AIR POLLUTION CONTROL EQUIPMENT CALCULATIONS

Louis Theodore

An Introduction by
Humberto Bravo Alvarez

WILEY

A JOHN WILEY & SONS, INC., PUBLICATION

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TO

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a true patriot
AND
THE O'REILLY FACTOR
for battling the enemy from within
and
helping protect/represent the silent majority

CONTENTS

NOTE

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PREFACE

I fear the Greeks, even when bearing gifts.

—Virgil (70–19 B.C.), *Aeneid*, Book II

In the last four decades, the technical community has expanded its responsibilities to society to include the environment, with particular emphasis on air pollution from industrial sources. Increasing numbers of engineers, technicians, and maintenance personnel are being confronted with problems in this most important area. The environmental engineer and scientist of today and tomorrow must develop a proficiency and an improved understanding of air pollution control equipment in order to cope with these challenges.

This book serves two purposes. It may be used as a textbook for engineering students in an air pollution course. It may also be used as a reference book for practicing engineers, scientists, and technicians involved with air pollution control equipment. For this audience, it is assumed that the reader has already taken basic courses in physics and chemistry, and should have a minimum background in mathematics through calculus. The author's aim is to offer the reader the fundamentals of air pollution control equipment with appropriate practical applications and to provide an introduction to design principles. The reader is encouraged through references to continue his or her own development beyond the scope of the presented material.

As is usually the case in preparing any text, the question of what to include and what to omit has been particularly difficult. However, the problems and solutions in this book attempt to address calculations common to both the science and engineering professions. The book provides the reader with nearly 500 solved problems in the air pollution control equipment field. Of the 12 chapters, 4 are concerned with gaseous control equipment and 6 with airborne particulate pollutants. The interrelationship between both classes of pollutants is emphasized in many of the chapters, Each chapter contains a number of problems, with each set containing anywhere from 30 to 50 problems and solutions.

As indicated above, the book is essentially divided into two major parts: air pollution control equipment for gaseous pollutants (Chapters 3–6), and control equipment for particulate pollutants (Chapters 7–12). Following two introductory chapters, the next four chapters examine control equipment for gaseous pollutants, including incineration, absorption, and adsorption. The last six chapters are devoted to gravity settlers, cyclones, electrostatic precipitators, scrubbers, and baghouses. Each chapter contains a short introduction to the control device, which is followed by problems dealing with performance equations, operation and maintenance, and recent developments. The Appendix contains writeups on hybrid systems, the SI system (including conversion constants), and a cost equipment model.

This project was a unique undertaking. Rather than prepare a textbook in the usual format—essay material, illustrative examples, nomenclature, bibliography, problems, and so on—the author considered writing a calculations book that could be used as a self-teaching aid. One of the key features of this book is that the solutions to the problems are presented in a near stand-alone manner. Throughout the book, the problems are laid out in such a way as to develop the reader's understanding of the control device in question; each problem contains a title, problem statement and data, and the solution, with the more difficult problems located at or near the end of each chapter set. (Additional problems and solutions are available at a Website for all readers, but particularly for classroom/training purposes.) Thus, this book offers material not only to individuals with limited technical background but also to those with extensive industrial experience. As such, this book can be used as a text in either a general environmental and engineering science course and (perhaps primarily) as a training tool for industry.

Knowledge of the information developed and presented in the various chapters is essential not only to the design and selection of industrial control equipment for atmospheric pollutants but also to their proper operation and maintenance. It will enable the reader to obtain a better understanding of both the equipment itself and those factors affecting equipment performance.

Hopefully, the text is simple, clear, to the point, and imparts a basic understanding of the theory and mechanics of the calculations and applications. It is also hoped that a meticulously accurate, articulate, and practical writing style has helped master the difficult task of explaining what was once a very complicated subject matter in a way that is easily understood. The author feels that this delineates this text from others in this field.

The author cannot claim sole authorship to all the problems and material in this book. The present book has evolved from a host of sources, including notes, homework problems, and exam problems prepared by J. Jeris for graduate environmental engineering courses; notes, homework problems, and exam problems prepared by L. Theodore for several chemical and environmental engineering graduate and undergraduate courses; problems and solutions drawn (with permission) from numerous Theodore Tutorials; and, problems and solutions developed by faculty participants during National Science Foundation (NSF) Undergraduate Faculty Enhancement Program (UFEP) workshops.

