34
Hazardous Waste Management and Engineering

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34.1
Introduction

Environmental technological industries are increasing at a rapid pace. As new technological advances are introduced, many other technologies are becoming obsolete or are no longer a viable option. As the focus is now on sustainable and renewable energy technologies, the current focus will facilitate the need for industries to reinvent themselves and evaluate various strategies for waste management. For example, a company may devise a strategy for how best to take a contaminant or toxic substance and produce a marketable raw material. Furthermore, using the substitution method, a company may take a specific substance and devise a means to develop the material where it will damage the environment.

Waste materials are an integral aspect of our daily lives. This is a direct result of the standard of living in an industrialized society. The manufacture of products that we use results in the generation of hazardous wastes which may be explosive, flammable, or toxic. Aircraft construction and related maintenance activities generate solvent, petroleum, and heavy metal wastes. The computer, which is now a necessity, requires halogenated solvents.

The technological explosion has increased the complexity and quantity of hazardous wastes. Furthermore, the term hazardous waste does not have an exact scientific definition due to the wide range of properties than can make a chemical a threat to public health or the environment. Hazardous effects of chemicals may include short-term toxicity to humans, long-term toxicity to humans, flammability, explosivity, corrosivity, and ecotoxicity. Additionally, there is a varying degree of hazard for the thousands of chemicals used in industry (Watts, 1998).

34.2
Impact of Hazardous Waste

Waste management includes three general categories of activities: disposal, treatment, and recycling. Facilities can dispose of waste on land, usually by placing it in

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landfills or injecting it into deep underground wells. They can also treat waste by using chemical processes that vary with the kind of waste. For example, treatment can render waste inert through vitrification, a process that converts waste to a glass-like substance. Few treatments avoid the need to dispose of some residuals later, but they may result in a waste product that is less toxic or less mobile than the pretreated substance. Also, facilities can avoid disposal by reusing organic waste as fuel or by recycling some hazardous waste, especially waste that contains metals and spent solvents (Portney and Stavins, 2000).

The environment is impacted by hazardous waste in several ways. Land disposal of hazardous waste may contaminate groundwater. Liquids that migrate through landfilled wastes, such as rainwater, may carry hazardous substances into underground aquifers. Scientists are evaluating conditions that allow substances to migrate into the groundwater and the behavior of contaminated water once present in the groundwater (Portney and Stavins, 2000). Human health is impacted from groundwater contamination when groundwater is extracted for drinking water or irrigation. Furthermore, groundwater flows into surface waters, such as lakes and wetlands, and may cause ecological damage (Portney and Stavins, 2000).

A primary objective for hazardous waste regulation is to protect groundwater, but there are also other concerns. Land disposal can impact soils and surface waters if hazardous substances migrate into these environmental media. Landfills provide a potential consequence for air pollutant releases, negatively impacting air quality.

Treatment can have harmful consequences. Incineration destroys most of the waste and provides an alternative to land disposal. However, similarly to land disposal, incinerators can contribute to harmful air emissions.

34.3
Hazardous Waste Regulation

The Resource Conservation and Recovery Act (RCRA), legislation that requires total documentation of where a waste is generated and where it is disposed of, was passed in 1976 in response to widespread environmental contamination. Later, in 1984, Congress passed the Hazardous and Solid Waste Amendments (HSWA) of 1984 that provided more technical guidance than the RCRA. The 1984 amendments strengthened the original act considerably and allowed less latitude for the US Environmental Protection Agency (EPA) (Watts, 1998).

The definition of solid waste under the RCRA is any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material including solid, liquid, semisolid, or contained gaseous materials resulting from industrial, commercial, mining, and agricultural activities and from community activities, but does not include solid or dissolved materials in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial charges which are point sources subject to permits under Section 402 of the Federal Water Pollution Control Act (Watts, 1998).

Under the RCRA, a hazardous waste is defined as a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may: (i) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible illness, or (ii) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed (Watts, 1998).

34.4
Hazardous Waste Management Strategies

The following hierarchy is useful to provide a framework for waste management strategies. As noted, treatment and disposal are the least preferred options.

1) Waste reduction at the source through, for example, process modifications.
2) Waste segregation, separation, and concentration through available engineering approaches in order to facilitate identification of the waste and the application of the remaining steps.
3) Material recovery, either on-site or off-site, to make use of the valuable materials, including the use of waste exchanges so that waste from one generator can be made available as a resource for another operation.
4) Energy recovery from waste or its components, perhaps as a fuel supplement.
5) Waste treatment to reduce the hazard level and possibly the amount of waste requiring disposal.
6) Ultimate disposal or disposal in a manner that holds release of hazardous constituents into the environment at acceptable levels (Office of Technology Assessment, 1995).

