent in drug manufacturing Solvent in the manufacture of smokeless explosive powders

Explosives Industry*

*Geographic distribution data not available.

Table 2-2. (continued)

Industry	Solvents	How Solvents are Used
Paint Manufacturing and Application	Acetone	Solvent for paints, varnishes, lacquers, paint thinner, and printing inks
	n-Butyl alcohol	Solvent for paint and lacquer
	Cyclohexanone	Paint remover and ink constituent; Solvent for lacquer
	Ethyl acetate	Solvent for paint thinner
	Ethylbenzene	Solvent for paints and varnishes and lacquers
	Isobutanol	Solvent in paints and lacquers and paint and varnish remover
	1,2-Dichlorobenzene, methylene chloride	Solvent in paint and varnish removers
	Methylethyl ketone, Methanol	Solvent in paint removers
	Methyl isobutyl ketone, Toluene	Solvent for paints, lacquers, and varnishes and paint thinner
	Xylene	Solvent for paints, varnishes, and enamels
Dyes and Pigments Manufacturing	Cresols and Cresylic acids	Solvent for magnetic wire enamel
	Ethylbenzene, Xylene	Solvent for dyes
	Methanol	Solvent for dye manufacture
	1,2-Dichlorobenzene	Process solvent for toluene diisocyanate
	Tetrachloroethylene	Solvent for silicones
	Chlorobenzene	Solvent for the production of an isocyanate alkane
	Methanol	Solvent for the production of a diphenyl methane, isocyanate
	Ethyl acetate	Solvent in the production of alkenes
	Acetone	Solvent in the production of an aldehyde furan
	Carbon disulfide	Chemical processing solvent
Organic Chemicals Manufacturing	Carbon tetrachloride	Solvent in waxes, oils, and sulfur compounds
	Ethyl ether	Solvent in waxes, oils, and fats
	Methyl ethyl ketone	Extraction and concentration of acetic acid
	Methyl isobutyl ketone	Extraction solvent for fats, oils, and waxes
	Nitrobenzene	Purification solvent for terephthalate
	Pyridine	Nitrocellulose coatings solvent
		Solvent for butadiene and acrylonitrile
		Solvent for chlorination reactions and in alkylation reactions
		Solvent in production of an organic phosphate ester

Table 2-2. (continued)

Industry	Solvents	How Solvents are Used
Agricultural Chemicals Manufacturing	1,1,1-Trichloroethane, Chlorobenzene Ethylbenzene, Xylene Methyl isobutyl ketone Xylene, Ethyl acetate, Methyl ethyl ketone, Methylene chloride, Toluene, Methanol	Solvent for pesticides Carrier solvent for agricultural sprays and pesticides Solvent for insecticides, agricultural pesticides, and sprays Solvent in the production of pesticides
Membrane Products and Manufacturing*	Acetone, n-Butyl alcohol, Methanol	Membrane production
Printing Industry	Nitrobenzene 1,2-Dichlorobenzene Toluene, Ethyl acetate, Acetone 1,1,1-Trichloroethane, Cyclohexanone Methanol Methyl ethyl ketone	Solvent for cellulose ethers used in printing inks Solvent in printing preparations Solvent for inks Solvent in printing inks Solvent in production of inks Extraction solvent in production of printing inks
Can Coating Industry*	n-Butyl alcohol Cyclohexanone Ethylbenzene, Methyl ethyl ketone, Methyl isobutyl ketone, Xylene Toluene	Solvent in can coatings Solvent for metal coating Solvent for can coating Solvent in can varnishes
Commercial Testing Laboratories	Acetone, Ethylbenzene, Xylene	Laboratory uses include cleaning instruments, glassware, and equipment Extraction solvents Solvent for extraction of metals
Coil Coating Industry*	Methyl isobutyl ketone n-Butyl alcohol, Ethylbenzene, Methyl ethyl ketone, Xylene Toluene	Solvent in coil coatings Solvent in coil varnishes

*Geographic distribution data are not available.

Table 2-2. (continued)

Industry	Solvents		How Solvents are Used
Electronics Components Manufacturing	Acetone 1,1,2-Trichloro-1,2,2-trifluoroethane		Solvent in cleaning and drying of printed circuits Solvent for cold cleaning electronic parts Solvent for vapor phase cleaning of electronic parts
Semiconductors Manufacturing	Methylene chloride 1,1,1-Trichloroethane		Cleaning solvent
Inorganic Chemicals Industry*	Carbon disulfide		Solvent for sulfur production
Synthetic Rubber Industry	Carbon tetrachloride		Solvent in manufacture of sulfonated polyethylene
Tire Industry	Cyclohexanone Ethyl ether		Solvent for manufacture of crude rubber Extraction solvent for rubber
Textiles Industry	1,1,1-Trichloroethane Cyclohexanone Methylene chloride, Tetrachloroethylene Trichloroethylene Methanol		Solvent in spot remover Spot remover Solvent in textile sizing Prelaundry garment spray and textile scouring Solvent in textile spotting fluids and textile sizing Solvent for coating fabrics
Leather and Tanning Industry	Cyclohexanone		Spot remover
Transportation Vehicles Manufacturing	Ethyl acetate		Solvent for coatings
Machinery Industry*	Ethyl acetate		Solvent for coatings

*Geographic distribution data are not available.

Table 2-2. (continued)

Industry	Solvents	How Solvents are Used
Paper Coating Industry	Methyl isobutyl ketone, Toluene, Xylene, Ethyl acetate, Ethylbenzene, Methyl ethyl ketone, Acetone	Solvent for paper coatings
Film Industry*	Ethyl acetate Methylene chloride, 1,1,2-trichloro-1,1,2-trifluoroethane	Solvent for film coating Solvent for photographic film manufacturing
Building Products Industry*	Ethyl acetate Methyl isobutyl ketone	Solvent for coatings Solvent for wood panelling coatings
Automotive Industry*	Methanol Ethyl acetate	Solvent for windshield wiper preparations Solution in automotive topcoat and primer
Adhesives and Sealants Industry	1,1,1-Trichloroethane Toluene	Resin solvent in adhesives Solvent for adhesives, especially pressure sensitive tapes and labels
	Methyl isobutyl ketone, Trichloroethylene, Methyl ethyl ketone, Acetone Nitrobenzene	Solvent use for adhesives Solvent for depolymerization of rubber for adhesives
Cement Industry	Methyl isobutyl ketone	Solvent for acrylonitrile cements
Food Industry	Methylene chloride Trichloroethylene	Solvent for extracting caffeine, edible fats, butter, and hops flavoring Solvent for food extractions
Dry Cleaning Industry	Tetrachloroethylene, Trichloroethylene, 1,1,2-Trichloro-1,2,2-trifluoroethane	Solvent for dry cleaning

*Geographic distribution data are not available.

Table 2-2. (continued)

Industry	Solvents	How Solvents are Used
Wool Weaving and Finishing Industry	Trichloroethylene	Solvent in wool cleaning
Magnetic Tape Industry*	1,1,2-Trichloro-1,2,2-trifluoroethane	Solvent for magnetic tape
Brazing, Welding, and Soldering Industry*	Acetone	Solvent for acetylene absorbance in cylinders
Cleaning Products Industry*	1,1,1-Trichloroethane 1,2-Dichlorobenzene Methanol	Solvent in drain cleaning; Solvent in shoe polishes Solvent in engine cleaning Solvent for windshield washing preparations
Aerosols Manufacturing*	1,1,1-Trichloroethane	Solvent for active ingredients in aerosols (including deodorants and antiperspirants)
Petroleum Refining Industry	Methanol Nitrobenzene Methyl ethyl ketone	Solvent in gasoline and heating oil refining Solvent in petroleum refining Lube oil in dewaxing by solvent extraction

*Geographic distribution data not available.

Reference: Organic Solvent Use Study - Final Report.

Table 2-3. Industries Involved in Surface
Cleaning and Degreasing

Textile Industry
Metal Furniture Manufacturing
Primary Metals Manufacturing
Fabricated Metal Products
Non-Electrical Machinery Manufacture
Electrical Equipment Manufacture
Transportation Vehicles Manufacturing
Instruments and Clocks Manufacture
Automotive Repair Shops
Gasoline Stations*

Listed Hazardous Solvents Used in Degreasing

Chlorobenzene
Cyclohexanone
Methylene chloride
1,2-Dichlorobenzene
Toluene
1,1,1-Trichloroethane
Trichloroethylene
Tetrachloroethylene
Trichlorofluoromethane
1,1,2-Trichloro-1,2,2-trifluoroethane
Xylene

*Geographic distribution data not available.

Reference: Organic Solvent Use Study - Final Report.

Tables 2-2 and 2-3. The tables present information on solvent use in industry for permit writers, enforcement personnel and the regulated community. It is not intended to establish the applicability of the regulation.

The primary industries that generate spent solvents through surface cleaning and degreasing operations are presented in Table 2-3. Table 2-3 also includes a list of solvents commonly used for degreasing.

2.4 Spent Solvent Waste Generation

There are many ways in which spent solvent wastes are generated in industry. In processes which involve reactions, solvents are sometimes used to solubilize reactants or products to keep the reaction single-phased or to aid in the purification or drying of products. Spent solvent wastes can be generated in subsequent product purification or solvent recovery steps. Typical spent solvent wastes generated in solvent recovery operations include distillation bottoms or wastewater from steam stripping and other types of treatment. In addition, if no recovery processes are employed, solvents that are no longer useful as solvents are themselves spent solvent wastes.

Many industries such as the paint, ink, and dye industries manufacture solvent-containing products. Solvents are used to solubilize active ingredients and to aid in the application of the product. Solvent waste is usually generated during cleaning of the above products. For example, a printer may use solvent to clean printing presses between jobs requiring different batches of ink. A paint plant may use solvents to clean paint residue from tanks and equipment. Industrial applicators of paints or other solvent-containing coatings may have solvent vapor recovery systems or water-scrubber systems to reduce solvent emissions to the atmosphere.

2.4.1 Surface Cleaning

Surface cleaning includes both industrial degreasing of metal products and repair work. Degreasing operations occur in all of the industries presented in Table 2-3. Solvent cleaning is used to remove oily dirt, grease, smears, and fingerprints from metal workpieces before the final finishing operation, such as porcelain enameling, is performed (Reference 7). Solvent cleaners are also used to remove oil and grease based lubricants that have been applied to the surface of nonferrous metals during mechanical forming operations (Reference 8). Repair work encompasses degreasing operations with respect to industrial maintenance and repair of manufacturing equipment, commercial service and repair, and consumer-performed maintenance and repair.

Establishments that practice surface cleaning may use one of four types of degreasing operations: cold cleaning, open top vapor degreasing, conveyORIZED degreasing, and fabric scouring. These degreasing operations are described below. Spent solvents can be generated from all four types of degreasing operations. In cold cleaning operations, the solvent is maintained below its boiling point. The item to be cleaned may either be immersed in an agitated solvent or suspended above the solvent tank and sprayed with the solvent. Cold cleaning can also consist of a solvent-filled tank where items to be cleaned are simply dipped in the tank. Spent solvents will be generated when the solvent is too contaminated to do further useful cleaning.

Solvents used in cold degreasing include halogenated solvents, aliphatic and aromatic non-halogenated solvents, and oxygenated compounds (Reference 2). The halogenated solvents include trichloroethylene, 1,1,1-trichloroethane, tetrachloroethylene, methylene chloride, and trichlorotrifluoroethane. The non-halogenated solvents are petroleum products including naphtha, kerosene, benzene, toluene, xylene, cyclohexane, and heavy aromatics. Oxygenated solvents include acetone, methyl ethyl ketone, butyl alcohols, and ethers.

In open top vapor degreasing an item is cleaned as it is suspended over a boiling solvent in a vat. Solvent vapor condenses on the dirty object until the temperature of the object reaches that of the solvent. The object may also be sprayed with liquid solvent for additional cleaning. Halogenated solvents are used for vapor degreasing. Petroleum products are too flammable and their boiling points are too low to safely use them for vapor degreasing. The same halogenated compounds named above for use in cold degreasing operations are used in vapor degreasing.

Conveyorized degreasing consists of vapor degreasing or cold degreasing. Objects to be cleaned are continuously moved through the solvent spray.

Fabric scouring operations use conveyorized degreasing machines to clean fabric. Tetrachloroethylene is the solvent predominantly used for scouring. Scouring solvents are removed from the fabric with an aqueous solution of alcohol (Reference 4).

2.4.2 Equipment Cleaning

Listed F001-F005 solvents are used in virtually every industry for equipment and process cleaning. Spent solvent wastes are generated when equipment such as reaction vats, storage tanks, pumps, and process lines

are cleaned. Process equipment is often cleaned between production of different types of products that contain solvents and during general good housekeeping procedures. Equipment cleaning may be synonymous with surface cleaning or degreasing in some instances (e.g., degreasing of a pump).

2.5 Geographical Distributions

Included in Tables 2-4 through 2-34 are state and EPA regional distribution data for many of the industries listed in Table 2-2. A United States map (Figure 2-1) is included to illustrate the EPA region boundaries.

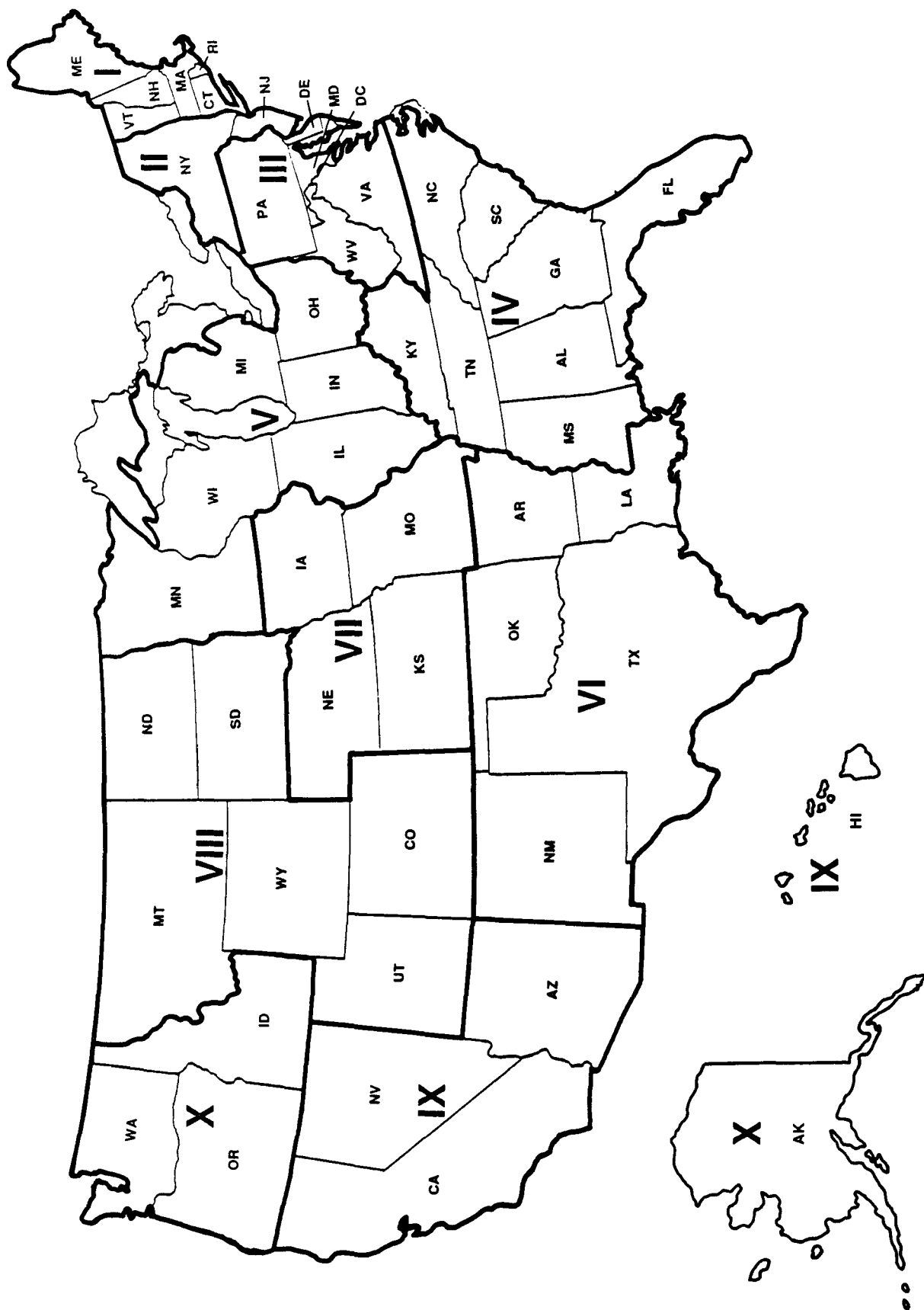


Figure 2-1. EPA Regions

Table 2-4

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Wood Furniture Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>	
AL (IV)	71	MT (VIII)		I	217
AK (X)		NE (VII)	2	II	403
AZ (IX)	38	NV (IX)		III	281
AR (VI)	44	NH (I)	31	IV	823
CA (IX)	661	NJ (II)	81	V	416
CO (VIII)	39	NM (VI)		VI	220
CT (I)	34	NY (II)	322	VII	78
DE (III)		NC (IV)	236	VIII	39
DC (III)		ND (VIII)		IX	706
FL (IV)	214	OH (V)	66	X	101
GA (IV)	79	OK (VI)	19		
HI (IX)	7	OR (X)	44		
ID (X)		PA (III)	129		
IL (V)	92	RI (I)			
IN (V)	101	SC (IV)	23		
IA (VII)	3	SD (VIII)			
KS (VII)	20	TN (IV)	116		
KY (IV)	27	TX (VI)	139		
LA (VI)	18	UT (VIII)			
ME (I)	25	VT (I)	24		
MD (III)	22	VA (III)	67		
MA (I)	103	WA (X)	57		
MI (V)	86	WV (III)			
MN (V)	33	WI (V)	38		
MS (IV)	57	WY (VIII)			
MO (VII)	53				

*Includes Data for SIC codes 2521, 2517, and 2511

Reference: 1977 Census of Manufacturers

Table 2-5

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Metal Furniture Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	13	MT (VIII)		I 21
AK (X)		NE (VII)		II 130
AZ (IX)		NV (IX)		III
AR (VI)	4	NH (I)		IV
CA (IX)	116	NJ (II)	26	V
CO (VIII)		NM (VI)		VI
CT (I)	4	NY (II)	104	VII
DE (III)	1	NC (IV)	26	VIII
DC (III)		ND (VIII)		IX 116
FL (IV)	39	OH (V)	29	X
GA (IV)	14	OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)	46	
IL (V)	42	RI (I)		
IN (V)	11	SC (IV)		
IA (VII)	2	SD (VIII)		
KS (VII)	2	TN (IV)	13	
KY (IV)	7	TX (VI)	22	
LA (VI)	4	UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)	10	
MA (I)	17	WA (X)		
MI (V)	19	WV (III)	1	
MN (V)	3	WI (V)	10	
MS (IV)	4	WY (VIII)		
MO (VII)	15			

*Includes data for SIC codes 2522 and 2514

Reference: 1977 Census of Manufacturers

Table 2-6

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Plastics and Resins Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 34
AK (X)		NE (VII)		II 70
AZ (IX)		NV (IX)		III 39
AR (VI)		NH (I)		IV 59
CA (IX) 48		NJ (II) 45		V 86
CO (VIII)		NM (VI)		VI 44
CT (I) 10		NY (II) 15		VII 6
DE (III) 7		NC (IV) 11		VIII
DC (III)		ND (VIII)		IX 48
FL (IV) 9		OH (V) 26		X 11
GA (IV) 11		OK (VI)		
HI (IX)		OR (X) 8		
ID (X)		PA (III) 21		
IL (V) 31		RI (I)		
IN (V) 8		SC (IV) 5		
IA (VII) 2		SD (VIII)		
KS (VII)		TN (IV) 6		
KY (IV) 9		TX (VI) 31		
LA (VI) 13		UT (VIII)		
ME (I)		VT (I)		
MD (III) 3		VA (III) 3		
MA (I) 24		WA (X) 3		
MI (V) 10		WV (III) 5		
MN (V) 5		WI (V) 6		
MS (IV) 8		WY (VIII)		
MO (VII) 4				

*Includes data for SIC Code 2821

Reference: 1977 Census of Manufacturers

Table 2-7

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Fiber Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	5	MT (VIII)		I 3
AK (X)		NE (VII)		II
AZ (IX)		NV (IX)		III 18
AR (VI)		NH (I)		IV 47
CA (IX)		NJ (II)		V 1
CO (VIII)		NM (VI)		VI
CT (I)	2	NY (II)		VII
DE (III)	1	NC (IV)	13	VIII
DC (III)		ND (VIII)		IX
FL (IV)	3	OH (V)	1	X
GA (IV)	2	OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)	3	
IL (V)		RI (I)	1	
IN (V)		SC (IV)	15	
IA (VII)		SD (VIII)		
KS (VII)		TN (IV)	9	
KY (IV)		TX (VI)		
LA (VI)		UT (VIII)		
ME (I)		VT (I)		
MD (III)	4	VA (III)	9	
MA (I)		WA (X)		
MI (V)		WV (III)	1	
MN (V)		WI (V)		
MS (IV)		WY (VIII)		
MO (VII)				

*Includes data for SIC Codes 2823 and 2824
Reference: 1977 Census of Manufacturers

Table 2-8

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Pharmaceutical Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 38
AK (X)		NE (VII)	3	II 180
AZ (IX)	5	NV (IX)		III 81
AR (VI)		NH (I)		IV 67
CA (IX)	96	NJ (II)	82	V 150
CO (VIII)	7	NM (VI)		VI 30
CT (I)	16	NY (II)	98	VII 53
DE (III)	3	NC (IV)	12	VIII 11
DC (III)		ND (VIII)		IX 101
FL (IV)	20	OH (V)	23	X 8
GA (IV)	12	OK (VI)		
HI (IX)		OR (X)	8	
ID (X)		PA (III)	47	
IL (V)	60	RI (I)		
IN (V)	19	SC (IV)	4	
IA (VII)	14	SD (VIII)		
KS (VII)	6	TN (IV)	13	
KY (IV)		TX (VI)	30	
LA (VI)	7	UT (VIII)	4	
ME (I)		VT (I)		
MD (III)	17	VA (III)	12	
MA (I)	22	WA (X)		
MI (V)	29	WV (III)	2	
MN (V)	11	WI (V)	8	
MS (IV)	6	WY (VIII)		
MO (VII)	30			

*Includes data for SIC Code 2834

Reference: 1977 Census of Manufacturers

Table 2-9

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Paint Manufacturing and Application*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	13	MT (VIII)		I 69
AK (X)		NE (VII)		II 279
AZ (IX)		NV (IX)		III 103
AR (VI)	8	NH (I)		IV 208
CA (IX)	232	NJ (II)	146	V 389
CO (VIII)	10	NM (VI)		VI 121
CT (I)	21	NY (II)	133	VII 72
DE (III)	4	NC (IV)	22	VIII 15
DC (III)		ND (VIII)		IX 232
FL (IV)	78	OH (V)	97	X 44
GA (IV)	37	OK (VI)	16	
HI (IX)		OR (X)	18	
ID (X)		PA (III)	61	
IL (V)	142	RI (I)		
IN (V)	32	SC (IV)	4	
IA (VII)	14	SD (VIII)		
KS (VII)	7	TN (IV)	23	
KY (IV)	22	TX (VI)	87	
LA (VI)	10	UT (VIII)	5	
ME (I)		VT (I)		
MD (III)	24	VA (III)	14	
MA (I)	48	WA (X)	26	
MI (V)	67	WV (III)		
MN (V)	20	WI (V)	31	
MS (IV)	9	WY (VIII)		
MO (VII)	51			

*Includes data for SIC Code 2851

Reference: 1977 Census of Manufacturers

Table 2-10

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Cyclic Crudes and Intermediates Including Dyes Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	4	MT (VIII)		I 10
AK (X)		NE (VII)		II 54
AZ (IX)		NV (IX)		III 26
AR (VI)		NH (I)		IV 22
CA (IX)	8	NJ (II)	42	V 33
CO (VIII)		NM (VI)		VI 16
CT (I)	2	NY (II)	12	VII
DE (III)	2	NC (IV)	7	VIII
DC (III)		ND (VIII)		IX 8
FL (IV)		OH (V)	13	X
GA (IV)		OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)	14	
IL (V)	16	RI (I)	2	
IN (V)		SC (IV)	8	
IA (VII)		SD (VIII)		
KS (VII)		TN (IV)	2	
KY (IV)	1	TX (VI)	13	
LA (VI)	3	UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)		
MA (I)	3	WA (X)		
MI (V)	6	WV (III)	7	
MN (V)	4	WI (V)		
MS (IV)		WY (VIII)		
MO (VII)				

*Includes data for SIC Code 2865

Reference: 1977 Census of Manufacturers

Table 2-11

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Pigments Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 4
AK (X)		NE (VII)		II 25
AZ (IX)		NV (IX)		III 12
AR (VI)		NH (I)		IV 7
CA (IX) 11		NJ (II) 18		V 19
CO (VIII)		NM (VI)		VI
CT (I)		NY (II) 7		VII 5
DE (III) 1		NC (IV)		VIII
DC (III)		ND (VIII)		IX 11
FL (IV)		OH (V) 11		X
GA (IV) 3		OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III) 11		
IL (V) 8		RI (I)		
IN (V)		SC (IV)		
IA (VII)		SD (VIII)		
KS (VII)		TN (IV) 3		
KY (IV)		TX (VI)		
LA (VI)		UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)		
MA (I) 4		WA (X)		
MI (V)		WV (III)		
MN (V)		WI (V)		
MS (IV) 1		WY (VIII)		
MO (VII) 5				

*Includes data for SIC Code 2816

Reference: 1977 Census of Manufacturers

Table 2-12

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Organic Chemicals Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	9	MT (VIII)		I 29
AK (X)		NE (VII)		II 112
AZ (IX)		NV (IX)		III 46
AR (VI)	6	NH (I)	2	IV 79
CA (IX)	42	NJ (II)	73	V 96
CO (VIII)	5	NM (VI)		VI 110
CT (I)	13	NY (II)	39	VII 20
DE (III)	4	NC (IV)	14	VIII 15
DC (III)		ND (VIII)		IX 42
FL (IV)	6	OH (V)	31	X
GA (IV)	15	OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)	23	
IL (V)	28	RI (I)	4	
IN (V)	6	SC (IV)	12	
IA (VII)	3	SD (VIII)		
KS (VII)	6	TN (IV)	12	
KY (IV)	11	TX (VI)	72	
LA (VI)	32	UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)	5	
MA (I)	10	WA (X)		
MI (V)	20	WV (III)	14	
MN (V)		WI (V)	11	
MS (IV)		WY (VIII)		
MO (VII)	11			

*Includes data for SIC Code 2869

Reference: 1977 Census of Manufacturers

Table 2-13

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Agricultural Chemicals Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	8	MT (VIII)		I 2
AK (X)		NE (VII)		II 38
AZ (IX)		NV (IX)		III 12
AR (VI)	7	NH (I)		IV 76
CA (IX)	56	NJ (II)	18	V 35
CO (VIII)		NM (VI)		VI 62
CT (I)	2	NY (II)	20	VII 25
DE (III)		NC (IV)	13	VIII
DC (III)		ND (VIII)		IX 56
FL (IV)	25	OH (V)	12	X 10
GA (IV)	16	OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)	12	
IL (V)	18	RI (I)		
IN (V)	5	SC (IV)		
IA (VII)		SD (VIII)		
KS (VII)	6	TN (IV)	6	
KY (IV)		TX (VI)	42	
LA (VI)	13	UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)		
MA (I)		WA (X)	10	
MI (V)		WV (III)		
MN (V)		WI (V)		
MS (IV)	8	WY (VIII)		
MO (VII)	19			

*Includes data for SIC Code 2879

Reference: 1977 Census of Manufacturers

Table 2-14

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Printing Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>	
AL (IV)	563	MT (VIII)	199	I	3,835
AK (X)	46	NE (VII)	537	II	10,861
AZ (IX)	503	NV (IX)	150	III	5,473
AR (VI)	436	NH (I)	248	IV	7,968
CA (IX)	7,647	NJ (II)	2,548	V	13,348
CO (VIII)	959	NM (VI)	210	VI	5,690
CT (I)	1078	NY (II)	8,313	VII	4,215
DE (III)	43	NC (IV)	1,097	VIII	1,947
DC (III)	456	ND (VIII)	182	IX	8,429
FL (IV)	2,497	OH (V)	2,613	X	1,667
GA (IV)	1,209	OK (VI)	769		
HI (IX)	129	OR (X)	601		
ID (X)	176	PA (III)	2,746		
IL (V)	4,202	RI (I)	196		
IN (V)	1,291	SC (IV)	401		
IA (VII)	1,137	SD (VIII)	277		
KS (VII)	822	TN (IV)	1,150		
KY (IV)	650	TX (VI)	3,658		
LA (VI)	617	UT (VIII)	242		
ME (I)	202	VT (I)	152		
MD (III)	941	VA (III)	995		
MA (I)	1,959	WA (X)	844		
MI (V)	2,162	WV (III)	292		
MN (V)	1,567	WI (V)	1,513		
MS (IV)	401	WY (VIII)	88		
MO (VII)	1,719				

*Includes data for SIC Codes 2711 through 2795 and 2893

Reference: 1977 Census of Manufacturers

Table 2-15

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Commercial Testing Laboratories*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	28	MT (VIII)	10	I 105
AK (X)	7	NE (VII)	6	II 194
AZ (IX)	25	NV (IX)	6	III 157
AR (VI)	14	NH (I)	6	IV 280
CA (IX)	247	NJ (II)	81	V 327
CO (VIII)	52	NM (VI)	11	VI 333
CT (I)	29	NY (II)	113	VII 72
DE (III)	4	NC (IV)	27	VIII 105
DC (III)	3	ND (VIII)	14	IX 281
FL (IV)	100	OH (V)	81	X 70
GA (IV)	33	OK (VI)	40	
HI (IX)	3	OR (X)	20	
ID (X)	5	PA (III)	82	
IL (V)	89	RI (I)	9	
IN (V)	28	SC (IV)	12	
IA (VII)	20	SD (VIII)	3	
KS (VII)	18	TN (IV)	32	
KY (IV)	26	TX (VI)	200	
LA (VI)	68	UT (VIII)	17	
ME (I)	7	VT (I)	1	
MD (III)	23	VA (III)	33	
MA (I)	53	WA (X)	38	
MI (V)	64	WV (III)	12	
MN (V)	29	WI (V)	36	
MS (IV)	22	WY (VIII)	9	
MO (VII)	28			

*Includes data for SIC Code 7397

Reference: 1977 Census of Service Industries

Table 2-16

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Electronic Components Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	19	MT (VIII)		I 416
AK (X)		NE (VII)	5	II 615
AZ (IX)	53	NV (IX)		III 265
AR (VI)	1	NH (I)	43	IV 243
CA (IX)	964	NJ (II)	276	V 676
CO (VIII)	44	NM (VI)	15	VI 199
CT (I)	117	NY (II)	339	VII 94
DE (III)		NC (IV)	37	VIII 50
DC (III)		ND (VIII)		IX 1,017
FL (IV)	128	OH (V)	113	X 68
GA (IV)	15	OK (VI)	27	
HI (IX)		OR (X)	29	
ID (X)		PA (III)	180	
IL (V)	265	RI (I)	14	
IN (V)	76	SC (IV)	7	
IA (VII)	28	SD (VIII)	6	
KS (VII)	25	TN (IV)	25	
KY (IV)	7	TX (VI)	156	
LA (VI)		UT (VIII)		
ME (I)	14	VT (I)	2	
MD (III)	47	VA (III)	38	
MA (I)	226	WA (X)	39	
MI (V)	85	WV (III)		
MN (V)	8	WI (V)	57	
MS (IV)	5	WY (VIII)		
MO (VII)	36			

