SEPARATION PROCESSES
IN WASTE MINIMIZATION

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Preface

The U.S. Environmental Protection Agency has made the minimization of hazardous waste production its top priority in hazardous waste management. The principal ways to achieve this minimization are (1) reduction of the amounts of waste generated at the source, (2) recovery and reuse through recycling of specific hazardous materials recovered from the waste streams, and (3) removal of the hazardous materials from the waste stream to both reduce the volume of hazardous material and render the waste stream nonhazardous. Separation processes play a major role in all three of these methods.

Chemical engineering explores the science and technology of separation processes and provides the technical basis for design, construction, and operation of equipment used for waste minimization through separations. However, the operators of separation equipment and their immediate supervisors in the waste management industry usually are not chemical engineers familiar with the theory of separation processes. Therefore, this book was written to provide a simplified discussion of the separation processes used in waste minimization. It describes for laymen how separation processes work in practice and provides guidelines for troubleshooting the operation of separations equipment.

The book begins with a background section, which is followed by three sections devoted to describing individual separation processes in some detail. These latter three sections group the processes roughly according to the principles on which they are based, that is, by mechanical forces, by differences in rates of motion, or by differences in equilibrium concentrations between different states of matter in contact. Related processes are discussed together in the same chapter.

The three chapters in the first section provide an overview of what is and what is not waste minimization, a simplified summary of separation science, and a discussion of the types of separation processes used in waste minimization, including where they are described in this book. Each chapter in the remaining sections explains the fundamentals of the separation processes discussed, the applications of these processes to waste minimization, the types of equipment that are available along with the vendors, and the solutions to some of the common problems encountered operating the equipment.

The separation processes included in the book are all commonly used industrially but are at various stages of growth in their application to waste minimization. The economic incentive for their use changes as the cost of alternatives for waste disposal changes. At present, the cost of waste disposal continues to increase. On the other hand, many valuable materials can be recovered from streams that formerly went to waste. Thus, many separation processes once thought too expensive for processing wastes are finding their way into broad application due to the value of the products recovered for recycling.

This book is a cross between an operating manual and a text; it is definitely not a design manual. There are many good texts on separation processes written for design engineers. Four of them were used as primary references in writing this book. There are many books written on waste management, treatment, and disposal, also used as references. This book is confined to the separation processes either currently used in waste minimization or that have good potential for use in the future. It excludes both separations not expected to be applied to waste minimization and waste treatments that are not separation processes. The book attempts to give enough understanding of the separation processes covered to permit intelligent operation of such equipment after a little practical experience. Including only enough theory to grasp the basic concepts underlying the various separations discussed, it is truly aimed at the operators of separation equipment for waste minimization. However, it may also be useful as a text for introductory courses in environmental engineering and chemical engineering.

U.S. hazardous waste regulations are written in both the metric (centimeter, gram, second) and English (foot, pound, hour) systems of units. Both of these systems are used by chemical engineers, whose training is in a transition from the historically used English system to the metric system. To make this book more easily understandable to more people, the English system of units is used as the primary nomenclature. The exceptions to this practice are when the common unit in the trade for a given measurement is not in the English system. For example, with very small dimensions, as with particle sizes, the unit is the micron. At times, for the sake of clarity, units for both systems are given. The International System of Units (SI), which is commonly used only by scientists, is not used in this book.

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1.1 INTRODUCTION

The United States is in the midst of a very exciting period of change in the way hazardous wastes are managed. This has been brought about by a change in the philosophy of regulating hazardous wastes. This change has resulted in the passing of two statutes by the Congress in the mid 1980s which removed ambiguities and closed loopholes in the basic waste management laws. These statutes also showed a much needed strong support from Congress for the management of hazardous wastes. They provided the Environmental Protection Agency (EPA) with clear and specific direction from the legislation itself. However, complying with the regulations is shooting at a moving target as the laws are changed to make sure they are effective at protecting the people and the environment.

The EPA had been established as the environmental regulatory agency of the federal government by the President in 1970. It is an independent agency in the executive branch of the U.S. Government. It has regulatory responsibility for administering the laws governing air pollution, water pollution, solid wastes, pesticides, and environmental radiation. The laws governing these areas of concern are the Clean Air Act (CAA), the Clean Water Act (CWA), the Toxic Substances Control Act (TSCA), the Resource Conservation and Recovery Act (RCRA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the Atomic Energy Act of 1954. The administration of the federal waste management laws thus fell under EPA jurisdiction. EPA experience in trying to operate under the existing waste management laws had demonstrated to the EPA and to Congress by the early 1980s the need for major amendments to these laws.