The metal-finishing industry has demonstrated process modification success. For example, in plating processes and metal cleaning, the metal-finishing industry has been successful in eliminating on-site and operated wastewater treatment facility requirements. By modifying these processes to eliminate sludge, the effluent can be discharged directly to a municipal wastewater treatment facility. Also, this process modification can save millions of dollars in capital investment.

The hierarchy provides opportunities for permanent solutions at some point before dispersal and disposal. Therefore, risks and costs are minimized in the future. An emphasis on waste reduction will significantly reduce costs of waste management or, possibly, avoid them altogether. The strategy should be to use materials as resources versus disposing of them, immediately provides economic benefits.

34.5
Hazardous Waste Treatment

Remediation and treatment of hazardous waste present society with considerable challenges usually not seen with municipal and industrial wastewaters (Watts, 1998). Concentrations of hazardous substances vary from those in contaminated groundwater to those in drums and tanks containing spent non-aqueous waste solvents. Treatment is defined as the application of a technology to a specific medium (e.g., air, water, or soil) to remove contaminants by processes such as partitioning or destruction. Partitioning describes the tendency of a contaminant to exist at equilibrium between two phases. Partitioning not only describes contaminants distributed between solids and water, but also air–water and water–biotic equilibria. Conversely, remediation is ''cleaning the environment'' or an entire environmental system such as a CERCLA site, a wetland, or an area surrounding an abandoned chemical plant.

Hazardous waste treatment processes differs from wastewater treatment due the range of media involved. In wastewater treatment, most of the contamination is in the water and the majority of compounds are treated as water soluble. Hazardous wastes, however, require treatment in a variety of media, including non-aqueous liquid materials, contaminated soils and sludges, hazardous waste treatment facilities, and groundwater remediation systems. Furthermore, hazardous wastes are often present in slurries and other mixed media systems, which creates additional challenges.

Many waste treatment technologies can provide immediate, permanent, and very high degrees of hazard reduction (Office of Technology Assessment, 1995). Source segregation is the easiest and most economical method of reducing the volume of hazardous waste. Many large industrial companies have used this waste reduction method successfully. Process modifications are not as widely used. Product substitutes have been implemented to improve performance. Recovery and recycling are usually deployed in many facilities, especially when extensive recovery is not required.

Process modifications provide an opportunity for plants to increase production efficiencies while also providing a proactive hazardous waste management strategy. Also, product improvements and reductions in manufacturing costs are possible outcomes. Modifications may include small changes in operational methods, such as temperature or pressure changes, or in raw material composition. Larger changes include new equipment or entire new processes. The following examples demonstrate the potential for process modifications (Office of Technology Assessment, 1995).

The metal-finishing industry has shown that modifications to metal cleaning and plating processes have enabled requirements for on-site owned and operated wastewater treatment facilities to be eliminated. Processes have eliminated the formation of hazardous sludge and subsequently the effluent may be discharged directly to a municipal wastewater treatment facility, possibly saving a considerable amount of capital investment.

The chlor-alkali industry has seen process developments that resulted in reductions of major types of hazardous waste through modifications to the mercury electrolysis cell. The modifications increased process efficiency, reduced production costs, and reduced hazardous waste.

34.6
Hazardous Waste Minimization

Hazardous waste minimization and pollution prevention strategies provide an opportunity to solve hazardous waste challenges. Minimization and pollution prevention will allow an organization to comply with environmental standards, increase production efficiency, lower costs, and reduce wastes (Watts, 1998). Increases in pollution prevention practices have been emphasized through the 1984 HSWA to the RCRA. Furthermore, the RCRA outlines specific requirements for pollution prevention plans as part of the generator’s responsibility. Additionally, seven Executive Orders and nine major environmental statutes affect federal, State, and local entities and require pollution prevention implementation (Watts, 1998). Section 3-302(a) of Executive Order 12856 (1993) requires each federal agency to develop ‘‘voluntary goals to reduce the agency’s total releases of toxic chemicals for treatment and disposal from facilities covered by the order by 50%.’’ Executive Order 12856 targets reductions in the release and use of toxic and extremely hazardous chemicals at a facility.