During the preparation of this book, the author was ably assisted in many ways by a number of graduate students in Manhattan College's Chemical Engineering Master's Program. These students, particularly Agogho Pedro and Alex Santos, contributed much time and energy researching and classroom testing various problems in the book.

My sincere thanks go to Anna Daversa, Andrea Paciga, and Kevin Singer for their invaluable help and assistance in proofing the manuscript.

Louis Theodore

April 2008

INTRODUCTION

By Humberto Bravo Alvarez

Two fundamental reasons for the cleaning of gases in industry, particularly waste gases, are *profit* and *protection*. For example, profits may result from the utilization of blast furnace gases for heating and power generation, but impurities may have to be removed from the gases before they can be burned satisfactorily. Some impurities can be economically converted into sulfur, or solvent recovery systems can be installed to recover valuable hydrocarbon emissions. Protection of the health and welfare of the public in general, of the individual working in industry, and of property is another reason for cleaning gases.

The enactment of air pollution control regulations (see Chapter 2) reflects the concern of government for the protection of its people. For example, waste gases containing toxic constituents such as arsenic or lead fumes constitute a serious danger to the health of both plant operators and the surrounding population. Other waste gases, although not normally endangering health in the concentrations encountered, may kill plants, damage paintwork and buildings, or discolor wallpaper and curtains, thus making an industrial location a less pleasant area in which to live.

The extent to which industry cleans polluted gas streams depends largely on the limits imposed by four main considerations:

1. Concentration levels harmful to humans, physical structures, and plant and animal life

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2. Legal limitations imposed by the country, state, county, or city for the protection of the public health and welfare
3. Reduction of air pollution to establish civic goodwill
4. The reduction and/or elimination of potential liability concerns

These considerations are not necessarily independent. For example, the legal limits on emissions are also closely related to the degree of cost needed to prevent concentrations that can damage the ecosystem.

Earth is a huge sphere covered with water, rock, and soil, and is surrounded by a mixture of gases. These gases are generally referred to as *air*. Earth's gravity holds this blanket of air—the atmosphere—in place. Without gravity, these gases would drift into space. Pristine or "clean" air, which is found in few (if any) places on Earth, is approximately composed of nitrogen (78.1%), oxygen (20.9%), argon (0.9%), and other components (0.1%). Other components include carbon dioxide [330 parts per million by volume (ppmv)], neon (18 ppmv), helium (5 ppmv), methane (1.5 ppmv), and very small amounts (less than 1.0 ppmv) of other gases. Air can also include water droplets, ice crystals, and dust, but they are not considered part of the composition of the air. Also, the nitrogen, oxygen, etc., content of air almost always refers to the composition of dry air at ground level.

The aforementioned air pollutants may be divided into two broad categories, *natural* and *human-made* (synthetic). Natural sources of air pollutants include the following:

1. Windblown dust
2. Volcanic ash and gases
3. Ozone from lightning and the ozone layer
4. Esters and terpenes from vegetation
5. Smoke, gases, and fly ash from forest fires
6. Pollens and other aeroallergens
7. Gases and odors from natural decompositions
8. Natural radioactivity

Such sources constitute background pollution and that portion of the pollution problem over which control activities can have little, if any, effect. Human-made sources cover a wide spectrum of chemical and physical activities, and are the major contributors to urban air pollution. Air pollutants in the United States pour out from over 100 million vehicles, from the refuse of 300 million people, from the generation of billions of kilowatts of electricity, and from the production of innumerable products demanded by everyday living.

Air pollutants may also be classified by *origin* and *state of matter*. Under the classification by origin, the following subdivisions pertain: *primary*—emitted to the atmosphere from a process; and *secondary*—formed in the atmosphere as a result of a chemical reaction. Under the state of matter, there exist the classifications *particulate* and *gaseous*. Although gases need no introduction, particulates have been defined as solid or liquid matter whose effective diameter is larger than a molecule but smaller than approximately 1000 μm (micrometers). Particulates dispersed in a gaseous medium may be collectively termed an *aerosol*. The terms *smoke*, *fog*, *haze*, and *dust* are commonly used to describe particular types of aerosols, depending on the size, shape, and characteristic behavior of the dispersed particles. Aerosols are rather difficult to classify on a scientific basis in terms of their fundamental properties such as their settling rate under the influence of external forces, optical activity, ability to absorb electric charge, particle size and structure, surface-to-volume ratio, reaction activity, physiological action, etc. In general, the combination of particle size and settling rate has been the most characteristic properties employed. For example, particles larger than 100 μm may be excluded from the category of dispersions because they settle too rapidly. On the other hand, particles on the order of 1 μm or less settle so slowly that, for all practical purposes, they are regarded as permanent suspensions.