The first of the amending statutes was the Hazardous and Solid Waste Amendments (HSWA) passed in 1984. It tightened up the Resource Conservation and Recovery Act (RCRA) of 1976 and changed the philosophy of hazardous waste management from "bury it" to "don't produce it." RCRA was, and with its amendments still is, the basic hazardous waste management law. It was designed as a preventive regulatory policy to cover hazardous waste management and provide "cradle-to-grave" control over hazardous wastes. However, this law as it was originally written relied heavily on unrestricted land disposal as the primary method of managing hazardous wastes. This discouraged industrial firms from investing capital in more effective, but more expensive, waste management technologies. Such more expensive technologies would often put them at a cost disadvantage when competing with companies relying solely on low cost land disposal. The changes made by the HSWA statute began a phasing out of landfills as the primary disposal method for hazardous wastes. It thus encouraged development and use of innovative alternate treatment technologies.

The second important amending statute, passed in 1986, was the Superfund Amendments and Re-authorization Act (SARA), also known as the CERCLA amendments, or Superfund amendments. This law amended the Comprehensive Environmental Response and Compensation Liability Act (CERCLA) of 1980, widely known as Superfund. In contrast to RCRA, which is a prevention law, Superfund is a remediation law to control cleanup of past mistakes. It provides for cleanup, compensation, and assignment of liability for release of hazardous substances into the air, land, or water. Thus, it is the primary law controlling cleanup of abandoned landfill sites which contain hazardous wastes. In its original form it relied heavily on sealing, flushing, treating, or excavating and moving hazardous wastes found in old landfills. The hazardous waste problems that were the reason for the remediation in the first place usually returned after a period of time to the dismay of all. The Superfund amendments changed the emphasis in cleaning up hazardous waste sites from (1) sealing in place or (2) excavating and transporting the hazard to a new disposal site to the much more desirable alternative of actual destruction of the hazardous waste. This led to the development of mobile equipment for on-site waste treatment to remove, concentrate, or destroy the hazardous material. It also led to the formation of commercial companies for the destruction of hazardous wastes. Destruction solves the problem once and for all, preventing later recurrence.

These two amending statutes, the RCRA amendments and SARA, have provided a strong regulatory framework to guide hazardous waste management in the United States. They provide a sense of certainty to waste management regulation and encourage industry to make the necessary investments to comply with hazardous waste minimization and treatment. Together, they are the main reason for the sense of excitement in hazardous waste management in the United States. They represent a national commitment to minimizing the hazardous component of waste management. They will be discussed in more detail in the following sections, particularly as they influence waste minimization.

1.2 WASTE MINIMIZATION

The Congress of the United States made hazardous waste minimization the policy of the country by the following statement in the 1984 amendments to RCRA:

> The Congress hereby declares it to be the national policy of the United States that, wherever feasible, the generation of hazardous wastes is to be reduced or eliminated as expeditiously as possible. Waste that is nevertheless generated should be treated, stored, or disposed of so as to minimize the present and future threat to human health and the environment (RCRA Amendments, 1984).

In its 1986 Report To Congress (EPA, 1986), EPA felt that specific quota regulations for waste minimization at that time would not be helpful but promised to update its viewpoint by 1990. This viewpoint still prevails at EPA in 1995, although strong support exists for voluntary waste minimization. Thus, mandatory quota regulations for hazardous waste minimization are not yet the law of the land.

1.2.1 Definition of Waste Minimization

EPA has adopted the following priority order for the management of hazardous wastes:

1. Source reduction
2. Recycling and recovery
3. Treatment
4. Disposal

Waste minimization is defined as the first two terms of this heirarchy, which are further defined as follows:

> *Source reduction*: The reduction or elimination of hazardous waste at the source, usually within a process. Source reduction measures include

process modifications, feedstock substitutions, improvements in feedstock purity, housekeeping and management practice changes, increases in the efficiency of equipment, and recycling within a process.

Recycling and recovery: The use or reuse of hazardous waste as an effective substitute for a commercial product or as an ingredient or feedstock in an industrial process. It includes the reclamation of useful constituent fractions within a waste material or the removal of contaminants from a waste to allow it to be reused.

Waste minimization does not include the various waste treatment techniques such as incineration, chemical oxidation, encapsulation, etc., which are highly effective in minimizing or eliminating the hazards of disposal of hazardous wastes. Furthermore, it deals with newly generated wastes and not with the aged materials found in Superfund sites.