The most popular strategies for source and volume reductions include source segregation, process modifications, materials substitution, reuse, recycling, and housekeeping practices.

Waste segregation is one of the easiest pollution prevention methods. Wastes often contain multiple different chemicals that are difficult to manage and dispose of under normal RCRA hazardous waste management schemes.

Process modifications, such as a catalytic fluidized-bed reactor process or the incorporation of flow controllers to decrease the volume of water used in rinsing, can ensure that waste generation is reduced or reactions associated with chemical processing are more efficient or proceed further to completion so that potentially hazardous by-products are reduced.

Material substitution is a waste minimization strategy that uses less toxic source materials, especially chemicals that are not subject to RCRA authority.

Wastes can often be reused on-site. Solvents that are still relatively clean or acids with low concentrations of metals or other contaminants may be used in an application where a clean stock of chemical is not required.

Significant progress has been made in reducing hazardous chemical wastes. While source reduction and volume reduction are preferred pollution prevention practices, recycling is an effective practice for recovering spent hazardous chemicals. A simple waste minimization approach is improved housekeeping practices (Watts, 1998).

34.7
Hazardous Waste Remediation

Hazardous waste remediation is an ongoing concern, as land contaminated by industrial and municipal waste in industrial and developing countries presents many challenges. These sites provide a large marketplace for new technologies.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, National Priority List (NPL) identifies sites that are a priority for remedial action. Many industrial countries have policies that regulate the creation and disposition of wastes. Many requirements are decades old and include air and water pollution controls. Recent regulations focus on chemical pollution that has impacted the land, such as contaminants in industrial dumps whose legacy is the continued contamination of groundwater, surface water, soil, and the air. Current innovative technologies include new approaches for remediation or new applications of conventional methods. Before the optimum hazardous waste remediation technology is selected, there are five considerations: regulations, economics, public health, engineering, and community perception (O'Brien & Gere Engineers, 1995).

Regulations may influence decisions. An example is the RCRA ''land ban'' prohibition that protects against the disposal before treatment of certain hazardous wastes in landfills. These regulations prohibit from land disposal certain hazardous wastes unless specific post-treatment standards are met or unless treatment approved by the EPA is applied first. Regulations can dictate solutions for specific circumstances. For example, land bans (40 CFR 268) can prohibit the disposal of certain hazardous wastes in landfills before treatment (EPA, 1986). These regulations bar certain hazardous wastes from land disposal unless pretreatment standards are met or treatment is first approved by EPA. These requisite treatment technologies are called best demonstrated available technology (BDATs). Other regulations also affect remediation; they range from rules governing the injection of wastewater into wells to State drinking water criteria.

Financial considerations are extremely important. The costs of remedial alternatives are used to compare their relative capabilities. If alternatives are similarly proficient, the lowest cost is selected. Economic factors are important in the development and application of innovative technologies and also innovative applications of conventional technologies.

Although new solutions for treating contaminated sediments have emerged recently, cost remains a major obstacle, especially when combined with initial expenses of dredging, permitting issues, and disposal of remaining residuals. Costs may be a few thousand dollars per cubic yard. At one polychlorinated biphenyl (PCB) hot-spot several years ago, proposed remediation including dredging, dewatering, stabilization, incineration, and landfill disposal cost nearly \$1500 per cubic yard (McGrath, 1995). Project delays can push costs even higher.

Often a hazardous waste site does not pose a serious and immediate threat to public health. Therefore, concerns over the health effects of a hazardous waste site seldom dictate the decision-making process. However, when public health factors are significant, they can play an integral role in hazardous waste remediation technology selection. Sometimes, the best technique is no remediation – other than what occurs naturally. Moving contaminated sediments to remediate them often poses a greater risk than leaving them in place (Hill, 1996).

In the absence of regulatory requirements, usually engineering and economic requirements of a remediation project takes precedence. Technologies frequently place engineering as a focal point for remediation. Finally, the public plays a key role in the remediation selection process. Citizens usually have an unrealistic expectation of ‘‘zero risk,’’ but a community can greatly impact the remediation selected (Hill, 1996). If, due to the contaminants or media involved, few alternative techniques are available, the remedial approach is, in essence, established before the decision-making process begins. In the absence of regulatory requirements, engineering and economic requirements often rule. The RCRA and CERCLA or Superfund use engineering, economic, and health-based criteria to evaluate and select alternatives.