When a liquid or solid substance is emitted to the air as particulate matter, its properties and effects may be changed. As a substance is broken up into smaller and smaller particles, more of its surface area is exposed to the air. Under these circumstances, the substance—whatever its chemical composition—tends to physically or chemically combine with other particulates or gases in the atmosphere. The resulting combinations are frequently unpredictable. Very small aerosol particles ranging from 1.0 to 150 nm (nanometers) can act as condensation nuclei to facilitate the condensation of water vapor, thus promoting the formation of fog and ground mist. Particles less than 2 or 3 μm in size—about half (by weight) of the particles suspended in urban air—can penetrate into mucous membranes and attract and convey harmful chemicals such as sulfur dioxide. By virtue of the increased surface area of the small aerosol particles, and as a result of the adsorption of gas molecules or other such activities that are able to facilitate chemical reactions, aerosols tend to exhibit greatly enhanced surface activity.

Many substances that oxidize slowly in a given state can oxidize extremely rapidly or possibly even explode when dispersed as fine particles in air. Dust explosions, for example, are often caused by the unstable burning or oxidation of combustible particles, brought about by their relatively large specific surfaces. Adsorption and catalytic phenomena can also be extremely important in analyzing and understanding particulate pollution problems. For example, the conversion of sulfur dioxide to corrosive sulfuric acid assisted by the catalytic action of iron oxide particles, demonstrates the catalytic nature of certain types of particles in the atmosphere.

The technology of control (as it applies to this book) consists of all the sciences and techniques that can be brought to bear on the problem via air pollution control equipment. These include the analysis and research that enter into determinations of technological and economic feasibility, planning, and standard-setting, as well as the application of specific hardware, fuels, and materials of construction. Technology also includes the process of evaluating and upgrading the effectiveness of air pollution control practices.

At the heart of the control strategy process is the selection of the best air pollution control measures from among those available. To eliminate or reduce emissions from a polluting operation, four major courses of action are open:

1. Eliminate the operation
2. Regulate the location of the operation

3. Modify the operation
4. Reduce or eliminate discharges from the operation by applying control devices and systems

The ability to achieve an acceptable atmosphere in a community often requires a combination of these measures aimed at all or a major fraction of the contaminant sources within any control jurisdiction.

Control technology is self-defeating if it creates undesirable side effects in meeting (limited) air pollution control objectives. Air pollution control should be considered in terms of both the total technological system and ecological consequences. The former considers the technology that can be brought to bear on not only individual pieces of equipment but also the entire technological system. Consideration of ecological side effects must also take into account, e.g., the problem of disposal of possibly unmanageable accumulations of contaminants by other means. These may be concentrated in the collection process, such as groundwater pollution resulting from landfill practices or pollution of streams from the discharges of air pollution control systems.

Gaseous and particulate pollutants discharged into the atmosphere can be controlled. The five generic devices available for particulate control include gravity settlers, cyclones (centrifugal separators), electrostatic precipitators, wet scrubbers, and baghouses (fabric filtration). The four generic devices for gases include absorbers, adsorbers, and enumerators. These control devices are discussed in individual chapters later in the text.

There are a number of factors to be considered prior to selecting a particular piece of air pollution control hardware. In general, they can be grouped in three categories: environmental, engineering, and economic. These three categories are discussed below.

1. Environmental
   a. Equipment location
   b. Available space
   c. Ambient conditions
   d. Availability of adequate utilities (power, compressed air, water, etc.) and ancillary systems facilities (waste treatment and disposal, etc.)
   e. Maximum allowable emission (air pollution codes)
   f. Aesthetic considerations (visible steam or water vapor plume, etc.)
   g. Contribution of air pollution control system to wastewater and land pollution
   h. Contribution of air pollution control system to plant noise level
2. Engineering
   a. Contaminant characteristics [physical and chemical properties, concentration, particulate shape and size distribution (in the case of particulates), chemical reactivity, corrosivity, abrasiveness, toxicity, etc.]

