CHAPTER 19

Environmental Engineering: Regulation and Compliance

ROBERT B. JACKO
TIMOTHY M. C. LABRECHE
Purdue University

1. OVERVIEW

This chapter provides industrial, plant, and facilities engineers with a brief overview of some environmental engineering considerations in process and manufacturing operations. This information will be helpful to engineers who are designing or operating new industrial processes or involved in the modification of existing facilities.

2. ENVIRONMENTAL LAW

2.1. Overview

Regulations designed to protect and improve the environment play a substantial role in the design and management of industrial processes. These regulations should be incorporated into the initial

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process design and not as an afterthought. This section provides a brief overview of some major environmental laws and organizations.

2.2. Environmental Protection Act

Prior to the Environmental Protection Act, environmental regulations were divided along media lines (air, water, earth). In 1970, President Nixon submitted to Congress a proposal to consolidate many of the environmental duties previously administered by agencies including the Federal Water Quality Administration, the National Air Pollution Control Administration, the Bureau of Solid Waste Management, the Bureau of Water Hygiene, the Bureau of Radiological Health; certain functions with respect to pesticides carried out by the Food and Drug Administration; certain functions of the Council on Environmental Quality; certain functions of the Atomic Energy Commission and the Federal Radiation Council; and certain functions of the Agricultural Research Service (Nixon 1970a).

President Nixon recognized that some pollutants exist in all forms of media and that successful administration of pollution-control measures required the cooperation of many of the federal bureaus and councils. A more effective management method would be to recognize pollutants, observe their transport and transformation through each medium, observe how they interact with other pollutants, note the total presence of the pollutant and its effect on living and nonliving entities, and determine the most efficient mitigation process. This multimedia approach required the creation of a new agency to assume the duties of many existing agencies, thus eliminating potential miscommunication and interdepartmental biases that could hinder environmental protection. Thus, the President recommended the establishment of an integrated federal agency that ultimately came to be called the Environmental Protection Agency (EPA).

The roles and functions of the EPA were to develop and enforce national standards for the protection of the environment; research the effects of pollutants, their concentrations in the environment, and ways of controlling them; provide funding for research and technical assistance to institutions for pollutant research, and propose new legislation to the President for protection of the environment (Nixon 1970b).

In the words of William D. Ruckelshaus, EPA's first administrator,

> EPA is an independent agency. It has no obligation to promote agriculture or commerce; only the critical obligation to protect and enhance the environment. It does not have a narrow charter to deal with only one aspect of a deteriorating environment; rather it has a broad responsibility for research, standard-setting, monitoring and enforcement with regard to five environmental hazards; air and water pollution, solid waste disposal, radiation, and pesticides. EPA represents a coordinated approach to each of these problems, guaranteeing that as we deal with one difficulty we do not aggravate others. (Ruckelshaus 1970)

The EPA has instituted numerous programs and made significant changes in the way businesses operate in the United States. A brief summary of the EPA's milestones (Table 1) shows the many ways the course of business and the environment have been altered since the agency's inception in 1970.

2.3. Clean Air Acts

2.3.1. Air Pollution Control Concept in the United States

Air pollution control in the United States is said to be a "command and control" regulatory approach to achieving clean air. That is, regulations are promulgated at the federal level and via state implementation plans (SIPs) at the state level and air pollution sources are required ("commanded") to comply. These regulations have been set up to operate on the air we breathe as well as the sources that produce the air pollution. The regulations established to control the air we breathe are called National Ambient Air Quality Standards (NAAQSs). Their engineering units are concentration based, that is, micrograms-pollutant per cubic meter of air or parts per million by volume (ppm_v). These NAAQSs also have a time-averaging period associated with them such as a 24-hour or an annual averaging period. Additionally, the NAAQSs have primary standards and secondary standards associated with them. The primary standards are for the protection of human health and the secondary standards are for the protection of things. For example, the primary 24-hour average standard for sulfur dioxide is 365 $\mu g/m^3$ and the secondary standard is a 3-hour average standard of 1300 $\mu g/m^3$. The 365 $\mu g/m^3$ standard protects humans from a high-level short-term dose of sulfur dioxide, while the 1300 $\mu g/m^3$ standard could protect a melon crop from a high-level, short-term dose of sulfur dioxide. Table 2 contains the NAAQSs for the six EPA criteria pollutants.