Decision-making is a complex exercise that demands consideration of several criteria. Usually, the criteria of the initiating party dominate. The purpose of scientific and engineering innovation is to improve remediation technologies. Innovation should produce technologies that are less expensive than conventional technologies or that more effectively reduce risks. Chemical reduction is inexpensive and has a good separation efficiency (50–80%). When selecting an alternative, the effectiveness of available technologies must be evaluated. Specific evaluation requirements under RCRA and CERCLA or Superfund are as follows:

- protection of human health and the environment
- reduction of toxicity, mobility, or volume through treatment
- compliance with legal requirements.

Finally, the public often has a simplistic perception of complex health issues and risk factors posed by a hazardous waste site. In addition, their expectation of ‘‘zero risk’’ is unattainable. Owing to misinformation, however, politicians may force regulators or the responsible party to take unwarranted action. Thus, selection of a remedial action alternative may be propelled by politics rather than science.

34.8
Hazardous Waste Technologies

There are over 50 technologies available designed to remediate soil and groundwater (Kraft, 2001). However, there are still limited data to assess the effectiveness of different contaminants or complex hydrogeologic environments. Therefore, sometimes remedial technologies are improperly applied.

Containment and soil vapor extraction have achieved moderate success in remediating contaminated soil. Bioremediation has achieved considerable success as an emerging technology in remediating both soil and groundwater, while air sparging has proved successful in remediating both soil and groundwater. Rotary kiln technology is an extensively used thermal destruction technology, whereas solidification has only recently gained popularity. Fungal remediation is an alternative to bioremediation in some applications, while oxidation technologies can minimize contaminant toxicity and volume (Shosky, 1995).

Bioremediation uses microorganisms to degrade contaminants. It is applied to environmental contaminants in order to eliminate or reduce their toxicity and, thus, reduce risks posed to human health and the environment. The technology offers many advantages and is effective when the following environmental conditions are satisfied:

1) Appropriate microorganisms are present or added.
2) Contaminant concentrations fall within a range that stimulates microbial activity.
3) Contaminants are biodegradable.
4) Sufficient nutrients and oxygen are present for aerobic degradation (Shosky, 1995) Microorganisms will grow if given the proper conditions. An energy and carbon source is needed. Many hazardous organics satisfy either or both of these requirements.

Nutrients such as phosphorus, trace metals, and nitrogen are needed. Aerobic organisms need a source of oxygen. Some organisms can use oxidized inorganics as a substitute for oxygen. The temperature and pH must be controlled as needed and substances that are toxic to the organism (i.e., heavy metals) must be removed. Hazardous organics can be treated biologically given that the proper organism distribution is established. A substance that is hazardous for one group or organisms may be a valuable food source for another group. Figure 34.1 shows a contaminated soil remediation process using a mixing tank.

Bioremediation is an economical alternative. Being a natural process, it usually gains public approval. Furthermore, the technique has been successfully used to remediate several types of petroleum compounds in soil and groundwater. Disadvantages include monitoring, and controlling the rate or extent of bioremediation is difficult.

Although most bioremediation processes involve bacteria, fungi can degrade many compounds where bacteria are ineffective. Studies have demonstrated the effectiveness of both white rot and non-white rot fungi for degrading heavy petroleum hydrocarbons, chlorinated pesticides, and creosote. Under laboratory

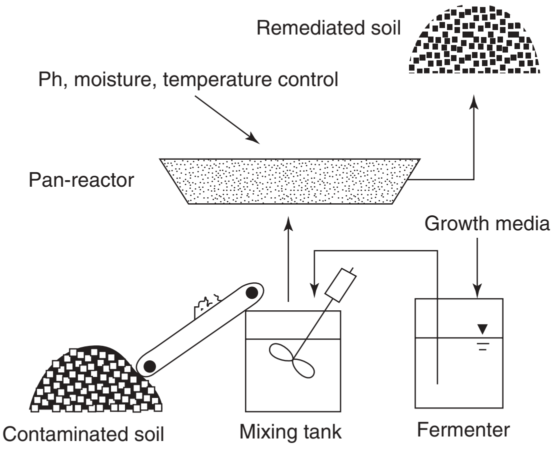

Figure 34.1 Soil remediation.

conditions, bacteria-resistant contaminants can be treated up to 10 times faster than fungi (Shosky, 1995). During the next few years, fungi will be used in above-ground bioremediation systems for complex organics.

In air sparging, air is injected at several points beneath the remediation zone. As air rises, contaminants volatilize and rise to the surface of the water table, where they are captured, typically via a soil vapor extraction system. This method is most efficient when the following environmental conditions are met: (i) a uniform, permeable zone of groundwater contamination is present and (ii) contaminants are readily volatile.