*Includes data for SIC Codes 3675, 3676, 3677, 3678, and 3679

Reference: 1977 Census of Manufacturers

Table 2-17

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Semiconductors and Related Devices Manufacture*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 68
AK (X)		NE (VII)		II 93
AZ (IX) 16		NV (IX)		III 31
AR (VI)		NH (I)		IV 20
CA (IX) 180		NJ (II) 34		V 21
CO (VIII) 8		NM (VI)		VI 39
CT (I) 13		NY (II) 59		VII 4
DE (III)		NC (IV)		VIII 11
DC (III)		ND (VIII)		IX 196
FL (IV) 19		OH (V) 13		X 5
GA (IV)		OK (VI) 3		
HI (IX)		OR (X) 4		
ID (X) 1		PA (III) 31		
IL (V)		RI (I) 4		
IN (V) 5		SC (IV)		
IA (VII)		SD (VIII)		
KS (VII)		TN (IV) 1		
KY (IV)		TX (VI) 36		
LA (VI)		UT (VIII) 3		
ME (I) 3		VT (I) 2		
MD (III)		VA (III)		
MA (I) 46		WA (X)		
MI (V)		WV (III)		
MN (V) 3		WI (V)		
MS (IV)		WY (VIII)		
MO (VII) 4				

*Includes data for SIC Code 3674

Reference: 1977 Census of Manufacturers

Table 2-18

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Synthetic Rubber Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I
AK (X)		NE (VII)		II
AZ (IX)		NV (IX)		III
AR (VI)		NH (I)		IV 3
CA (IX)		NJ (II)		V 11
CO (VIII)		NM (VI)		VI 14
CT (I)		NY (II)		VII
DE (III)		NC (IV)		VIII
DC (III)		ND (VIII)		IX
FL (IV)		OH (V) 4		X
GA (IV)		OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)		
IL (V)		RI (I)		
IN (V)		SC (IV)		
IA (VII)		SD (VIII)		
KS (VII)		TN (IV)		
KY (IV) 2		TX (VI) 10		
LA (VI) 4		UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)		
MA (I)		WA (X)		
MI (V) 7		WV (III)		
MN (V)		WI (V)		
MS (IV) 1		WY (VIII)		
MO (VII)				

*Includes data for SIC Code 2822

Reference: 1977 Census of Manufacturers

Table 2-19

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Tire Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	9	MT (VIII)		I 7
AK (X)		NE (VII)		II 5
AZ (IX)		NV (IX)		III 20
AR (VI)	6	NH (I)		IV 52
CA (IX)	21	NJ (II)		V 38
CO (VIII)		NM (VI)		VI 24
CT (I)	2	NY (II)	5	VII 10
DE (III)		NC (IV)	9	VIII
DC (III)		ND (VIII)		IX 21
FL (IV)		OH (V)	21	X
GA (IV)	12	OK (VI)	6	
HI (IX)		OR (X)		
ID (X)		PA (III)	13	
IL (V)	7	RI (I)		
IN (V)	5	SC (IV)	4	
IA (VII)	5	SD (VIII)		
KS (VII)	1	TN (IV)	11	
KY (IV)	4	TX (VI)	12	
LA (VI)		UT (VIII)		
ME (I)	1	VT (I)		
MD (III)	1	VA (III)	6	
MA (I)	4	WA (X)		
MI (V)	3	WV (III)		
MN (V)		WI (V)	2	
MS (IV)	3	WY (VIII)		
MO (VII)	4			

*Includes data for SIC Code 3011

Reference: 1977 Census of Manufacturers

Table 2-20

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Textiles Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	10	MT (VIII)		I 240
AK (X)		NE (VII)		II 450
AZ (IX)		NV (IX)		III 165
AR (VI)	2	NH (I)	14	IV 396
CA (IX)	95	NJ (II)	215	V 47
CO (VIII)		NM (VI)		VI 10
CT (I)	34	NY (II)	235	VII
DE (III)	2	NC (IV)	160	VIII
DC (III)		ND (VIII)		IX 95
FL (IV)	6	OH (V)	22	X 7
GA (IV)	104	OK (VI)		
HI (IX)		OR (X)	6	
ID (X)		PA (III)	125	
IL (V)	13	RI (I)	61	
IN (V)		SC (IV)	85	
IA (VII)		SD (VIII)		
KS (VII)		TN (IV)	29	
KY (IV)		TX (VI)	8	
LA (VI)		UT (VIII)		
ME (I)	11	VT (I)		
MD (III)	6	VA (III)	32	
MA (I)	120	WA (X)	1	
MI (V)	7	WV (III)		
MN (V)		WI (V)	5	
MS (IV)	2	WY (VIII)		
MO (VII)				

*Includes data for SIC Codes 2231, 2261, 2262, 2269, and 2295
Reference: 1977 Census of Manufacturers

Table 2-21

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Leather and Tanning Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 138
AK (X)		NE (VII)		II 116
AZ (IX)		NV (IX)		III 25
AR (VI)		NH (I)	14	IV 21
CA (IX)	36	NJ (II)	31	V 58
CO (VIII)		NM (VI)		VI 10
CT (I)		NY (II)	85	VII 9
DE (III)		NC (IV)	3	VIII
DC (III)		ND (VIII)		IX 36
FL (IV)		OH (V)	7	X
GA (IV)	3	OK (VI)		
HI (IX)		OR (X)		
ID (X)		PA (III)	19	
IL (V)	14	RI (I)		
IN (V)		SC (IV)	2	
IA (VII)	6	SD (VIII)		
KS (VII)		TN (IV)	11	
KY (IV)	2	TX (VI)	10	
LA (VI)		UT (VIII)		
ME (I)	13	VT (I)	1	
MD (III)	2	VA (III)	2	
MA (I)	110	WA (X)		
MI (V)	8	WV (III)	2	
MN (V)	5	WI (V)	24	
MS (IV)		WY (VIII)		
MO (VII)	3			

*Includes data for SIC Code 3111

Reference: 1977 Census of Manufacturers

Table 2-22

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Transportation Vehicles Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	97	MT (VIII)		I 450
AK (X)		NE (VII)	22	II 619
AZ (IX)	81	NV (IX)		III 596
AR (VI)	64	NH (I)	5	IV 1,327
CA (IX)	1,905	NJ (II)	212	V 2,077
CO (VIII)	86	NM (VI)	3	VI 1,067
CT (I)	151	NY (II)	407	VII 450
DE (III)	6	NC (IV)	150	VIII 128
DC (III)		ND (VIII)	3	IX 1,991
FL (IV)	631	OH (V)	465	X 534
GA (IV)	165	OK (VI)	174	
HI (IX)	5	OR (X)	185	
ID (X)	17	PA (III)	340	
IL (V)	278	RI (I)	41	
IN (V)	444	SC (IV)	43	
IA (VII)	88	SD (VIII)	5	
KS (VII)	152	TN (IV)	126	
KY (IV)	70	TX (VI)	623	
LA (VI)	203	UT (VIII)	34	
ME (I)	78	VT (I)	2	
MD (III)	114	VA (III)	125	
MA (I)	173	WA (X)	332	
MI (V)	599	WV (III)	11	
MN (V)	120	WI (V)	171	
MS (IV)	45	WY (VIII)		
MO (VII)	183			

*Includes data for SIC Codes 3711 through 3799
Reference: 1977 Census of Manufacturers

Table 2-23

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Paper Coating Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 64
AK (X)		NE (VII)		II 88
AZ (IX)		NV (IX)		III 31
AR (VI)		NH (I)	4	IV 47
CA (IX)	59	NJ (II)	40	V 149
CO (VIII)		NM (VI)		VI 32
CT (I)	10	NY (II)	48	VII 18
DE (III)		NC (IV)	10	VIII
DC (III)		ND (VIII)		IX 59
FL (IV)	10	OH (V)	40	X 8
GA (IV)	9	OK (VI)		
HI (IX)		OR (X)	3	
ID (X)		PA (III)	31	
IL (V)	45	RI (I)	9	
IN (V)	11	SC (IV)	4	
IA (VII)	8	SD (VIII)		
KS (VII)		TN (IV)	10	
KY (IV)	2	TX (VI)	28	
LA (VI)	4	UT (VIII)		
ME (I)		VT (I)		
MD (III)		VA (III)		
MA (I)	41	WA (X)	5	
MI (V)	22	WV (III)		
MN (V)	10	WI (V)	21	
MS (IV)	2	WY (VIII)		
MO (VII)	10			

*Includes data for SIC Code 2641

Reference: 1977 Census of Manufacturers

Table 2-24

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Adhesives and Sealants Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)		MT (VIII)		I 46
AK (X)		NE (VII)		II 94
AZ (IX)		NV (IX)		III 35
AR (VI)		NH (I)		IV 47
CA (IX)	78	NJ (II)	45	V 138
CO (VIII)		NM (VI)		VI 32
CT (I)	10	NY (II)	49	VII 19
DE (III)		NC (IV)	11	VIII
DC (III)		ND (VIII)		IX 78
FL (IV)		OH (V)	42	X 11
GA (IV)	20	OK (VI)		
HI (IX)		OR (X)	11	
ID (X)		PA (III)	27	
IL (V)	54	RI (I)		
IN (V)		SC (IV)		
IA (VII)		SD (VIII)		
KS (VII)		TN (IV)	10	
KY (IV)	6	TX (VI)	32	
LA (VI)		UT (VIII)		
ME (I)		VT (I)		
MD (III)	8	VA (III)		
MA (I)	36	WA (X)		
MI (V)	28	WV (III)		
MN (V)		WI (V)	14	
MS (IV)		WY (VIII)		
MO (VII)	19			

*Includes data for SIC Code 2891

Reference: 1977 Census of Manufacturers

Table 2-25

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Food Industry - Beer, Edible Fats, and Butter*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	9	MT (VIII)		I 18
AK (X)		NE (VII)	16	II 48
AZ (IX)		NV (IX)		III 59
AR (VI)		NH (I)	1	IV 71
CA (IX)	53	NJ (II)	20	V 167
CO (VIII)	14	NM (VI)		VI 61
CT (I)		NY (II)	28	VII 64
DE (III)		NC (IV)	14	VIII 14
DC (III)		ND (VIII)		IX 53
FL (IV)	11	OH (V)	21	X 21
GA (IV)	13	OK (VI)		
HI (IX)		OR (X)	1	
ID (X)		PA (III)	42	
IL (V)	27	RI (I)	2	
IN (V)	18	SC (IV)		
IA (VII)	19	SD (VIII)		
KS (VII)	14	TN (IV)	16	
KY (IV)	2	TX (VI)	44	
LA (VI)	17	UT (VIII)		
ME (I)	6	VT (I)		
MD (III)	5	VA (III)	12	
MA (I)	8	WA (X)	20	
MI (V)	17	WV (III)		
MN (V)	44	WI (V)	40	
MS (IV)	6	WY (VIII)		
MO (VII)	15			

*Includes data for SIC Codes 2021, 2077, 2082

Reference: 1977 Census of Manufacturers

Table 2-26

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Dry Cleaning Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>	
AL (IV)	984	MT (VIII)	186	I	2,421
AK (X)	61	NE (VII)	323	II	6,170
AZ (IX)	488	NV (IX)	176	III	4,773
AR (VI)	580	NH (I)	156	IV	9,357
CA (IX)	5,615	NJ (II)	1,712	V	9,681
CO (VIII)	695	NM (VI)	277	VI	5,964
CT (I)	690	NY (II)	4,458	VII	2,699
DE (III)	113	NC (IV)	1,347	VIII	1,540
DC (III)	182	ND (VIII)	144	IX	6,437
FL (IV)	2,453	OH (V)	2,267	X	1,477
GA (IV)	1,349	OK (VI)	716		
HI (IX)	158	OR (X)	476		
ID (X)	186	PA (III)	2,138		
IL (V)	2,661	RI (I)	190		
IN (V)	1,323	SC (IV)	773		
IA (VII)	619	SD (VIII)	179		
KS (VII)	578	TN (IV)	1,029		
KY (IV)	750	TX (VI)	3,518		
LA (VI)	873	UT (VIII)	232		
ME (I)	191	VT (I)	88		
MD (III)	842	VA (III)	1,158		
MA (I)	1,106	WA (X)	754		
MI (V)	1,803	WV (III)	340		
MN (V)	727	WI (V)	900		
MS (IV)	672	WY (VIII)	104		
MO (VII)	1,179				

*Includes data for SIC Codes 7215, 7216, and 7217

Reference: 1977 Census of Service Industries

Table 2-27

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Wool Weaving and Finishing Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	1	MT (VIII)		I 60
AK (X)		NE (VII)		II 23
AZ (IX)		NV (IX)		III 19
AR (VI)		NH (I)	6	IV 5
CA (IX)		NJ (II)		V 2
CO (VIII)		NM (VI)		VI 8
CT (I)	2	NY (II)	23	VII
DE (III)		NC (IV)		VIII
DC (III)		ND (VIII)		IX
FL (IV)		OH (V)	2	X 7
GA (IV)	4	OK (VI)		
HI (IX)		OR (X)	6	
ID (X)		PA (III)	13	
IL (V)		RI (I)	17	
IN (V)		SC (IV)	4	
IA (VII)		SD (VIII)		
KS (VII)		TN (IV)		
KY (IV)		TX (VI)	8	
LA (VI)		UT (VIII)		
ME (I)	11	VT (I)		
MD (III)		VA (III)	6	
MA (I)	24	WA (X)	1	
MI (V)		WV (III)		
MN (V)	3	WI (V)		
MS (IV)		WY (VIII)		
MO (VII)				

*Includes data for SIC Code 2231

Reference: 1977 Census of Manufacturers

Table 2-28

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Petroleum Refining Industry*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>	
AL (IV)	6	MT (VIII)	7		
AK (X)		NE (VII)		II	15
AZ (IX)		NV (IX)		III	25
AR (VI)	4	NH (I)		IV	18
CA (IX)	41	NJ (II)	8	V	48
CO (VIII)	4	NM (VI)	4	VI	126
CT (I)		NY (II)	7	VII	16
DE (III)	1	NC (IV)		VIII	31
DC (III)		ND (VIII)	3	IX	43
FL (IV)		OH (V)	10	X	7
GA (IV)		OK (VI)	16		
HI (IX)	2	OR (X)			
ID (X)		PA (III)	18		
IL (V)	17	RI (I)			
IN (V)	9	SC (IV)			
IA (VII)		SD (VIII)			
KS (VII)	12	TN (IV)	2		
KY (IV)	5	TX (VI)	76		
LA (VI)	26	UT (VIII)	7		
ME (I)		VT (I)			
MD (III)		VA (III)	3		
MA (I)		WA (X)	7		
MI (V)	7	WV (III)	3		
MN (V)	3	WI (V)	2		
MS (IV)	5	WY (VIII)	10		
MO (VII)	4				

*Includes data for SIC Code 2911

Reference: 1977 Census of Manufacturers

Table 2-29

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Primary Metals Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	156	MT (VIII)		I 704
AK (X)	35	NE (VII)	17	II 931
AZ (IX)	23	NV (IX)	1	III 876
AR (VI)	50	NH (I)	28	IV 557
CA (IX)	908	NJ (II)	370	V 2,738
CO (VIII)	30	NM (VI)	3	VI 504
CT (I)	280	NY (II)	561	VII 267
DE (III)	8	NC (IV)	78	VIII 47
DC (III)		ND (VIII)		IX 932
FL (IV)	22	OH (V)	750	X 93
GA (IV)	91	OK (VI)	62	
HI (IX)		OR (X)	42	
ID (X)	2	PA (III)	710	
IL (V)	672	RI (I)	100	
IN (V)	344	SC (IV)	50	
IA (VII)	67	SD (VIII)		
KS (VII)	41	TN (IV)	38	
KY (IV)	73	TX (VI)	363	
LA (VI)	26	UT (VIII)	16	
ME (I)	1	VT (I)	10	
MD (III)	46	VA (III)	67	
MA (I)	285	WA (X)	14	
MI (V)	637	WV (III)	45	
MN (V)	102	WI (V)	233	
MS (IV)	49	WY (VIII)	1	
MO (VII)	142			

*Includes data for SIC Codes 3312 through 3399

Reference: 1977 Census of Manufacturers

Table 2-30

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Fabricated Metals Manufacturing*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>	
AL (IV)	418	MT (VIII)		I	2,624
AK (X)		NE (VII)	84	II	4,058
AZ (IX)	194	NV (IX)	3	III	2,592
AR (VI)	149	NH (I)	41	IV	3,240
CA (IX)	4,368	NJ (II)	1,533	V	9,689
CO (VIII)	255	NM (VI)	7	VI	2,637
CT (I)	988	NY (II)	2,525	VII	2,138
DE (III)	21	NC (IV)	451	VIII	366
DC (III)	3	ND (VIII)	3	IX	4,568
FL (IV)	808	OH (V)	2,371	X	756
GA (IV)	428	OK (VI)	354		
HI (IX)	3	OR (X)	365		
ID (X)	4	PA (III)	1,929		
IL (V)	2,635	RI (I)	377		
IN (V)	923	SC (IV)	216		
IA (VII)	1,205	SD (VIII)	16		
KS (VII)	243	TN (IV)	518		
KY (IV)	294	TX (VI)	1,915		
LA (VI)	212	UT (VIII)	92		
ME (I)	35	VT (I)	5		
MD (III)	286	VA (III)	261		
MA (I)	1,178	WA (X)	387		
MI (V)	2,406	WV (III)	92		
MN (V)	583	WI (V)	771		
MS (IV)	107	WY (VIII)			
MO (VII)	606				

*Includes data for SIC Codes 3411 through 3499

Reference: 1977 Census of Manufacturers

Table 2-31

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Non-Electric Machinery Manufacture*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	444	MT (VIII)		I 3,374
AK (X)		NE (VII)	201	II 4,891
AZ (IX)	236	NV (IX)	38	III 3,334
AR (VI)	278	NH (I)	177	IV 4,176
CA (IX)	6,383	NJ (II)	2,097	V 14,902
CO (VIII)	414	NM (VI)	121	VI 4,010
CT (I)	1,258	NY (II)	2,794	VII 2,102
DE (III)	36	NC (IV)	787	VIII 598
DC (III)		ND (VIII)		IX 6,657
FL (IV)	912	OH (V)	3,663	X 1,127
GA (IV)	559	OK (VI)	564	
HI (IX)		OR (X)	493	
ID (X)	99	PA (III)	2,464	
IL (V)	3,452	RI (I)	263	
IN (V)	1,332	SC (IV)	356	
IA (VII)	535	SD (VIII)	11	
KS (VII)	514	TN (IV)	535	
KY (IV)	380	TX (VI)	2,702	
LA (VI)	345	UT (VIII)	136	
ME (I)	92	VT (I)	45	
MD (III)	285	VA (III)	374	
MA (I)	1,539	WA (X)	535	
MI (V)	3,929	WV (III)	180	
MN (V)	1,047	WI (V)	1,479	
MS (IV)	203	WY (VIII)	37	
MO (VII)	852			

*Includes data for SIC Codes 3511 through 3599

Reference: 1977 Census of Manufacturers

Table 2-32

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Electric Equipment Manufacture*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	80	MT (VIII)	1	I 1,210
AK (X)		NE (VII)	19	II 2,422
AZ (IX)	104	NV (IX)	8	III 1,079
AR (VI)	72	NH (I)	73	IV 1,267
CA (IX)	3,027	NJ (II)	908	V 3,005
CO (VIII)	100	NM (VI)	27	VI 838
CT (I)	381	NY (II)	1,514	VII 380
DE (III)	1	NC (IV)	181	VIII 139
DC (III)		ND (VIII)		IX 3,139
FL (IV)	455	OH (V)	634	X 242
GA (IV)	133	OK (VI)	82	
HI (IX)		OR (X)	92	
ID (X)	3	PA (III)	767	
IL (V)	1,068	RI (I)	43	
IN (V)	310	SC (IV)	55	
IA (VII)	73	SD (VIII)	6	
KS (VII)	70	TN (IV)	221	
KY (IV)	85	TX (VI)	636	
LA (VI)	21	UT (VIII)	32	
ME (I)	39	VT (I)	7	
MD (III)	153	VA (III)	149	
MA (I)	667	WA (X)	147	
MI (V)	451	WV (III)	9	
MN (V)	250	WI (V)	292	
MS (IV)	57	WY (VIII)		
MO (VII)	218			

*Includes data for SIC Codes 3612 through 3699

Reference: 1977 Census of Manufacturers

Table 2-33

CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION

Instruments and Clocks Manufacture*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>
AL (IV)	33	MT (VIII)		I 728
AK (X)		NE (VII)	24	II 1,285
AZ (IX)	26	NV (IX)	3	III 552
AR (VI)	19	NH (I)	33	IV 406
CA (IX)	1,458	NJ (II)	430	V 1,382
CO (VIII)	88	NM (VI)	4	VI 375
CT (I)	209	NY (II)	855	VII 163
DE (III)	7	NC (IV)	56	VIII 110
DC (III)		ND (VIII)		IX 1,487
FL (IV)	222	OH (V)	326	X 81
GA (IV)	35	OK (VI)	20	
HI (IX)		OR (X)	41	
ID (X)	12	PA (III)	409	
IL (V)	484	RI (I)	38	
IN (V)	96	SC (IV)	15	
IA (VII)	19	SD (VIII)	3	
KS (VII)	31	TN (IV)	47	
KY (IV)	23	TX (VI)	332	
LA (VI)		UT (VIII)	19	
ME (I)	7	VT (I)	6	
MD (III)	63	VA (III)	70	
MA (I)	435	WA (X)	28	
MI (V)	251	WV (III)	3	
MN (V)	119	WI (V)	106	
MS (IV)	8	WY (VIII)		
MO (VII)	89			

*Includes data for SIC Codes 3811 through 3873

Reference: 1977 Census of Manufacturers

Table 2-34
CENSUS DATA (1977) FOR NUMBER OF FACILITIES
IN EACH STATE AND EPA REGION
Automotive Repair Shops*

<u>State</u>	<u>Facilities</u>	<u>State</u>	<u>Facilities</u>	<u>EPA Region Totals</u>	
AL (IV)	2,192	MT (VIII)	770	I	7,911
AK (X)	315	NE (VII)	1,439	II	12,157
AZ (IX)	1,525	NV (IX)	447	III	14,602
AR (VI)	1,871	NH (I)	789	IV	23,920
CA (IX)	14,226	NJ (II)	4,027	V	23,973
CO (VIII)	1,989	NM (VI)	909	VI	17,260
CT (I)	1,431	NY (II)	8,130	VII	9,532
DE (III)	299	NC (IV)	4,176	VIII	5,106
DC (III)	156	ND (VIII)	452	IX	16,745
FL (IV)	5,756	OH (V)	5,575	X	5,560
GA (IV)	3342	OK (VI)	2,355		
HI (IX)	547	OR (X)	1,886		
ID (X)	742	PA (III)	8,718		
IL (V)	5,796	RI (I)	587		
IN (V)	3,469	SC (IV)	2,008		
IA (VII)	2,488	SD (VIII)	607		
KS (VII)	2,030	TN (IV)	2,719		
KY (IV)	2,218	TX (VI)	9,891		
LA (VI)	2,234	UT (VIII)	905		
ME (I)	1,072	VT (I)	480		
MD (III)	1,823	VA (III)	2,683		
MA (I)	3,552	WA (X)	2,617		
MI (V)	3,934	WV (III)	923		
MN (V)	2,583	WI (V)	2,616		
MS (IV)	1,509	WY (VIII)	383		
MO (VII)	3,575				

*Includes data for SIC Codes 7538, 7531, 7535 and parts of 7539 including transmission repair shops, auto electrical and fuel system services, and other automotive repair shops.

Reference: 1977 Census of Service Industries

REFERENCES - SECTION 2

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5. U.S. Department of Commerce, Bureau of the Census. 1977 Census of Manufacturers. August 1981.
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3. WASTE CHARACTERIZATION

3.1 Introduction

Characterization data for spent solvent wastes from several industries are presented in this section. Table 3-1 lists industries for which characterization data are available to EPA. Data are presented in tabular form with a description of the process generating the spent solvent waste.

The characterization data were obtained from delisting petitions, the Industrial Technology Division of the Office of Water, the Industry Studies Data Base compiled by the Characterization and Assessment Division of the Office of Solid Waste, a Hazardous Waste Treatment Workshop, and other literature sources. Sampling data which were collected by EPA in support of the land disposal restrictions for solvents are also presented.

3.2 Waste Characterization Data

Characterization data for spent solvent wastes are presented in Tables 3-2 through 3-29. Process flowsheets, where available to EPA, are included. Sample points are indicated on the flowsheet by an X.

Table 3-1

SUMMARY OF INDUSTRIES FOR WHICH SPENT SOLVENT WASTE
CHARACTERIZATION DATA ARE AVAILABLE

<u>Industry</u>	<u>Description of the Spent Solvent Waste</u>
Furniture Manufacturing	Spent thinner and solvent
Plastics and Resins Manufacturing	Still bottoms and caustic Epoxy resin waste Phenolic and polyester/alkyd resin waste
Fiber Manufacturing	Solvent recovery bottoms, laboratory sol- vents, and chrome plating solution
Pharmaceutical Manufacturing	Solvent recovery bottoms
Paint Manufacturing	Paint tank wash Spent thinner
Dyes and Pigments Manufacturing	Dyes and pigments waste
Organic Chemicals Manufacturing	Still bottoms and caustic Isocyanates manufacturing wastes Alkenes manufacturing waste Aldehyde furan manufacturing wastes
Agricultural Chemicals Manufacturing	Pesticide manufacturing waste
Printing Industry	Spent recovery bottoms Spent ink wash
Can Coating Industry	Spent can coating residue
Membrane Production Industry	Spent solvents and organics

3.2.1 Furniture Manufacturing

Waste characterization data for spent solvent wastes generated by the furniture manufacturing industry are presented in Tables 3-2 through 3-5.

Table 3-2

Waste Description: Dirty, reclaimed lacquer thinner used to rinse solvent-based furniture finishing material (F001, F003, and F005) from spray lines between color changes. The spent thinner is also used to wash off culled or miscolored pieces of wooden casegood furniture.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Cyclohexanol	20
Methylene chloride	43
Chloroform	10
Toluene	17
Styrene	10
Suspended solids	<5
Dissolved solids	4

<u>Constituent</u>	<u>Concentration (ppm)</u>
Arsenic	<0.001
Barium	0.009
Cadmium	0.002
Chromium	0.007
Lead	0.01
Mercury	<0.001
Selenium	<0.001
Silver	<0.01
Endrin	<0.005
Lindane	<0.005
Methoxychlor	<0.005
Toxaphene	<0.005
Dichlorophenoxyacetic acid	<0.005
Trichlorophenoxypropionic acid	<0.005

Flash Point (cc): <100°F

pH: acid

Reference: Delisting petition number 488 for Plant A.

Table 3-3

Waste Description: Dirty, reclaimed lacquer thinner used to rinse solvent-based furniture finishing material (F001, F003, and F005) from spray lines between color changes. The spent thinner is also used to wash off culled or miscolored pieces of wooden casegood furniture.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Aliphatic naphtha	31
Methylene chloride	6
Xylene	8
Toluene	14
Carbitol	38
Suspended solids	<5
Dissolved solids	8

<u>Constituent</u>	<u>Concentration (ppm)</u>
Arsenic	<0.001
Barium	0.04
Cadmium	0.01
Chromium	0.002
Lead	0.1
Mercury	<0.01
Selenium	<0.001
Silver	<0.01
Endrin	<0.005
Lindane	<0.005
Methoxychlor	<0.005
Toxaphene	<0.005
Dichlorophenoxyacetic acid	<0.005
Trichlorophenoxypropionic acid	<0.005

Flash Point (cc): <100°F
pH: acid

Reference: Delisting petition number 488 for Plant B.

Table 3-4

Waste Description: Dirty, reclaimed lacquer thinner used to rinse solvent-based furniture finishing material (F001, F003, and F005) from spray lines between color changes. The spent thinner is also used to wash off culled or miscolored pieces of wooden casegood furniture.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Aliphatic naphtha	51
Methylene chloride	2
Xylene	4
Toluene	34
Methyl ethyl ketone	6
1,1,1-Trichloroethane	1
Suspended solids	5-20
Dissolved solids	6

<u>Constituent</u>	<u>Concentration (ppm)</u>
Arsenic	<0.001
Barium	0.11
Cadmium	<0.005
Chromium	0.03
Lead	0.02
Mercury	<0.001
Selenium	<0.001
Silver	<0.01
Endrin	<0.005
Lindane	<0.005
Methoxychlor	<0.005
Toxaphene	<0.005
Dichlorophenoxyacetic acid	<0.005
Trichlorophenoxypropionic acid	<0.005

Flash Point (cc): <100°F
pH: neutral

Reference: Delisting petition number 488 for Plant C.

Table 3-5

Waste Description: Dirty, reclaimed lacquer thinner used to rinse solvent-based furniture finishing material (F001, F003, and F005) from spray lines between color changes. The spent thinner is also used to wash off culled or miscolored pieces of wooden casegood furniture.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Aliphatic and aromatic hydrocarbon solvents	90
Adipate plasticizer	10
Suspended solids	<5
Dissolved solids	8

<u>Constituent</u>	<u>Concentration (ppm)</u>
Arsenic	<0.001
Barium	0.007
Cadmium	<0.005
Chromium	<0.005
Lead	0.007
Mercury	<0.001
Selenium	<0.001
Silver	<0.001
Endrin	<0.005
Lindane	<0.005
Methoxychlor	<0.005
Toxaphene	<0.005
Dichlorophenoxyacetic acid	<0.005
Trichlorophenoxypropionic acid	<0.005

Flash Point (cc): <100°F
pH: neutral

Reference: Delisting petition number 488 for Plant D.

3.2.2 Plastics and Resins Industry

Waste characterization data for spent solvent wastes generated by the plastics and resins industry are presented in Tables 3-6 through 3-8.

Table 3-6

Waste Description: Methanol concentrations contained in plant wastewater from the production of alkyd resins are presented here. Alkyd resin is produced via a polymerization reaction and is recovered by a stripping system (see Figure 3-1). Methanol is used as a solvent in the production of one of the resins produced at this plant; therefore, the product recovery stripping bottoms contain methanol (F003). The stripping bottoms are mixed with caustic rinsewater from cleaning kettles and mixtures between different batches.