The other thrust of the air pollution regulations applies to the sources of the pollutants. These regulations are emission standards called the New Source Performance Standards (NSPSs). These sources include stationary sources such as power plants and industrial manufacturing operations as well as mobile sources such as automobiles, trucks, and aircraft. These regulations are mass flow rate-based, that is, grams-pollutant/hr or lb-pollutant/10^6 Btu. Pollutant-specific emission limits were

TABLE 1 Timeline of Environmental Regulation

Year	Event
1970	Agency established December 2, 1970. Clean Air Act Amendments set national health-based standards.
1971	Bans use of lead-containing interior paints in residences built or renovated by the federal government.
1972	Bans the use of DDT. Commits to a national network of sewage-treatment plants to provide fishable and swimmable waterways. United States and Canada sign the International Great Lakes Water Quality Agreement.
1973	Phase-out of lead-containing gasoline begins. First industrial wastewater discharge permit issued.
1974	New Safe Water Drinking Act establishes health-based standards for water treatment. Standards limiting industrial water pollution established.
1975	Fuel economy standards allow consumers to include fuel efficiency in their purchasing considerations. EPA emission standards require catalytic convertors to be installed on automobiles.
1976	Resource Conservation and Recovery Act established to track hazardous waste from "cradle to grave." Toxic Substance Control Act developed to reduce public exposure to pollutants that pose an unreasonable threat of injury. Included in this act is a ban on polychlorinated biphenyls (PCBs).
1977	Air quality in pristine natural areas is addressed by Clean Air Act Amendments.
1978	Chlorofluorocarbons (CFCs) banned for use as a propellant in most aerosol cans. CFCs are implicated as ozone-depleting chemicals.
1979	Dioxin is indicated as a carcinogen. Two herbicides containing dioxins banned.
1980	Under the new Superfund law a nationwide program for the remediation of hazardous waste sites is established.
1984	Amendments to the RCRA Resource Conservation and Recovery Act enacted to prevent contamination from leaking underground storage tanks (USTs) and landfills and require treatment of hazardous wastes prior to land disposal.
1985	EPA joins international movement calling for worldwide ban on the use of Ozone-Depleting Chemicals (ODCs).
1986	A major toxic chemical release in Bhopal, India, stimulates the passage of the Community Right to Know Law, requiring that individuals in possession of chemicals maintain records of location, quantity, and use and any releases of chemicals. The EPA is charged with maintaining a public database of these records. The EPA begins assisting communities in the development of Emergency Response Plans.
1987	The United States and 23 other countries sign the Montreal Protocol to phase out the production of chloroflourocarbons (CFCs).
1989	The new Toxic Releases Inventory provides the public with the location and character of toxic releases in the United States.
1990	EPA assesses $15 billion fine to a single company for PCB contamination at 89 sites. New Clean Air Act Amendments require states to demonstrate continuing progress toward meeting national air quaility standards.
1992	EPA bans dumping of sewage sludge into oceans and coastal waters.
1993	EPA's Common Sense Initiative announces a shift from pollutant-by-pollutant regulation to industry-by-industry regulation.
1994	Grants initiated to revitalize inner-city brownfields. Clinton administration nearly doubles the list of toxic chemicals that must be reported under the Community Right to Know laws.
1995	Two thirds of metropolitan areas that did not meet air quality standards in 1990 now do meet them, including San Francisco and Detroit. EPA requires municipal incinerators to reduce toxic emissions by 90%.

From EPA OCEPA 1995.

assigned to both existing sources and proposed new sources under the 1970 Clean Air Act. The existing-source emission limits were less stringent than the new source limits because new sources had the opportunity to incorporate the latest technology into the process or manufacturing design.

To determine what emission standards apply to your new proposed operation, refer to the Code of Federal Regulations (CFR) part 60, which is also Title I under the 1990 Clean Air Act Amend-

TABLE 2 National Ambient Air Quality Standards

Criteria Pollutant	Averaging Period	Primary NAAQS $\mu g/m^3$	Secondary NAAQS $\mu g/m^3$
PM-10	Annual	50	50
	24 hour	150	150
Sulfur dioxide (SO_2)	Annual	80	
	24 hour	365	
	3 hour		1,300
Nitrogen dioxide (NO_2)	Annual	100	100
Ozone	1 hour	235	235
Carbon monoxide (CO)	8 hour	10,000	
Lead	Quarterly	1.5	1.5

ments. The NSPSs are shown for a large number of industrial classifications. Look for your type of industry and you will find the applicable new source emission standards.

2.3.2. The 1970 Clean Air Act

Control of outdoor air pollution in the United States certainly grew its regulatory roots prior to the 1970 Clean Air Act. However, for the practicing industrial engineer, the passage of the 1970 Clean Air Act is the real beginning of contemporary outdoor or ambient air pollution control. Therefore, this section will focus on those aspects of the Clean Air Act of 1970 and the subsequent amendments of 1977 and 1990 that will be most meaningful to the industrial engineer.

The 1970 Clean Air Act was the first piece of air pollution legislation in this country that had any real teeth. The establishment of an autonomous federal agency that ultimately came to be known as the EPA was a result of the 1970 Act. Prior to this time, matters relating to outdoor air pollution had their home in the United States Public Health Service. Furthermore, it is historically interesting to note that the EPA went through a number of name changes in the months following promulgation of the 1970 Clean Air Act before the current name was chosen.