   b. Gas stream characteristics (volumetric flow rate, temperature, pressure, humidity, composition, viscosity, density, reactivity, combustibility, corrosivity, toxicity, etc.)
   c. Design and performance characteristics of the particular control system [size and/or weight fractional efficiency curves (in the case of particulates), mass transfer and/or contaminant destruction capability (in the case of gases or vapors), pressure drop, reliability and dependability, turndown capability, power requirements, utility requirements, temperature limitations, maintenance requirements, flexibility of complying with more stringent air pollution codes, etc.]
3. Economic
   a. Capital cost (equipment, installation, engineering, etc.)
   b. Operating cost (utilities, maintenance, etc.)
   c. Expected equipment lifetime and salvage value

Prior to the purchase of control equipment, experience has shown that the following points should be emphasized:

1. Refrain from purchasing any control equipment without reviewing *certified independent test data* on its performance under a similar application. Request the manufacturer to provide performance information and design specifications.
2. In the event that sufficient performance data are unavailable, request that the equipment supplier provide a small pilot model for evaluation under existing conditions.
3. Request participation of the appropriate regulatory authorities in the decision-making process.
4. Prepare a good set of specifications. Include a *strong performance guarantee* from the manufacturer to ensure that the control equipment will meet all applicable local, state, and federal codes/regulations at specific process conditions.
5. Closely review the process and economic fundamentals. Assess the possibility for emission trade-offs (offsets) and/or applying the "bubble concept" (see Chapter 2). The bubble concept permits a plant to find the most efficient way to control its emissions as a whole. Reductions at a source where emissions can be lessened for the least cost can offset emissions of the same pollutant from another source in the plant.
6. Make a careful material balance study before authorizing an emission test or purchasing control equipment.
7. Refrain from purchasing any equipment until *firm* installation cost estimates have been added to the equipment cost. *Escalating installation costs are the rule rather than the exception.*
8. Give operation and maintenance costs high priority on the list of equipment selection factors.

9. Refrain from purchasing any equipment until a solid commitment from the vendor(s) is obtained. Make every effort to ensure that the new system will utilize fuel, controllers, filters, motors, etc., that are compatible with those already available at the plant.
10. The specification should include written assurance of *prompt* technical assistance from the equipment supplier. This, together with a completely understandable operating manual (with parts list, full schematics, consistent units, and notations, etc.), is essential and is too often forgotten in the rush to get the equipment operating.
11. Schedules, particularly on projects being completed under a court order or consent judgment, can be critical. In such cases, delivery guarantees should be obtained from the manufacturers and penalties identified.
12. The air pollution equipment should be of fail-safe design with built-in indicators to show when performance is deteriorating.
13. Withhold 10–15% of the purchase price until compliance is clearly demonstrated.

The usual design, procurement, construction, and/or startup problems can be further compounded by any one or a combination of the following:

1. Unfamiliarity of process engineers with air pollution engineering
2. New and changing air pollution codes/regulations
3. New suppliers, frequently with unproven equipment
4. Lack of industry standards in some key areas
5. Interpretations of control by agency field personnel
6. Compliance schedules that are too tight
7. Vague specifications
8. Weak guarantees for the new control equipment
9. Unreliable delivery schedules
10. Process reliability problems

Proper selection of a particular system for a specific application can be extremely difficult and complicated. In view of the multitude of complex and often ambiguous pollution control regulations, it is in the best interest of the prospective user (as noted above) to work closely with regulatory officials as early as possible in the process.

The final choice in equipment selection is usually dictated by that piece of equipment capable of achieving compliance with regulatory codes at the lowest uniform annual cost (amortized capital investment plus operation and maintenance costs). More recently, there have been attempts to include liability problems, neighbor/consumer goodwill, employee concerns, etc., in the economic analysis, but these effects—although important—are extremely difficult to quantify.

In order to compare specific control equipment alternatives, knowledge of the particular application and site is also essential. A preliminary screening, however, may be performed by reviewing the advantages and disadvantages of each type of air pollution control equipment. For example, if water or a waste treatment system is not available at the site, this may preclude the use of a wet scrubber system and instead focus particulate removal on dry systems such as cyclones, baghouses, and/or electrostatic precipitators. If auxiliary fuel is unavailable on a continuous basis, it may not be possible to combust organic pollutant vapors in an incineration system. If the particulate-size distribution in the gas stream is relatively fine, gravity settlers and cyclone collectors most probably would not be considered. If the pollutant vapors can be reused in the process, control efforts may be directed to adsorption systems. There are many other situations where knowledge of the capabilities of the various control options, combined with common sense, will simplify the selection process.