<u>Date</u>	<u>% Methanol</u>	<u>Flash Point</u>
09/16/81	0.60	NR
11/09/81	0.80	NR
12/23/81	0.54	>200°F
01/12/82	1.96	NR
05/10/82	0.74	>200°F
06/09/82	0.41	NR
08/12/82	1.13	>200°F
08/31/82	1.43	NR
01/24/83	0.29	>200°F
03/16/83	0.62	>200°F
04/06/83	1.24	>200°F
04/14/83	0.70	>200°F

NR = Not Reported

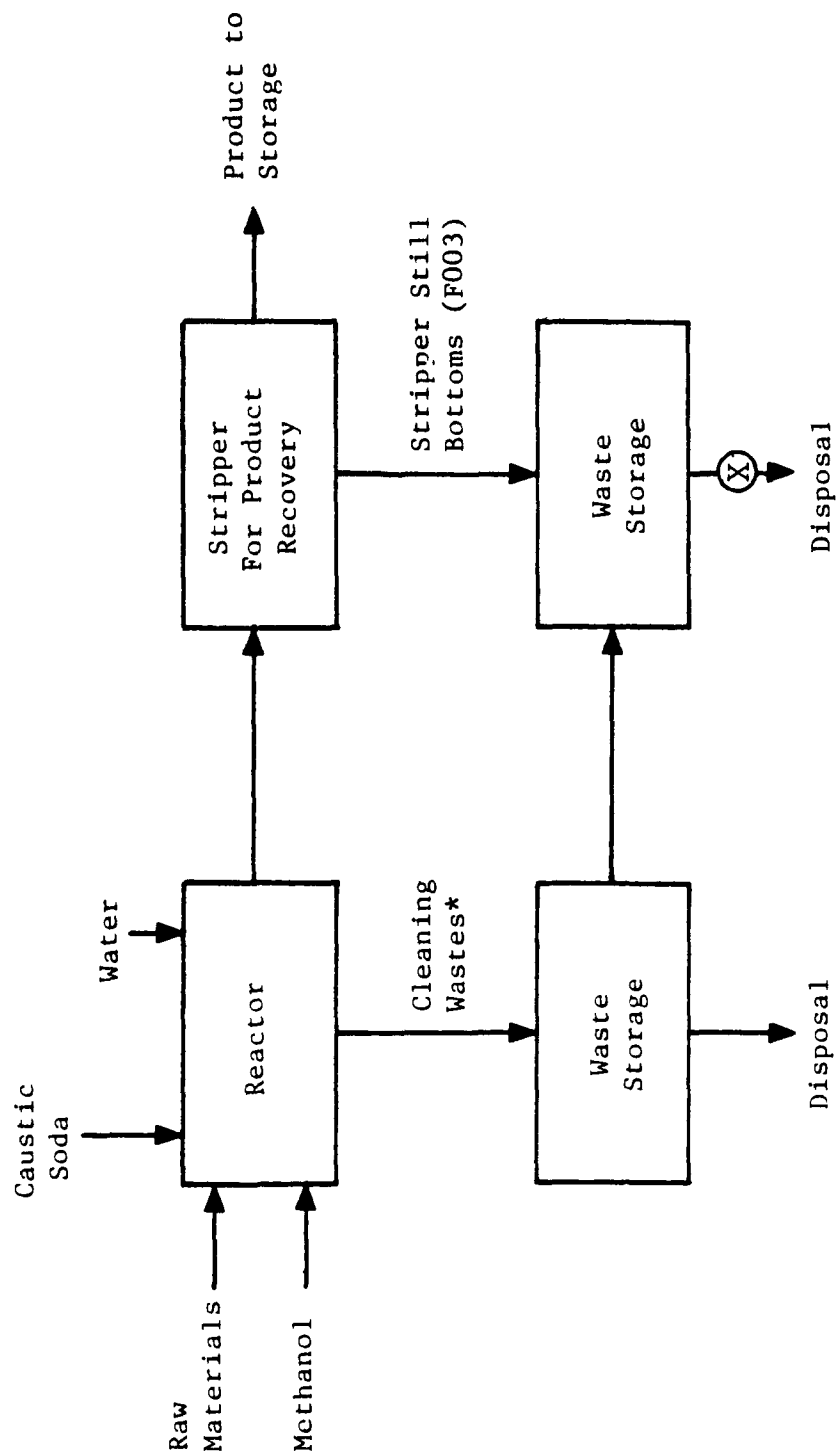
Reference: Delisting petition number 476.

Table 3-7

Waste Description: Spent solvent waste from the manufacture of epoxy resin. Methyl ethyl ketone (F003) is used as a solvent to purify epoxy resins.

<u>Constituent</u>	<u>Concentration (ppm)</u>
Epoxy resin	1-10
Methyl ethyl ketone	>50
Surfactant	0.1-1
Water	1-10

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.



*Reactors are cleaned between batches.

Figure 3-1
RESIN PRODUCTION PROCESS

Table 3-8

Waste Description: Data are for a waste stream generated from the production of polyester/alkyd resin. Alkyd resins are produced using a condensation polymerization reaction. Methanol (F003) is used as a solvent to maintain a single-phase system which permits the condensation reaction to proceed rapidly. Solvents such as xylene (F003) or toluene (F005) are also added to the reactor to form an azeotrope with the water. The azeotrope leaves the reactor as a vapor and is condensed and settled in a decanter. The solvent layer is recycled. The water layer from the decanter comprises the spent solvent waste stream.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Hydroxyl dialkyl ether	0.01-0.1
Diether	1-10
Ether	0.01-0.1
Alkyl hetero-aliphatic compound	1-10
Alkyl benzene	<0.01
Acetaldehyde	0.1-1
Acetone	0.01-0.1
Diethylene glycol	0.1-1
Ethanol	0.1-1
Ethylene glycol	0.1-1
Methanol	>50
Methyl acetate	<0.01
o-Xylene	1-10
Toluene	0.1-1
Water	1-10
1,4-Dioxane	0.1-1

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

3.2.3 Fiber Industry

Waste characterization data for spent solvent wastes generated in the fiber industry are presented in Table 3-9.

Table 3-9

Waste Description: This waste is generated by a fiber company which produces cellulose acetate resin, yarn, and tow. Resin is made from wood pulp, acetic acid, and acetic anhydride using sulfuric acid as a catalyst. The plant uses a solvent extraction system consisting of benzene, methyl ethyl ketone (F005), and ethyl acetate (F003) to recover acetic acid. A distillation column recovers the acetic acid, and a second column recovers the solvents. The still bottoms from the solvent recovery column form part of the plant's spent solvent waste stream. After the cellulose acetate resin is produced, it is dissolved in acetone (F003), filtered, and extruded through spinnerets into yarn or tow. Acetone vapors are recovered using a carbon adsorption system along with distillation. The still bottoms from this column are the second source of spent solvent in the plant waste stream. Also present in the waste stream are small amounts of laboratory solvents including acetone, benzene, methylene chloride (F002), ethyl acetate, methyl ethyl ketone, and small amounts of chrome plating solution from a chrome plating system for jet spinnerets.

<u>Constituent</u>	<u>Concentration (mg/L)</u>			
	<u>Sample 1</u>	<u>Sample 2</u>	<u>Sample 3</u>	<u>Sample 4</u>
Acetone	54	24	24	52
Benzene	43	8.5	2.7	2.4
Ethyl acetate	0.56	12	6.1	8.8
Methylene chloride	0.007	<0.0003	0.008	<0.010
Methyl ethyl ketone	0.56	26	15	15
Methanol	4.5	0.61	5.8	<1.0
Chloroform	0.0009	0.0003	<0.0004	<0.01
Ethyl ether	0.0009	<0.0002	<0.001	<0.019
Trichlorotrifluoroethane	<0.00007	<0.00007	<0.00006	<0.01
Pyridine	<0.004	<0.004	<0.019	<0.01
Toluene	0.002	<0.00008	<0.006	<0.01
Xylenes	<0.00004	<0.00004	<0.0005	<0.01

Reference: Delisting petition number 0254.

3.2.4. Pharmaceutical Manufacturing

Waste characterization data for spent solvent wastes generated in the pharmaceuticals manufacturing industry are presented in Tables 3-10 and 3-11.

Table 3-10

Waste Description: Pharmaceutical manufacturing operations at this facility involve chemical reactions which occur in solvents (F002, F003, and F005). Both batch and continuous operations are performed. Products are recovered from the solvent using crystallization, filtration, and centrifugation. Solvents and reaction by-products are further treated by evaporation and/or fractionation to recover solvents. The spent solvent waste is comprised of various still bottoms and fractionator cuts from solvent recovery. The hazardous liquid wastes are segregated into primary and secondary waste before being incinerated on-site. Primary waste contains less than 15 percent water, and secondary waste contains greater than 15 percent water. The following data are for primary waste.

<u>Constituent</u>	<u>Average Concentration (% by weight)</u>
Acetone	10.8289
Acetonitrile	3.2735
Benzene	ND
Bromodichloromethane	ND
Bromoform	ND
Bromomethane	ND
Carbon disulfide	ND
Carbon tetrachloride	ND
Chlorobenzene	0.0015
Chlorodibromomethane	ND
Chloroethane	ND
2-Chloroethylvinylether	ND
Chloroform	0.0889
Chloromethane	ND
Cyclohexanone	0.1350
1,2-Dibromoethane	ND
1,2-Dichlorobenzene	ND
1,3-Dichlorobenzene	ND
1,4-Dichlorobenzene	ND
Dichlorodifluoromethane	ND

ND = Not Detected

Table 3-10 (Continued)

<u>Constituent</u>	<u>Average Concentration (% by weight)</u>
1,1-Dichloroethane	0.0006
1,2-Dichloroethane	0.6628
1,1-Dichloroethylene	0.0015
t-1,2-Dichloroethylene	ND
1,2-Dichloroethylene	0.0006
c-1,2-Dichloropropene	ND
t-1,2-Dichloropropene	ND
Ethyl acetate	9.5240
Ethyl benzene	0.0169
Ethyl ether	0.7256
Isobutanol	0.0271
Methanol	12.7553
Methylene chloride	4.4733
Methyl ethyl ketone	0.0518
Methyl isobutyl ketone	0.1130
n-Butanol	2.8430
Pyridine	<0.2500
1,1,2,2-Tetrachloroethane	0.1523
1,1,2,2-Tetrachloroethylene	0.0029
Toluene	4.0435
1,1,1-Trichloroethane	0.0029
1,1,2-Trichloroethane	0.4630
1,1,2-Trichloroethylene	0.0010
Trichlorofluoromethane	ND
Trichlorotrifluoroethane	ND
Vinyl chloride	ND
Xylene	0.0697

ND = Not Detected

Reference: Delisting petition number 559.

Table 3-11

Waste Description: Pharmaceutical manufacturing operations at this facility involve chemical reactions which occur in solvents (F002, F003, and F005). Both batch and continuous operations are performed. Products are recovered from the solvent using crystallization, filtration, and centrifugation. Solvents and reaction by-products are further treated by evaporation and/or fractionation to recover solvents. The spent solvent waste is comprised of various still bottoms and fractionator cuts from solvent recovery. The hazardous liquid wastes are segregated into primary and secondary waste before being incinerated on-site. Primary waste contains less than 15 percent water, and secondary waste contains greater than 15 percent water. The following data are for secondary waste.

<u>Constituent</u>	<u>Average Concentration (% by weight)</u>
Acetone	2.1428
Acetonitrile	0.7550
Benzene	ND
Bromodichloromethane	ND
Bromoform	ND
Bromomethane	ND
Carbon disulfide	ND
Carbon tetrachloride	ND
Chlorobenzene	0.0001
Chlorodibromomethane	ND
Chloroethane	ND
2-Chloroethylvinylether	ND
Chloroform	0.0013
Chloromethane	ND
Cyclohexanone	0.0028
1,2-Dibromoethane	ND
1,2-Dichlorobenzene	ND
1,3-Dichlorobenzene	ND
1,4-Dichlorobenzene	ND
Dichlorodifluoromethane	ND
1,1-Dichloroethane	0.00000625
1,2-Dichloroethane	0.0007
1,1-Dichloroethylene	0.0001
t-1,2-Dichloroethylene	ND
1,2-Dichloroethylene	<0.00000625
c-1,2-Dichloropropene	ND
t-1,2-Dichloropropene	ND
Ethyl acetate	0.1609

ND = Not Detected

Table 3-11 (Continued)

<u>Constituent</u>	<u>Average Concentration (% by weight)</u>
Ethylbenzene	0.000015
Ethyl ether	0.0157
Isobutanol	0.0413
Methanol	0.6115
Methylene chloride	0.2361
Methyl ethyl ketone	0.0039
Methyl isobutyl ketone	0.0028
n-Butanol	0.0404
Pyridine	0.0078
1,1,2,2-Tetrachloroethane	0.0008
1,1,2,2-Tetrachloroethylene	0.00000625
Toluene	0.0854
1,1,1-Trichloroethane	0.0001
1,1,2-Trichloroethane	0.0004
1,1,2-Trichloroethylene	0.00000625
Trichlorofluoromethane	ND
Trichlorotrifluoroethane	ND
Vinyl chloride	ND
Xylene	0.0001

ND = Not Detected

Reference: Delisting petition number 559.

3.2.5 Paint Formulation

Waste characterization data for spent solvent wastes generated by the paint formulation industry are presented in Tables 3-12 and 3-13.

Table 3-12

Waste Description: Wastewater stream from paint tank washing. The waste contains sodium hydroxide and spent solvent (F003) from paint residue.

<u>Constituent</u>	<u>Concentration (ug/L)</u>	<u>Detection Limit (ug/L)</u>
Bis(2-ethylhexyl)phthalate	27,953	NR
Ethylbenzene	6,336	NR
Phenol	20,009	NR

NR = Not Reported in data base

Reference: Development Document for Effluent Limitations Guidelines for Paint Formulation Point Source Category.

Table 3-13

Waste Description: Spent paint thinner (F003 and F005).

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Toluene	9.4
Isopropyl acetate	9.1
Ethanol	6.9
Methyl ethyl ketone	6.8
Acetone	3.8
Isopropanol	3.1
Butyl acetate	2.4
Methanol	3.0
Ethyl acetate	3.0
Xylene	2.8
Cellosolve acetate	1.6
n-Propanol	1.2
Ethylbenzene	1.2
Methyl isobutyl ketone	0.7
Other trace organics	2.9
Non-distillable constituents	42.1

Reference: Treatment and Recovery of Ignitables, Solvents, and Solvent Bearing Wastes. Hazardous Waste Treatment Workshop #3, April 9, 1984. Sample Number 820930.

3.2.6 Dyes and Pigments Manufacturing

Waste characterization data for a spent solvent waste generated in the dyes and pigments industry are presented in Table 3-14.

Table 3-14

Waste Description: Spent solvent waste (F003) from the production of dyes and pigments.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Di/triester	0.01-0.1
Di/triester	0.01-0.1
Di/triester	0.01-0.1
Diphenyl ether	0.1-1
Biphenyl	0.1-1
Ethanol	>50
Methanol	10-50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

3.2.7 Organic Chemicals Manufacturing

Waste characterization data for spent solvent wastes generated by the organic chemicals manufacturing industry are presented in Tables 3-15 through 3-19.

Table 3-15

ORGANIC CHEMICALS MANUFACTURING

Waste Description: Solvent waste containing pyridine (F005) is generated at an organic chemical manufacturing plant which produces an organic phosphate ester used as an additive in the preparation of flame retardant, flexible polyurethane foams. The product is produced in a three-step process using phosphorus trichloride and ethylene oxide as starting materials. Chlorine, ethylene glycol, and hydrogen chloride are introduced at intermediate stages of the process. Following a chlorination step, the reaction intermediate undergoes esterification to produce the crude product. The crude product is then refined and stored. The solvent pyridine is used in the esterification step and is later recovered by distillation for reuse in the production process, as shown in Figure 3-2. The pyridine still bottoms are mixed with vent scrubber water, residuals from product recovery processes, and other plant wastewater before being pumped to biological treatment.

<u>Month (1981)</u>	<u>Concentration (ppm) Pyridine</u>
January	23
February	37
March	28
April	24
May	32
June	13
July	22
August	Plant not operating
September	28
October	23

Reference: Delisting petition number 381.

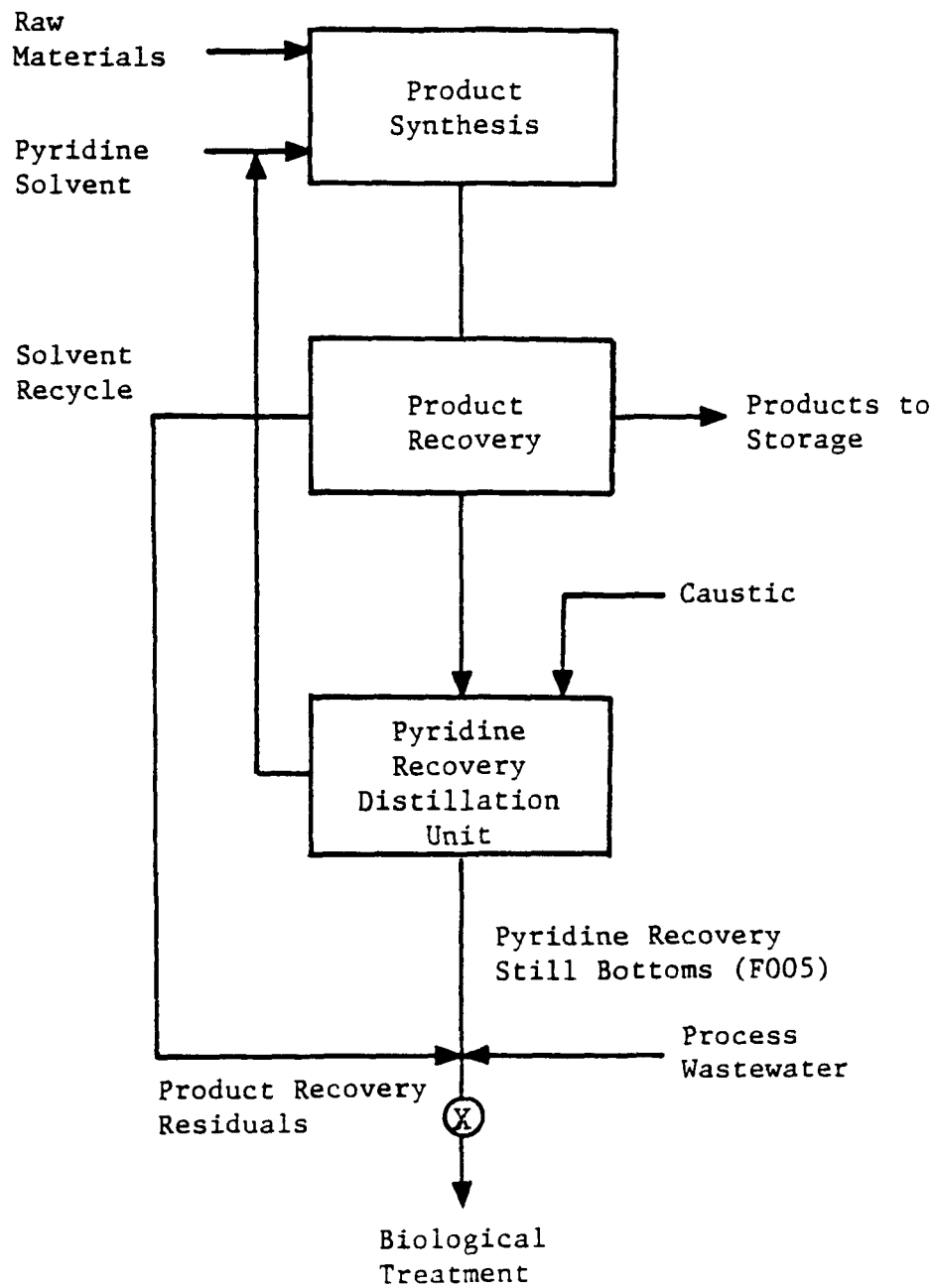


Figure 3-2
ORGANIC PHOSPHATE ESTER PRODUCTION PROCESS

Table 3-16

Waste Description: Spent solvent waste (F002) from the production of isocyanate alkane.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Carbon tetrachloride	<0.01
Chlorobenzene	>50
Hydrochloric acid	1-10
Phosgene	1-10
Polymer	<0.01
Trichloromethane	<0.01

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-17

Waste Description: Spent solvent waste (F002) from the production of diphenyl methane, isocyanate.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Carbon tetrachloride	<0.01
Chlorobenzene	>50
Hydrochloric acid	<0.01
Phosgene	1-10
Polymer	<0.01
Trichloromethane	<0.01

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-18

Waste Description: Spent solvent waste (F003) from the production of alkenes.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Inorganic sulfide	0.1-1
Calcium chloride	1-10
Hydrochloric acid	1-10
Iron chloride	0.1-1
Methanol	1-10
Water	>50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-19

Waste Description: Spent solvent waste (F003) from the production of aldehyde furan.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Acetic acid	1-10
Ethanol	10-50
Ethyl acetate	1-10
Furfural	1-10
Methanol	10-50
Water	10-50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

3.2.8 Organic Pesticides Manufacturing

Waste characterization data for spent solvent wastes generated by the organic pesticides manufacturing industry are presented in Tables 3-20 through 3-25. Toluene (F005) is listed as a constituent in four of the following six data sets. The Industry Studies Data Base from which these six data sets were obtained includes 40 waste streams from the organic pesticide industry. Fifteen of these 40 waste streams listed toluene as a constituent. Other constituents commonly occurring in spent solvent waste streams from the pesticide industry are methanol (F003), methylene chloride (F001), and xylene (F003). The 34 data sets which are not included here did not list specific composition or concentrations of spent solvents.

Table 3-20

Waste Description: Spent solvent waste (F003) from the production of cyclic ester.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Cyclic ester	10-50
Non-cyclic aliphatic alcohol	0.1-1
Ethyl acetate	10-50
Xylene	10-50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-21

Waste Description: Spent solvent waste (F005) from the production of phosphoroamidothioate.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Phosphoroamidothioates	1.1-11
Reaction/decomposition product #1	1-10
Reaction/decomposition product #2	0.1-1
Toluene	>50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-22

Waste Description: Spent solvent still bottoms (F002) from a distillation process in the production of phosphoroamidothioate.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Cyano, nitrile alkane	1-10
Phosphoroamidothioate	1-10
Polymer	10-50
Reaction/decomposition product #1	1-10
Reaction/decomposition product #2	1-10
Reaction/decomposition product #3	1-10
Dimethyl sulfide	10-50
Dimethyl sulfate	1-10
Methylene chloride	1-10
Toluene	0.1-1

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-23

Waste Description: Spent solvent waste (F003 and F005) from the production of chloroimide.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Dichloroalkane	1-10
Amide	1-10
Chloroimide	<0.01
Methanol	10-50
Sodium chloride	0.1-1
Toluene	>50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-24

Waste Description: Spent solvent solid residue (F005) from the production of n-alkyl carbamate.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
n-Alkyl carbamate	10-50
Hydroxyl naphthalene	10-50
Toluene	10-50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

Table 3-25

Waste Description: Spent solvent waste (F005) from the production of ketocarbamate.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Alkane, isocyanate	0.1-1
Ketocarbamate	10-50
Methyl ethyl ketone	10-50

Reference: Industry Studies Database. Prepared for US EPA, Office of Solid Waste, Waste Identification Branch, 1985.

3.2.9 Printing Industry

Waste characterization data for spent solvent wastes generated by the printing industry are presented in Tables 3-26 and 3-27.

Table 3-26

Waste Description: Data presented are from a plastics facility which performs decorative printing of polyvinyl chloride film which is used primarily in the furniture industry. The printing solution is a 95 percent methyl ethyl ketone (F003) solvent containing pigment suspension. Toluene (F005) is used as a solvent in vinyl coating preparations. Cyclohexanone (F003) is used in minute quantities in some products as a drying retardant ingredient in the coating preparations. The plant operates a direct contact steam distillation system to recover F003 and F005 solvents. Solvents are recovered from waste printed polyvinyl chloride film, from waste cleanup solvent (methyl ethyl ketone) used to clean printing equipment, drums, and containers, and from waste inks which cannot be reused. The waste polyvinyl chloride is fed to the distillation system in granular form. The solvent recovery bottoms on which the analysis is performed is essentially polyvinyl chloride in granular form with printing ink solids and cleanup solutions encapsulated in the polyvinyl chloride.

<u>Constituent</u>	<u>Concentration (mg/L)</u>
Arsenic	0.02
Barium	0.80
Cadmium	0.06
Chromium	<0.10
Lead	2.40
Antimony	0.11
Zinc	1.50
Xylene	<0.10
Cyclohexanone	<0.10
Toluene	1.40
Methyl ethyl ketone	8.80
Methyl isobutyl ketone	<0.10

Reference: Delisting petition number 0032.

Table 3-27

Waste Description: Ink wash residual spent solvent waste (F003).

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Ethyl acetate	30
Ethanol	21.5
Propyl acetate	8.1
Methanol	2.1
Isopropyl acetate	1.7
Isopropanol	1.4
Other trace organics	3.2
Non distillable constituents	32.0

Reference: Treatment and Recovery of Ignitables, Solvents, and Solvent Bearing Wastes. Hazardous Waste Treatment Workshop #3,
April 9, 1984, presented by Chemical Waste Management, Inc.
 Sample Number 840169.

3.2.10 Can Coating Industry

Waste characterization data for a spent solvent waste generated by the can coating industry are presented in Table 3-28.

Table 3-28

Waste Description: Spent solvents are generated at a can assembly plant from cleaning coating and ink residues (varnishes, lacquers and sealing compounds) from applicators and machinery. Clean-up solvents include methyl ethyl ketone (F005), toluene (F005), cellosolve acetate, butyl cellosolve, mineral spirits, ethyl alcohol, and n-butyl alcohol (F003). This plant cuts, decorates, assembles, and coats many different types of cans. Figures 3-3, 3-4, 3-5, and 3-6 illustrate the processes which generate spent cleanup solvents. Clean-up solvents contain coating residue from equipment cleaning. The coatings are composed of non-hazardous food grade solids blended with various carrier solvents (F003 and F005). The plant lists 24 different coatings and the primary carrier solvent constituents. The following analysis gives the approximate quantities of carrier solvents that would be contained in an "average" blend of coating residues.

<u>Constituent</u>	<u>Concentration (% by weight)</u>
Xylene	6.7
Cellosolve acetate	4.4
n-Butyl alcohol	3.9
Butyl cellosolve	3.6
Mineral spirits	2.9
Methyl isobutyl ketone	1.5
Methyl ethyl ketone	1.3
Hexane	1.2
Isopropyl alcohol	1.0
Diacetone alcohol	0.8

Reference: Delisting petition number 597.