2.3.3. The 1977 Clean Air Act Amendments

The 1970 Clean Air Act had a deadline of July 1, 1975, by which all counties in the United States were to comply with concentration-based standards (NAAQSs) for specified air pollutants. However, when July 1, 1975, arrived, very few counties in industrialized sections of the country met the standards. As a consequence, much debate took place in Congress and the result was the promulgation of the 1977 Clean Air Act Amendments. In some quarters, this amendment was viewed as the strongest piece of land use legislation the United States had ever seen. This legislation required each state to evaluate the air sheds in each of its counties and designate the counties as either attainment or non-attainment counties for specified air pollutants, according to whether the counties attained the National Ambient Air Quality Standards (NAAQS) for those pollutants. If the state had insufficient data, the county was designated unclassified. A company in a non-attainment county had to take certain steps to obtain an air permit. This ultimately added a significant increased cost to a manufactured product or the end result of a process.

Under this same amendment were provisions for ‘‘protecting and enhancing’’ the nation’s air resources. These provisions, called the Prevention of Significant Deterioration (PSD) standards, prevented an industrial plant from locating in a pristine air shed and polluting that air shed up to the stated ambient air standard. They classified each state’s counties as to their economic status and air polluting potential and established ceilings and increments more stringent than the ambient air standards promulgated under the 1970 Clean Air Act. No longer could a company relocate to a clean air region for the purpose of polluting up to the ambient air standard. In essence, the playing field was now level.

2.3.4. The 1990 Clean Air Act Amendments

Due to a number of shortcomings in the existing air pollution regulations at the end of the 1980s, the Clean Air Act was again amended in 1990. The 1990 Clean Air Amendments contain a number of provisions, or titles, as they are referred to. These titles, some of which carry over existing regulations from the 1970 and 1977 amendments, are listed below, along with a general statement of what they cover:

- Title I:
  - National Ambient Air Quality Standards (NAAQS), Clean Air Act sections 105–110 and 160–193; 40 CFR Parts 50–53, 55, 58, 65, 81, and 93. Establishes concentration-based ambient air standards.
  - New Source Performance Standards (NSPSs), Clean Air Act section 111; 40 CFR Part 60. Establishes emission limitations for specific categories of new or modified sources.
- Title II:
  Mobile Sources Program, Clean Air Act sections 202–250; 40 CFR Parts 80 and 85–88. Covers tailpipe emission standards for aircraft, autos, and trucks, including fuel and fuel additives, clean fuel vehicles, and Hazardous Air Pollutants (HAPS) research for mobile sources.
- Title III:
  National Emission Standards for Hazardous Air Pollutants (NESHAPS), Clean Air Act section 112; 40 CFR Parts 61, 63, and 68. Includes an accidental release program, list of HAPS and sources, residual risk standards, and maximum achievable control technology (MACT) standards.
- Title IV:
  Acid Rain Program, Clean Air Act sections 401–416; 40 CFR Parts 72–78. Acid deposition control via sulfur and nitrogen oxide controls on coal- and oil-burning electric utility boilers.
- Title V:
  Operating permit program, Clean Air Act sections 501–507; 40 CFR Parts 70–71. Requires operating permits on all sources covered under the Clean Air Act.
- Title VI:
  Stratospheric Ozone Protection Program, Clean Air Act sections 601–618; 40 CFR Part 82. Contains a list of ozone-depleting substances. Bans certain freons, requires freon recycling.
- Title VII:
  Enforcement Provisions, Clean Air Act sections 113, 114, 303, 304, 306, and 307. Compliance certification, enhanced monitoring, record keeping and reporting, $25,000/day fines, civil and criminal penalties, entry/inspector provisions, citizen lawsuits and awards up to $10,000, and public access to records.

2.4. Worker Right to Know

The Hazard Communication Standard of the Occupational Safety and Health Act requires that all employees be informed of the hazards associated with the chemicals they are exposed to or could be accidentally exposed to. In addition to chemical hazards, OSHA requires workers be trained to recognize many other types of hazards. Hazards may include chemical, explosion and fire, oxygen deficiency (confined spaces, for example), ionizing radiation, biological hazards, safety hazards, electrical hazards, heat stress, cold exposure, and noise. Compliance with Worker Right to Know laws general requires a written plan that explains how the Hazard Communication Standard will be executed. The only operations where a written Hazard Communication Plan is not required are handling facilities where workers contact only sealed chemical containers and laboratories. These facilities must still provide hazard training to employees, retain the original labeling on the shipping containers, and make material safety data sheets (MSDSs) available to all employees. In general, no employees should be working with any chemical or equipment that they are not familiar with. OSHA statistics indicate that failure to comply with the Hazard Communication Standard is its most cited area (OSHA 1999b).