1

AIR POLLUTION HISTORY

BANG! The Big Bang. In 1948 physicist George Gamow proposed the Big Bang theory on the origin of the universe. He believed that the universe was created in a gigantic explosion as all mass and energy were created in an instant of time. On the basis of this thesis, estimates on the age of the universe at the present time range between 7 and 20 billion years with 12 billion years often mentioned as the age of planet Earth.

Gamow further believed that the various elements present today were produced within the first few minutes after the Big Bang when near-infinitely high temperatures fused subatomic particles into the chemical elements that now constitute the universe. More recent studies suggest that hydrogen and helium would have been the primary products of the Big Bang, with heavier elements being produced later within the stars. The extremely high density within the primeval atom caused the universe to expand rapidly. As it expanded, the hydrogen and helium cooled and condensed into stars and galaxies. This explains the expansion of the universe and the physical basis of Earth.

As noted in Dr. Bravo's Introduction, one might assume that the air surrounding Earth has always been composed primarily of nitrogen and oxygen, but that is not the case. Since Earth's atmosphere was first formed, its composition undoubtedly has undergone great changes. The "normal" composition of air today is not likely the same as it was when the first primitive living cells inhabited this planet. Some scientists believe that

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Earth's earliest atmosphere probably contained almost no free oxygen. The oxygen in today's atmosphere is probably the result of several million of years of photosynthesis.

Over the history of Earth, plants and animals have adapted—albeit very slowly—to changes in the environment. When environmental changes occur more rapidly than a species' ability to adapt, however, the species oftentimes either does not thrive or does not survive. Human contributions to environmental changes in recent history, e.g., global warming, have come relatively quickly compared to the natural rate of change, and Earth's and its inhabitants' natural adaptation capabilities might not be adequate to meet this challenge.

Air pollution has been around for a long time. Natural phenomena such as volcanoes, windstorms, forest fires, and decaying organic matter contribute substantial amounts of air pollutants. Plants and trees also emit organic vapors and particles. For the most part, Earth, which has a well-balanced natural "cleansing" system, is able to keep up with natural pollution.

Air pollution has bedeviled humanity since the first person discovered fire. However, humans did not significantly affect the environment until relatively recent times. This is due to two reasons: (1) the human population has been large for only a small part of recorded history, and (2) the bulk of human-made produced air pollution is intimately related to industrialization. In fact, humans did not begin to alter the environment until they began to live in communities.

From the fourteenth century until recently, the primary air pollutants have been released in industrialized areas. Unfortunately, the control of pollutants rarely takes place prior to public outcry, even though the technology for controlling pollutants may be available. Early recognition of pollutants as health hazards have not resulted in pollution reduction; traditionally, only when personal survival is at stake has effective action been taken.

During the reign of the English King Edward I (1271–1307), there was a protest by the nobility against the use of "sea" coal. In the succeeding reign of Edward II (1307–1327), a man was put to torture for filling the air with a "pestilential dust" resulting from the use of coal. Under Richard III (1377–1399), and later under Henry V (1413–1422), England took steps to regulate and restrict the use of coal. Both taxation and regulation of the movement of coal in London were employed. Other legislations, parliamentary studies, and literary comments appeared sporadically during the next 250 years. In 1661, a pamphlet was published by the Royal Command of Charles II entitled "Fumifugium; or the Inconveniences of Air and Smoke in London Dissipated; Together with Some Remedies Humbly Proposed." The paper was written by John Evelyn, one of the founding fathers of the Royal Society. Later, in 1819, a Select Committee of the British Parliament was formed to study smoke abatement. As is the case of most civic actions, by the time the committee submitted its report, the problem had subsided and no action was taken.

Air pollution was a fact of life during the first half of the twentieth century. Comments such as "good, clear soot," "it's our lifeblood," "the smell of money," "an index to local activity and enterprise," and "God bless it" were used to describe air pollution. However, society began to realize that air pollution was a "deadly" problem. The term "smog" originated in Great Britain, where it was used to describe the over 1000 smoke–fog deaths that occurred in Glasgow, Scotland in 1909. The smoke problem in London reached its peak in December 1952; during this "air pollution episode" approximately 4000 people died, primarily of respiratory problems. In 1948, 20 people died and several hundred became ill in the industrial town of Donora, Pennsylvania. New York City, Birmingham, the entire state of Tennessee, Columbia River, St. Louis, Cincinnati, and Pittsburgh have had similar problems. Additional details of these often-referenced episodes are briefly summarized below.