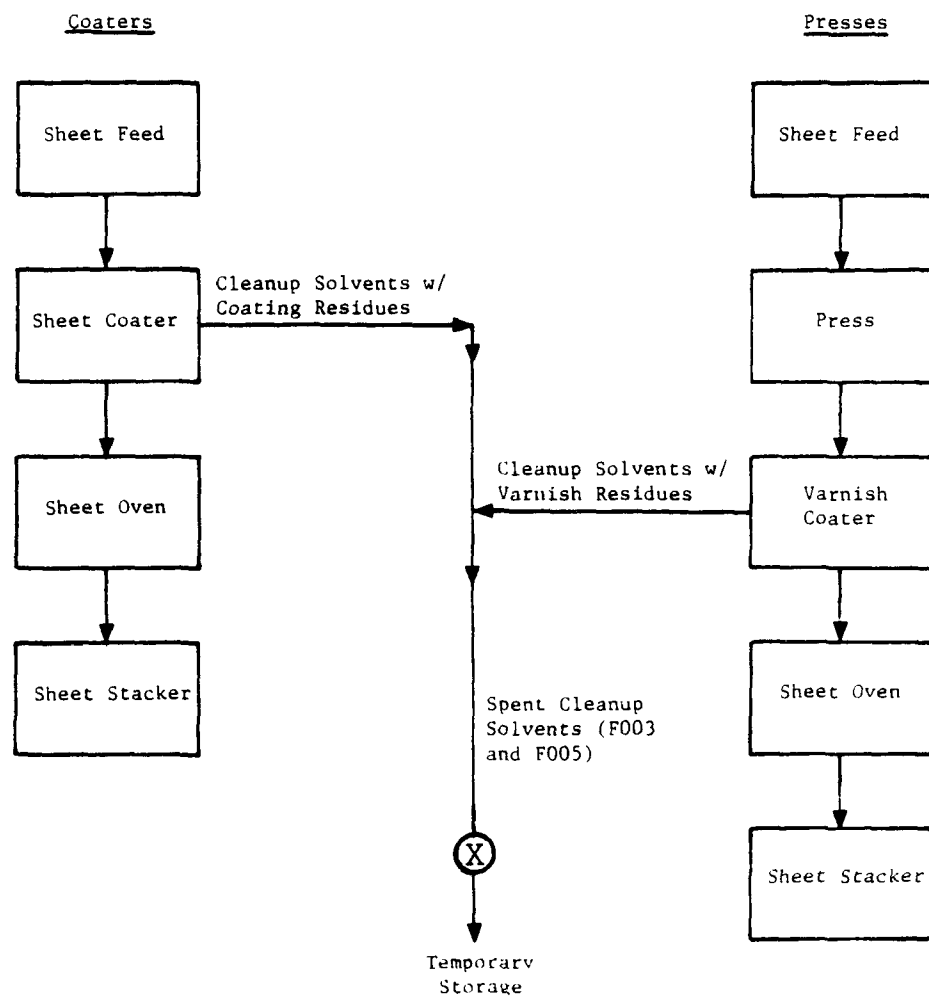


Figure 3-3

LITHO PRESSING OF THREE PIECE CANS

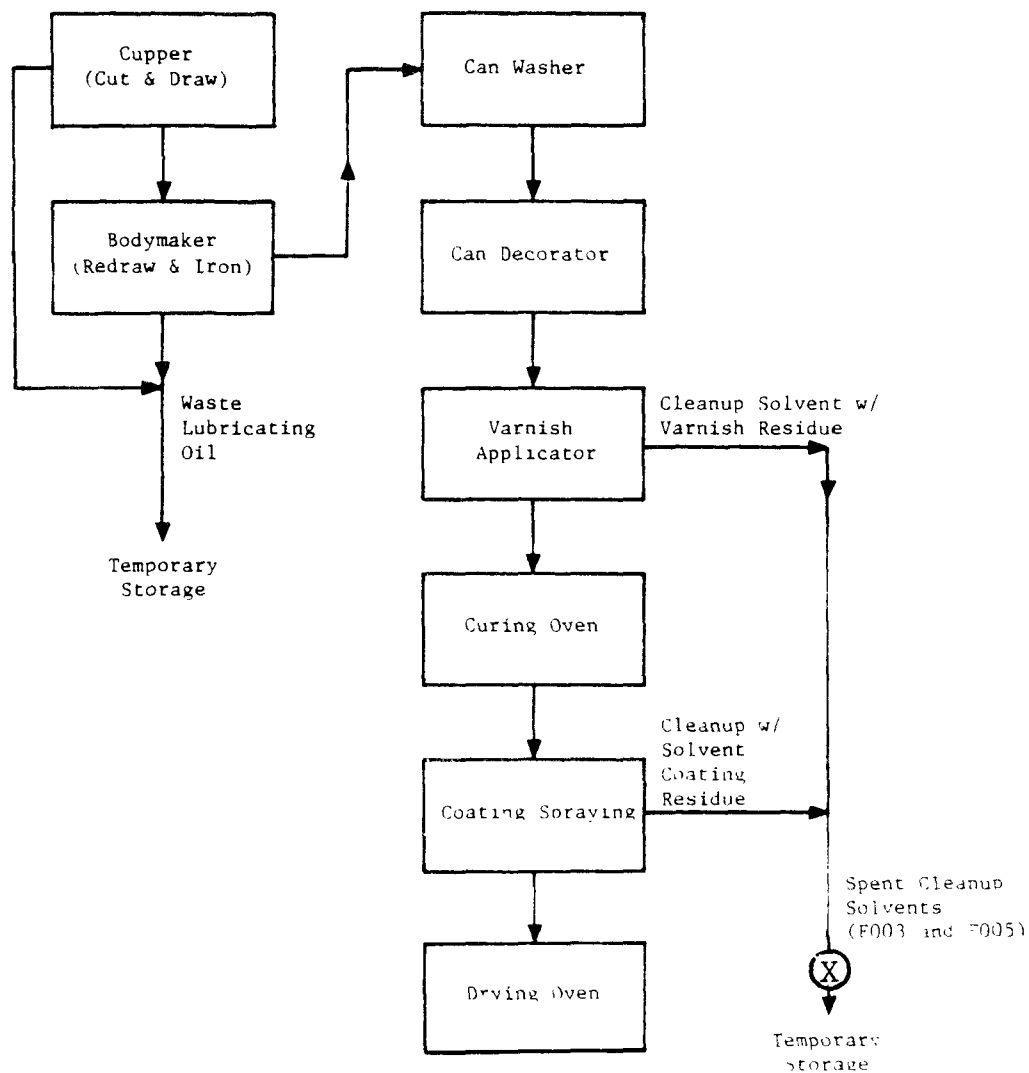


Figure 3-4
PRODUCTION OF TWO PIECE CAN BODIES

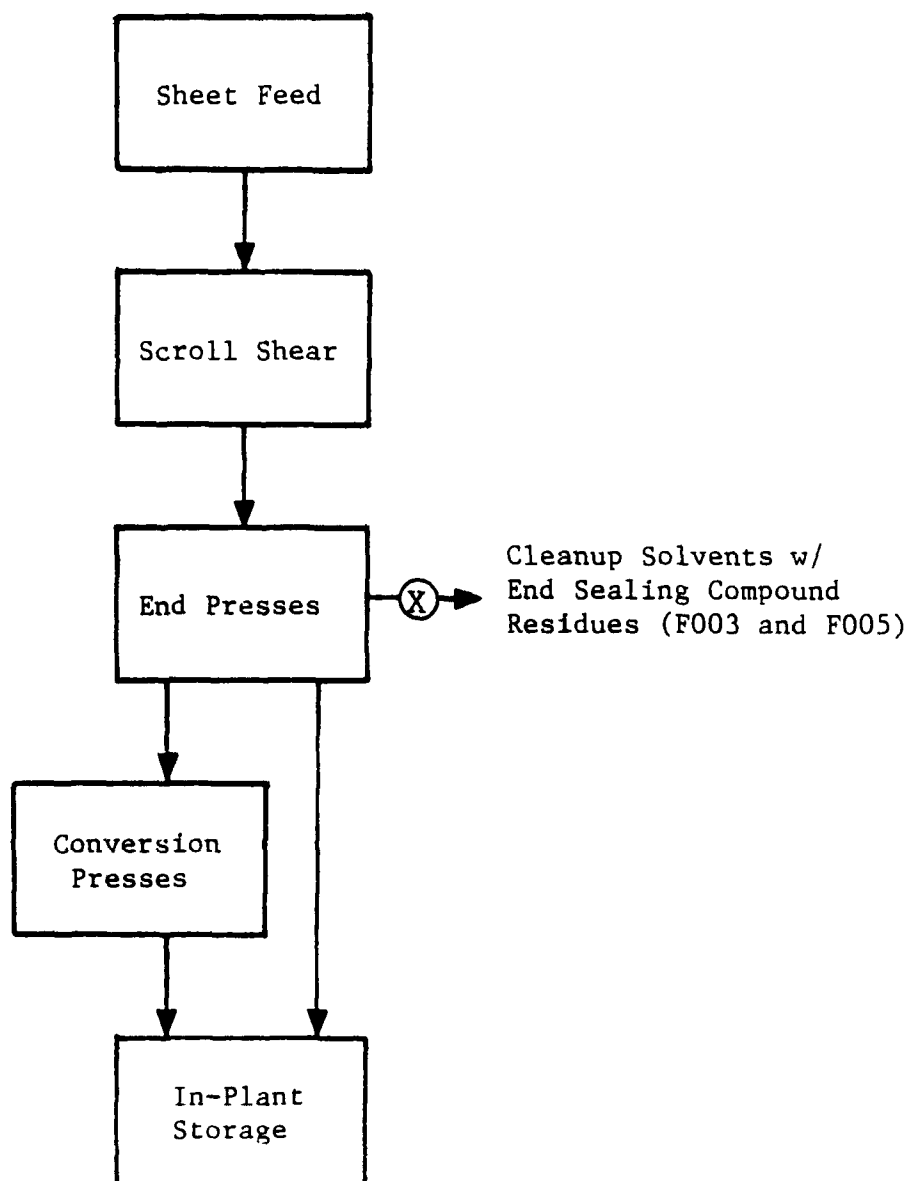


Figure 3-5
PRESSING OF CAN ENDS

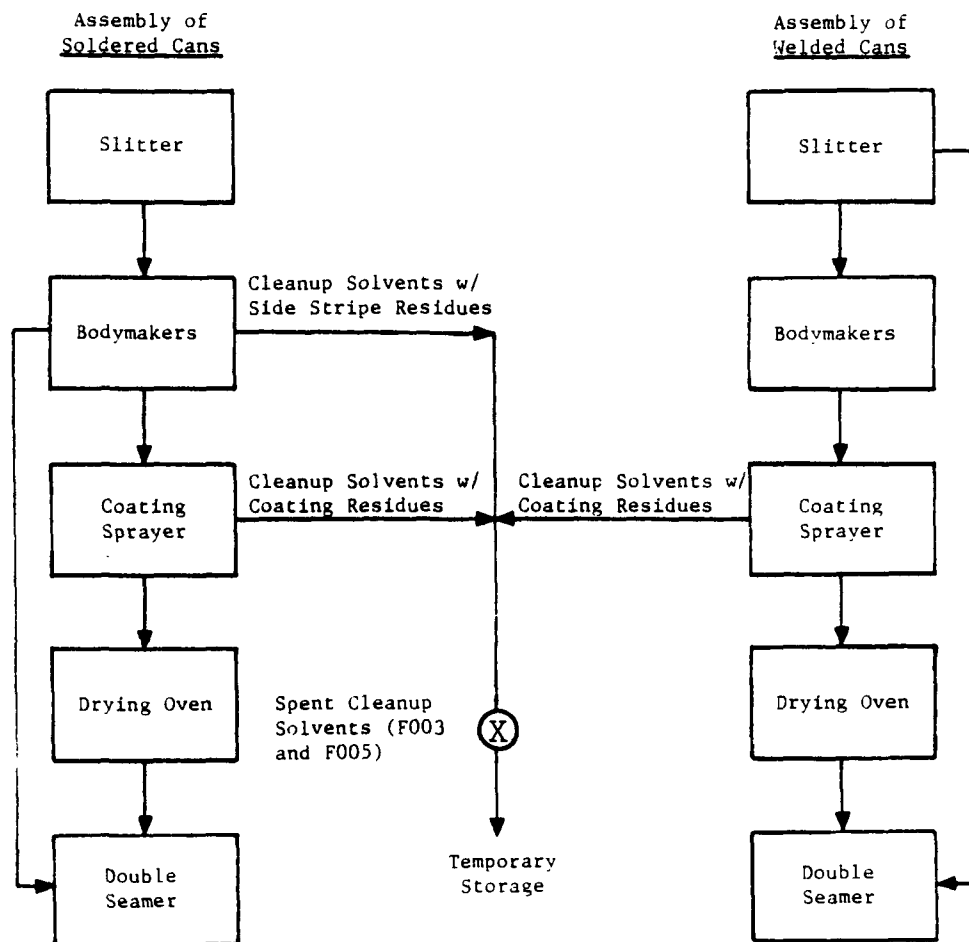


Figure 3-6
ASSEMBLY OF THREE PIECE CANS

3.2.11 Membrane Production Industry

Waste characterization data for a spent solvent generated by the membrane production industry are presented in Table 3-29.

Table 3-29

Waste Description: Presented are characteristics of waste generated by a plant which manufactures and markets membranes for precision separation for the pharmaceuticals, microelectronics, and health care industries. The raw wastewater stream contains spent solvents (F003). This data set was presented in an article on the performance of an activated sludge treatment system designed to treat this waste. Based upon the results of a pilot study and the projected waste load, a full-scale pretreatment system was designed and constructed.

<u>Constituent</u>	<u>Concentration (mg/L)*</u>
Methanol	180-2,900 (1,140)
Ethanol	240-4,400 (1,458)
Butanol	190-2,000 (958)
Acetone	49-2,700 (571)
Dimethylacetamide	5-200 (80)
Dimethylsulfoxide	(<10)
Dimethylformamide	<3-190 (23)
Influent solvents (total)	1,900-10,900 (4,230)
Influent COD	3,100-10,000 (6,700)

*Average values are presented in parentheses.

Reference: Marston, Kurt B. and Franklin E. Woodard. "Treatment of High Strength Wastewater Containing Organic Solvents". Purdue Industrial Waste Conference, Vol. 39. 1985.

REFERENCES

1. Chemical Waste Management, Inc. "Treatment and Recovery of Ignitables, Solvents and Solvent-Bear Wastes." Hazardous Waste Treatment Workshop #3, EPA Communication. April 9, 1984.
2. U.S. Environmental Protection Agency. Proposed Development Document for Effluent Limitations Guidelines for Paint Formulating Point Source Category. EPA 400/1-79/049-b.
3. Marston, Kurt R. and Franklin E. Woodard. "Treatment of High Strength Wastewater Containing Organic Solvents." Purdue Industrial Waste Conference, Vol. 39. 1985.
4. Industry Studies Data Base. Prepared for U.S. EPA, Office of Solid Waste, Waste Identification Branch. 1985.
5. Delisting Petition 0032, Intex Plastics, Inc., Corinth, MS.
6. Delisting Petition 0254, Celanese Fibers, Narrows, VA.
7. Delisting Petition 0381, Olin Chemicals Group, Lake Charles, LA.
8. Delisting Petition 0476, CE Cast Industrial Products, Muse, PA.
9. Delisting Petition 0488, Stanley Furniture Company, Stanleytown, VA.
10. Delisting Petition 0559, Eli Lilly and Company, Clinton, IN.
11. Delisting Petition 0597, Continental Can Company, Milwaukee, WI.

4. DEMONSTRATED TREATMENT TECHNOLOGIES

4.1 Introduction

Treatment technologies that are demonstrated for F001-F005 spent solvent wastes are discussed in this section. Five treatment technologies demonstrated for wastewaters containing F001-F005 spent solvents are carbon adsorption, distillation (steam stripping), biological treatment, wet air oxidation and air stripping. Carbon adsorption is discussed in Section 4.2; distillation is discussed in Section 4.3, biological treatment is discussed in Section 4.4, wet air oxidation is discussed in Section 4.6 and air stripping is discussed in Section 4.7. Three technologies demonstrated for non-wastewater spent solvent wastes are distillation, incineration and fuel substitution. Incineration is discussed in Section 4.5 and fuel substitution is discussed in Section 4.8. Incineration and fuel substitution are not demonstrated for wastewaters containing F001-F005 spent solvents.

4.2 Carbon Adsorption

4.2.1 Applicability

This technology is demonstrated for the F001-F005 spent solvent wastewater. For purposes of the F001-F005 spent solvent rulemaking, wastewaters contain by definition less than one percent total organic carbon (TOC). EPA analyzed full-scale carbon adsorption treatment performance data from four plants and pilot-scale data from two plants. At one of these full-scale plants, carbon adsorption is used after biological treatment. The Agency obtained data on chlorobenzene, 1,2-dichlorobenzene, methylene chloride, nitrobenzene, toluene, and trichloroethylene from this facility. At another full-scale plant, carbon adsorption follows steam stripping. The Agency obtained data on nitrobenzene and toluene from this facility. In the third case, EPA has full-scale data from a plant in the pesticides industry which generates wastewater containing cresols. EPA has full-scale data for process wastewater containing cresol at the fourth plant. Pilot-scale data for trichloroethylene are available on treatment of contaminated drinking water. Pilot-scale data are also available for methylene chloride, toluene, and xylene on treatment of runoff water from a waste disposal site. The Agency believes that these data represent treatment of wastes which are similar to wastes that will be subject to this rule. The data are presented in Section 5 of this document. This section also discusses the use of data relative to the development of the treatment standards.

Activated carbon adsorption is a widely recognized technology for the removal of organic compounds from wastewaters. The concentrations of

organics which can be effectively removed vary widely depending on the overall chemical and physical characteristics of the wastewater. Literature citations for treatment applicability range from several hundred parts per million to five percent organic content in the wastewater. For treatment effectiveness of spent solvent wastewaters not similar to those evaluated in Section 5 of this document, facilities need to conduct bench- and pilot-scale evaluations as discussed in subsections 4.2.5 and 4.2.6. They should also review the "underlying principle" section and the section on design and operating parameters affecting performance for identification of other factors that should be considered in applying this technology to a particular wastewater.

The underlying principles of operation for carbon adsorption are presented in subsection 4.2.2. A description of activated carbon adsorption is presented in subsection 4.2.3. Parameters which affect the performance of activated carbon adsorption are presented in subsection 4.2.4. Bench-scale and pilot-scale tests commonly used to determine design and operating parameters for treatment of a specific waste are discussed in subsections 4.2.5 and 4.2.6, respectively.

4.2.2 Underlying Principles of Operation

Adsorption is the collection and concentration of a molecule onto a solid surface from a liquid or gas. The activated carbon selectively adsorbs hazardous constituents by surface attraction within the internal pores of the carbon granules. The principal factor which affects carbon adsorption is the chemical affinity between the carbon and the organic compound. Other characteristics such as solubility, temperature and pH also influence the effectiveness of carbon adsorption.

The rate of adsorption is dependent upon three distinct steps: transport, diffusion and binding. The first step is transport of the constituent to be removed from the solvent waste solution through a surface film to the exterior of the carbon. Second, the constituent molecule to be removed must diffuse into the pores of the activated carbon. This step is very important since most of the active surface area for activated carbons used in wastewater treatment occurs within the particle pores. The final step is the physical or chemical binding of the constituent of concern to the surface of the activated carbon.

The effectiveness of adsorption generally improves with increasing contact time. Exceptions to this rule include chemical compounds which are not preferentially adsorbed onto the carbon surface. These compounds can be desorbed from adsorption sites in favor of compounds that have a higher affinity for the carbon.

Typically, the wastewater to be treated is passed downward through a stationary bed of carbon. The constituent to be removed is adsorbed most rapidly and effectively by the upper few layers of fresh carbon during the initial stages of operation. These upper layers are in contact with the wastewater at its highest concentration level. The small amounts of the constituent to be removed which escape adsorption in the first few layers of the activated carbon are then removed from solution in the lower or down stream portion of the bed. Initially, none of the constituent to be removed escapes from the adsorbent.

As the waste stream continues to flow into the bed, the top layers of carbon become saturated with the constituent being removed and less effective for further adsorption. As the adsorption zone moves downward, more and more of the constituent to be removed escapes in the effluent. As the adsorption zone moves downward to the end of the bed, the concentrations in the effluent increase rapidly approaching the influent concentration. This point in the operation is referred to as breakthrough. A breakthrough curve is the plot of the ratio of effluent to influent concentrations versus time of operation. This curve shows how the ratio of effluent to influent concentrations increases as the adsorption zone moves through the column (See Figure 4-1). Breakthrough on this curve represents the point in operation where all of the carbon in the column is in equilibrium with the influent water and beyond which little additional removal of the constituent will occur. At this stage of operation, the spent carbon is either replaced or reactivated. The time to reach breakthrough is generally decreased by increased particle size of the carbon, increased concentration of the constituent to be removed in the influent, increased pH of the water, increased flow rate, and decreased bed depth. In application, breakthrough is determined by measuring the effluent concentration of the constituent of concern. In situations where the constituent can not be measured directly by continuous monitoring instruments, an operating curve determined by initial pilot-scale calibration of the adsorption system is used to predict breakthrough (see Section 4.2.6 for discussion of pilot-scale testing).

4.2.3 Description of Activated Carbon Manufacture and Carbon Regeneration

(1) Activated Carbon Manufacture. Wastewater treatment by activated carbon adsorption utilizes specially prepared carbon granules or powder¹ to adsorb and thereby remove organic contaminants from the wastewater. The term "activated carbon" refers to any amorphous form of carbon that has been treated to increase the surface area to volume ratio of the carbon.

¹This section addresses the use of granular carbon only.

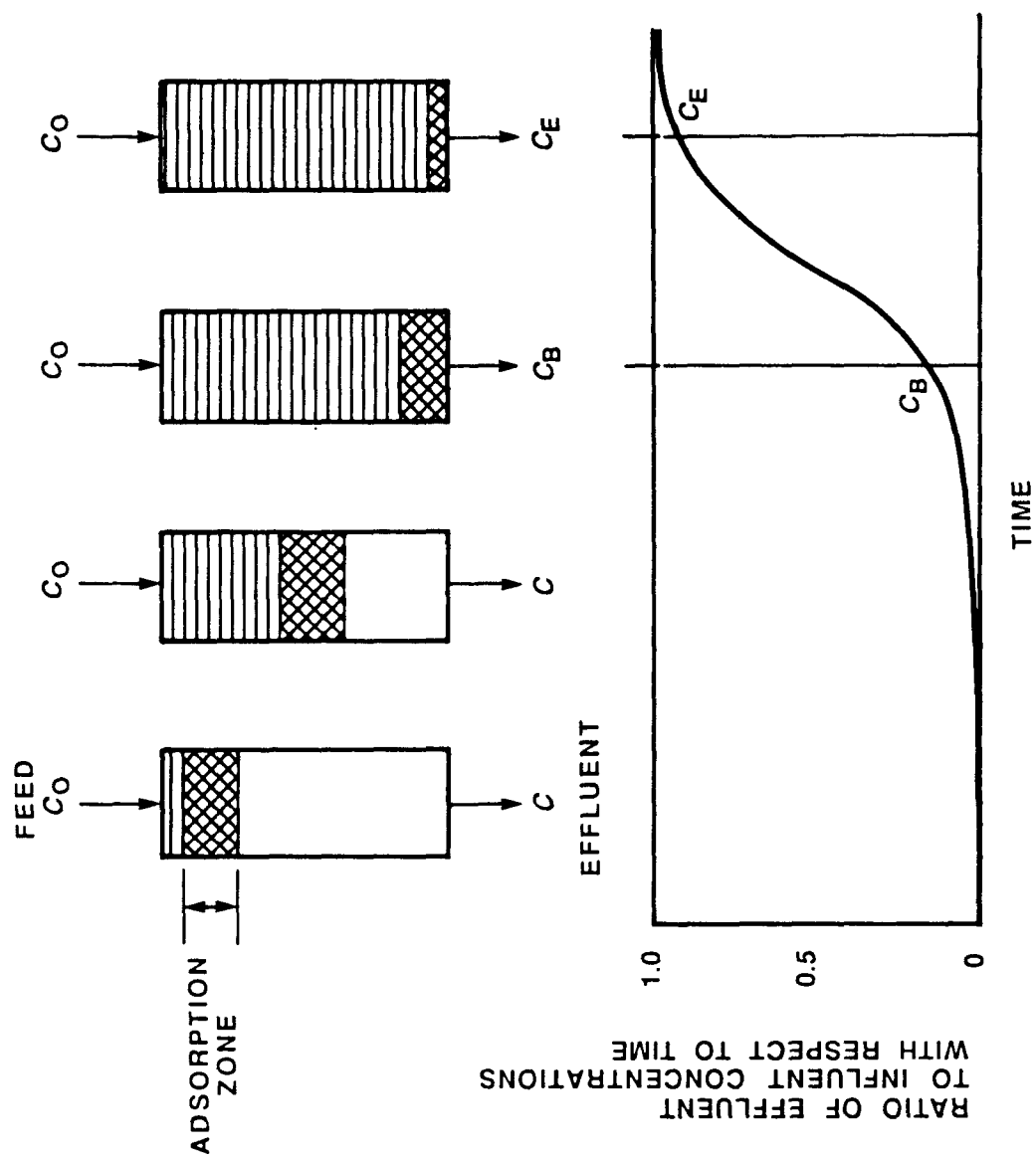


FIGURE 4-1. PLOT OF BREAKTHROUGH CURVE

Activated carbon is derived from virtually any carbonaceous material including wood, coal, coke, peat, lignin, nut shells, sugar cane pulp, sawdust, lignite, bone, and petroleum residues. Pores are formed on the carbon surface during activation processes by burning away carbon layers. The surface area of the carbon is greatly increased through the formation of the surface porosity.

In general, carbon used in wastewater treatment is activated through thermal activation processing. There are three steps involved in the thermal activation process: dehydration, carbonization, and activation. Dehydration of the starting material is accomplished by heating at temperatures of up to 170°C. Carbonization converts the organic material to primary carbon and occurs as the temperature is increased above 170°C. In this step, the material is degraded, releasing CO, CO₂, acetic acid, methanol, and tar. When the temperature reaches 400 to 600°C, the organic material has been converted to approximately 80 percent primary carbon. High temperature steam (750 to 950°C) is generally used to activate the carbon by exposing and widening pores plugged by tars and other decomposition products.

(2) Carbon Regeneration. The most common method of carbon regeneration is thermal regeneration. This process is performed in a multiple hearth furnace or a rotary kiln at temperatures of approximately 850°C. The carbon can be regenerated with minimal carbon losses. Virgin carbon is added to replace that which is lost through the regeneration process. Other regeneration processes, termed "nondestructive processes," include treating the spent carbon with chemicals (e.g., acids and alkali), hot water or steam. There is a loss of performance with each regeneration step; therefore, the activity is never restored to its original level. The number of times that the carbon can be regenerated is determined by the extent of physical erosion and the loss of adsorptive capacity. Isotherm tests on the regenerated carbon can be used to determine adsorptive capacity, thereby aiding in the prediction of the number of times the carbon can be regenerated.

Environmental emissions can result from the carbon regeneration processes. For example, if carbon is regenerated by high temperature heating in a multiple hearth furnace or a rotary kiln, aqueous wastes can be generated from wet air pollution control devices on the furnace or kiln stack. Aqueous wastes can also be generated from nondestructive carbon regeneration processes. The aqueous wastes from regeneration may require further treatment prior to discharge or disposal. For carbon adsorption of very toxic or hazardous materials, the carbon may be incinerated or disposed rather than regenerated.

4.2.4 Design and Operating Parameters Affecting Performance

There are a number of design and operating parameters which must be considered in the selection of an effective carbon adsorption system to treat a specific waste. An integral part of the design usually includes the process bench-scale or pilot-scale evaluation of these parameters. Further description of bench-scale tests and pilot-scale testing are presented in subsections 5 and 6, respectively.

(1) Design parameters. The design parameters to consider include carbon properties, equipment configuration, contact time, and hydraulic loading. As contact time and hydraulic loading are also the key operating parameters, these parameters are discussed below under operating parameters.

(a) Carbon properties. When applying carbon adsorption technology, there are several properties of the activated carbon which must be considered to ensure that adequate system performance is achieved. The properties include surface area, pore size, particle size, the iodine number, and the hardness number.

(i) Surface area. Because adsorption occurs on the surface of the carbon, highly porous or permeable carbon is used. Typical particle surface area to mass ratios range from 500 to 1,400 square meters per gram (Reference 4). The total surface area of a particle is dependent upon pore size and to a lesser extent, particle size.

(ii) Pore size. The optimal pore size for a specific application is dependent upon the sizes of the waste constituent molecules that the column is designed to adsorb. The greatest binding force occurs when the molecule size and the pore size are equal. Exceptions to this rule include wastes having high solvent concentrations where slightly larger pores are most efficient (pores quickly fill with the constituent to be removed making them too small for further adsorption).

(iii) Particle size. Activation of carbon is performed to increase the surface area to volume ratio. As the particle size diminishes, more of the internal pore surface area is exposed and available for adsorption. This increased area affects the rate of adsorption rather than the adsorptive capacity because all of the pore volume is eventually used regardless of the surface area. This occurs because the constituents diffuse throughout the particle. As a practical matter, selection of particle size is limited because very small particles can be carried out of the bed by the fluid stream. Very small particles do not readily settle from the effluent.

(iv) Iodine number. The iodine number is defined as the ratio of the mass (in milligrams) of iodine adsorbed by one gram of activated carbon when the iodine concentration of the effluent filtrate reaches 0.02N in a bench-scale test. This number correlates to the capacity of a specific carbon to adsorb iodine (molecular weight 254). The test is useful to evaluate the adsorptive capacity of low molecular weight organics.

(v) Hardness Number. The hardness number is a measure of a specific carbon's resistance to degradation. This value is derived from a bench-scale test and used to indicate the carbon's ability to withstand repeated regeneration cycles and the physical stresses encountered during operation without damage to the adsorption surface.

(b) Column Configuration. Column configuration can also be an important consideration in the performance of an adsorption treatment system. Granular activated carbon systems can be operated as fixed bed (downflow) or moving or expanded bed (upflow) systems.

(i) Fixed bed. Fixed bed adsorbers operate in a downflow direction. Downflow operation acts to filter suspended solids from the influent wastewater. However, solids filtered by the carbon bed result in pressure drop build-up and must be periodically removed by backwashing the bed. Backwash water may require treatment prior to disposal. Most fixed bed carbon adsorption columns must be taken off-line for carbon regeneration. To keep adequate carbon capacity on-line, fixed bed processes may use two carbon columns, one on-line for treatment, and one off-line undergoing carbon regeneration. For large flow rates, columns can be placed in parallel and rotated as they become exhausted. Several columns can also be placed in series so that carbon exhaustion in one column will not significantly affect the quality of the overall effluent. Also, this series configuration can be used to improve treatment performance by designing each column to selectively adsorb different organic compounds. Since fixed-bed carbon columns are not replenished, they do not achieve steady state operation, and, thus, the effluent concentration is continually changing.

(ii) Moving bed. In a moving bed system, the carbon adsorbent continuously moves down the column and is drawn off at the bottom of the column for regeneration (Figure 4-2). Virgin or regenerated carbon enters the column at the top. These units operate with approximately 10 percent void space between the particles to allow movement of the particles.

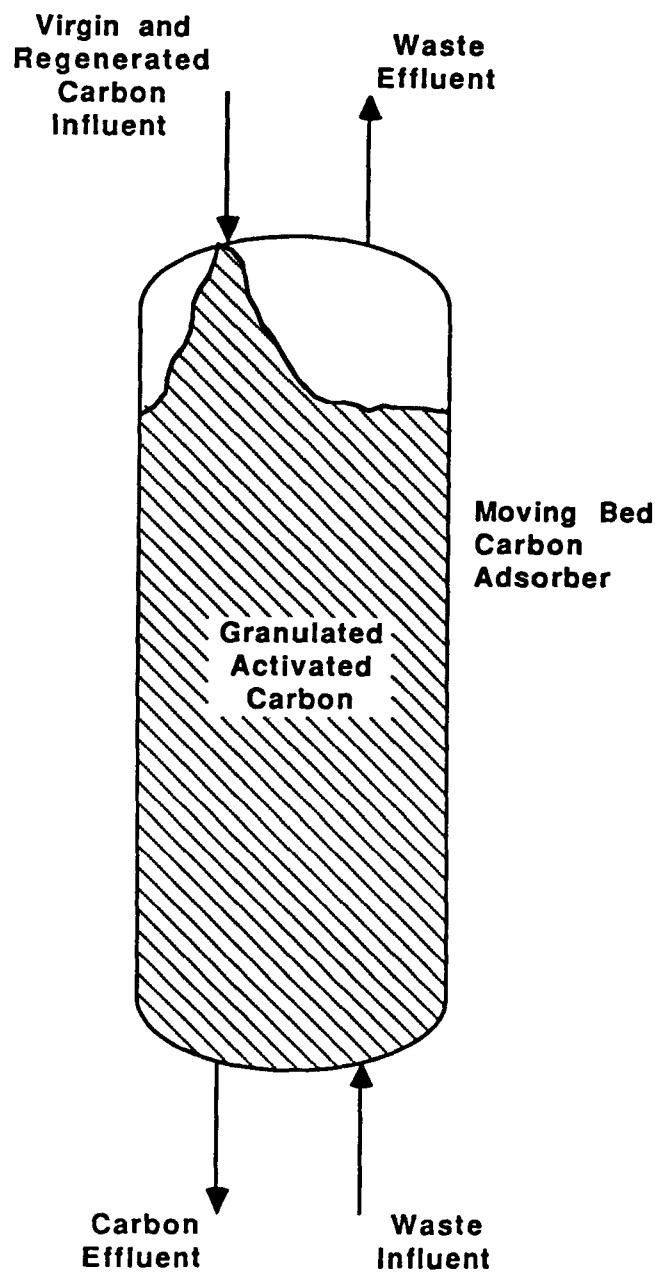


Figure 4-2
Moving Bed
Carbon Adsorption

The moving bed systems do not have the ability to filter suspended solids because the void space allows the solids to flow through the column. Thus, solids will not be removed from the wastewater in this mode of operation. Wastewaters containing suspended solids should be filtered or clarified prior to carbon treatment in upflow systems to prevent discharge of solids in the treatment effluent. As discussed under "fixed bed," moving bed systems can also be run in series with different carbon beds to remove compounds with different adsorption characteristics.

(c) Flow distribution. Uniform flow distribution over the carbon bed insures maximal contact between the waste and the carbon and results in effective constituent removal. Non-uniform flow distribution can occur from a number of phenomena such as channelling or flooding. These occur from improper design of the column or packing and will vastly reduce the surface area available for adsorption and column capacity. Channelling, where an uneven carbon distribution results in the fluid bypassing a portion of the carbon bed, produces an effluent that exceeds the desired composition. Uniform flow distribution is achieved in the design through proper selection of the flow distribution mechanisms including incoming fluid distribution devices (e.g., rings, plates, or nozzles), carbon loading procedures, and bed support materials.

(2) Operating Parameters. Operating parameters include several related variables such as carbon bed volume, contact time, hydraulic loading, temperature, and pH.

(a) Carbon bed volume. A fixed contact time at a given hydraulic loading establishes the minimum required bed volume. Excess bed volume can be provided to increase the time between regeneration cycles. The bed size is optimized by balancing costs associated with pumping requirements against the frequency and associated costs of carbon regeneration.

(b) Contact time. A minimum contact time is required to obtain a desired effluent concentration for a fixed hydraulic loading. Insufficient contact time can result in poor treatment performance.

(c) Hydraulic loading. Hydraulic loading directly affects the rate and efficiency of adsorption. For a fixed bed volume, an increase in flow rate increases the rate of adsorption while the contact time is reduced. At too high a flow rate, the contact time is inadequate and adsorbate removal is adversely affected. At very low flows, the mass transfer becomes diffusion-limited, and the mass transfer rate is so adversely affected that the adsorbate removal is not complete. Thus, the

flow rate is selected to avoid the above ranges of poor operation. The optimization of flow is a function of bed geometry (cross-sectional area and bed height) and required treatment rate.

(d) Temperature. In general, since adsorption reactions are exothermic, lower temperatures should favor adsorption (Reference 3). The effects of operating temperature are investigated during bench-scale testing.

(e) pH. The effect of pH on adsorbability can vary significantly from compound to compound. Adsorption is most effective at the pH which imparts the least polarity to the molecules. A weak acid, such as phenol, is adsorbed best at low pH values. For amines (a weak base) adsorption favors higher pH values (Reference 3).

4.2.5 Bench-Scale Testing

Bench-scale tests can be a valuable tool in determining the applicability of different carbons for adsorption of specific constituents from a given waste stream.

Adsorptive capacity is measured by the adsorption isotherm of the waste stream. An isotherm is a graph relating the amount of solute adsorbed at a given temperature to the mass of carbon used for the adsorption. The plot is usually derived from bench-scale tests where premeasured amounts of activated carbon are placed in a measured amount of the wastewater at a constant temperature for a specified period of time. By measuring contaminant concentration in solution before and after treatment, the amount which has been adsorbed can be determined. Plots are generated from several test points taken at the same temperature. Operating parameters can be varied in generation of each test point, e.g., plots generated at various temperatures or pH.