The Hazard Communication Standard requires each facility to conduct a hazard assessment for each chemical in the workplace, maintain an inventory of chemicals in the workplace, retain MSDSs for each chemical in the workplace, properly label each chemical according to a uniform labeling policy, train each employee to understand the MSDSs, product labels, and Hazard Communication Standard, and develop a written program that explains how the Hazard Communication Standard is to be implemented at the facility.

2.5. Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) of 1976, an amendment to the Solid Waste Disposal Act of 1965, and the Hazardous and Solid Waste Amendments of 1984, which expanded RCRA, were enacted to protect human health and environment, reduce waste and energy, and reduce or eliminate hazardous waste as rapidly as possible. Three programs addressing hazardous waste, solid waste, and underground storage tanks are included in RCRA.

Subtitle C requires the tracking of hazardous waste from "cradle to grave," which refers to the requirement that hazardous waste be documented by a paper trail from the generator to final disposal, whether it be incineration, treatment, landfill, or some combination of processes. Subtitle D establishes criteria for state solid waste management plans. Funding and technical assistance are also provided for adding recycling and source reduction implementation and research. Subtitle I presents rules for the control and reduction of pollution from underground storage tanks (USTs).

A RCRA hazardous waste is any substance that meets physical characteristics such as ignitibility, corrosivity, and reactivity or may be one of 500 specific hazardous wastes. They may be in any physical form: liquid, semisolid, or solid. Generators and transporters of hazardous waste must have federally assigned identification numbers and abide by the regulations pertinent to their wastes. Individuals treating and disposing of hazardous wastes must meet stringent operating guidelines and be permitted for treatment and disposal technologies employed. RCRA hazardous waste regulations apply to any commercial, federal, state, or local entity that creates, handles, or transports hazardous waste.

A RCRA solid waste is any sludge, garbage, or waste product from a water treatment plant, wastewater treatment plant, or air pollution control facility. It also includes any discarded material from industrial, mining, commercial, agricultural, and community activities in contained gaseous, liquid, sludge, or solid form. RCRA solid waste regulations pertain to owners and operators of municipal solid waste landfills (EPA OSW 1999a,b).

2.6. Hazardous Materials Transportation Act

The Hazardous Materials Transportation Act of 1975 (HMTA) and the 1990 Hazardous Materials Uniform Safety Act were promulgated to protect the public from risks associated with the movement of potentially dangerous materials on roads, in the air, and on waterways. They do not pertain to the movement of materials within a facility. Anyone who transports or causes to be transported a hazardous material is subject to these regulations, as is anyone associated with the production or modification of containers for hazardous materials. Enforcement of the HMTA is delegated to the Federal Highway Administration, Federal Railway Administration, Federal Aviation Administration, and Research and Special Programs Administration (for enforcement of packaging rules).

The regulations of the HMTA are divided into four general areas: procedures and policies, labeling and hazard communication, packaging requirements, and operational rules. Proper labeling and hazard communication requires the use of the standard hazard codes, labeling, shipping papers, and placarding. Hazardous materials must be packaged in containers compatible with the material being shipped and be of sufficient strength to prevent leaks and spills during normal transport (DOE OEPA 1996).

2.7. Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Superfund Amendments and Reauthorization Act (SARA)

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) was enacted in 1980 to provided a federal Superfund for the cleanup of abandoned hazardous waste sites. Funding for the Superfund was provided through fines levied or lawsuits won against potentially responsible parties (PRPs). PRPs are those individuals having operated at or been affiliated with the hazardous waste site. Affiliation is not limited to having physically been on the site operating a process intrinsic to the hazardous waste creation. Affiliation can include those parties that have provided transportation to the site or customers of the operation at the hazardous waste site that transferred raw materials to the site for processing (EPA OPA 1999a).

The Superfund Amendment Reauthorization Act (SARA) of 1986 continued cleanup authority under CERCLA and added enforcement authority to CERCLA (EPA OPA 1999b). Within SARA was the Emergency Planning and Community Right-to-Know Act (EPCRA) also know as SARA Title III. EPCRA established the framework for communities to be prepared for chemical emergencies that could occur at industrial sites in their neighborhoods. EPCRA required states to form State Emergency Response Commissions (SERCs). SERCs divided the states into Emergency Planning Districts and formed Local Emergency Planning Committees. These committees consist of a broad range of community leaders, emergency officials, and health professionals (EPA OPA 1999c). SERCs use information acquired through Section 313 of SARA, the Toxic Releases Inventory (TRI), to make emergency planning decisions. Chemical producers and consumers must annually report releases of chemicals during the year to the EPA. These releases may occur continuously throughout the year or in a single large burst and include releases that a company is legally permitted to make, such as through air permits. Included in these reports are the type and volume of chemical released, the media the chemical was released to, how much of the chemical was transported from the site for recycling or disposal, how the chemical was treated for disposal, the efficiency of treatment, and pollution prevention and recycling activities at the reporting company. Reporting is required if a facility employs 10 or more full-time employees and (EPA OPPT 1999):