Air sparging is preferred to pumping and treating groundwater because it removes contaminants sorbed on soil grains. The technique also enhances the possibility that bioremediation will occur by stimulating indigenous microorganisms via the addition of oxygen. Air sparging has been successful in remediating petroleum compounds and degreasing solvents (O'Brien & Gere Engineers, 1995).

Solidification on heavy metals is useful as it binds the metals in place and prevents them from re-entering the environment. Solidification also reduces risks associated with hazardous materials because the materials are converted to their soluble, mobile, or toxic form. In addition, these technologies reduce a contaminant's ability to leach, because the after-treatment product is less likely to release the contaminant into the environment. Unlike thermal technologies that reduce the volume of a material after treatment, solidification increases the volume.

Solidification has only recently gained popularity. Owing to the high costs, it was previously used solely for treating radioactive wastes. In addition to limiting the solubility or toxicity of hazardous waste constituents, its two other objectives are (i) improve waste handling or other physical characteristics of the waste and (ii) decrease the active surface area for containment transfer or loss (Theodore and Reynolds, 1987).

Oxidation involves the movement of a contaminant to a higher oxidized or more environmentally benign state (Figure 34.2). Applied effectively, these technologies can reduce or eliminate contaminant volume and toxicity. Oxidation technologies include the use of hydrogen peroxide, protolysis, chlorine dioxide, and ultraviolet radiation with ozone. Hydrogen peroxide and chlorine dioxide can easily be incorporated into various environmental media under treatment; these media include water, wastewater, soil, leachate, and air. Hydrogen peroxide and chlorine dioxide are frequently used as disinfectants and oxidizing agents.

When these agents cannot completely degrade contaminants, they may transform contaminants into constituents that are amenable to other forms of degradation (i.e., biological processes). Oxidation technologies can also be combined to effect treatment.

Soil vapor extraction is a technology commonly used to remediate soil containing volatile organic compounds (VOCs). A vacuum is applied to the soil in order to induce air movement across a contaminant zone; movement of air within the zone causes volatile contaminants to vaporize. These vapors are then captured and removed, slowly reducing contaminant concentrations in the soil. Air sparging can supplement these techniques in some cases. Advantages include the following:

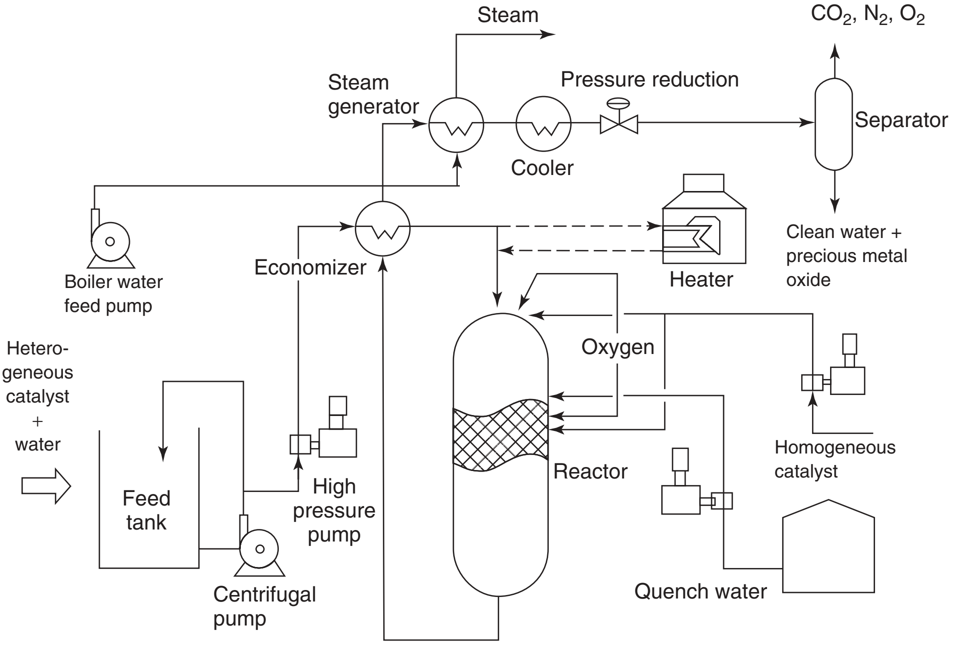

Figure 34.2 Fluid oxidation process.