1. On Friday December 5, 1952, static weather conditions turned the air of London, England into a deadly menace. A prolonged temperature inversion held in the city's air close to the ground and an anticyclonic high pressure system prevented the formation of winds that would have dispersed the pollutants that were accumulating heavily at ground level. For 5 days the greater London area was blanketed in airborne pollution. Few realized it at the time, but there were 4000 more deaths than normal for a 5-day period, hospital admissions were 48% higher, and sickness claims to the national health insurance system were 108% above the average, and 84% of those who died had preexisting heart or lung diseases. Hospital admissions for respiratory illness increased 3-fold, and deaths due to chronic respiratory disease increased 10-fold.
2. The same static atmospheric conditions in London caused a similar incident in Donora, Pennsylvania in 1948. A town of only 14,000, it had 15–20 more deaths than normal during the episode. More than 6000 of its residents were adversely affected, 10% of them seriously. Among those with preexisting illnesses, 88% of the asthmatics, 77% of those with heart diseases, and 79% of those with chronic bronchitis and emphysema, were adversely affected. Allowing for the difference in population, Donora paid a much higher price for air pollution than did London.
3. New York City has experienced similar periods of atmospheric stagnation on numerous occasions since the mid-1940s. During one such episode in 1953, the city reported more than 200 deaths above normal.
4. Birmingham, Alabama is another high-exposure area whose residents have frequently exhibited a greater than average incidence of respiratory irritation symptoms such as coughing, burning throats or lungs, and shortness of breath. EPA monitoring studies indicated that nonsmokers in these two cities developed respiratory symptoms 2 or 3 times more frequently than did nonsmokers in cleaner communities.
5. In the early 1900s, gases from short stacks at two copper smelters near the Georgia border of Tennessee caused widespread damage to vegetation in the surrounding countryside. When taller stacks were built, damage extended 30 miles into the forests of Georgia. An interstate suit resulted, which was finally carried to the United States Supreme Court. The problem was eventually solved by means of a byproduct sulfur dioxide recovery plant.
6. Two decades later, a similar case involved the lead and zinc smelter of the Consolidated Mining and Smelting Company of Canada at Trail, BC (British

> Columbia). The smelter was located on the west bank of the Columbia River, 11 miles north of the international boundary between Canada and the United States. When extensive damage to vegetation occurred on the U.S. side of the border, a damage suit was filed and finally settled by an international tribunal. In this case, after damages were assessed, the problem was solved partly by sulfur recovery and partly by operating the smelter according to a plan based on meteorological considerations.

Unfortunately, the climatic conditions and human activities that combine to form critical buildups of pollutants are by no means uncommon in the United States. They occur periodically in various parts of the country and will continue to threaten public health as long as air pollutants are emitted into the atmosphere in amounts sufficient to accumulate to dangerous levels.

Approximately 200 million tons of waste gases are released into the air annually. Regarding sources, slightly over half of the pollution comes from the internal-combustion engines of cars and other motor vehicles. Roughly 25% comes from fuel burned at stationary sources such as power-generating plants, and another 15% is emitted from industrial processes.

The average person breathes 35 lb of the air containing these discharges each day—6 times as much as the food and drink normally consumed in the same period of time. While low levels of air pollution can be detrimental or even deadly to the health of some people, extremely high levels can be detrimental to large numbers of people. Dangerously high concentrations of air pollutants can occur during *air pollution episodes* described above and *air pollution accidents* such as those that occurred in Flixborough (England), Seveso (Italy), Three Mile Island, Chernobyl, Bhopal, etc. (Details on these accidents are available in the text/reference book by A. M. Flynn and L. Theodore, *Health, Safety and Accident Management in the Chemical Process Industries*, CRC Press/Taylor & Francis, Boca Raton, FL, 2002.) These episodes and accidents continue to occur in various parts of the world, and are well documented.

Perhaps the federal government of the United States could have done more earlier to protect the land and resources as well as public health. But for most of the nineteenth century, the government was still a weak presence in most areas of the country. There was, moreover, no body of laws with which the government could assert its authority. By the end of that century there was a growing body of information about the harm being done and some new ideas on how to set things straight. Yet, there was no acceptable ethic that would impel people to treat the land, air, and water with wisdom and care.