Manufactures or processes over 25,000 lb (total) of approximately 600 designated chemicals or 28 chemical categories
OR
Manfactures or processes over 10,000 lb of an individual designated chemical or chemical category
OR
Is among facilities grouped into Standard Industrial Classification Codes 20–39
OR
Is a federal facility ordered to report by August 1995 President Clinton executive decree.

2.8. Clean Water Act (CWA)

The 1972 Water Pollution Control Act, the 1977 Clean Water Act amendments, and the 1987 reauthorization of the Clean Water Act provide the basis for regulation of discharges to receiving water bodies in the United States. Both point sources, discharges such as a pipe or channel, and nonpoint sources, such as runoff from fields or parking lots, are regulated by the Clean Water Act. Both direct dischargers and dischargers to a municipal treatment works must obtain National Pollution Discharge Elimination System (NPDES) permits that govern the character of pollutants in waste streams and mandatory control technologies (EPA OW 1998).

The objectives of the CWA were to achieve fishable and swimmable waters and to eliminate the discharge of pollutants into navigable waterways. To achieve these goals, industries were required to meet performance standards for pollutant emissions, states were charged with developing criteria for their waterways as well as programs to protect them, funding was provided for the construction of public wastewater treatment plants and other technologies to mitigate discharges, and development was regulated via a permit process to protect wetlands and minimize impacts on water resources.

In addition to the permit requirements of the 1977 amendments, the 1987 amendments permitted citizen suits that allowed any individual to bring a legal suit against any party believed to be in conflict with the provisions of the CWA. Citizen suits were also permitted against any party responsible for the enforcement and administration of the CWA that was believed derelict in its responsibilities. This expanded the responsibility of clean water enforcement to include the public as well as government bodies.

3. COMPLYING WITH ENVIRONMENTAL LAWS

3.1. Overview

In the early 1970s, compliance with environmental regulations by most industrial entities was not a top priority. Indeed, some major corporations brought lawsuits and attempted to lessen the impact of the regulations. However, in the intervening years, continued research on the human health effects of water and air pollution has resulted in a heightened awareness of their deleterious impact on the human system. As a result, compliance with environmental regulations is now the norm rather than the exception for the industrial sector. An example of this is the tightening of the ambient air quality standards for particulates over the years. In the early years, dustfall buckets (measured particulates >40 μm diameter) and total suspended particulates (measured particulates <40 μm diameter) were targeted by the NAAQS. Human health research indicated that finer particulates (10 μm and less), which penetrate deeper into the human respiratory system, are more harmful than the larger particulate matter. Fine particulate matter has a much greater surface area-to-volume ratio relative to larger particulate matter, which allows the fine particulate matter to adsorb and absorb hazardous volatile substances and carry them deep into the human lung. This "piggyback" effect of fine particulate matter with hazardous air pollutants has resulted in the diameter of the particulate standard being reduced over the years. The current NAAQS standard for fine particulate matter is PM-10, which means particles less than or equal to 10 μm. But a PM-2.5 NAAQS standard has been proposed by the EPA and awaits promulgation at the time of writing.

3.2. Permits

3.2.1. Air Permits

One of the provisions of the 1970 Clean Air Act initiated the requirement for air pollution sources to obtain a permit for construction of the source and a permit to operate it. The construction permit application must be completed prior to the initiation of construction of any air pollution source. Failure to do so could result in a $25,000 per day fine. In some states, initiation of construction was interpreted as issuance of a purchase order for a piece of equipment; in others, groundbreaking for the new construction. Therefore, to ensure compliance with the air permit requirement, this author suggests that completion of the air permit be given first priority in any project involving air emissions into the atmosphere. The best practice is to have the state-approved permit in hand before beginning construction. Most states have their permit forms on the Internet, and a hard copy can be downloaded. Alternatively, the permit forms can be filled out electronically and submitted.

Recently, many states have offered the option of allowing an air pollution source to begin construction prior to obtaining the approved construction permit. However, the required paperwork is not trivial, and it may still be easier to fill out the permit form unless extenuating circumstances demand that construction begin before the approved permit is in hand. The caveat is the state could disapprove the construction (which the company has already begun) if, after reviewing the permit application, the state disagrees with the engineering approach taken to control the air pollution.