1.2.2 EPA Policy on Waste Minimization

EPA (1987) summarized its policy on waste minimization in a report issued in 1987 entitled "The Hazardous Waste System." This summary is directly quoted below.

> EPA strongly favors preventing the generation of waste rather than controlling waste after it is generated. It is a national policy that the generation of hazardous waste be reduced as expeditiously as possible.

Within the private sector, strong incentives already exist to promote waste minimization. These incentives include:

- Large increases in the price of treating and disposing of hazardous wastes
- Difficulties in siting and permitting new hazardous waste units
- Concern with liability associated with managing hazardous waste
- Public pressure on industry to reduce waste generation

According to a recent EPA study, "Waste Minimization Issues and Options," a 20–30% reduction in waste volume may be possible through process changes, product substitution, and good housekeeping practices. Many firms have already markedly reduced and are continuing to reduce the amount of hazardous waste they produce. This is done through a variety of waste minimization techniques including:

- Source reduction
- Waste separation and concentration
- Waste exchange
- Reuse and recycling of waste

At present, there are three statutory requirements relating to waste minimization, all of them enacted in the 1984 Hazardous and Solid Waste Amendments. The requirements are summarized in the following:

- Generators must certify on their manifests that they have a program in place to reduce the volume and toxicity of waste [Section 3002(b)].
- Any new treatment, storage, or disposal permit must include a waste minimization certification statement [Section 3005(h)].
- As part of a generator's biennial report, generators must describe the efforts undertaken during the year to reduce the volume and toxicity of wastes generated [Section 3002(a)(b)] and document actual reduction achieved.

EPA's waste minimization program has as its main objective to foster the use of waste minimization through dissemination of technology and information. As mentioned earlier, EPA does not recommend mandatory quotas for hazardous waste reduction. However, EPA has launched a voluntary air pollution reduction program with targets of 33% reduction by 1992 and 50% reduction by 1995 for 17 chemicals which are produced in high volume, are considered of serious health and environmental concern, and can be reduced by pollution prevention. This program has been well received by industry and is being rapidly implemented.

In conclusion, concern over economic and liability issues are driving generators to reduce the volume and toxicity of hazardous waste produced. Waste minimization can alleviate the capacity problem by reducing the volume of waste requiring treatment and disposal.

1.2.3 Where Separation Processes Fit

The principal applications of separation and purification processes to hazardous waste minimization are (1) the removal of small amounts of hazardous material from large volumes of non-hazardous diluent to permit easier disposal of both the purified diluent and the much smaller volume of recovered hazardous waste and (2) the recovery for reuse of high quality components which have become contaminated in use and are no longer suitable for use unless the contaminants are removed. Typical of the first type of application are pretreatments of various wastewaters to remove toxic materials which prevent their treatment in public water treating plants. After the pretreatment, the purified water can usually be disposed of in the same way as more conventional wastewaters. The separation processes usually involved are adsorption, membrane processes, ion exchange, gas stripping, filtration, settling, and flotation, among others.

The second type of application is represented by the recovery and recycling of waste solvents, waste oils, waste paper, waste plastic, and scrap metals, to name a few. Recovery of useful materials for recycling is greatly simplified if the mixture of materials in the waste is not overly complex. This means that careful segregation of wastes by the generator can make recovery and reuse much less complex and more economically attractive. For example, if a generator pours all waste solvents and waste oils into the same container, it becomes very difficult to recover any of the specific solvents or oils in sufficient purity for reuse. On the contrary, if individual waste solvents are segregated as they are generated, their recovery in sufficient purity for reuse can be achieved using relatively simple separation processes. Economical small recovery units are available for these applications. Thus, effective recycling starts with segregation of wastes by the generator. The separation processes involved in these applications are sorting, magnetic and electrostatic separations, distillation, solvent extraction, evaporation, absorption, stripping, scrubbing, etc.

1.2.4 Segregation, Labeling, and Manifesting

Segregation of wastes is of paramount importance to the success of any recycling or reclamation program. The requirements for segregation depend upon the quality and quantities of waste available at each location, plus a knowledge of the viable options for recycling and disposal.

Labeling and proper manifesting of the segregated product is essential to maintaining the integrity of individual waste types. Each container should be labeled with the common name of the contents to permit decisions on recycling versus disposal, and to minimize cross contamination. Also, a large easy-to-read sign should be placed on top of or over the collection container.