Isotherm plots are usually fitted with a smooth curve using the Freundlich Equation which describes the adsorbability characteristics of a constituent for a given carbon. The equation is usually written as follows:

$$X/m = KC^{1/n}$$

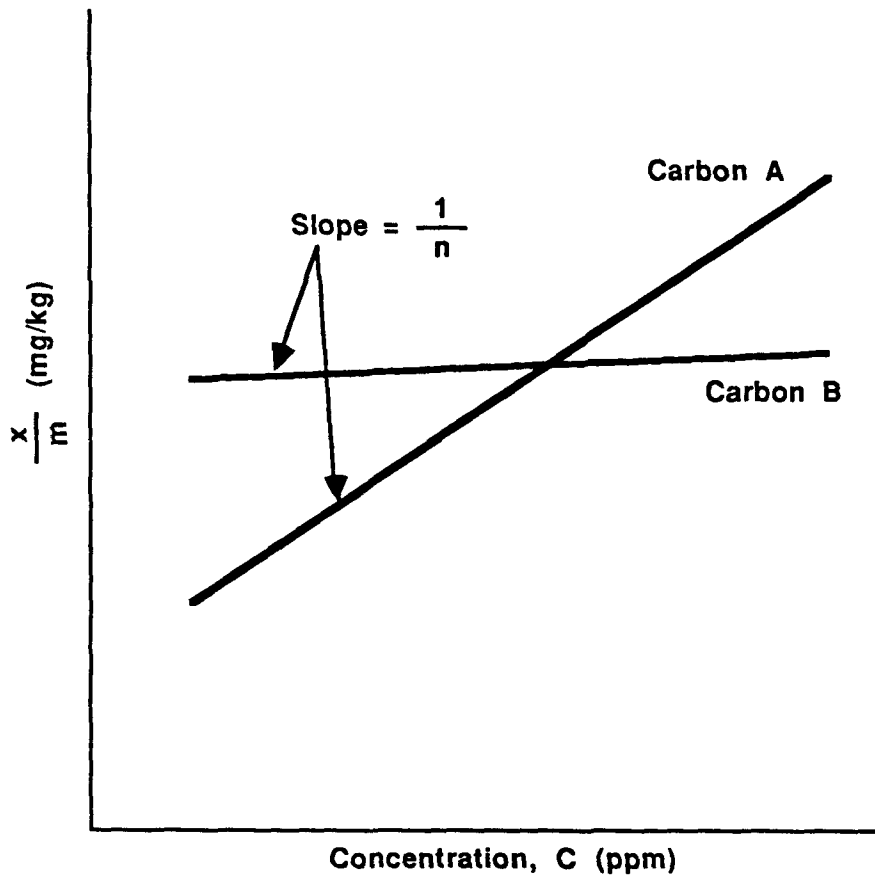
where, X = amount of contaminant adsorbed, mg
m = weight of carbon, kg
C = equilibrium concentration of contaminant left in solution, ppm
K = empirical constant, dimensionless
n = empirical constant, dimensionless

Plotting the log of the Freundlich Equation will generate a straight line with $1/n$ representing the slope. The constant "K" is a measurement of relative adsorption capacity. A large value of "K" indicates high carbon adsorptivity (Reference 4). The value "n" is a measure of the effects of concentration on adsorption capacity. Typical carbon adsorption isotherms are shown in Figure 4-3 for two different types of carbon. Isotherms obtained under identical conditions using the same test solutions for two test carbons can be compared to reveal the relative effectiveness of the carbons.

4.2.6 Pilot-Scale Testing

Although the treatability of a particular wastewater by activated carbon adsorption and the relative capacity of different types of activated carbon for treatment may be estimated from adsorption isotherms, activated carbon performance and design criteria are best determined by pilot-scale tests. Adsorption isotherms are determined in a batch test, but the treatment of wastewaters by granular activated carbon most often is accomplished in a continuous system involving packed beds. Pilot-scale tests provide more accurate estimates of the actual performance of a full-scale unit.

Pilot-scale granular activated carbon column tests are performed for the purpose of obtaining design data for full-scale plant construction. Pilot-scale column tests allow a wide range of testing necessary to establish the design of a full-scale plant including the following: compare the performance of different carbon types under the same dynamic flow conditions; determine the minimum contact time required to produce the desired quality of carbon column effluent can be; verify the manufacturer's data for pressure drop at various flow rates through different bed depths; verify the backwash flow rate necessary to expand the carbon bed for cleaning purposes; establish the carbon bed volume required which will also determine the necessary capacity of the carbon regeneration furnaces and auxiliaries; the effect of various methods of pretreatment (influent water quality) upon carbon column performance, carbon dosage and overall plant costs; evaluate the practical advantages and disadvantages for alternatives such as use of upflow or downflow carbon columns or the particle size of carbon to be used. In all of the pilot-scale plant tests, the pH and temperature should be observed to be certain that they correspond to the values for the full-scale plant operation, since their values are influential to proper operation of the activated carbon adsorption unit.



Key:

Freundlich Equation

$$x/m = KC^{\frac{1}{n}}$$

x = Amount of Waste Constituent Adsorbed, mg

m = Weight of Carbon, kg

C = Concentration of Waste Constituent Left in Solution, ppm

K = Empirical Constant, Dimensionless

n = Empirical Constant, Dimensionless

Figure 4-3
Isotherms for Carbon Adsorption

CARBON ADSORPTION REFERENCES

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4.3 Distillation

This subsection presents a general discussion of four types of distillation systems used to treat F001-F005 spent solvent wastes. These are steam stripping, batch distillation, thin film evaporation, and fractionation. There is a section for each technology that contains a discussion of the applicability of the technology to F001-F005 spent solvent wastes, a discussion of the underlying principles of operation, a description of the technology, and finally a discussion of the design and operating parameters affecting performance.

4.3.1 Steam Stripping

(1) Applicability. Steam stripping is a demonstrated technology for wastewaters containing the F001-F005 spent solvent wastes. The Agency has full-scale steam stripping treatment performance data from 4 plants and pilot-scale data on treatment of contaminated ground water. The full scale data represent treatment of F001-F005 spent solvent wastewater at one plant; the remaining three plants were treating wastewater containing F001-F005 constituents generated as process contaminants. The Agency believes that these data represent treatment of wastes which are similar to wastes that will be subject to this rule. The Agency analyzed steam stripping data on ethylbenzene, methylene chloride, methyl isobutyl ketone, nitrobenzene, toluene, 1,1,1-trichloroethane, and trichloroethylene. These data are presented in Section 5 of this document.

Steam stripping is a widely recognized technology for the removal of organic compounds from wastewaters. The concentrations of organics which can be effectively removed vary widely depending on the overall chemical and physical characteristics of the wastewater. Literature citations for treatment applicability range from several parts per million to one percent organic content in the wastewater. For treatment effectiveness of spent solvent wastewaters not similar to those evaluated in Section 5 of this document, facilities need to conduct bench- and pilot-scale evaluations. They should also review the "underlying principles of operation" section and the section on "design and operating parameters affecting performance" for identification of other factors that should be considered in applying this technology to a particular wastewater.

(2) Underlying Principles of Operation.

(a) General. Distillation is broadly defined as the separation of more volatile materials from less volatile materials by a process of vaporization and condensation. Distillation involves application of heat

to a liquid mixture to vaporize part of the mixture and subsequent removal of heat from the vaporized portion. The resultant condensed liquid, the distillate (overhead), is richer in the more volatile components and the residual unvaporized bottoms are richer in the less volatile components.

Central to the concept of distillation is the phenomena of vapor-liquid equilibrium which is the relationship between the composition of the vapor phase and the composition of the liquid phase. When a liquid mixture of two or more components is brought to the boiling point of the mixture, a vapor phase is created above the liquid phase. The composition of the vapor phase is different from the composition of the liquid phase and is a function of the concentrations of the constituents in the liquid phase and the vapor pressures that the pure components would exhibit at the temperature corresponding to the boiling point of the mixture. If the vapor pressures of the pure components are different (which is usually the case), then the constituent(s) having the higher vapor pressure will be more concentrated in the vapor phase than the constituent(s) having the lower vapor pressure. If the vapor phase above the liquid phase were cooled to yield a liquid called the condensate a partial separation of the constituents would result. The degree of separation would depend on the relative differences in the vapor pressures of the constituents; the larger the difference in the vapor pressures, the larger the separation.

However, unless the difference between the vapor pressures is extremely large, a single separation cycle or single equilibrium stage of vaporization and condensation would not achieve a significant separation of the constituents. In order to achieve greater separations multiple equilibrium stages are used. In practice, the multiple equilibrium stages are obtained by stacking trays or packing into a column. The vapor phase from a tray rises to the tray above it and the liquid phase falls to the tray below it. In simplistic terms, each tray represents one equilibrium stage. In a packed distillation column, the individual equilibrium stages are not discernible, but the number of equivalent trays can be calculated from mathematical relationships.

To facilitate distillation calculations, the vapor liquid equilibrium is expressed as relative volatility or the ratio of the vapor to liquid concentration for a constituent divided by the ratio of the vapor to liquid concentration of the other constituent. The relative volatility is a direct measure of the ease of separation. If the numerical value is 1, then separation is impossible because the constituents have the same concentrations in the vapor and liquid phases. Separation by distillation becomes easier as the value of the relative volatility becomes increasingly greater than unity.

With some combinations of constituents an azeotropic condition can be reached during distillation. An azeotrope is defined as a mixture that will vaporize continuously without change in composition, i.e. without separation of the constituents. Thus, such a system is called a constant boiling mixture. Usually, the azeotrope exists over a limited range of concentration for the constituents so that separation of the constituents can be made until the composition of the liquid in the still reaches the azeotropic concentration range.

Distillation processes can be classified into three general categories, simple or batch distillation, stripping, and fractionation. The differences between these three categories can best be explained by the basic steps that take place in the distillation process. These steps are summarized below and discussed in greater detail under the sections for the individual distillation technologies.

In the batch distillation process, the mixture is vaporized in the boiler and the vapor is cooled and condensed to a liquid in a condenser. Since the batch distillation process uses only one equilibrium stage the degree of separation is very limited unless there is a great difference in the relative volatilities.

The stripping process uses multiple equilibrium stages with the initial waste mixture entering the uppermost equilibrium stage. The boiler is located below the lowermost equilibrium stage so that vapor generated moves upward in the column coming into contact with the falling liquid. As the vapor comes into contact with the liquid at each stage, the more volatile components are stripped from the liquid by the vapor phase, thus giving the process the name stripper. The concentration of the emerging vapor is slightly enriched (as it is in equilibrium with the incoming liquid), but the bottoms in the boiler are considerably concentrated in the lower vapor pressure constituent. The process of stripping is very effective for wastewaters where the relative volatilities are large.

The fractionation process uses multiple equilibrium stages with the initial waste feed entering the column at a point between the first and last equilibrium stages. The stages at and below the point of entry are called the stripping section because the stages function as described above under the stripping process. The stages located above the point of feed are called the rectification section. These additional stages allow the vapor to become further enriched in the volatile components compared to incoming feed. A portion of the condensed vapor is returned as liquid to the uppermost stage to aid in rectification. This step of returning a portion of the condensed vapor to the column is called reflux.

(b) Steam Stripping. The underlying principle for steam stripping is the same as described above for a stripper except that steam (introduced directly at the bottom of the stripping section or generated from the wastewater through indirect heating in the boiler) is used to strip the organic volatiles from the wastewater. The water effluent from the bottom of a well designed and operated unit is considerably reduced in organic content and usually can be discharged in compliance with NPDES requirements or municipal treatment standards. The vapors at the top of the column containing steam and organics are condensed. Organics in the condensate which form a separate phase in water can be physically separated. Depending upon the concentration of soluble organics in the remaining condensate, it is either recycled to the stripper, disposed, or treated further with another technology (e.g. biological treatment).

(3) Description of Steam Stripping. A steam stripping unit consists of a boiler, a stripping section, a condenser and a product receiver. Figure 4-4 is a schematic showing the major components of a steam stripper. The boiler is a device that provides the heat required to vaporize the liquid fraction of the waste. The stripping section is composed of a set of trays or packing in a vertical column. The feed enters at the top of the stripping section. In the stripping section, vapor rising from the boiler is contacted with the downflowing liquid feed. Through this contacting, the lower boiling point constituents are concentrated in the vapor. The rising vapor is collected at the top of the column, cooled and condensed. The cooled liquid product stream is then routed to a product receiver.

(4) Design and Operating Parameters Affecting Performance. Unlike the other distillation processes discussed below, steam stripping is not generally designed and operated from a perspective of product recovery but rather for the purpose of removing contaminants from wastewater to comply with NPDES requirements or municipal treatment standards.

There are a number of design and operating parameters which must be considered in the selection of an effective steam stripping system to treat a specific waste.

(a) Design Parameters. The design parameters to consider include: vapor liquid equilibrium data (required to determine the number of equilibrium stages and the liquid and vapor flow rates), column temperature and pressure, column internals and condenser temperature.

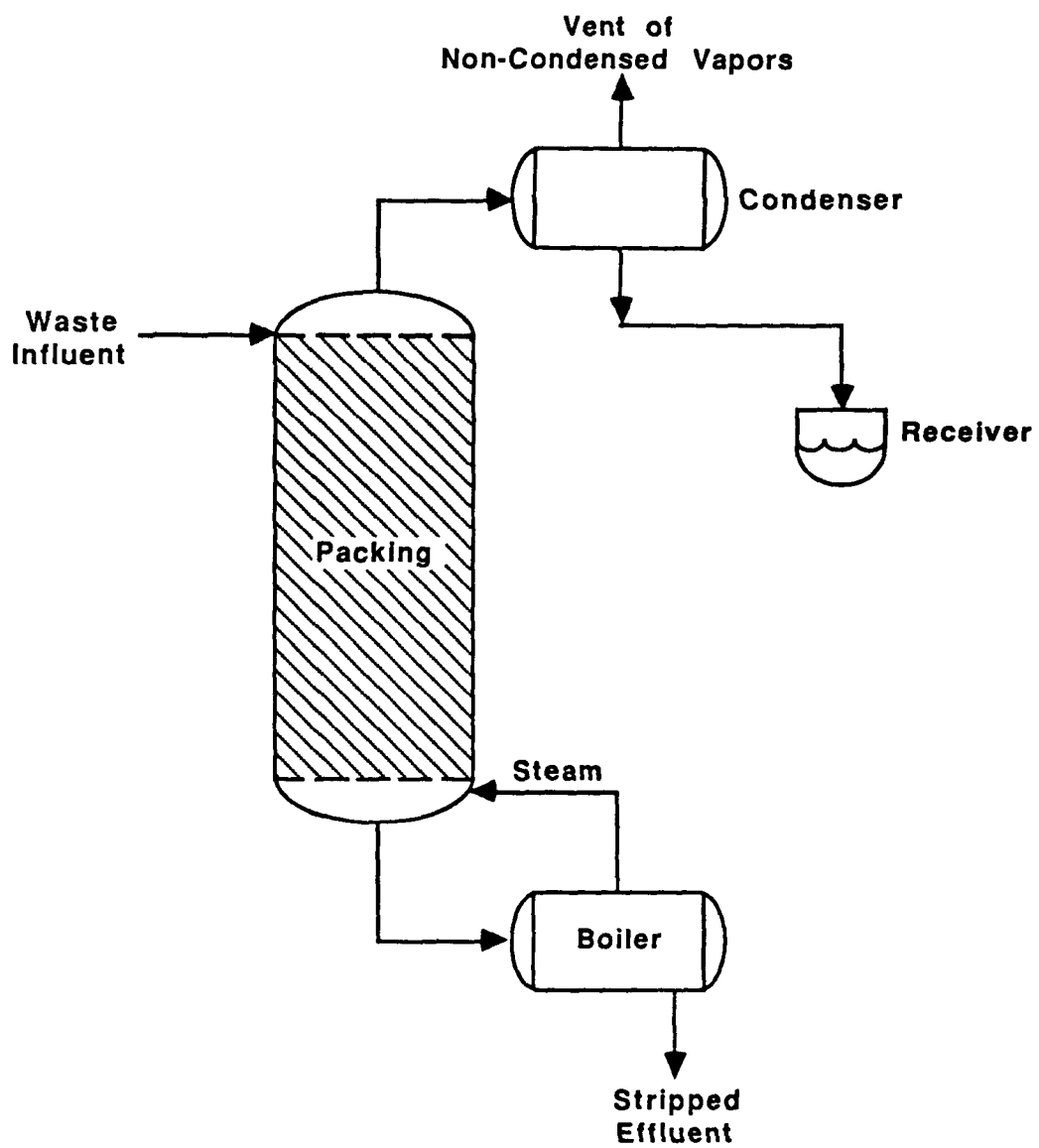


Figure 4-4
Steam Stripping

(i) Vapor Liquid Equilibrium Data. The vapor liquid equilibrium data are determined in laboratory tests unless already available. The use of these data are required for several reasons. First, they are used to calculate the number of theoretical stages required to achieve the desired separation. Using the theoretical number of stages, the actual number of stages can then be determined through the use of empirical tray efficiency data supplied by an equipment manufacturer (refer to column internals discussion below).

Secondly, the vapor liquid equilibrium data are used to determine the liquid and vapor flow rates that ensure sufficient contact between the liquid and vapor streams. These rates are in turn used to determine the column diameter.

(ii) Column Temperature and Pressure. These parameters are integrally related to the vapor liquid equilibrium conditions. The design column temperature is calculated by developing an enthalpy (heat) balance around the steam stripping unit, accounting for the heat removed in the condenser, heat input in the feed, heat input from steam injectors and heat loss from the column. Column pressure influences the boiling point of the liquid. For example, the column temperature required to achieve the desired separation can be reduced by operating the system under vacuum. These parameters are also critical to operation of the system and will be discussed in the following section, operating parameters.

(iii) Column internals. Column internals are designed to accommodate the physical and chemical properties of the wastewater to be stripped. Two types of internals may be used in steam stripping: trays or packing. Tray types include bubble cap, sieve, valve and turbo-grid. Trays have several advantages over packing. Trays are less susceptible to blockage by solids or polymerization products, they have a lower capital cost for large diameter columns (greater than or equal to 3 feet), and they accommodate a wider range of liquid and vapor flow rates. A comparison of various tray types can be found in the Chemical Engineer's Handbook (3) and Distillation Design in Practice (5). Packing types include raschig rings, pall rings, saddles and sulzer-structures. Compared to trays, packing has the advantages of having a lower pressure drop per theoretical stage, being more resistant to corrosive materials, having a lower capital cost for small diameter column (less than 3 feet), and finally being less susceptible to foaming because of a more uniform flow distribution. A comparison of various packing types can be found in the Chemical Engineer's Handbook (3) and Distillation Design in Practice (5).

As indicated above, the different types of trays and packing have associated with them different separation efficiencies. Efficiency needs to be accounted for in determining the actual number of trays or height of packing required. Efficiency data can be supplied by the manufacturer.

(iv) Condenser Temperature. The condenser temperature is calculated in the design to ensure that the overhead product recovery rate is maximized and emissions from the condenser venting are minimized. In practice, the design condenser temperature is achieved by balancing the size of the condenser with the cooling or chilled water throughput.

(b) Operating Parameters. The parameter that requires control to ensure that the steam stripper is properly operated is the temperature at the top of column before the vapor exits to the condenser (the uppermost stage). There are a number of operating parameters that can be adjusted to maintain the design specification for temperature. These include condenser temperature, column pressure, steam rate and feed rate.

From the perspective of minimizing air emissions it is important to control the temperature of the liquid leaving the condenser. The higher that this temperature is, the greater the amount of vapor that could potentially be discharged to the atmosphere in the absence of further emission controls. In practice, the temperature of the condenser must be matched with the other parameters that affect the column temperature.

4.3.2 Batch Distillation

(1) Applicability. Batch distillation is a demonstrated technology for F001-F005 spent solvent wastes, other than wastewaters, as wastewaters are defined for purposes of this rulemaking (i.e., less than one percent total organic carbon (TOC)). It is estimated that at least 400 facilities perform full scale batch distillation for on-site or commercial treatment of these wastes. This technology is sometimes referred to as pot distillation, "cooking", still pot distillation, or simple distillation. In general, it is applied to spent solvent wastes where a crude separation is acceptable and the wastes are highly concentrated and yield significant amounts of recoverable material upon separation. For wastes with constituents having a large relative volatility, batch distillation is capable of providing a good separation. Batch distillation is particularly applicable for wastes with high solids concentrations since the more volatile constituents are separated leaving the solids in the still bottoms. In this way it may also be effective to reduce the quantity of waste requiring subsequent land disposal or incineration.

Batch distillation processes yield a residue (the still bottoms) that may contain a high amount of suspended solids and may be quite viscous. Whether this residue can be land disposed directly or requires further treatment depends upon the level of F001 - F005 constituents in the TCLP* extract of this residue.

(2) Underlying Principles of Operation. The underlying principles of operation for batch distillation are discussed generally in the general subsection under steam stripping.

In the batch distillation process, the mixture is vaporized in the boiler and the vapor is cooled and condensed to a liquid in a condenser. Since the batch distillation process uses only one equilibrium stage the degree of separation is very limited unless there is a great difference in the relative volatilities.

(3) Description of Batch Distillation. A batch distillation unit consists of a boiler, a condenser, and a product receiver. Figure 4-5 is a schematic showing the major components of a batch distillation unit. The boiler is a device that provides the heat required to vaporize the liquid fraction of the waste. The rising vapor is collected at the top of the column, cooled and condensed. The liquid product stream is then routed to a product receiver.

(4) Design and Operating Parameters Affecting Performance.

(a) Product Recovery. To establish the efficiency for product recovery, the design and operating parameters are optimized between the amount of product recovered and the energy and equipment sizing requirements. In consideration of these factors, facilities will adjust operating temperature, duration of the process, sizing of the condenser, and finally the temperature of the condenser cooling water.

(b) Environmental Considerations. In optimizing a batch distillation unit from the perspective of minimizing releases to the environment, many of the same factors are considered but the optimal operating conditions can be quite different. For example, the optimal temperature out of the condenser may need to be significantly lower from

*TCLP is the Toxicity Characteristic Leaching Procedure. This procedure is referenced as Appendix I in 40 CFR 268.41, Treatment Standards Expressed as Concentrations in Waste Extract. In some cases it may be possible to further reduce the F001 - F005 constituent concentrations by increasing the operating temperature or duration of the batch.

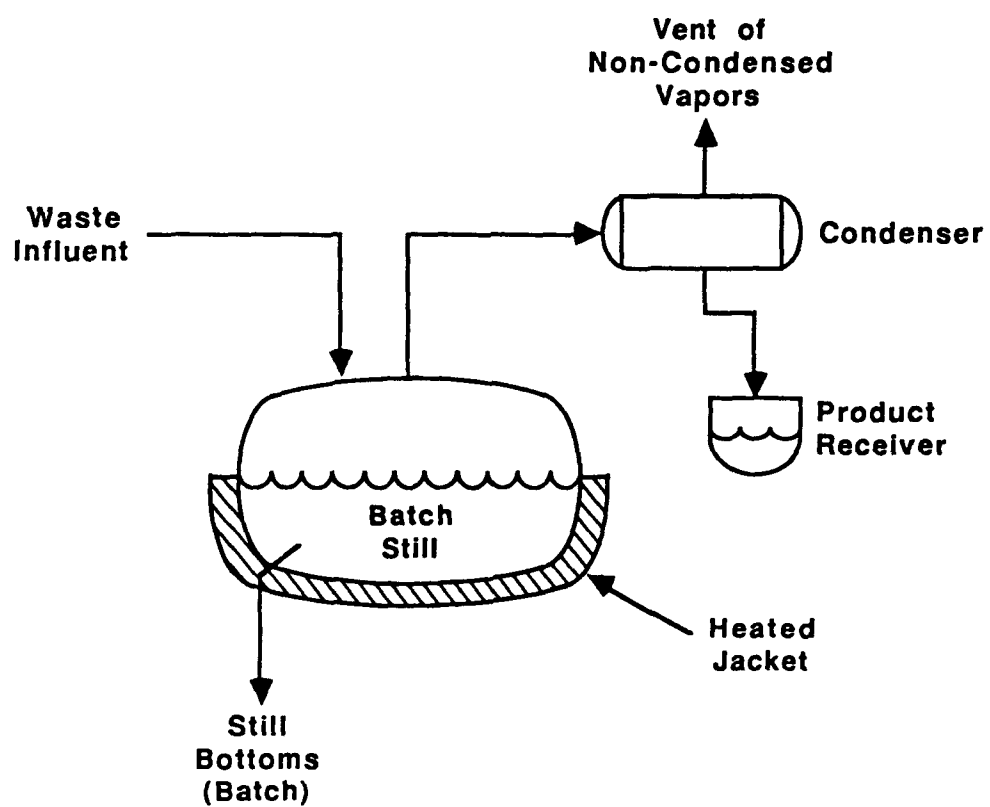


Figure 4-5
Batch Distillation

the perspective of minimizing air emissions than for achieving cost effective product recovery. Additionally, the optimal temperature and duration of a batch distillation run may be different from the perspective of minimizing organics in the batch distillation residue than from the standpoint of cost effective product recovery. It is important to point out that facilities may find in some instances that higher temperatures and longer distillation runs may result in a residual that could be land disposed directly rather than require incineration. The amount of noncondensable vapor in the waste feed can also influence the amount of vapor vented.

4.3.3 Thin Film Evaporation

(1) Applicability. Thin film evaporation is also a demonstrated distillation technology for F001-F005 spent solvent wastes other than wastewater, as wastewater is defined for the purposes of this rulemaking (i.e., less than one percent total organic carbon). It is also used to treat highly concentrated wastes; it differs, however, from batch distillation in that the feed stream to a thin film evaporator must contain considerably lower suspended solids concentrations. Use of this technology results in a product stream which almost always can be reused as a solvent directly or after further treatment, and a bottoms stream which often is used as fuel for incinerators. Because the waste feeds are usually concentrated and contain little or no suspended solids, treatment using thin film evaporation rarely results in a residue that requires land disposal.

(2) Underlying Principles of Operation. As discussed previously in this section in reference to steam stripping, the basic principle of thin film evaporation is the separation of a liquid mixture into various components by a process of vaporization-condensation. As in batch distillation, the vapors are removed as they are formed, so that thin-film units contain only one-equilibrium stage and are thus limited in the degree of separation by the relative volatilities of the constituents.

The principal objective of this type of thin film apparatus is to provide the heat and surface area for separation to occur. The cylinder walls are heated by steam from the outside as the feed trickles down the inside walls. The feed rate of waste is controlled to allow the solvent material adequate time to vaporize. The heat transfer from the steam to the waste is determined by their relative temperatures and the heat transfer coefficient of the vessel materials.

As in a batch distillation unit, as more of the volatiles are removed, the temperature must be continually raised to vaporize the remaining waste. Thus the highly volatile components escape near the top of the evaporator while heavier components fall to the bottom of the evaporator.

(3) Description of Thin Film Evaporation. Thin film evaporation consists of a steam jacketed cylindrical vessel, a condenser, and a product receiver. Figure 4-6 is a schematic showing the major components of a thin film evaporator. The steam heated surface of the cylindrical vessel provides the heat required to vaporize the liquid fraction of the waste. The rising vapor is collected at the top of the column, cooled and condensed. The cooled liquid product stream is then routed to a product receiver. The significant feature of this technology is the distribution device that spreads a thin film over the heated surfaces.

(4) Design and Operating Parameters Affecting Performance.

(a) Product Recovery. To establish the efficiency for product recovery, the design and operating parameters are optimized between the amounts of the various products recovered and the energy usage and equipment sizing requirements. In consideration of these factors, facilities will adjust operating temperature, sizing of the condenser, and the temperature of the condenser cooling water.

(b) Environmental Considerations. The vapors which result from thin film evaporation are collected and condensed for reuse or for further purification. The recovery of solvents from the unit is similar to batch distillation in regard to the final temperature of the product leaving the condenser. The higher the temperature of the product, the greater the amount of solvents that will be vented into the atmosphere unless controlled by air emission devices such as secondary condensers. The amount of uncondensed vapor potentially vented to the atmosphere depends on the temperature of the product leaving the condenser. The amount of non-condensibles in the waste feed can also influence the amount of vapor vented.

4.3.4 Fractionation

(1) Applicability. Fractionation is another demonstrated distillation technology for F001-F005 spent solvent wastes other than wastewater, as wastewater is defined for the purposes of this rulemaking (i.e., less than one percent total organic carbon). It differs from batch distillation, steam stripping and thin film evaporation in that it is designed to achieve the highest degree of distillate purity of any of these treatment technologies. Fractionation can be operated to produce

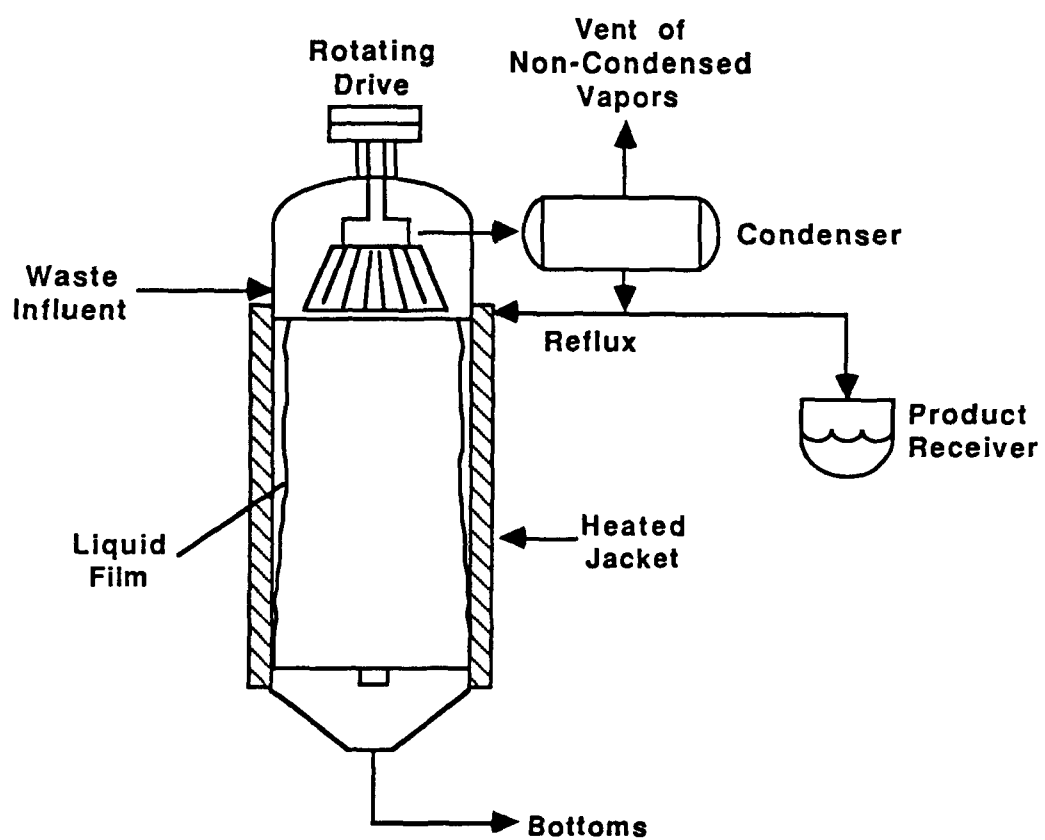


Figure 4-6
Thin Film Evaporation
4-25

multiple product streams for recovery of more than one solvent constituent from a waste, while generating minimal amounts of residue to be land disposed. In general, this technology is used where recovery of multiple constituents is desired and where the waste contains minimal amounts of suspended solids. It is frequently used as a recycle/reuse operation within manufacturing processes.