3.2.2. Water Permits

Any person discharging a pollutant from a point source must have a National Pollution Discharge Elimination System (NPDES) permit. This applies to persons discharging both to a public treatment works or directly to a receiving water body. These permits will limit the type of pollutants that can be discharged and state the type of monitoring and reporting requirements and other provisions to prevent damage to the receiving body or treatment facility. In most states, the state department of environmental quality is responsible for issuing permits. In states that have not received approval to issue NPDES permits, you should contact the regional EPA office.

Wastewater permits that regulate the discharge of many pollutants can be broken down into the general categories of conventional, toxic, and nonconventional. Conventional pollutants are those contained in typical sanitary waste such as human waste, sink disposal waste, and bathwater. Conventional wastes include fecal coliform and oil and grease. Fecal coliform is present in the digestive tracts of mammals, and its presence is commonly used as a surrogate to detect the presence of pathogenic organisms. Oils and greases such as waxes and hydrocarbons can produce sludges that are difficult and thus costly to treat. Toxic pollutants are typically subdivided into organics and metals. Organic toxins include herbicides, pesticides, polychlorinated biphenyls, and dioxins. Nonconventional pollutants include nutrients such as phosphorus and nitrogen, both of which can contribute to algal blooms in receiving waters.

The EPA maintains many databases of environmental regulatory data. Among these is the Permit Compliance System (PCS) database http://www.epa.gov/enviro/html/ pcs/pcs_query_java.html. This database provides many of the details governing a facility's wastewater discharges. Specific limitations typically depend on the classification and flow of the stream to which a facility is discharging. Surface waters are classified as to their intended use (recreation, water supply, fishing, etc.), and then the relevant conditions to support those uses must be maintained. Discharge limitations are then set so that pollution will not exceed these criteria.

Total suspended solids, pH, temperature, flow, and oils and grease are typical measures that must be reported. In the case of a secondary sewage treatment, the minimum standards for BOD_5, suspended solids, and pH over a 30-day averaging period are 30 mg/L, 30 mg/L, and 6–9 pH, respectively. In practice, these limits will be more stringent, and in many cases there will be separate conditions for summer and winter conditions as well as case-by-case limitations.

4. ESTIMATING PLANT-WIDE EMISSIONS

4.1. Overview

A part of the overall air pollution requirements is an annual emissions inventory to be submitted to the state in which the source resides. This inventory identifies and quantifies all significant atmospheric discharges from the respective industrial plant. Most states now have this inventory in electronic form and require submission electronically. The Indiana Department of Environmental Management uses a commercial package called i-STEPS, which is an automated tool for storing, reporting, and managing air emissions data. i-STEPS facilitates data compilation for pollution management and reporting emissions data to government agencies.*

4.2. Estimating Methods

4.2.1. Mass Balance

From an engineering viewpoint, the most direct way to estimate pollution emissions from an industrial plant is by mass balance. The concept is ''mass in = mass out''—that is, everything the purchasing department buys and is delivered to the plant must somehow leave the plant, whether within the manufactured product; as solid waste to a landfill; as air emissions either through a stack or vent; or as liquid waste either to an on-site treatment plant or to the sewer and the municipal wastewater treatment plant.

* i-STEPs Environmental Software is available from Pacific Environmental Services, Inc., 5001 South Miami Boulevard; Suite 300, P.O. Box 12077, Research Triangle Park, NC 27709-2077, www.i-steps.com.

The mass balance approach, however, does not necessarily yield exceptional accuracy. Accuracy is a function of understanding the way in which a particular feed stock or raw material is used and how much of it is released to the atmosphere or perhaps transformed in the process. The mass balance approach would probably be used if measured parameters were not available, such as stack emission data and wastewater effluent data.

An example where a mass balance approach would yield inaccurate emissions to the atmosphere would be an industrial resin coating line. This process uses an organic carrier solvent, such as ethanol, which is volatized from the resin solids in a drying oven. The vapors (volatile organic compounds [VOCs]) are then incinerated. The ethanol can be transformed into other organic compounds in the incinerator. The total mass of applied carrier solvent (ethanol) would not be accounted for in the incinerator exhaust gas stream due to its transformation into other organic compounds.

4.2.2. Emission Factors

Emission factors are unique to the air pollution field. They are usually based on stack emission test data for a specific process and are presented as a ratio of two flow rates. The numerator is the mass flow rate of the air pollutant parameter and the denominator is the flow rate of the process or manufactured product. In the spraypainting of automobiles, for example, the carrier solvent in the paint (VOC) is released to the atmosphere as the paint is dried in an oven. A stack test quantifies the amount of paint VOC released during the painting of some quantity of autos. The resulting VOC emission factor would be lb-VOC/hr divided by # of autos/hr painted. Note that the hour (hr) unit cancels and the emission factor is expressed as lb-VOC/# autos.