Labeling of containers for collection should be done by the generator. The labels should include the waste accumulation start date, the name or type of waste, and the designation "Hazardous Waste," if appropriate. When the containers are ready for transportation to either an on-site or off-site recovery and recycling facility, it is good practice to use a manifesting system for record keeping, even though the universal manifest system is required only for off-site transportation.

1.2.5 On-Site Recovery

The decision between on-site and off-site recovery of recyclable materials depends upon the volumes and complexity of the wastes generated, the potential liability of moving them off-site, the degree of sophistication of the generator at operating recovery equipment, and the organizational philosophy of the generating entity. For large corporations having major capital resources, technically sophisticated personnel, and large volumes of a variety of hazardous wastes, it is probably preferable to organize a waste managemment group. This group would operate a waste minimization program companywide, including source reduction, waste segregation, waste movements and record keeping, and recovery and recycling. This group could be part of a larger group whose responsibilities also include hazardous waste treatment and disposal.

At the other extreme there are the smaller, less sophisticated generators who might produce only one or two kinds of waste in relatively small quantities. Examples of such generators might be dry cleaning establishments, automotive shops, and printing shops. These shops frequently have choices among (1) installing their own solvent recovery equipment, (2) dealing with a solvent supplier who provides fresh solvent and picks up waste solvent for off-site recovery and recycling, and (3) sending waste solvent to a commercial recycler. The choice depends on the volume and value of the solvent being recovered, the availability and costs of solvent suppliers who pick up waste solvent, and the transportation distance to commercial recyclers. In general, high volume or high solvent cost favor on-site recycling. Off-site recycling is favored by small operations and others with readily availabile commercial recyclers or solvent suppliers who recycle purified solvents recovered from waste solvents.

1.2.6 Off-Site Recovery

In most cases the best place to recover hazardous wastes is within the generator's facility because of the additional potential liability of moving the wastes off-site. However, when the volumes generated are small and the recovered material cannot be used on-site, it is probably best to recover the wastes at an off-site facility. Preference should usually be given to a raw material supplier who picks up the waste, recovers the raw material, and returns it for reuse, thus satisfying the requirements for recycling and waste minimization.

If the recovered material is not of sufficient quality to be recycled to its original use, the material can enter commerce for less demanding uses. Commercial off-site recyclers exist who will take waste solvents, recover and purify them to the extent that they can reenter commerce, and thus qualify the waste solvent as being recycled for waste minimization purposes. If the original generator does not have alternate uses for the recovered solvent, it is sold in the open market by the commercial recycler.

1.3 SUMMARY

The revisions to the hazardous waste management laws passed by the U.S. Congress in the 1980s and administered by the EPA have provided a firm basis for cradle-to-grave management of hazardous materials. This is to protect both the public and the environment. The emphasis of the law has changed the waste management priority from disposal of hazardous wastes in landfills to the minimization of the amount of hazardous waste generated in the first place. This minimization is achieved by waste reduction at the source, waste separation and concentration for volume reduction, waste exchange for reuse, or waste recovery and recycling for reuse. By definition, waste minimization does not include treatment and disposal techniques such as incineration, oxidation, and combustion, which also can protect the public and the environment from the undesirable effects of hazardous wastes.

This shift in emphasis has caused a corresponding shift in required expertise toward chemical engineering technology with particular emphasis on separation processes, reaction kinetics, heat and mass transfer, mixing, diffusion, and the like. Separation processes are of particular utility in waste concentration and in waste recovery for recycling. Their use in these applications is the subject of the rest of this book.

REFERENCES

Clean Air Act Amendments (1990). Clean Air Act Law and Explanation, Commerce Clearing House, Inc., Chicago.

Environmental Protection Agency (1986). Report to Congress: Waste Minimization, Vols I and II, EPA/530-SW-86-033 and EPA/530-SW-86-034.

Environmental Protection Agency (1987). The Hazardous Waste System, EPA Office of Solid Waste and Emergency Response, June, 1987, p. 3-30.

Environmental Protection Agency (1990). The Nation's Hazardous Waste Management Program at a Crossroads, EPA/530-SW-90-069.

Pollution Prevention Act (1990). Public Law 101-508, Nov. 5, 1990.

RCRA Amendments (1984). Hazardous and Solid Waste Amendments of 1984 (HSWA), Public Law 48-616, 1984, included in 40 CFR 260-272, July 1, 1991.

RCRA (1991). Protection of Environment, 40 CFR 260-272, July 1, 1991.