(2) Underlying Principles of Operation. The underlying principles of operation for fractionation are discussed generally in the general subsection under steam stripping. Fractionation processes use multiple equilibrium stages with the initial waste feed entering at a point between the first and last equilibrium stages. The stages at and below the point of entry are called the stripping section because the stages function as described above. The stages located above the point of feed are called the rectification section. These additional stages allow the vapor to become further enriched in the volatile components compared to the incoming feed mixture. A portion of the condensed vapor is returned as liquid to the uppermost stage to aid in rectification. This step of returning a portion of the condensed vapor to the column is called reflux.

(3) Description of Fractionation. A fractionation unit consists of a boiler, a stripping section, a rectification section, a condenser, a reflux system, and a product receiver. Figure 4-7 is a schematic showing the major components of a fractionation unit. The boiler is a device that provides the heat required to vaporize the liquid fraction of the waste. The stripping section is composed of a set of trays or packing in a vertical column. In the stripping section, vapor rising from the boiler is contacted with the downflowing liquid feed. Through this contacting, the lower boiling point constituents are concentrated in the vapor. In the rectification section, the vapor rising above the feed tray is contacted with downflowing condensed liquid product (reflux). Through this contacting, further enrichment of the vapor is achieved. The rising vapor is collected at the top of the column, cooled, and condensed. The liquid product stream is then routed to a product receiver.

(4) Design and Operating Parameters Affecting Performance.

(a) Product Recovery. To establish the efficiency for product recovery, the design and operating parameters are optimized between the amounts of the various products recovered and the energy usage and equipment sizing requirements. In consideration of these factors, facilities will adjust operating temperature, sizing of the condenser, and the temperature of the condenser cooling water.

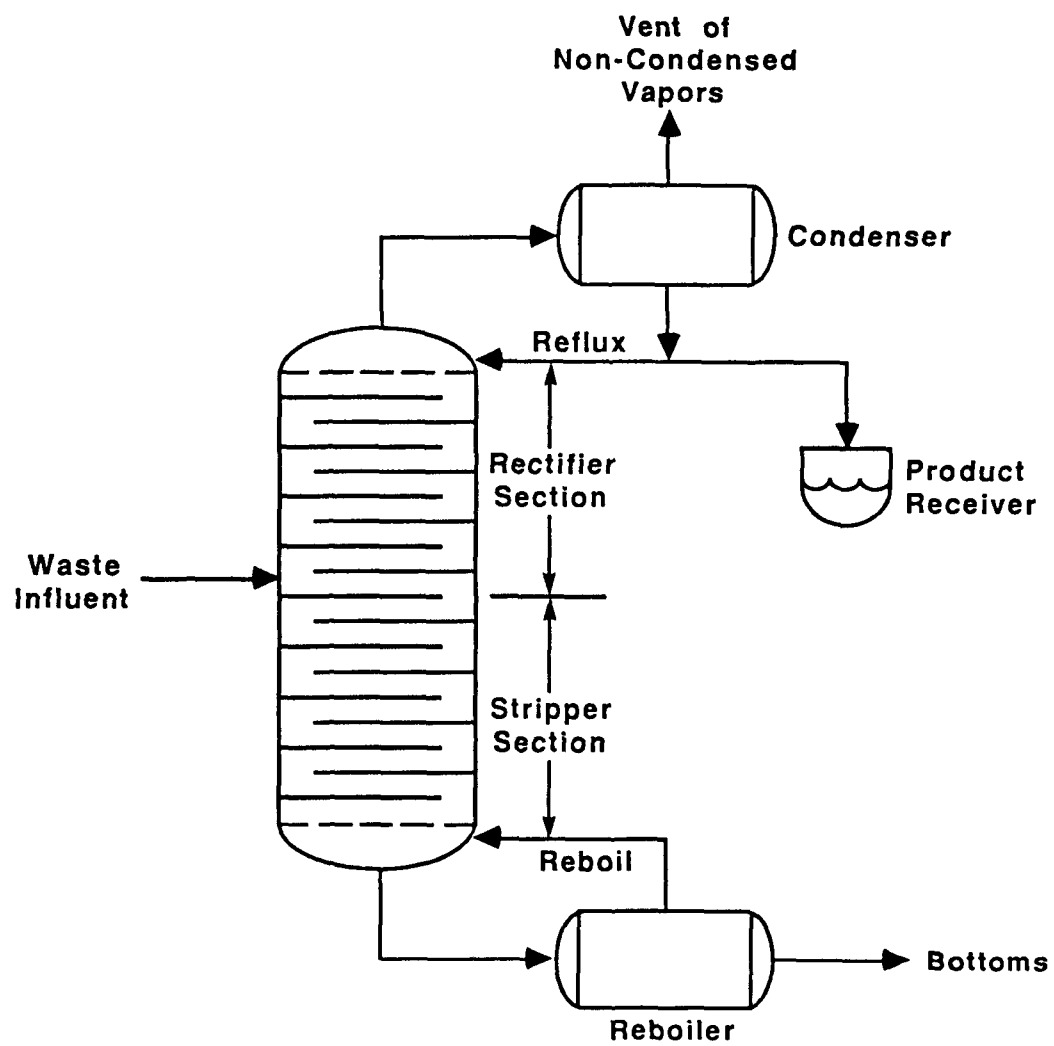


Figure 4-7
Tray Fractionation Column
4-27

(b) Environmental Considerations. The vapors which result from thin film evaporation are collected and condensed for reuse or for further purification. The recovery of solvents from the unit is similar to batch distillation in regard to the final temperature of the product leaving the condenser. The higher the temperature of the product, the greater the amount of solvents that will be vented into the atmosphere unless controlled by air emission devices such as secondary condensers. The amount of uncondensed vapor potentially vented to the atmosphere depends on the temperature of the product leaving the condenser. The amount of non-condensibles in the waste feed can also influence the amount of vapor vented.

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4.4 Biological Treatment

4.4.1 Applicability

This technology is demonstrated for wastewaters containing the F001-F005 spent solvents. The Agency has full scale biological treatment performance data from 28 plants in the organic chemicals, plastics, and synthetic fibers industries which manufacture, in total, over 200 different products. These data were from treatment of wastes containing F001-F005 constituents as a result of process contamination. While the wastes are not included in EPA's definition of spent solvent wastes, the Agency believes that these wastes are similar to spent solvent wastes. The Agency has biological treatment data on carbon tetrachloride, chlorobenzene, cresols, 1,2-dichlorobenzene, ethylbenzene, methylene chloride, nitrobenzene, tetrachloroethylene, toluene, trichloroethylene, 1,1,1 trichloroethane, and trichlorofluoromethane. These data are presented in Section 5 of this document.

Biological treatment is a widely recognized technology for the removal of organic compounds from wastewaters. The concentrations of organic constituents that can be effectively removed vary widely depending on the overall chemical and physical characteristics of the wastewater. Treatment applicability ranges from 0.01 to several hundred parts per million in the wastewater. For treatment effectiveness of spent solvent wastewaters not similar to those evaluated in Section 5 of this document, facilities should review the "underlying principles of operation" section and the "design and operating parameters affecting performance" section for identification of other factors that should be considered in applying this technology to a particular wastewater.

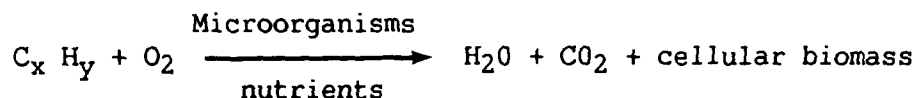
The underlying principles of biological treatment are presented in subsection 4.4.2 below. Descriptions of biological treatment processes, including activated sludge, aerated lagoons, trickling filters, and rotating biological contactors, are presented in subsection 4.4.3. Parameters which affect the performance of biological treatment are presented in subsection 4.4.4.

4.4.2 Underlying Principles of Operation

Biological treatment involves the use of naturally occurring, acclimated or genetically-altered microorganisms to degrade organic contaminants in wastewater. During aerobic (presence of oxygen) biological treatment, organic constituents are converted by microorganisms to carbon dioxide, water, and cell protein. In anaerobic (absence of oxygen) biological treatment, wastes are converted by microorganisms to methane, carbon dioxide, and cell protein.

(1) Anaerobic biological treatment. While anaerobic biological processes have been shown to be effective in treating complex organic wastes that generally cannot be treated aerobically, these are still in developmental stages. Since the anaerobic processes currently find limited application for the treatment of hazardous wastes, only aerobic biological treatment will be discussed in detail.

(2) Aerobic biological treatment. Aerobic processes use microorganisms which require oxygen (as air or oxygen containing compounds) for biodegradation of organic contaminants. In addition, nutrients are needed in the form of nitrogen and phosphorous. The aerobic biodegradation process can be represented by the following generic equation:



The aerobic bacteria degrade the organic waste to obtain energy for cell metabolism and cell growth. A fraction of the waste is also oxidized to products such as nitrates (NO_3), sulfates (SO_4), H_2O , and carbon dioxide (CO_2).

Biological oxidation of wastewaters containing organic constituents will result in the net accumulation of a biomass of expired microorganisms consisting mainly of cell protein. However, the cellular biomass or sludges may also contain entrained constituents of the wastewater, partially degraded constituents, or intermediate products which have not been degraded. If biological treatment is carried out in a land-based, unlined impoundment or lagoon with no drain-collection system, such as aerated lagoons, any underlying soil materials may be contaminated by leachate from the overlying sludges or the wastewater itself.

Biological oxidation sludges must be periodically wasted in order to maintain proper operation of the wastewater treatment system. Waste biological sludges may be routed to a clarification tank where they are allowed to settle. Settled sludges may be further dewatered on sludge drying beds or by mechanical dewatering. The final dewatered, settled waste sludge is a residual which must be disposed. If a TCLP analysis of the waste for compliance purposes shows the leachate from the sludge to contain F001-F005 solvents in excess of the BDAT treatment standard, it would most likely have to be incinerated. At present, land disposal is one of the methods of disposition for residuals generated from biological wastewater treatment.

For the application of biological treatment to industrial wastes, it is important that the wastes be compatible with the physical-chemical needs of the microorganisms, including consideration of the physical-chemical and nutritional needs of the microorganisms, and the effects of any toxic constituents on the microorganisms. Treatment process modifications and/or waste pretreatment may be required to provide the proper environment necessary for maintaining an active microbial population.

4.4.3 Description of Biological Treatment

There are four types of biological treatment processes:

- Activated sludge,
- Aerated lagoons,
- Trickling filters, and
- Rotating biological contactors (RBCs).

(1) Activated sludge. The activated sludge process is currently the most widely used biological treatment process. This is due in part to the fact that recirculation of the biomass, which is an integral part of the process, allows microorganisms to adapt to changes in wastewater composition by relatively short acclimation processes and also allows a greater degree of control over the acclimated bacterial population.

A schematic diagram of the activated sludge process is shown in Figure 4-8. Wastewater which contains organic contaminants enters a basin or tank where an aerobic bacterial population is maintained in suspension and aeration is provided. The contents of the basin are referred to as the mixed liquor.

Oxygen is supplied to the aeration basin by mechanical or diffused aeration. A portion of the mixed liquor is continuously discharged from the aeration basin into a clarifier, where the biomass is separated from the treated wastewater by sedimentation. A portion of the biomass is recycled to the aeration basin in order to maintain an optimum concentration of acclimated microorganisms in the aeration basin. The remainder of the separated biomass is discarded or "wasted" and the clarified effluent is discharged. The recycled biomass is referred to as activated sludge. The term "activated" is used because the recycled biomass contains living and acclimated microorganisms which will metabolize and assimilate organic material at a high rate when returned to the aeration basin. This is because of the low food to microorganism ratio in the sludge from the clarifier.

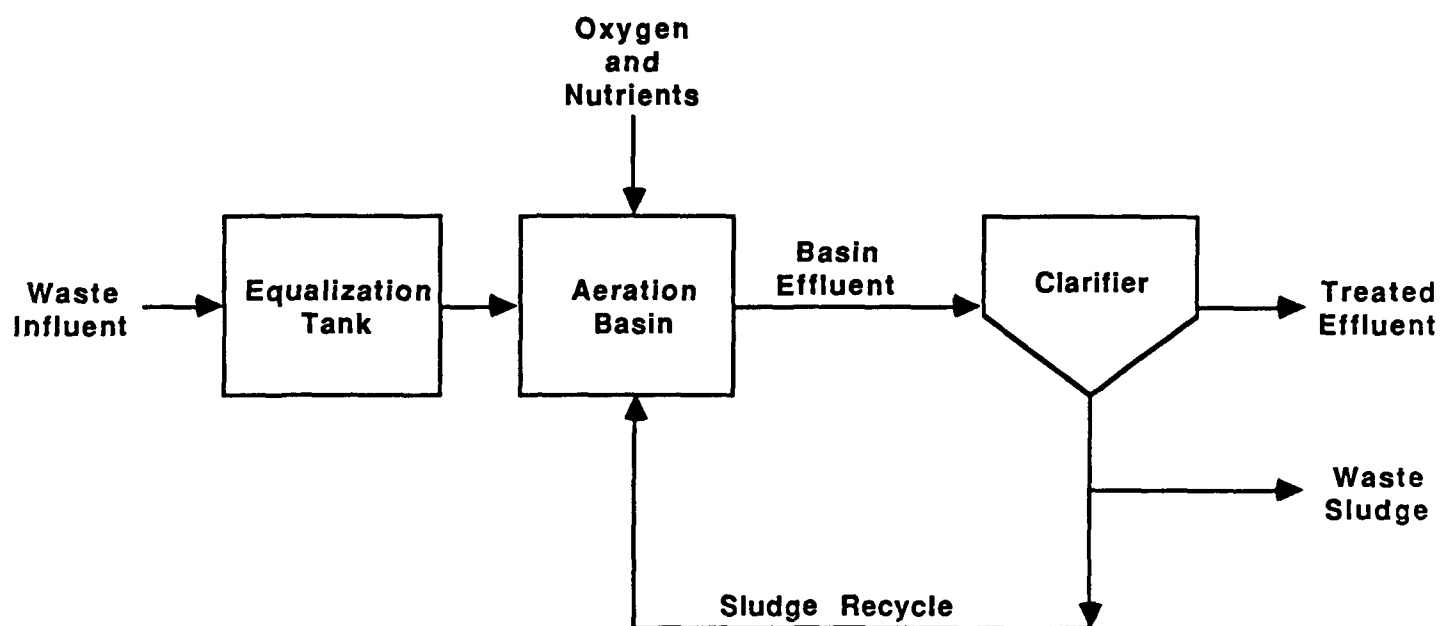


Figure 4-8
Activated Sludge

An important variation on the activated sludge process is the PACT® process, developed by DuPont Corporation and licensed by Zimpro, Inc. This process offers a combined treatment and pre-treatment unit whereby non-compatible and toxic constituents are adsorbed onto activated carbon and microorganism compatible waste remains in solution. Powdered activated carbon is added directly to the aeration basin of the activated sludge treatment system. Overall removal efficiency is improved because compounds which are not readily biodegradable or which are toxic to the microorganisms are adsorbed onto the surface of the powdered activated carbon. The carbon is removed from the wastewater in the final clarifier along with the biological sludge. Both the carbon and the biological sludge must be treated further or disposed. Generally, the activated carbon is recovered, regenerated, and recycled.

(2) Aerated lagoons. Aerated lagoons are another form of aerobic biological wastewater treatment. An aerated lagoon is a large pond or tank which is equipped with mechanical aerators to maintain an aerobic environment and to avoid settling of the suspended biomass. In the beginning, the population of microorganisms in an aerated lagoon is much lower than in an activated sludge system because there is no sludge recycle. A significantly longer residence time is therefore required in order to achieve a specified effluent quality. However, this longer residence time may be an advantage when complex organic chemicals are to be degraded. Biodegradation of the organic contaminants in the wastewater occurs throughout the lagoon. The effluent from the lagoon may flow to a secondary sedimentation unit for removal of suspended solids. Alternatively, the mechanical aerators may be shut off in the aerated lagoon for a period of time to facilitate settling and sedimentation prior to discharge of the effluent.

Aerated lagoons are exposed to variations in ambient air temperature and thus perform better in warmer climates. This is due to the fact that, as the temperature of the lagoon drops, the activity of the microorganisms decrease and the efficiency with which the microorganisms degrade organic material declines. Because there is usually no mechanism for increasing the number of microorganisms in a lagoon (recycle is not usually practiced), the performance of a lagoon may suffer at low temperatures. The microorganisms used in aerated lagoons are also more resistant to upsets by organic influent and pH shock loads compared to activated sludge and fixed biomass processes because of longer detention times and larger tank volume. Aerated lagoons also perform like cooling towers, so no additional cooling is required to treat wastes with relatively high temperatures. Compared to other biological treatment systems, aerated lagoons are easy to operate and require little maintenance. However, aerated lagoons require a large land area, are susceptible to hydraulic shock loads, and there is little operational control for adjustment to sustained changes in influent loading.

(3) Trickling filters. The trickling filter biological treatment process involves contact between wastewater containing organic contaminants and a population of microorganisms which are fixed or attached to the surface of filter media. Rocks or synthetic material such as plastic rings and saddles are typically used as filter media. The wastewater is distributed over the top of the filter by a rotating distribution arm or a fixed distributor system. Wastewater forms a thin layer as it flows downward through the filter and over the microorganism layer on the surface of the media. As the distribution arm rotates, the microorganism layer is alternately exposed to a flow of wastewater and air. In the fixed distributor system, the wastewater flow is cycled on and off at a specified dosing rate to ensure that an adequate supply of oxygen is available to the microorganisms. A schematic diagram of a trickling filter is shown in Figure 4-9.

The microorganism layer on the filter media is commonly called the slime layer. The slime layer consists of a variety of organisms including aerobic, anaerobic, and facultative bacteria, fungi, algae and protozoans. Worms, insect larvae and snails may also be present. These higher animal forms feed on the slime layer in the trickling filter, thereby maintaining the bacterial population in a state of rapid growth and food utilization. The presence of the varied organisms limits the overgrowth of any particular type of organism.

Oxygen from the air reaches the microorganisms through the void spaces in the media. Oxygen is necessary for aerobic degradation of the organic contaminants in the wastewater. Trickling filters have an underdrain system to collect the treated wastewater and any biological solids which have become detached from the media. This underdrain system acts both as a collection unit and as a structure through which air can reach the void space of the filter media.

Organic material present in wastewater is adsorbed onto the biological film or slime layer. Near the surface of the biological slime layer, the attached microorganisms are exposed to oxygen. In this zone, organic material is degraded by aerobic microorganisms. This degradation of organic material causes the microorganisms to grow, resulting in an increase in the thickness of the slime layer. The oxygen that diffuses into the slime layer is consumed before it can fully penetrate the entire slime layer. Therefore, an anaerobic environment is established near the surface of the support media.

Eventually, as the slime layer continues to increase in thickness, the adsorbed organic material is fully metabolized before it reaches the microorganisms at the support media surface. Because no organic material is present to feed the microorganisms at the support media surface, they

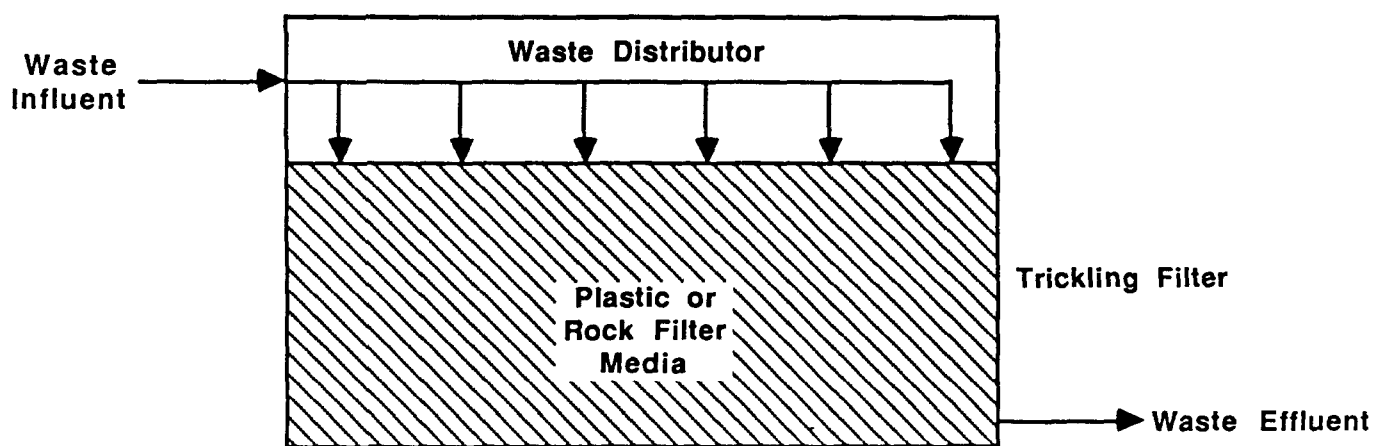


Figure 4-9
Trickling Filter

enter into an endogenous phase of growth (a state of reduced respiration and metabolism) and lose their capability to cling to the surface. The wastewater washes the slime from the media, and a new slime layer begins to grow. This process is referred to as sloughing and is primarily a function of the organic and hydraulic loading on the filter. The organic loading affects the rate of metabolism in the slime layer while the hydraulic loading determines shear velocities on the slime layer. Based on the hydraulic and organic loading rates, trickling filters are classified as low-rate or high-rate filters. Maintenance of a regulated flow rate is very crucial in this process. Any fluctuation in the flow rate would result in the sloughing off effect where the slime layer will get detached from the support.

Trickling filter systems are typically used as a roughing filter, to reduce the organic loading on a downstream activated sludge process. Trickling filters can be used for the treatment of wastewaters which produce bulking sludge (a sludge with poor settling characteristics and poor compactibility) in an activated sludge process because the microbial film which sloughs off the trickling filter is relatively dense and can be readily removed by sedimentation.

Trickling filter biological treatment has been demonstrated in the organic chemicals, plastics, and synthetic fibers industries. A trickling filter system is used to treat aqueous waste containing toluene and ethylbenzene at one plant.

(4) Rotating biological contactors. The rotating biological contactor (RBC) consists of a series of closely spaced, parallel disks which are rotated while partially immersed in a trough of wastewater. The disks are constructed of polystyrene, polyvinyl chloride, or similar materials. Rotating biological contactors can be customized depending on the type of influent waste requiring biodegradation. Each disk is covered with a biological slime which degrades dissolved organic matter present in the wastewater. The rotation of disks facilitates exposure of microorganisms to the air. As the disk is rotated out of the tank, it carries a film of the wastewater into the air where oxygen is available for aerobic biological decomposition. As excess biomass is produced, it sloughs off the disk and is separated from the process effluent in a final clarifier. The sloughing off process is similar to what occurs in a trickling filter, which was described above. A schematic diagram of a rotating biological contactor is shown in Figure 4-10.

RBCs can be used to treat dilute aqueous wastes containing biodegradable organics, including solvents. The large amount of biological cell mass permits the system to withstand organic and hydraulic surges effectively. RBCs allow a greater degree of control

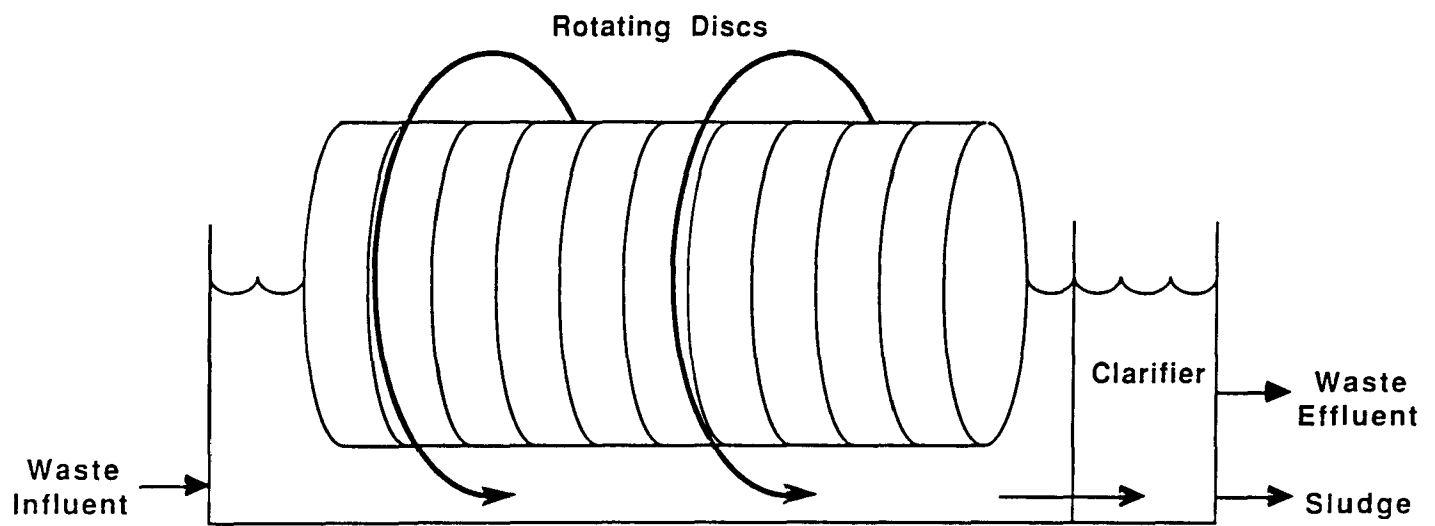


Figure 4-10
Rotating Biological Contactor

over treatment variables than trickling filters. The rate of contact between the microorganisms, the organic waste, and atmospheric oxygen can be controlled by adjusting the depth to which the disks are submerged in the wastewater and the rate at which the disks rotate. RBCs tend to be susceptible to operational problems; deflection of the central shaft and difficulty in controlling growth (slime layer tends to overgrow or slough off completely) are common problems.

4.4.4 Design and Operating Parameters Affecting Performance

There are a number of parameters affecting the performance:

- Equalization,
- Nutrients,
- Aeration/oxygen supply,
- Wastewater-biomass contact,
- Microorganism growth phase,
- Temperature,
- pH, and
- Selection of microorganisms.

These parameters are discussed in the following paragraphs. The way in which these parameters are controlled is specific to the type of biological treatment process employed.

(1) Equalization. Equalization is important because biological treatment systems are very sensitive to variations in influent flow rate and organic loadings. Sudden changes can cause process upsets, toxic effects or reduced dissolved oxygen levels, all of which will result in diminished treatment efficiency. The treatment influent should be monitored to detect variations in organic loadings and sufficient equalization time should be provided to yield a relatively constant loading to the treatment system.

(2) Nutrients. Nutrient addition is important in controlling the growth of microorganisms as insufficient nutrients will result in poor microbial growth with poor removal of organic compounds. The principal inorganic nutrients required are nitrogen and phosphorus. It has been shown that the percentage distribution of nitrogen and phosphorus in microbial cells varies with the age of the cell and environmental conditions. The total amount of nutrients required will depend on the net mass of organisms produced. In addition to the major nutrients, trace amounts of potassium, calcium, sulfur, magnesium, iron and manganese are required for optimum microbial growth.

(3) Aeration/Oxygen Supply. An adequate supply of oxygen is critical to maintain an environment in which aerobic microorganisms can grow and metabolize dissolved organic material. The way in which oxygen is supplied to the microorganisms varies with the type of biological treatment process used.

The oxygen can be provided as atmospheric oxygen or in the form of sulfates, nitrates, nitrites or other oxygen-containing organic compounds such as sugar or starch.

(a) Activated sludge. The suspended microorganisms in the aeration basin of an activated sludge treatment system obtain oxygen directly from the wastewater being treated. For this reason, the dissolved oxygen (D.O.) concentration in the aeration basin should be maintained close to the saturation level (approximately 8 mg/L) at all times. Ideally, the D.O. level should be monitored continuously to detect process upsets or deterioration of aeration efficiency. The D.O. level is controlled by adjusting the aeration rate. Mechanical and diffused aerators are both commonly used with activated sludge systems. Theoretical oxygen requirements are determined from biochemical oxygen demand (BOD) of the waste and the influent wastewater flow rate. The air supply must be adequate to satisfy the BOD of the waste, provide adequate mixing (i.e., to keep microbial population in suspension), and provide dissolved oxygen in the aeration basin as close to the saturation level as possible.

(b) Aerated lagoons. The suspended microorganisms in an aerated lagoon also obtain oxygen directly from the wastewater. The D.O. level in an aerated lagoon is controlled by adjusting the aeration rate and should be kept as high as possible at all times. Since the waste retention time is longer, aeration is accomplished by use of mechanical aerators because diffused aerators tend to become fouled with bottom sediment. Aeration performs the two functions of oxygen transfer and mixing.

(c) Tricking filters. The microorganisms in a trickling filter are attached to the filter media and obtain oxygen from air which permeates the void space in the media. The organisms are alternately exposed to the flowing layer of wastewater or air. If the organisms do not have a sufficiently long period of exposure to air between passes of the distribution arm or cycle times, efficient aerobic degradation of the waste is not possible. The only way to ensure an adequate supply of oxygen is to control the wastewater feed rate (hydraulic loading rate). The hydraulic loading rate (gallons per minute per square foot) will be affected by a number of variables including the biological oxygen demand of the wastewater and the characteristics of the support media,

particularly the void space. An increased void space will permit a higher hydraulic loading as well as enhanced oxygen transfer to the biological slime. Synthetic support media have more void space and surface area per unit volume than do conventional rock media.

Trickling filters are classified according to their hydraulic and organic loading rates as low-rate or high-rate filters. High-rate filters operate with hydraulic and organic loading rates of 0.156 to 0.47 gallons per minute per square foot and 90 pounds of BOD per day per 1,000 cubic feet of media, respectively. High-rate hydraulic loading rates of trickling filters with synthetic media are even higher, at 2.3 gallons per minute per square foot. The corresponding organic loading rates for low rate filters are 0.063 gallons per minute per square foot and 10 to 20 pounds of BOD per day per 1,000 cubic feet of media.

Recirculation is another important factor in the efficient operation of a trickling filter, especially for concentrated wastewaters. Recirculation of the effluent is often used to dilute the trickling filter influent and thereby reduce the organic loading to the filter. It also provides additional residence time in the unit that facilitates further degradation of organic constituents.

(d) Rotating biological contactors. The microorganisms in a rotating biological contactor system are attached to the rotating disks and obtain oxygen primarily through exposure to air. A portion of the disk is submerged in the wastewater at all times. As the disk rotates, a given area of organisms on the disk will alternatively be submerged and exposed to the air. In order for aerobic biodegradation to effectively occur, the portion of the disk which is submerged and the disk rotation rate must be adjusted to ensure that during each disk rotation cycle the organisms do not spend an excessive amount of time submerged, and an adequate exposure time to the air is provided. The optimal disk submergence time and rotation speed will primarily be a function of disk size and the biological oxygen demand of the wastewater. For treatment of concentrated wastewaters supplemental aeration may be required.

(4) Wastewater-Biomass Contact. In order for a specified amount of biodegradation of organic contaminants to be achieved, a sufficient amount of contact between the wastewater and microorganisms must occur. The amount of contact required is a function of the concentration of organic contaminants in the wastewater. The way in which this contact is achieved varies with the type of biological treatment system used.

(a) Activated sludge. An important parameter in the activated sludge process which is related to wastewater-biomass contact is the food to microorganisms (F/M) ratio. The F/M ratio is defined as the quantity

of organic material metabolized per day in the system divided by the total active biomass in the system. That is, the F/M ratio is a measure of the amount of biomass available to metabolize the influent organic loading to the system. The F/M ratio is controlled by adjusting the biomass recirculation rate.