The U.S. Environmental Protection Agency publishes AP-42, a well-known compilation of air pollutant emission factors that contains emission factors for many industrial process and manufacturing operations (EPA AP-42 1995).

To illustrate the use of an emission factor, let us turn to the fish-canning industry. From AP-42, section 9.13.1-7 and Table 3, entitled "Uncontrolled Emission Factors for Fish Canning and By-product Manufacture," emission factors are shown for particulate emissions, trimethylamine (fish odor), and hydrogen sulfide (rotten egg odor). Emissions from the fish scrap cookers for both fresh fish and stale fish are shown. Notice that the particulate emissions are negligible for the cookers. Trimethylamine (fish odor) has an emission factor of 0.3 lb-trimethylamine/ton of fresh fish cooked. If we are cooking 5 tons of fresh fish/hr, then the uncontrolled fish odor emission to the atmosphere is 0.3 lb-trimethylamine/ton of fresh fish cooked $\times$ 5 tons of fresh fish/hr = 1.5 lb-trimethylamine/hr. Since the chemical responsible for typical fish odor is trimethylamine, 1.5 lb/hr will certainly be noticed by residents' noses downwind of the plant.

For hydrogen sulfide (H_2S, rotten egg odor), the uncontrolled atmospheric emission factor is 0.01 lb-H_2S/ton of fresh fish cooked. If we are cooking 5 tons of fresh fish/hr, then the uncontrolled H_2S odor to the atmosphere is 0.01 lb-H_2S/ton cooked fresh fish $\times$ 5 tons cooked fresh fish/hr = 0.05 lb-H_2S/hr. It is interesting to note that if the cooking fish is stale, not fresh, the trimethylamine emission is over 10 times higher. Similarly, for the hydrogen sulfide, if the fish is stale, the hydrogen sulfide emission is 20 times greater. With the concept of the emission factor, uncontrolled emissions

TABLE 3 Uncontrolled Emission Factors for Fish Canning and Byproduct Manufacture[a]

EMISSION FACTOR RATING: C

	Particulate		Trimethylamine [$(CH_3)_3N$]		Hydrogen Sulfide (H_2S)	
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Cookers, canning (SCC 3-02-012-04)	Neg	Neg	–[c]	–[c]	–[c]	–[c]
Cookers, scrap						
Fresh fish (SCC 3-02-012-01)	Neg	Neg	0.15[c]	0.3[c]	0.005[c]	0.01[c]
Stale fish (SCC 3-02-012-02)	Neg	Neg	1.75[c]	3.5[c]	0.10[c]	0.2[c]
Steam tube dryer (SCC 3-02-012-05)	2.5	5	–[b]	–[b]	–[b]	–[b]
Direct-fired dryer (SCC 3-02-012-06)	4	8	–[b]	–[b]	–[b]	–[b]

[a] From Prokop (1992). Factors are in terms of raw fish processed. SCC = Source Classification Code. Neg = negligible.
[b] Emissions suspected, but data are not available for quantification.
[c] Summer (1963).

from fish cookers can be estimated without costly measurements. The expected accuracy of the estimate is alluded to at the top of the table as having an emission factor rating of C. This means that on a scale of A to E, with A being the relative best estimate, the C rating is mediocre. It is important to refer to the references associated with each emission factor so a value judgment can be made when using the factor.

5. TOTAL-ENCLOSURE CONCEPT FOR FUGITIVE AIR EMISSIONS

Most if not all industrial operations result in the generation of air pollution emissions to the atmosphere. The emissions may be partially captured by a ventilation hood and be taken to an oven, incinerator, baghouse, or other air pollution control device. The air pollutants not captured by the ventilation hood escape into the workplace and are referred to as fugitive emissions. These fugitive emissions eventually reach the outdoor atmosphere either through roof ventilation fans, open windows, doors, or exfiltration through the walls of the building structure itself. Ultimately, all the air pollutants generated by the industrial process reach the outdoor atmosphere. For this reason, the EPA and state regulatory agencies require an industrial process that generates air pollutants to be mass-balance tested prior to approving an air pollution operating permit. In other words, either the fugitive emissions must be quantified and figured in the overall destruction and removal efficiency (DRE) of the air pollution controls or it must be demonstrated that the ventilation hood(s) form a 100% permanent total enclosure of the pollutants. With 100% permanent total enclosure demonstrated, it is known that all air pollutants generated by the process are captured by the hood(s) or enclosure and taken to the ‘‘as-designed’’ air pollution control device, whether it be an integral oven, external incinerator, baghouse filter, electrostatic precipitator, or some other tail gas cleanup device.