- The technique is simple.
- Capital, operation, and maintenance costs are low, provided that the off-gas does not require treatment before discharge.
- Contaminant, or product, can sometimes be recovered.
- The process enhances the biodegradation of organic compounds in the soil because it promotes aerobic conditions (O'Brien & Gere Engineers, 1995).

Rotary kiln incineration is a widely used thermal destruction technology that provides for controlled combustion of solids, liquids, sludges, or gaseous wastes contaminated with organic compounds. There are two key advantages: (i) it provides for continuous mixing of incoming wastes and (ii) it may be used to treat a waste stream containing various materials. This technology is suitable for a range of homogeneous wastes and also for variable wastes (found at hazardous waste sites). It has been used at sites under the CERCLA program because it can treat wastes in several forms, including solids, sludges, and liquids.

The kiln accepts all types of solid and liquid waste materials with heating values between 1000 and 15 000 Btu lb^{-1}. (Theodore and Reynolds, 1987). Although frequently used to incinerate liquid wastes, rotary kilns are primarily designed for combustion of solid wastes. Kilns are versatile in this regard, capable of handling sludges, bulk solids of varying size, and containerized wastes. Problem wastes include aqueous organic sludges, which become sticky on drying and form a ring around the kiln's inner periphery, and solids (i.e., drums), which roll down the kiln and are not retained as long as bulk solids. To address this challenge, drums and other cylindrical containers are usually not introduced into an empty kiln. Other solids impede the rolling action. Disadvantages of rotary kiln incineration include the following: (i) operating and capital costs are high, (ii) highly skilled operators are required, and (iii) fine particulate is generated due to the cascading action of burning waste (Freeman, 1989).

In the case of Chemical Waste Management, Inc. versus the EPA, the EPA's treatment standards for leachate were challenged (Collin, 2006). Leachate as a result of hazardous waste is considered hazardous waste under EPA rules. Preferably, hazardous waste is preferred for treatment when it is contained. Hazardous substances leached into the ecosystem foster greater environmental impact and higher costs. Hazardous waste is an interesting subject, as some can become less hazardous over time, some can become more hazardous over time, and some can be made less hazardous.

Incineration is a controlled high-temperature oxidation process that converts the principal elements (carbon, hydrogen, and oxygen) in most organic compounds to CO_2 and H_2O (Figure 34.3). The toxic or hazardous nature of an organic molecule is usually due to the structure of the molecule, as opposed to the element that it contains. The existence of elements other than carbon, hydrogen, and oxygen in a waste may, on incineration, result in the production of gaseous or particulate pollutants that require removal in off-gas treatment systems. Incinerators have become more efficient over time with sophisticated off-gas treatment systems that emit only minimal amounts of pollutants. The capital and operating costs for incinerators are high, but air quality in surrounding areas has improved considerably. Rotary-kiln incinerators are highly versatile units that can accept virtually any type of combustible waste but are designed primarily to incinerate solids and tars that cannot be processed in liquid-injection incinerators. The

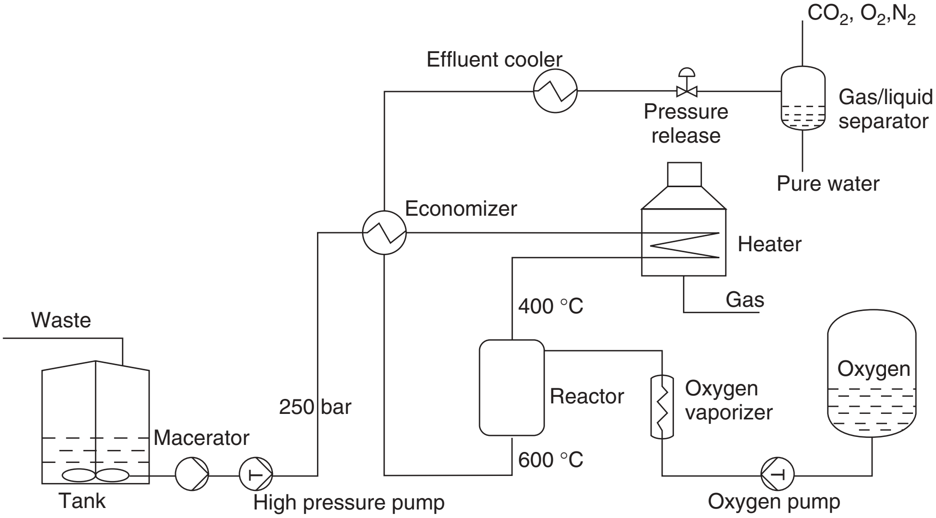

Figure 34.3 Incineration process.

rotary kiln is a cylindrical shell lined with refractory material that is mounted horizontally at a slight incline. The rotary kiln causes a tumbling action that effectively mixes combustible solids with air to promote complete burning of the waste. Non-combustible waste (e.g., scrap metal and ash) travels down the inclined kiln and is collected in drums after water quenching cooling. Owing to the high short-term costs, landfilling is increasingly preferred over incinerators. However,, long-term implications should also be considered.