The mixed liquor volatile suspended solids (MLVSS) concentration is a measure of the active microbial mass in the treatment system. As such, it is one of the process parameters which determines the food to microorganism ratio. The sludge wasting rate is important because it is the operating parameter which controls the MLVSS concentration in the aeration basin and consequently the F/M ratio.

(b) Aerated lagoon. In an aerated lagoon, sludge is neither removed (wasted) nor recycled. Therefore, the total active biomass in the system cannot be controlled. However, the amount of time that the wastewater spends in contact with the biomass is a variable operational parameter. The hydraulic detention time of the wastewater, defined as the volume of the lagoon divided by the influent wastewater flow rate, determines the contact between the wastewater and the suspended microorganisms in the system. A longer hydraulic detention time increases the wastewater biomass contact.

(c) Trickling filter. The amount of contact between the wastewater and the microorganisms in a trickling filter is a function of the hydraulic loading rate (gpm per foot). This rate will be affected by the specific surface area and depth of the support media. The type of media and the depth are design variables and are not operational parameters that can be controlled.

The type of media which is used in a trickling filter significantly impacts the operation of the filter. Greater surface area allows for the presence of a larger mass of microorganisms per unit volume. This in turn permits greater biodegradation of organic constituents in wastewater. A higher hydraulic loading is possible with an increased void space as well as enhanced oxygen transfer to the biological slime. Synthetic media have more void space and surface area per unit volume than do conventional rock media.

In addition to the type of media, the depth of a trickling filter bed is important in determining its performance. A filter with rock media usually has a bed depth between 0.9 and 2.5 meters (three and eight feet). The rock media have a lower percent void space which restricts the use of a deeper bed due to oxygen transfer requirements. The lighter-weight synthetic media allows for deeper beds, ranging in depth from 9 to 12 meters (30 to 40 feet). As mentioned above, the

synthetic-media filters also have greater void space and surface area than rock-media trickling filters, permitting greater oxygen transfer, and, hence, higher hydraulic loadings. These factors allow aerobic bacteria to be present throughout the depth of the bed. Organic degradation therefore occurs throughout the depth of the filter when synthetic media is used.

(d) Rotating biological contactors. Contact between wastewater and the microorganisms in a rotating biological contactor system is a function of the hydraulic loading rate (gpm/ft^2) which is defined as the total wastewater flow rate through the system divided by the total area of submerged disk in the system.

The total area of submerged disk in the system can be controlled by adjusting the depth of the disks submerged under wastewater and by adding or bypassing disk units. Like trickling filter media, RBC disk media are characterized by a specific surface area. The total surface area per stage and the number of stages in series are key design parameters for RBC systems.

(5) Microorganism Growth Phase. The growth phase of the microbial population in a biological treatment system is an important parameter in the performance of the system. This parameter can only be controlled, however, in the activated sludge process where biomass (sludge) wasting and recycle are practiced. In the activated sludge process, the mean cell residence time (MCRT), or sludge age, directly determines the growth phase of the microorganisms in the aeration basin.

In order to maintain a low level of dissolved organic material in the effluent, the bacterial population in the aeration basin must be kept in an endogenous or declining growth phase. This is accomplished by controlling the residence time of the biomass in the system. Also, to ensure that microorganisms will grow, they must be allowed to remain in the system long enough to reproduce. This period depends on their growth rate which is directly related to the rate at which they metabolize or utilize the waste. Sludge age is defined as the total active microbial mass in the treatment system divided by the total quantity of microbial mass withdrawn daily (wasted) from the treatment system.

(6) Temperature. Microbial growth can occur under a wide range of temperature, although the majority of the microbial species are active between 20° and 35°C . Kinetic rate parameters are sensitive to fluctuations in temperature. The rate of biochemical reactions in cells increase with temperature up to a maximum above which the rate of activity declines as enzyme denaturation occurs and microorganisms either die off or become less active.

(a) Activated sludges. Because of the ability to control the quantity of biological solids by sludge recycle and short residence time, the temperature in the activated sludge basins can be controlled effectively. As a result, the quality of effluent from activated sludge processes has been found to be relatively insensitive to changes in ambient temperature. The effect of increases in temperature will be to increase the amount of excess sludge produced and the amount of aeration required. An increase in rate of wasting will compensate for this effect. Decreases in temperature can be offset by increasing the sludge recycle rate.

Activated sludge aeration basins are typically sized to perform up to a critical summer temperature and down to a critical winter temperature. Temperature deviations outside of the design range can affect performance.

(b) Aerated lagoons. Aerated lagoons are more susceptible to temperature variations than activated sludge systems, primarily due to the large surface area available for heat transfer and the additional heat losses due to agitation. Estimation of the critical lagoon operating temperature is an important design factor. At long hydraulic residence times, mesophillic bacteria are relatively insensitive to temperature; however, sludge production and settleability will be affected.

(c) Trickling filters. In trickling filters, as in other biological treatment processes, temperature fluctuations cause changes in the rate of substrate removal and consequently affect the effluent quality. It is common to cover or enclose small trickling filters located in extreme climates to dampen temperature variation.

(d) Rotating biological contactors. As with trickling filters, low temperatures have an adverse effect upon RBC performance but the use of enclosures can essentially eliminate any heat loss. As a result, the temperature which controls process efficiency is the influent wastewater temperature.

(7) pH. In general, neutral or slightly alkaline pH favors bacterial growth. The optimum range for most microorganisms found in biological treatment systems is between 6 and 8. Treatment effectiveness is generally insensitive to changes within this range. However, excursions outside the range can lower treatment performance. The pH of the influent should be monitored and adjusted at the preliminary treatment or equalization step and in the aeration basin of activated sludge systems, and at the influent for aerated lagoons, trickling filters and RBCs.

(8) Selection of microorganisms. The nature and quantities of the toxic constituents in a waste affect the biodegradability of the waste. Microorganisms differ substantially in their tolerance to toxics and their ability to degrade compounds at differing concentrations and indifferent physico-chemical environments. In all biological treatment systems, the microorganisms naturally undergo a selection process by which organisms which are capable of efficient biodegradation under the given circumstances increase their numbers, and other microorganisms are killed or washed out.

Recently, microorganism additives have been developed which are essentially freeze-dried cultures of special microorganisms. These cultures can be added to the biological treatment system in order to enhance the population of specific microorganisms. For example, cultures of organisms that degrade hydrocarbons as well as specific pollutants are available.

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4.5 Incineration

4.5.1 Applicability

This technology is widely demonstrated for treatment of F001-F005 spent solvent wastes. The Agency estimates that there are over 200 full scale facilities, many of which incinerate F001-F005 spent solvents. The Agency has data for analyses of the TCLP extract of incinerator ash for ten incinerators at nine full scale facilities. All incinerators were operating treating a variety of wastes including spent solvents. The F001-F005 constituents for which data were available are acetone, carbon disulfide, chlorobenzene, 1,2-dichloro-benzene, ethylbenzene, methylene chloride, methyl ethyl ketone, methyl isobutyl ketone, nitrobenzene, tetrachloroethylene, toluene, 1,1,1-trichloroethane, trichloroethylene and xylene. The Agency believes that these data represent treatment of wastes which are the same or similar to wastes which will be subject to this rule. The data are presented in Section 5 of this document.

The underlying principles of incineration are presented in subsection 4.5.2. Descriptions of types of incinerators, including liquid injection, rotary kiln, fluidized bed, and hearth incinerators are discussed in subsection 4.5.4. Design and operating parameters which affect the performance of incinerators are presented in subsection 4.5.4.

4.5.2 Underlying Principles of Operation

Incineration is a controlled oxidation destruction process that uses flame combustion to destroy hazardous wastes with oxygen by converting the wastes to carbon dioxide, water and other combustion products. The specific products of incineration (combustion) vary depending on the types of wastes that are burned.

Incineration of simple, non-halogenated organic wastes involves the oxidation of carbon and hydrogen-containing molecules to form carbon dioxide and water. As in any chemical reaction, the proportion of reactants, in this case, oxygen, hydrogen, and carbon, should be balanced so that combustion reactions can go to completion. When the proportion of oxygen to hydrocarbon waste is balanced, the fuel to air ratio is said to be "stoichiometric." In practice, an excess of oxygen is used to ensure that all of the hydrocarbon is oxidized or burned. If the proportion of oxygen and hydrocarbon feed is sub-stoichiometric or oxygen deficient, carbon monoxide is also formed, and depending on the severity of the oxygen deficiency, products of incomplete combustion (PICs) can be formed. Too low a combustion temperature and inadequate dwell or residence time in the flame or high temperature zone are other factors that can lead to incomplete combustion and the possible formation of PICs.

The generation of carbon monoxide and PICs can be minimized by controlling temperature, residence time, and oxygen during combustion. Combustion reactions proceed most efficiently at high temperatures, with a correct stoichiometry or balance of oxygen (as air) and fuel, and with a sufficient residence time to match the kinetic rates of combustion. The relationship of these factors to the design and operation of incinerators is discussed in subsection 4.5.4. below.

4.5.3 Description of Incinerators

All waste incinerators consist of a waste feed system, an air or oxygen-feed burner system, a combustion chamber, combustion monitoring systems, and, if required, equipment for air pollution control, and ash removal. These elements are applied somewhat differently in the various types of incinerators. Four types of incineration systems are discussed in this section: liquid injection, rotary kiln, fluidized bed, and hearth incinerators.

(1) Liquid Injection. The liquid injection system is capable of incinerating a wide range of gases and liquids. The combustion system has a very simple design with virtually no moving parts. A burner or nozzle atomizes the liquid waste and injects it into the combustion chamber where it burns in the presence of air or oxygen. A forced draft system supplies the combustion chamber with air to provide oxygen for combustion and turbulence for mixing. The combustion chamber is usually a cylinder lined with refractory (i.e., heat resistant) brick, and may be fired horizontally, vertically upward, or vertically downward. The specific configurations are designed to satisfy the needs of the owner. Figure 4-11 illustrates a liquid injection incineration design.

(2) Rotary Kiln. Rotary kiln systems are capable of incinerating solid, liquid, and gaseous hazardous wastes either separately or simultaneously. In general, rotary kiln operations utilize high Btu liquid wastes in conjunction with lower Btu solids in order to enhance combustion. Because of their versatility, rotary kilns have been used for treatment in large commercial facilities. A rotary kiln is a slowly rotating, refractory-lined cylinder that is mounted at a slight incline from the horizontal (see Figure 4-12). Solid wastes enter at the high end of the kiln, and liquid or gaseous wastes enter through atomizing nozzles in the kiln or afterburner section. Rotation of the kiln exposes the solids to the heat, vaporizes them, and allows them to combust by mixing with air. The rotation then causes the ash to move to the lower end of the kiln where it can be removed. Rotary kiln systems usually have a secondary combustion chamber or afterburner following the kiln to ensure more complete combustion of the volatilized components of solid wastes.

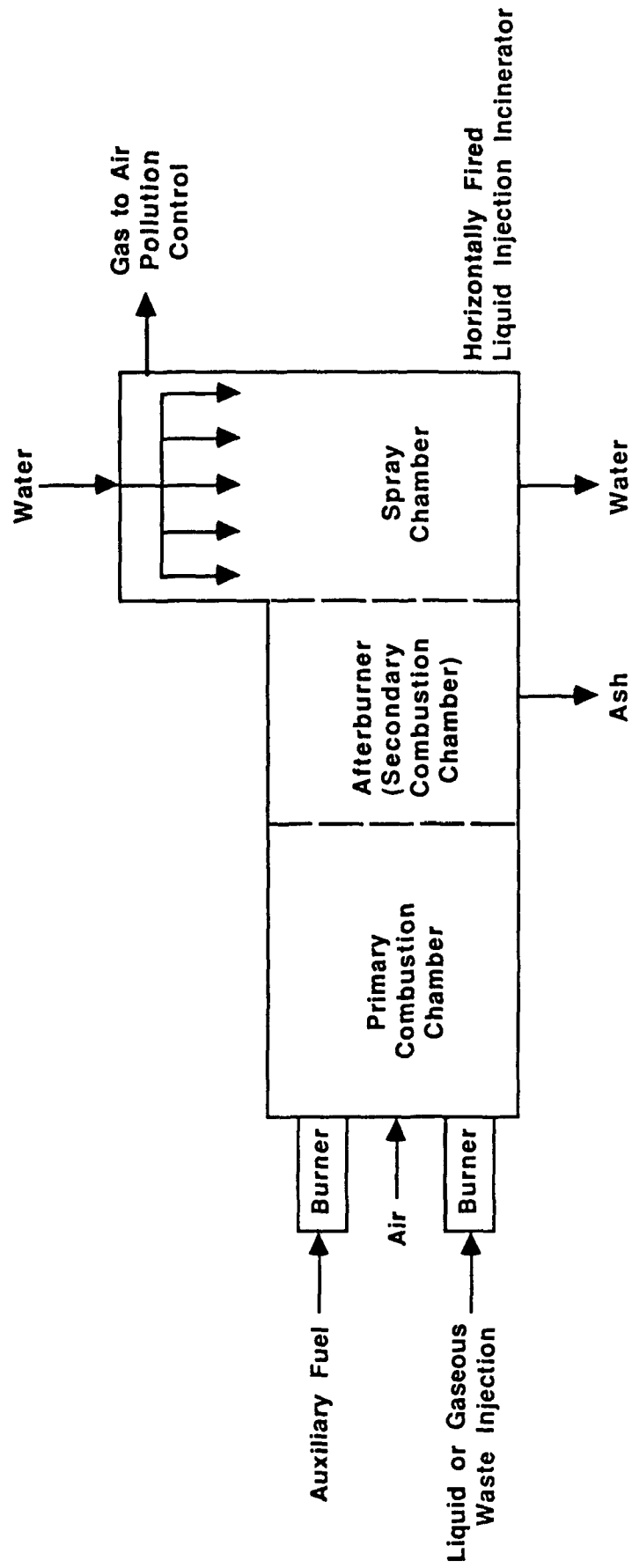


Figure 4-11
Liquid Injection Incinerator

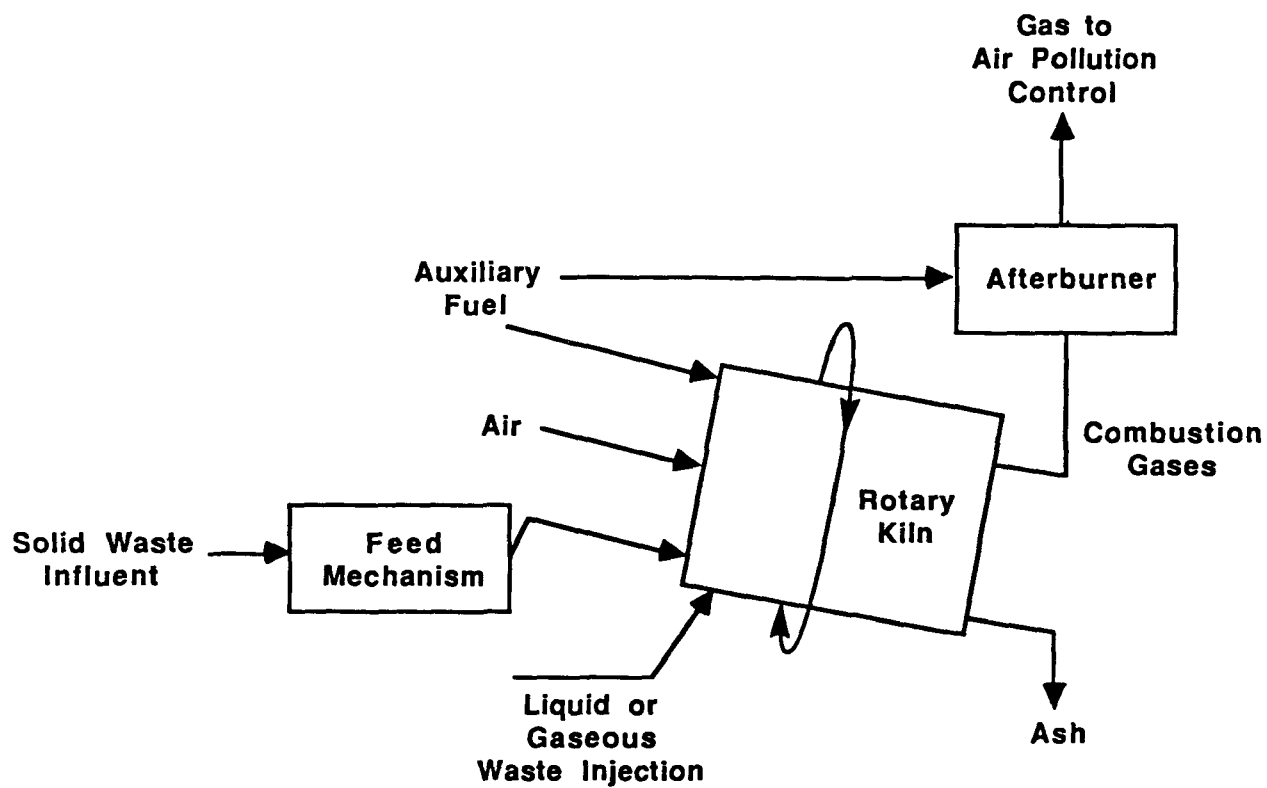


Figure 4-12
Rotary Kiln Incinerator

(3) Fluidized Bed. A fluidized bed incinerator consists of a column containing inert particles such as sand which is referred to as the bed (see Figure 4-13). Air, driven by a blower, enters the bottom of the bed to fluidize the sand. Air passage through the bed promotes rapid and uniform mixing of the injected waste material within the fluidized bed. The fluidized bed has an extremely high heat capacity (approximately three times that of flue gas at the same temperature), thereby providing a large heat reservoir. The injected waste reaches ignition temperature quickly and transfers the heat of combustion back to the bed. Continued bed agitation by the fluidizing air allows larger particles to remain suspended in the combustion zone.

(4) Hearth. Hearth incinerators, also called controlled air or starved air incinerators, are another major technology used for hazardous waste incineration. Hearth incineration is basically a two-stage combustion process (see Figure 4-14). Waste is ram-fed into the first stage, or primary chamber, and burned at roughly 50-80 percent of stoichiometric air requirements. This starved air condition causes most of the volatile fraction to be destroyed pyrolytically, with the required heat provided by the oxidation of the carbonaceous fraction in the waste. The resultant smoke and pyrolysis products, consisting primarily of volatile hydrocarbons and carbon monoxide, along with products of combustion, pass to the second stage, or secondary chamber. Here, additional air is injected to complete the combustion, which can occur either spontaneously or through the addition of supplementary fuels. It is this two-stage process that generally allows low stack emissions. The primary chamber combustion reactions and turbulent velocities are maintained at low levels by the starved air conditions so that particulate entrainment and carryover is minimized.

4.5.4 Design and Operating Parameters Affecting Performance

(1) Design Parameters. Excess air, temperature, residence time, mixing, chemical thermodynamic properties of the waste, burner design, and atomization are the primary variables affecting combustion efficiency in any incinerator design.

(a) Excess Air. The most basic requirement of any combustion system is a sufficient supply of air to completely oxidize the feed material. The stoichiometric, or theoretical air requirement is calculated from the chemical composition of the feed material. If perfect mixing could be achieved and the waste burned instantaneously, then only the stoichiometric requirement of air would be needed. Neither of these phenomena occur in real-world applications, however, so some excess air is always required to ensure adequate waste/air contact.

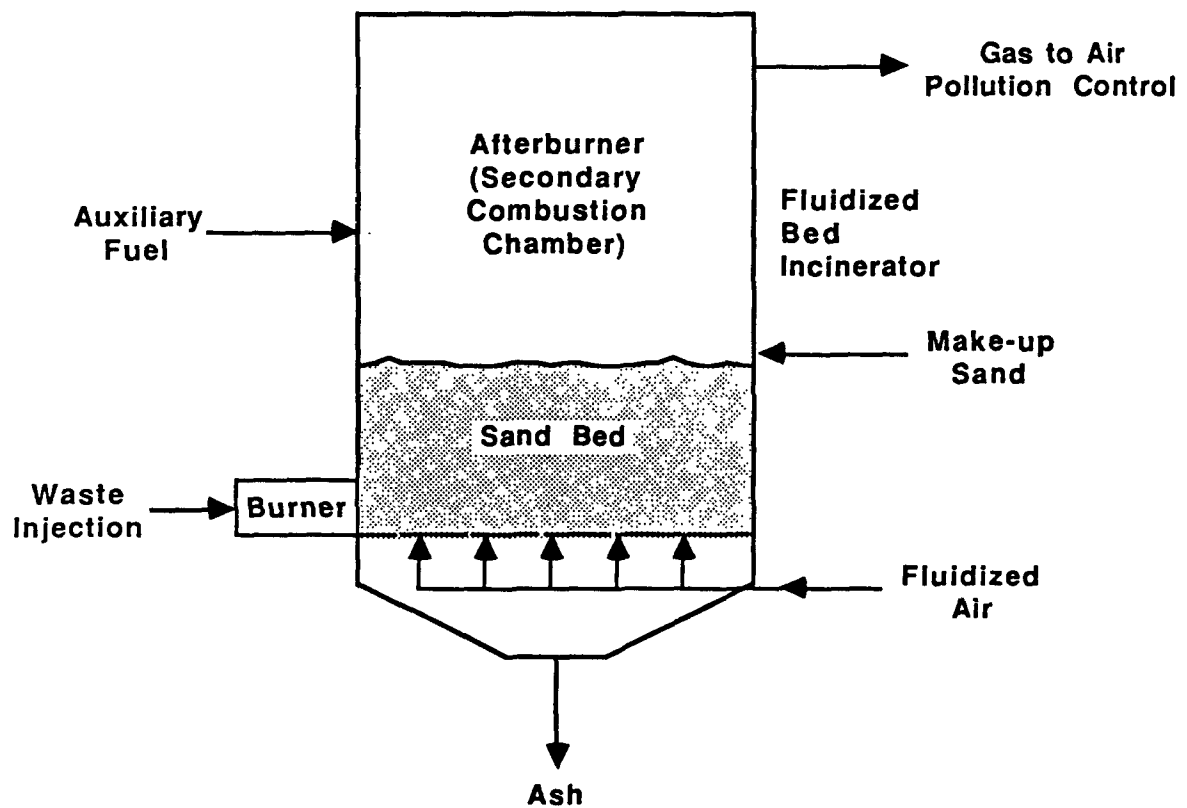


Figure 4-13
Fluidized Bed Incinerator

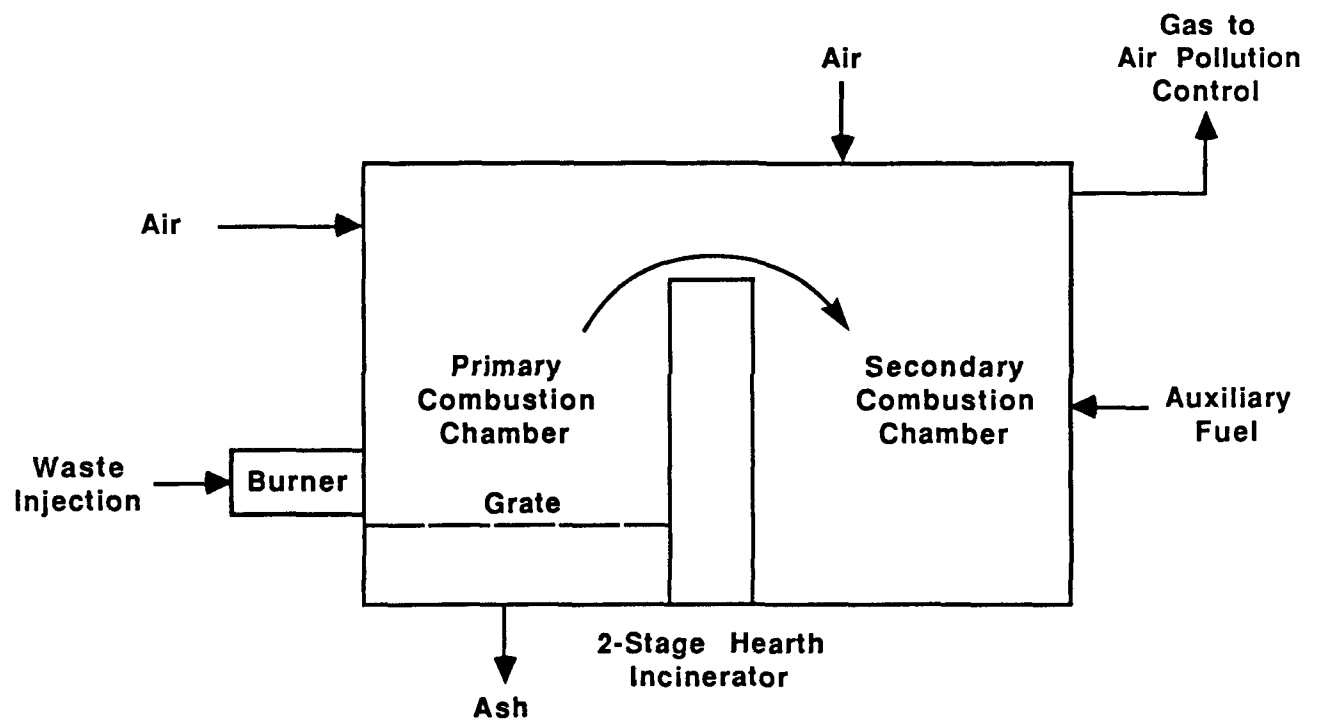


Figure 4-14
Hearth Incinerator

Excess air is usually expressed as a percentage of the stoichiometric air requirement. For example, 50 percent excess air implies that the total air supplied to the incinerator is 50 percent greater than the stoichiometric requirement.

The amount of excess air used or needed in a given application depends on the degree of air/waste mixing achieved in the primary combustion zone and the desired degree of combustion gas cooling. Since excess air acts as a diluent in the combustion process, it reduces the temperature in the incinerator (i.e., maximum theoretical temperatures are achieved at zero percent excess air). This temperature reduction is desirable when readily combustible, high heating value wastes are being burned in order to limit refractory degradation. When low heating value waste is being burned, however, excess air should be minimized to keep the system temperature as high as possible. Even with highly combustible waste, it is desirable for equipment design considerations to limit excess air to some extent so that combustion chamber volume and downstream air pollution control system capacities can be limited.

(b) Temperature. Three basic questions should be considered in evaluating whether or not a proposed operating temperature is sufficient for waste destruction:

- Is the temperature high enough to heat all waste components (and combustion intermediates) above their respective ignition temperatures and to maintain combustion?
- Is the temperature high enough for complete reaction to occur at the proposed residence time?
- At what point in the combustion chamber is the proposed temperature to be measured?

Complete waste combustion requires a temperature and heat release rate in the incinerator high enough to raise the temperature of the incoming waste constituents above their respective ignition temperatures (i.e., to provide energy input in excess of their respective activation energies so that combustion will occur). In cases where combustion intermediates are more stable than the original waste constituents, higher temperatures are required for complete combustion of the intermediates than for parent compound destruction.

Since heat transfer, mass transfer, and oxidation all require a finite length of time, temperature requirements must also be evaluated in relation to the proposed residence time in the combustion chamber. Heat transfer, mass transfer, and kinetic reaction rates all increase with increasing temperature, lowering the residence time requirements.

After addressing the temperature requirements for waste destruction, it is also necessary to determine whether the proposed temperature is within normal limits for the incinerator design, whether this temperature can be attained under the proposed firing conditions.

When identifying a minimum temperature acceptable for waste destruction, it is also important to identify the location in the combustion chamber at which this temperature should be measured. Temperature varies tremendously from one point to another in the combustion chamber, being highest in the flame and lowest at the refractory wall or at a point of significant air infiltration (e.g., in the vicinity of secondary air ports). Ideally, temperature should be measured in the bulk gas flow at a point after which the gas has traversed the combustion chamber volume that provides the specified residence time for the unit. It should not be measured at a point of flame impingement or at a point directly in sight of radiation from the flame.

(c) Residence Time. In addition to temperature and excess air, residence time is a key factor affecting the extent of combustion. This variable, also referred to as retention time or dwell time, is the mean length of time that the waste is exposed to the high temperatures in the incinerator. It is important in designing and evaluating incinerators because a finite amount of time is required for each step in the heat transfer/mass transfer/reaction pathway to occur.

In waste combustion, discrete (although short) time intervals are required for heat transfer from the gas to the surface of the atomized droplets or solids, for liquid evaporation, for mixing with oxygen in the gas stream, and for reaction which itself involves a series of individual steps depending on the complexity of the waste's molecular structure. The total time required for these processes to occur depends on the temperature in the combustion zone, the degree of mixing achieved, and the size of the liquid droplets. Residence time requirements increase as combustion temperature is decreased, as mixing is reduced, and/or as the size of discrete waste particles is increased.

(d) Mixing. Temperature, oxygen, and residence time requirements for waste destruction all depend to some extent on the degree of mixing achieved in the combustion chamber. This parameter is difficult to express in absolute terms, however. Many of the problems involved in interpreting burn data (i.e., data from previous incinerator tests) relate to the difficulty involved in quantifying the degree of mixing achieved in the incinerator, as opposed to the degree of mixing achieved in another incinerator of different design.

In liquid waste incinerators, the degree of mixing is determined by the specific burner design (i.e., how the primary air and waste/fuel are mixed), combustion product gas and secondary air flow patterns in the combustion chamber, and turbulence.

In rotary kiln incineration systems, both the solids retention time in the kiln and the gas residence time in the afterburner must be considered. Afterburner residence time considerations are essentially the same as those for liquid injection incinerators.

Air/solids mixing in the kiln is primarily a function of the kiln's rotational velocity, assuming a relatively constant gas flow rate. As rotational velocity is increased, the solids are carried up higher along the kiln wall and showered down through the air/combustion gas mixture.

Since solids retention time is also affected by rotational velocity, there is a tradeoff between retention time and air/solids mixing. Mixing is improved to a point by increased rotational velocity, but the solids retention time is reduced. Mixing is also improved by increasing the excess air rate, but this reduces the kiln operating temperature.

(e) Waste Chemical and Thermodynamic Properties. Chemical and thermodynamic properties of the waste that need to be considered in incinerator design evaluation are its elemental composition, its net heating value, and any special properties (e.g., explosive properties) that may interfere with incinerator operation or require special design considerations. The percentages of carbon, hydrogen, oxygen, nitrogen, sulfur, halogens, and phosphorus in the waste, as well as its moisture content, need to be known to calculate stoichiometric combustion air requirements and to predict combustion gas flow and composition. Once the weight fraction of each element in the waste has been determined, the stoichiometric oxygen requirements and combustion product yields can be calculated. The stoichiometric air requirement is determined directly from the stoichiometric oxygen requirement via the weight fraction of oxygen in air.

The heating value of a waste corresponds to the quantity of heat released when the waste is burned, commonly expressed as Btu per lb. Since all organic wastes have some finite heating value, all combustion reactions are exothermic. However, the magnitude of this heating value must be considered in establishing an energy balance for the combustion chamber and in assessing the need for auxiliary fuel firing. To maintain combustion, the amount of heat released by the burning waste must be sufficient to heat incoming waste up to its ignition temperature and to provide the necessary activation energy for the combustion reactions to occur. Activation energy is the quantity of heat needed to destabilize

molecular bonds and create reactive intermediates so that the exothermic combustion reaction with oxygen will proceed.

Waste heating values needed to sustain combustion without auxiliary fuel firing depend on the following criteria:

- physical form of the waste (i.e., gaseous vs. liquid vs. solid),
- temperature required for refractory waste component destruction,
- excess air rate, and
- heat transfer characteristics of the incinerator.