5.1. Criteria for 100% Permanent Total Enclosure of Air Pollutants

The United States Environmental Protection Agency has developed a criterion for determining 100% total enclosure for an industrial operation, EPA method 204 (EPA M204 2000). It requires that a series of criteria be met in order for a ventilation hooded industrial process to qualify as 100% permanent total enclosure. These criteria are:

1. The total area of all natural draft openings (NDOs) must be less than 5% of the total surface area of the enclosure.
2. The pollutant source must be at least four equivalent diameters away from any natural draft opening (NDO). The equivalent diameter is defined as $2(LW)/(L + W)$, where L is the length of the slot and W is the width.
3. The static pressure just inside each of the NDOs must be no less than a negative pressure of 0.007 in. of water.
4. The direction of flow must be into the enclosure as demonstrated by a device such as a smoke tube.

6. GREEN ENGINEERING

While many of the earlier legislative efforts were oriented toward ‘‘end-of-pipe’’ technologies, where pollution was captured and disposed of after being generated, the focus is now shifting to legislation that favors recycling, reuse, and reduction of waste generation. The problem with end-of-pipe technologies is that frequently the waste product, while no longer in the air, water, or earth, must still be disposed of in some manner. If a product is designed from its inception with the goal of reducing or eliminating waste not only during the production phase but also for its total life cycle, from product delivery to salvage, resources can be greatly conserved. This philosophy results in the design concept of ‘‘cradle to reincarnation’’ rather than ‘‘cradle to grave’’ because no well-designed product is ever disposed of—it is recycled (Graedel et al. 1995). Many phrases have been adopted into the expanding lexicon of green engineering. Total cost assessment (TCA), design for the environment (DFE), design for recycling (DFR), and life-cycle assessment are some of the many phrases that summarize efforts to look beyond the traditional design scope when designing and manufacturing a product.

6.1. Product Design

There is a threshold for the economic feasibility of recycling. If only a small portion of a product is recyclable or if great effort is required to extract the recyclable materials, then it may not be economically feasible to recycle a product. If, however, the product is designed to be largely recyclable and is designed in a manner that facilitates easy removal, then reuse and recycling will be economically reasonable. Consider the personal computer. The rapid rate at which computing power has expanded has resulted in a proportionate turnover in computers in the workplace. However, no such improvement in computer externals has accompanied that in computer internals, so last year’s computer case could in theory hold this year’s computer processor, motherboard, memory, and so on.

TABLE 4 Elements of Designing for Recycling

Element	Rationale
Minimize variety of materials	Multiple material types require more separation processes, thus increasing the cost of recycling.
Minimize use of toxics	Toxins must be removed prior to product reuse or recycling.
Do not plate plastics with metal.	Reduces the value of scrap plastic, may prevent recycling.
Place parts that are frequently improved and parts that frequently fail in accessible areas and make them easy to replace.	Designing a product that can be upgraded and easily repaired reduces the need for totally new products.
Use molded labels and details rather than adhesive labels or printed inks.	Adhesive labels and printed text must be removed prior to recycling.
Avoid polymeric materials with similar specific gravity to plastics used in product.	Gravimetric separation methods may be complicated or negated if incompatible materials with similar specific gravities are used.

The computer is an excellent example where design for recycling could be applied. While the elements in Table 4 are based on computer and electronic production, similar principles can be adopted for other processes.

6.2. Process Design

In many cases, recycling of process material streams is both environmentally and economically sound. While efforts to minimize the use of hazardous air pollutants (HAPs) such as toluene and xylene continue, some applications, such as cleanup solvents for spraypainting, still require the properties of HAP-containing solvents. However, HAP emissions can be minimized through the use of solvent-recovery systems. These systems reduce emissions to the atmosphere, thus reducing permitting costs, and they also reduce purchasing costs by reducing the total volume of virgin cleanup solvent necessary.

In other cases, waste minimization technologies can result in enhanced product quality. A continuous process data analysis system is one example. Rather than operator experience and intuition guiding when to cycle a process bath, computer analysis can be instituted to monitor key indicators of the process solution and automatically adjust the bath conditions. The result can be longer bath life, a more consistent product, and greater product engineer confidence (Dickinson 1995).

6.3. Total Cost Analysis

In some cases, an immediate benefit from a process change or recycling effort will not be evident. Any number of organizational, legal, or economic obstacles could distort the analysis of process options. Alternative budgeting and accounting methods are necessary to provide a more holistic perception of the process alternatives. Total cost analysis assesses the potential profitability of a green engineering proposal with several key differences from traditional methods. These differences are (White and Savage 1999):

1. Included in the inventory of costs, savings, and revenues are compliance training, testing, liability, and product and corporate image.
2. Rather than being lumped into overhead accounts, specific costs and savings are placed into process and product lines.
3. Longer time horizons are used to capture longer-term benefits.
4. Profitability indicators capable of incorporating the time value of money, long-term costs, and savings are used.

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