Landfilling will continue to be closely monitored and possibly phased out to a large extent in the future. Key preventive measures for minimizing the risk include the following (Watts, 1998):

1) siting waste disposal sites per environmental regulations
2) fixation and encapsulation
3) environmental surveillance and monitoring of water and air quality
4) incorporating environmental and safety considerations in the design, construction, and operation of the ultimate disposal facilities
5) preparing contingency plans for counteracting spills, fires, explosions, and contamination of air, water, and land resources
6) proper closure and perpetual care of completed disposal sites (Dawson and Mercer, 1986).

Contaminants can move through pathways from facilities via surface runoff, infiltration, vapor loss, and the generation of leachate. Leachate usually results in problems that are cost prohibitive and difficult to remediate. A landfill liner will minimize the potential for leachate exposure into the environment. Owing to potential releases via any pathway, secure landfills for hazardous waste disposal require additional design features over conventional sanitary landfills to provide long-term protection of groundwater, surface water, air, and human health.

Waste processing and handling are concerns as hazardous waste begins travel from the generator site to a secure long-term storage facility. Preferably, the waste can be stabilized, detoxified, or somehow rendered harmless in a treatment process.

Chemical stabilization/fixation involves a process when chemicals are mixed with waste sludge, the mixture is pumped on to land, and solidification occurs in several days or weeks. The result is a chemical nest that entraps the waste, and pollutants such as heavy metals may be chemically bound in insoluble complexes. Asphalt-like compounds form ‘‘cages’’ around the water molecules, while grout and cement form actual chemical bonds with the trapped substances. Chemical stabilization offers an alternative to digging up and moving large quantities of hazardous waste (Dawson and Mercer, 1986).

Volume reduction is usually accomplished by incineration, which takes advantage of the large organic traction of waste being generated by many industries, but could result in secondary issues for hazardous waste interested parties. Two concerns include air emissions in the stack of the incinerator and ash production in the base. Both by-products of incineration must be addressed in terms of risk and also legal and economic constraints. Thermal technologies are useful for contaminated soil that is used for treatment, disposal, or reuse (Figure 34.4).

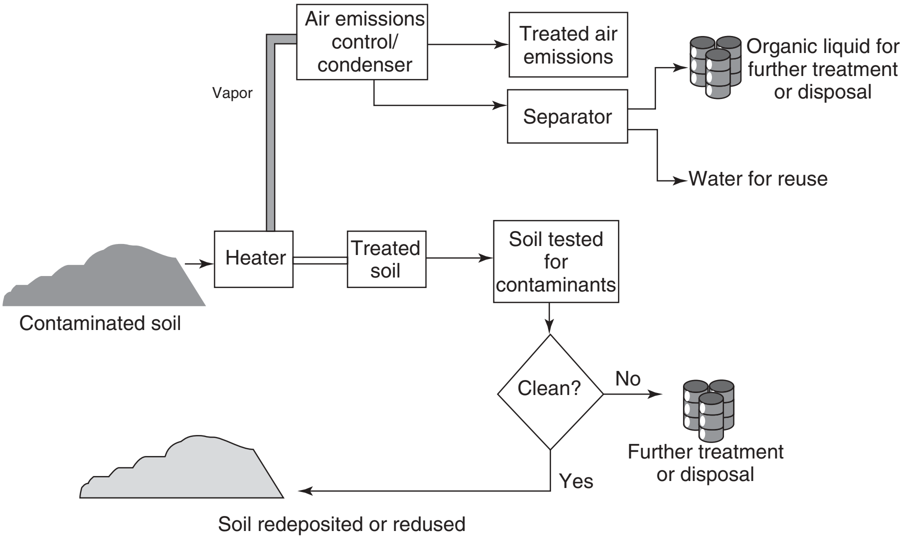

Figure 34.4 Thermal treatment process for contaminated soil.