In general, higher heating values are required for solids vs. liquids vs. gases, for higher operating temperatures, and for higher excess air rates, if combustion is to be sustained without auxiliary fuel consumption.

When an organic waste exhibits a low heating value, it is usually due to high concentrations of moisture or halogenated compounds. An increase in the moisture content of an organic waste proportionately decreases the overall heating value on a Btu/lb waste basis.

The heating value of a waste also decreases as the chlorine (or other halogen) content increases, although there is no simple mathematical relationship.

(f) Burner design. For incineration of liquids, the liquid wastes are injected through burners, atomized to fine droplets, and burned in suspension. To heat the unit to operating temperature before waste is introduced, all incinerator designs should also include an auxiliary fuel firing system. This may consist of separate burners for auxiliary fuel, dual-liquid burners, or single-liquid burners equipped with a premix system whereby fuel flow is gradually turned down and waste flow is increased after the desired operating temperature is attained. If auxiliary fuel firing is needed during routine operation the same types of systems are needed: fuel/waste premix, dual-liquid burners, or separate auxiliary fuel burners.

Each burner, regardless of type, is generally mounted in a refractory block or ignition tile. This is necessary to confine the primary combustion air introduced through the burner, to ensure proper air/waste mixing, and to maintain ignition. The shape of the ignition tile cavity also affects the shape of the flame and the quantity of primary air which must be introduced at the burner. Some burners and tiles are arranged to

aspirate hot combustion gases back into the tile, which aids in vaporizing the liquid and increasing flame temperature more rapidly.

The dimensions of the burner block, or ignition tile, vary depending on the burner design. Each manufacturer has his own geometrical specifications, which have been developed through past experience. Therefore, it is not possible to specify a single burner block geometry for design evaluation purposes. However, this aspect of the design can be checked to eliminate systems that do not provide for any flame retention.

The location of each burner in the incinerator and its firing angle, relative to the combustion chamber, should also be checked. In axial or side-fired nonswirling units, the burner is mounted either on the end firing down the length of the chamber or in a sidewall firing along a radius. Such designs, while simple and easy to construct, are relatively inefficient in their use of combustion volume. Improved utilization of combustion space and higher heat release rates can be achieved with the utilization of swirl or vortex burners or designs involving tangential entry. Regardless of the burner location and/or gas flow pattern, however, the burner is placed so that the flame does not impinge on refractory walls. Impingement results in flame quenching, and can lead to smoke formation or other forms of incomplete combustion. In multiple burner systems, each burner should be aligned so that its flame does not impact on other burners.

In a rotary kiln incinerator, both the afterburner and kiln are usually equipped with an auxiliary fuel firing system to bring the units up to the desired operating temperatures. As was discussed earlier, the auxiliary fuel system may consist of separate burners for auxiliary fuel, dual-liquid burners designed for combined waste/fuel firing, or single-liquid burners equipped with a premix system, whereby fuel flow is gradually turned down and liquid waste flow is increased after the desired operating temperature is attained.

If liquid wastes are to be burned in the kiln and/or afterburner, additional considerations are:

- flame retention characteristics of the burners,
- burner alignment to avoid flame impingement on refractory walls, and
- in multiple burner systems, burner alignment to avoid interference with the operation of other burners.

(g) Atomization. Before a liquid waste can be combusted, it must be converted to the gaseous state. This change from a liquid to a gas occurs inside the combustion chamber and requires heat transfer from the hot combustion gases to the injected liquid. To cause a rapid vaporization (i.e., increase heat transfer), it is necessary to increase the exposed liquid surface area. Most commonly the amount of surface exposed to heat is increased by finely atomizing the liquid to small droplets. Good atomization is particularly important when low heating value wastes are being burned. It is usually achieved in the liquid burner directly at the point of air/fuel mixing.

The degree of atomization achieved in any burner depends on the kinematic viscosity of the liquid and the amount of solid impurities present. Liquids should generally have a kinematic viscosity of 10,000 Saybolt Seconds Universal (SSU) or less to be satisfactorily pumped and handled in pipes. For atomization, they should have a maximum kinematic viscosity of about 750 SSU. If the kinematic viscosity exceeds this value, the atomization may not be fine enough. This may cause smoke or other unburned particles to leave the unit. However, this is only a rule of thumb. Some burners can handle more viscous fluids, while others cannot handle liquids approaching this kinematic viscosity.

Solid impurities in the waste can interfere with burner operation via pluggage, erosion, and ash buildup. Both the concentration and size of the solids, relative to the diameter of the nozzle, need to be considered. Filtration may be employed to remove solids from the waste prior to injection through the burner.

(2) Operating Parameters. The major factors governing incineration efficiency that can be directly controlled during operation are temperature and excess air. As discussed earlier, other factors affect incinerator effluent (e.g., turbulence) but these factors are not easily monitored and controlled.

(a) Temperature. Incinerator temperature is monitored on a continuous basis to assure that the minimum acceptable temperature for waste destruction is maintained. This requires one or more temperature sensors in the hot zone and a strip chart recorder or equivalent recording device.

Generally, wall temperature and/or gas stream temperatures are determined using shielded thermocouples as sensors. Thermocouples are the most commonly used contact sensors for measuring temperatures above 1,000°F.

Optical pyrometers are not recommended for these measurements due to spectral bias factors present in the combustion area which can cause unacceptable measurement error.

The location at which temperature measurements are taken is important, due to possible variations in temperature from one point to another in the combustion chamber. Temperatures are highest in the flame and lowest in the refractory wall or at a point of significant air infiltration. Ideally, temperatures are measured in the bulk gas flow at a point after which the gas has traversed the combustion chamber volume that provides the specified residence time for the unit. Generally, temperature measurement at a point of flame impingement or at a point directly in sight of radiation from the flame is not recommended.

(b) Excess Air. Instrumentation is available to measure and control oxygen and carbon monoxide (CO) concentrations in the combustion gas to ensure proper excess air levels.

Oxygen and CO concentrations in the combustion gas are usually measured at a point of high turbulence, after the gas has traversed the full length of the combustion chamber. A good location for measurement is at the inlet to the duct leading from the combustion chamber to the quench zone.

Oxygen and CO measurements are made on a continuous basis. Whichever type of sensor is used, it is typically equipped with a gas conditioning system specified by the manufacturer for the gas environment in which the instrument is used.

When measuring oxygen or CO concentration directly in the high-temperature flow, some difficulty can be experienced because of molten slag impingement on the probe. Trial-and-error solutions of location and probe length can minimize this problem. A redundant system for scheduled maintenance is desirable.

INCINERATION REFERENCES

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4.6 Wet Air Oxidation

4.6.1 Applicability

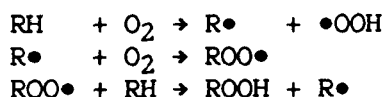
This technology is demonstrated for the F001-F005 spent solvent wastewaters. The Agency has treatment performance data for pilot-scale wet air oxidation treatment for methylene chloride, methanol, methyl ethyl ketone, tetrachloroethylene, toluene, 1,1,1-trichloroethane, and xylene. We believe these data represent treatment of wastes which are the same as or judged to be similar to spent solvent wastes that will be subject to this rule. The data are presented in Section 5 of this document.

The underlying principles of wet air oxidation are presented in subsection 4.6.2. Descriptions of conventional and catalyzed wet air oxidation are presented in subsection 4.6.3. Design and operating parameters affecting performance are discussed in subsection 4.6.4.

4.6.2 Underlying Principles of Operation

Wet air oxidation is a controlled oxidation destruction process conducted in a water solution at moderate temperatures (175-340°C) and elevated pressures (300-3000 psi) to destroy organic constituents in wastewater. The oxidation process converts organic compounds into carbon dioxide, water and simple organic acids. The specific end products of wet air oxidation vary depending on the chemical composition of the organics.

The chemistry of the wet air oxidation reaction includes several intermediate reaction steps that involve the formation and participation of free radicals:



The reactions above will not occur at room temperature and pressure because of the low solubility of oxygen in water at these conditions. Consequently, the wet air oxidation reaction is conducted at moderate temperatures and elevated pressures where the solubility of oxygen is much greater.

Pressurization of the reactor also keeps the water in a liquid state at the operating temperature of the system and prevents excess evaporation of the liquid phase. The oxygen partial pressure required depends on the oxidation reaction kinetics and the mass balance characteristics of the reactor.

In general, high molecular weight compounds are oxidized before lower molecular weight compounds; however, the ease of oxidation also depends on molecular structure. Electron donating functional groups, such as OH and NH₂, will enhance oxidation. The presence of electron withdrawing groups, such as halogens, will result in lower oxidation rates. With halogenated organics it may be necessary to use a cupric ion catalyst in the oxidation process.

The main advantage of wet air oxidation is that it allows the oxidation in water media at a lower temperature than other thermal treatment methods.

4.6.3 Description of Wet Air Oxidation

There are two types of wet air oxidation commercially available: conventional wet air oxidation and catalyzed wet air oxidation. Catalyzed wet air oxidation allows for either a higher destruction efficiency than conventional at the same temperature or the same destruction efficiency at a lower temperature.

(1) Conventional Wet Air Oxidation. A wet air oxidation system (see Figure 4-15) consists of a compressor, a heat exchanger, reactor vessel, and a vapor liquid separator. Wastewater containing the organic contaminants is pumped into the system using a high pressure pump to maintain pressure at a high enough level so that at the operating temperature, system pressure exceeds the steam pressure.

The waste stream is preheated to the reaction conditions by indirect heat exchange with the hot oxidized effluent. This enables the process to be thermally self-sufficient; the heat of combustion released in the reactor is used to preheat the influent and thereby sustain the reaction. In cases where the heat of combustion is insufficient to sustain the reaction (due to a low influent concentration of organics), additional heat may be necessary. This extra heat is added either by inserting start-up steam into the reactor, or by placing a start-up heat exchanger between the reactor and the effluent heat recovery exchanger.

Air or pure oxygen, used as the oxidant, is injected either into the feed line before the heat exchanger, or directly into the reactor vessel. The amount of oxygen which can be dissolved in the water increases with both temperature and pressure.

As the oxidation progresses, the heat of combustion is liberated increasing the temperature in the reactor. The reaction time varies from a few minutes to several hours depending on the waste type and the desired effluent concentrations.

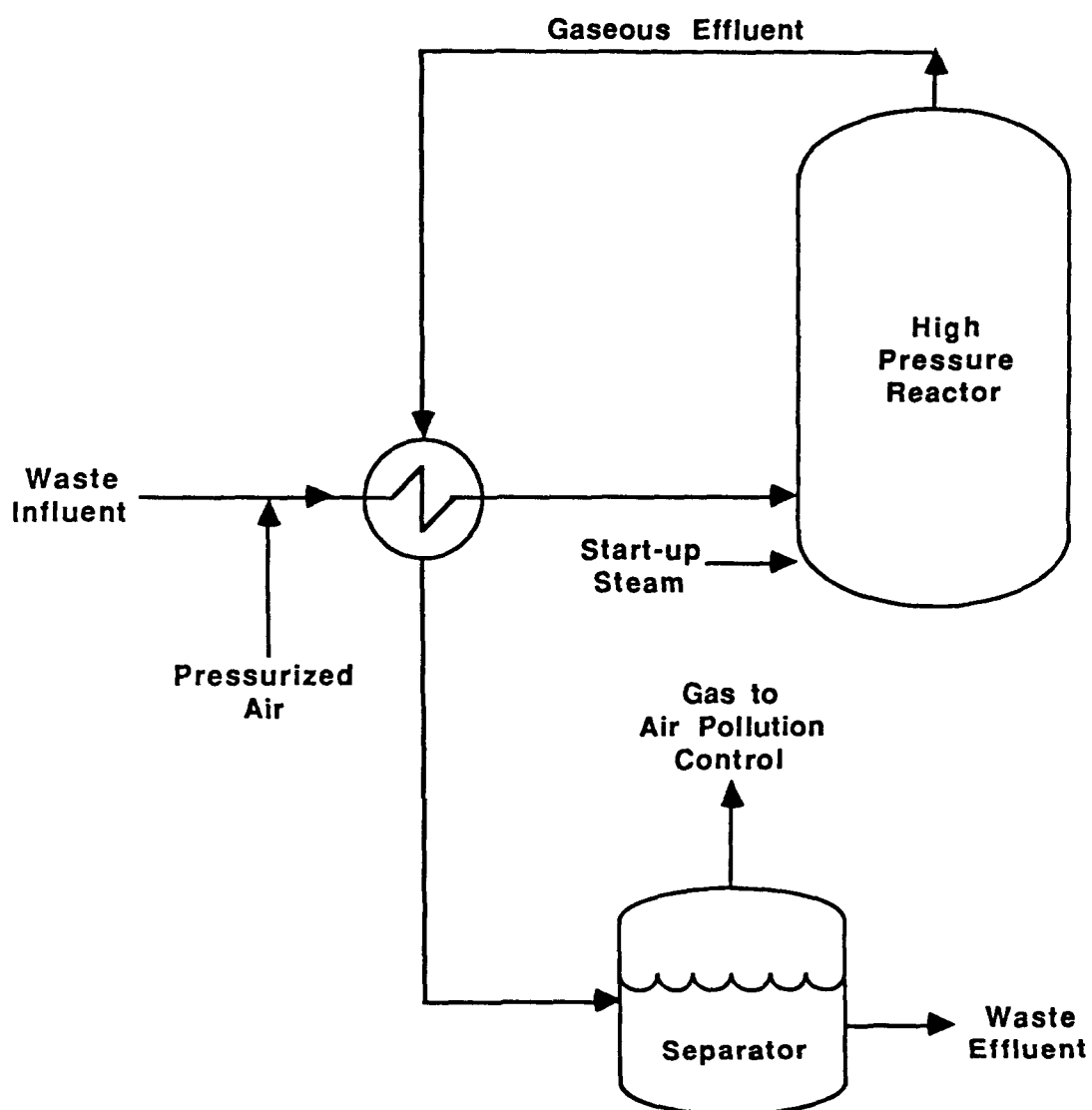


Figure 4-15
Wet Air Oxidation

After cooling, the oxidized effluent is reduced to atmospheric pressure through a pressure control valve. A gas liquid separator is then used to separate the gaseous and liquid elements of the effluent stream.

Wet air oxidation is not necessarily a "stand-alone" process. The vapor stream is normally sent to some type of air pollution control system such as a scrubber, activated carbon treatment, or a gas incinerator. The aqueous stream may require further treatment, such as biological treatment to remove low molecular weight acids or hydrochloric acid if chlorinated organics are oxidized.

(2) Catalyzed Wet Air Oxidation. The major impact of a catalyst on the system is either to lower the reaction temperature or increase the destruction efficiency. A catalyst has three roles in the reaction: oxygen fixation, generation of free radicals and organic oxidation. Two catalysts are mentioned in the literature: bromide-nitrate and cupric ion. The bromide-nitrate catalyst increases the transfer of oxygen to the aqueous phase at low temperature and accelerates the reactions. Cupric ion has shown high levels of catalytic activity over a wide range of conditions; it is particularly effective for halogenated compounds.

Catalytic wet air oxidation using bromide nitrate catalyst usually requires a reactor design different from the conventional design. A continuously stirred tank reactor (CSTR) contains the catalyst solution. Air and waste containing organics are pumped into the reactor and oxidized, with the heat of reaction driving off water. The water and any condensible organics are condensed and returned to the reactor. Inorganic salts or acids formed during the oxidation may have to be removed by treatment in a closed loop stream. The operating temperature of a catalytic wet air oxidation system ranges from 165°C to 275°C. (Reference 4).

4.6.4 Design and Operating Parameters Affecting Performance

There are four parameters which affect the performance of wet air oxidation systems:

- Temperature,
- Pressure,
- Residence time, and
- Waste type.

The temperature is the most important parameter affecting the system. The temperature must be high enough to allow the oxidation reactions to reach completion. The pressure affects the performance of

the system by causing dissolution of oxygen into solution. It also must be high enough to keep the water in the aqueous phase at the operating temperature. If the water is not kept in the aqueous phase the oxidation reactions will be slowed or stopped.

The residence time is important in assuring that the wastes are in the reactor long enough for the oxidation reactions to reach completion. Typically, the reaction rates are relatively fast for the first 30 minutes; after 60 minutes, the rates become slow. There is little increase in overall oxidation with extended reaction time. (Reference 3).

The operating conditions of the system (temperature, pressure, and residence time) need to be selected based on the type of waste being treated. Some wastes (such as aliphatics or chlorinated aliphatics) are relatively easy to oxidize; others (such as high molecular weight chlorinated species) require extreme operating conditions or a catalyst (such as CuCl_2) to achieve adequate destruction.

The effluent from the wet air oxidation unit primarily consists of carbon dioxide and water. For some complex wastes, the aqueous effluent may also contain simple organic acids. If very volatile chemicals are oxidized, some volatilization may occur during treatment producing low concentration organics in the vapor stream. If chlorinated compounds are oxidized, the vapor stream may contain HCl . The vapor stream may require further treatment such as by activated carbon adsorption or a scrubber to collect HCl and any residual organics. The aqueous effluent is usually treated biologically to destroy the organic acids.

WET AIR OXIDATION REFERENCES

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2. Dietrich, M.J., Copa, W.M., and Cannery, P.J. Demonstration of Full Scale Wet Air Oxidation of Hazardous Waste. Prepared for State of California Depart of Health Services under Contract No. 83-82053 ORR-54 A-1. November 1984.
3. Freeman, H. Innovative Thermal Hazardous Waste Treatment Processes. U.S. Environmental Protection Agency, Hazardous Waste Research Laboratory, Office of Research and Development. 1985.
4. Dietrich, M.J., Randall, T.L., and Cannery, P.J. Wet Air Oxidation of Hazardous Organics in Wastewater. Environmental Progress Vol 4, No.3, pp 171-177. August 1985.
5. Schultz, David W., Editor. Incineration and Treatment of Hazardous Waste. Proceedings of 8th Annual Research Symposium at Fort Mitchell, K.Y. EPA Contract No. 600/9-83-003. March 8-10 1982.

4.7 Air Stripping

4.7.1 Applicability

This technology is demonstrated for wastewaters containing F001-F005 spent solvents. The Agency has pilot-scale air stripping treatment performance data from treatment of ground water contaminated with 1,1,1-trichloroethane, methyl isobutyl ketone, toluene, tetrachloroethylene, and ethylbenzene and from treatment of tap water spiked with tetrachloroethylene and trichloroethylene. Though these data are not included in EPA's definition of spent solvent wastes, the Agency believes that such wastewaters are similar to spent solvent wastes that will be subject to this rule. The data are presented in Section 5 of this document.

The underlying principles of air stripping are presented in subsection 4.7.2. Descriptions of air stripping technologies are presented in subsection 4.7.3.

4.7.2 Underlying Principles of Operation

Air stripping is a mass transfer process in which an "organic" constituent dissolved in wastewater is transferred to the gas phase, air. Since air is a noncondensable medium, it does not directly influence the vapor liquid equilibrium relationship. The relative volatility of the organic constituents in water determines the ease with which the organic constituents are separated. The air effluent is generally not recovered because the concentrations of the organics are very low, and for recovery of the organics it would be necessary to cool the constituents to their respective dew points using mechanical refrigeration. In some instances, the air effluent may be routed to a catalytic combustor which is fed by auxiliary fuel or to carbon adsorption. The liquid effluent is generally discharged under an NPDES permit or to a municipal wastewater treatment system. With highly volatile constituents the system may be operated at ambient conditions. The wastewater feed may be preheated to enhance the vaporization of less volatile components.

4.7.3 Description of Air Stripping

Air stripping is accomplished in a packed column or through the use of aeration devices. In a packed column configuration, the wastewater feed is introduced at the top of the column and the air is drawn or blown into the bottom of the column. A schematic diagram of a packed air stripping column is shown in Figure 4-16.

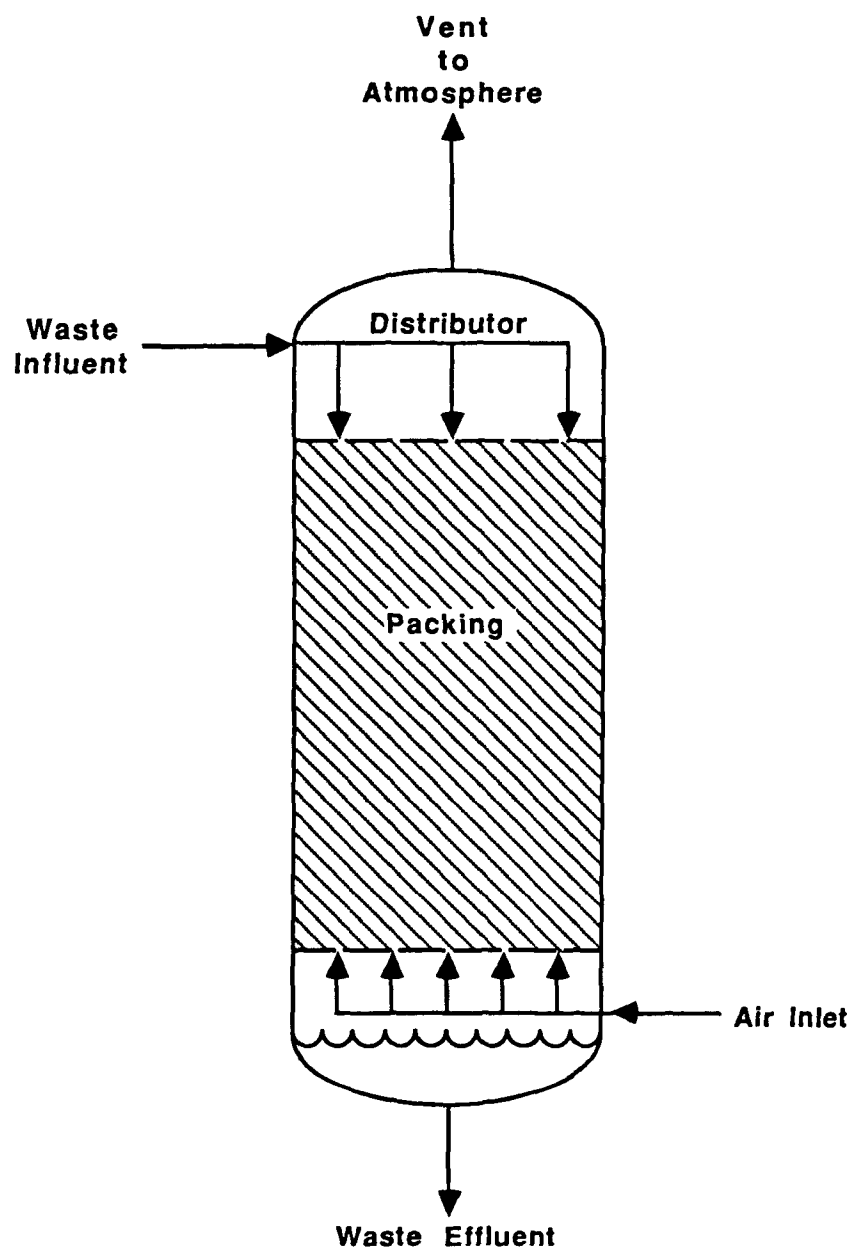


Figure 4-16
Air Stripping
4-69

The principal types of aeration devices used to strip volatiles from water are: mechanical surface aerators and diffused aerators.

(1) Mechanical Surface Aerators. These types of aerators are the simplest. Aeration is accomplished by submerged or partially submerged impellers that agitate the water vigorously. The turbulence entrains air in the wastewater and rapidly changes the air-water interface to facilitate solution of the air. Air stripping of volatiles within the water is also achieved by the agitation and increased air-water contact.

(2) Diffused Aerators. Air stripping is accomplished in diffused aeration by injecting air bubbles into water through submerged diffusers or porous plates. Ideally, the process is conducted counterflow, with the untreated water entering the top and the treated water exiting the bottom. Exhausted air leaves the top. Gas transfer can be improved by increasing the basin depth, improving contact basin geometry, and using a turbine to reduce the bubble size and increase bubble retention time. Diffused aeration is commonly used to strip volatiles prior to or during biological treatment processes.

AIR STRIPPING REFERENCES

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4.8 Fuel Substitution

4.8.1 Applicability

This technology is demonstrated for F001-F005 spent solvent wastes other than wastewater. According to a 1983 EPA survey, 4,934 industrial boilers and 868 industrial furnaces and kilns burned waste-derived fuel. A large volume of the hazardous wastes burned in these devices contained chlorinated and nonchlorinated solvent constituents. Data indicate that many of the solvent constituents listed in F001 and F005 wastes have been present in hazardous wastes burned as fuel substitutes. In cases where F001-F005 spent solvents contain high concentrations of chlorine, wastes must be blended with other organic wastes or fuel prior to burning to minimize corrosivity caused by the formation of hydrochloric acid vapor. In conclusion, fuel substitution is well-demonstrated for most boilers for wastes that are highly concentrated and that contain minimal amounts of suspended solids.

The underlying principles of operation for fuel substitution are presented in subsection 4.8.2. Descriptions of appropriate technologies are presented in subsection 4.8.3. Design and operating parameters affecting performance are discussed in subsection 4.8.4.

4.8.2 Underlying Principles of Operation

Fuel substitution involves the use of combustible organic wastes as substitutes for conventional fuels that are burned in high temperature industrial processes. As in incineration, the organic waste is destroyed in flame combustion yielding essentially carbon dioxide and water. If halogenated organics are burned, acid and free halogen are also among the products of combustion, e.g., combustion of chlorinated wastes yield hydrogen chloride and chlorine in the flue gas streams.

The underlying principles of operation for incineration are in large part equally applicable for fuel substitution. See Section 4.5 for a discussion of these principles.

4.8.3 Description of Fuel Substitution

There are many high temperature industrial processes with temperatures and residence time sufficient to destroy solvent wastes. In most cases, the organic waste is used to supplement primary fuels such as natural gas, fuel oil, or coal, thus lowering the total fuel cost required for the process, and providing an inexpensive means of destroying wastes. The more predominant industrial applications for this technology are discussed below (Reference 1).

(1) Industrial Boilers. A boiler is a closed vessel in which water under pressure is transformed into steam by the application of heat. Typically, heat is supplied by the combustion of pulverized coal, fuel oil, or gas. These fuels are fired into a combustion chamber with nozzles and burners that provide mixing with air. Liquid wastes, and granulated solid wastes in the case of grate-fired boilers, can be burned as fuels in a boiler by using these wastes as auxiliary fuels. However, it has been reported that few grate-fired boilers burn hazardous wastes. These boilers are not often used in the types of industries that produce combustible hazardous wastes.

In general, burning of solvent-containing wastes in industrial boilers is economically attractive when the waste possesses a heat content greater than or equal to 8,000 to 10,000 Btu per pound. Viscosity is also an important physical parameter for waste liquid injection systems, as discussed previously in the section on liquid injection incinerators.

Deposition of fly ash and slag on heating surfaces in a boiler can lead to serious fouling and potential burn-out of boiler tubes. Therefore, facilities may reject wastes if they contain unacceptable levels of ash content. Generally, oil-fired boilers are designed to be fired with oils containing less than 0.2 percent ash. Boilers fired with coal are reportedly designed to handle fuels containing roughly 8 to 20 percent ash.

Another important waste characteristic that should be taken into consideration is the chlorine content of the waste. Excess quantities of chlorine may lead to unacceptable corrosion of the unprotected metal surfaces within the boiler. Modern boilers operating at supercritical steam conditions are especially susceptible to chloride stress (corrosion failure of boiler tubes). Acceptable chloride levels in the fuel/waste mixture vary with type of boiler and owner preference.

(2) Industrial Kilns. Combustible wastes may also be used as fuel in industrial kilns. Three types of kilns are particularly applicable: (1) cement kilns, (2) lime kilns, and (3) light-weight aggregate kilns. There are other types of high-temperature industrial processes, such as blast furnaces, sulfur recovery furnaces, and brick ovens that may also be used.

Combustible waste liquids are often used to co-fire industrial kilns. Coal-fired kilns are capable of handling solid wastes if particle size is reduced.

Clinker, a primary additive of cement, is manufactured in a cement kiln, which is an application of rotary kiln technology. The cement kiln is a refractory-lined steel shell used to calcine a mixture of calcium, silicon, aluminum, iron, and magnesium. These raw materials are crushed, blended, and fed to the kiln as either a slurry or a dry mixture, thus the terms wet and dry kilns. In the wet process, water is added to the raw materials before they are ground. Over 50 percent of the cement kilns in the United States use the wet technology. The kiln is usually fired by coal or oil; liquid and solid combustible wastes then serve as auxiliary fuel. Temperatures within the kiln are typically between 1,380°C and 1,540°C (2,500°F and 2,800°F).

Lime (CaO) is manufactured in a calcination process using limestone (CaCO₃) or dolomite (CaCO₃ • MgCO₃). These raw materials are also heated in a refractory-lined rotary kiln to temperatures of 982°C to 1,260°C (1,800°F to 2,300°F). Light-weight aggregate kilns heat clay to produce an expanded lightweight inorganic material, which is used in Portland Cement formulations and other applications. The kiln has a temperature range of 1,100°C to 1,150°C (2,000°F to 2,100°F) with a residence time of 1.5 seconds.

As with industrial boilers, industrial kilns will generally accept wastes with sufficient heat content to promote combustion. For cement and lime kilns, product quality may degrade as the chlorine content of the fuel increases. For cement kilns, this level is about 0.7 percent of the total fuel feed; for lime kilns, about 0.5 percent. However, wastes with higher chlorine content may be blended with fuels of lower chlorine content to obtain a fuel that will not affect product quality.

4.8.4 Design and Operating Parameters Affecting Performance

The principal design and operating parameters affecting performance of industrial processes are the same as for incinerators, e.g., fuel/air stoichiometry, temperature, and residence time. However, for industrial processes these parameters are fixed by the requirements of the industrial process. Thus, the industrial processes that are suitable for burning wastes are those processes where the design and operating parameters match or exceed the equivalent specifications required for incineration wastes.

Temperatures are monitored and controlled in industrial boilers in order to provide the needed quality and flowrate of steam. The efficiency of combustion in industrial boilers is monitored by CO and O₂ instrumentation to ensure efficient utilization of fuel and to meet

air pollution standards. In larger boilers, it is also common to monitor flame stability, flame shape, and flame quality by means of video cameras and monitors.

Wastes should not be co-fired until temperature reaches the minimum needed for destruction of the wastes. Temperature, CO, and O₂ instrumentation and control should be designed to stop waste co-firing in the event of process upsets.

Monitoring and control of temperature in industrial kilns is critical to the production of quality product, i.e., lime, cement, or aggregate production requires minimum temperature for calcination. Kilns have very high thermal inertia in the refractory and in-process product, high residence times and high air flow rates, so that even in the case of momentary stoppage of fuel flow to the kiln, residual wastes would continue to be destroyed. The main operational control required for waste burning in kilns is to stop waste flow in the events of low kiln temperature, loss of the electrical power to the draft air fan, and loss of primary fuel flow.

Industrial boilers and kilns generally employ some means of particulate control, such as electrostatic precipitation or bag house. The ash or product fines collected by these devices are generally land disposed and, as a result, will have to meet any applicable land disposal restriction regulations in the future.

The Agency is currently developing regulations that will govern the use of hazardous waste as fuel. These standards are likely to control hydrogen chloride emissions. (The Agency already controls these emissions for incinerators.) To meet the emission standard, owner/operators could limit the chlorine levels in the waste or rely on emission control equipment, such as scrubbers. EPA believes that most industrial furnaces, and some boilers, will be able to meet these standards when burning hazardous solvent wastes as fuel.

FUEL SUBSTITUTION REFERENCES

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