Detoxification includes thermal, biological, and chemical processes that detoxify chemical wastes. Possible methods include ion exchange, incineration, neutralization, aerated lagoons, and waste stabilization ponds. These techniques are specific; ion exchange does not work for every chemical, and some forms of heat treatment may be prohibitively expensive for sludge that has a high water content (Dawson and Mercer, 1986; Peirce, Weiner, and Vesilind, 1998).

Methods are available that chemically degrade some hazardous wastes and the result is a less hazardous waste. Chemical degradation is a form of chemical detoxification. A waste-specific degradation process includes hydrolysis, which destroys organophosphorus and carbonate pesticides, and chemical dechlorination, which destroys some polychlorinated pesticides. Biological degradation generally includes incorporating the waste into the soil. Land farming relies on healthy soil microorganisms to metabolize the waste components. Land farming sites must be strictly controlled for potential water and air pollution that results from overactive and underactive organism populations (Sayler, Fox, and Blackburn, 1991; Sayler Sanseverino and Davis, 1997).

Encapsulation uses materials, such as a steel drum, clay plastics, and asphalt, to solidify the waste. Several layers of different materials are recommended for outside the drum, such as an inch or more of polyurethane foam to prevent corrosion.

34.8.1
Waste Exchange

Waste exchanges have provided an option for hazardous waste management. A transfer agent within the exchange normally identifies both generators and potential user of the waste. The exchange will buy or accept the waste, analyze its chemical and physical properties, identify buyers, reprocess the waste as necessary, and sell it at a profit.

There are several factors that will determine the success of an exchange. Highly skilled and competent technical resources are required to analyze waste flows and design and recommend methods for processing the waste into a marketable resource. The ability to diversify is critical to the success of an exchange. Local suppliers and buyers must be identified for the products and services.

Whereas the United States has experienced waste exchanges with marginal success, European nations have experienced a longer and more successful record with this approach. European waste exchanges include:

1) services offered without charge
2) waste availability made known through published advertisements
3) operation by national industrial associations
4) advertisements coded to maintain confidentiality
5) advertisements discussing chemical and physical properties, and also quantities, of waste.

The wastes that are normally recognized as having transfer value include (i) solvents, (ii) concentrated acids, (iii) high concentrations of metals, (iv) combustibles for fuel, and (v) oils (Peirce, Weiner, and Vesilind, 1998).

34.9
Life-Cycle Assessment

A life-cycle assessment (LCA) is an evaluation of the environmental effects associated with any given activity, from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth. This evaluation includes all sidestreams releases to the air, water, and soil from the production of raw materials (including energy), the use of the product, and its final disposal, and also from the processing of the product itself. LCAs are used to identify and measure both ‘‘direct’’ (i.e., emissions and energy during manufacturing processes) and ‘‘indirect’’ (i.e., energy use and impacts caused by raw material extraction, product distribution, consumer use, and disposal).

Life-cycle assessment has been defined as an attitude through which manufacturing accepts responsibility for the pollution control caused by their products from design to disposal. This is a significant change from the traditional approach that responsibility begins with the raw material acquisition and ends with the sale of the finished products (Bishop, 2000).

LCAs can be used for a number of purposes. LCAs performed for product and/or process improvement and/or cost reduction will remain the primary drivers, but LCAs performed for cost reduction reasons will likely increase in the future, as waste disposal costs continue to increase. Also, other drivers increasing in importance include customer expectations and using LCAs as a business strategic advantage.

LCA utilizes a systems approach to identify the environmental consequences of various industrial alternatives. The assessment should include waste management, recycling, manufacturing processes, and product use. Additional considerations should evaluate energy usage, resource consumption, and environmental releases.

34.10
Conclusion

Sustainability and renewable energy technologies increase the need for industries to evaluate and select the best waste management strategies. Waste reduction at the source is the preferred hazardous waste management strategy. Treatment of hazardous waste is not a preferred strategy, as considerable challenges are sometimes present. Wastewater treatment is an example. Hazardous waste and pollution prevention strategies will increase in importance as a result of environmental standards, cost reduction, and public expectations. Emerging technologies for hazardous waste reduction include segregation and biotechnology. Incineration and landfills are still popular hazardous waste management strategies, although landfills are closely scrutinized and targeted for phase-out in the future. Waste exchanges are growing in importance, although the United States has experienced marginal success in this area. LCAs will provide an opportunity to identify environmental consequences for various industrial alternatives.

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