As the nineteenth century was drawing to a close, three very special individuals made their entrance on the national stage. Gifford Pinchot, John Muir, and Theodore Roosevelt were to write the first pages of modern environmental history in the U.S., which in turn led to the birth of the modern environmental movement early in the twentieth century. The federal government ultimately entered into the environmental and conservation business in a significant and somewhat dramatic fashion when Teddy Roosevelt's second cousin Franklin entered the White House in 1933. It was his political ideology, as much as his love of nature, that led Roosevelt to include major conservation projects in his New Deal reforms. The Civilian Conservation

Corps, the Soil Conservation Service, and the Tennessee Valley Authority were among the many New Deal programs created to serve both the environment and the people.

At this point in time, muscle, animal, and steam power had been replaced by electricity, internal-combustion engines, and nuclear reactors. During this period, industry was consuming natural resources at an incredible rate. All of these events began to escalate at a dangerous rate after World War II. In 1962, a marine biologist named Rachel Carson, author of *Silent Spring* (Houghton-Mifflin, 1962), a best-selling book about ocean life, opened the eyes of the world to the dangers of ignoring the environment. It was perhaps at this point that America began calling in earnest for environmental reform and constraints on environmental degradation. Finally, in the 1970s, Congress began turning out environmental laws that addressed these issues. It all began in 1970 with the birth of the Environmental Protection Agency.

[For additional literature regarding early history and the environmental movement, the interested reader is referred to the book by Philip Shabecoff, titled *A Fierce Green Fire* (Farrar-Strauss-Giroux, 1993). This outstanding book is a "must" for anyone whose work is related to or is interested in the environment.]

2

AIR POLLUTION REGULATORY FRAMEWORK

2.1 INTRODUCTION

It is now 1970, a cornerstone year for modern environmental policy. The National Environmental Policy Act (NEPA), enacted on January 1, 1970, was considered a "political anomaly" by some. NEPA was not based on specific legislation; instead, it referred in a general manner to environmental and quality of life concerns. The Council for Environmental Quality (CEQ), created by NEPA, was one of the councils mandated to implement legislation. April 22, 1970 brought Earth Day, where thousands of demonstrators gathered all around the nation. NEPA and Earth Day were the beginning of a long, seemingly never-ending debate over environmental issues.

The Nixon Administration at that time became preoccupied with not only trying to pass more extensive environmental legislation but also implementing the laws. Nixon's White House Commission on Executive Reorganization proposed in the Reorganizational Plan 3 of 1970 that a single, independent agency be established, separate from the CEQ. The plan was sent to Congress by President Nixon on July 9, 1970, and this new US Environmental Protection Agency (EPA) began operation on December 2, 1970. The EPA was officially born.

In many ways, the EPA is the most far-reaching regulatory agency in the federal government because its authority is so broad. The EPA is charged by the Congress of the United States of America to protect the nation's land, air, and water systems. Under a mandate of national environmental laws, the EPA strives to formulate and implement actions that lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

The EPA works with the states and local governments to develop and implement comprehensive environmental programs. Amendments to federal legislations such as the Clean Air Act, the Safe Drinking Water Act, the Resource Conservation and Recovery Act, and the Comprehensive Environmental Response, Compensation and Liability Act, all mandate more involvement by state and local governments in the details of implementation.

This chapter presents the regulatory framework governing air management. It provides an overview of environmental laws and regulations used to protect human health and the environment from the potential hazards of air pollutants.

2.2 THE REGULATORY SYSTEM

Since the early 1970s, environmental regulations have become a system in which laws, regulations, and guidelines have become interrelated. Requirements and procedures developed under previously existing laws may be referenced to in more recent laws and regulations. The history and development of this regulatory system has led to laws that focus principally on only one environmental medium, i.e., air, water, or land. Some environmental managers feel that more needs to be done to manage all of the media simultaneously since they are interrelated. Hopefully, the environmental regulatory system will evolve into a truly integrated, multimedia management framework in the future.

Federal laws are the product of Congress. Regulations written to implement the law are promulgated by the Executive Branch of government, but until judicial decisions are made regarding the interpretations of the regulations, there may be uncertainty about what regulations mean in real situations. Until recently, environmental protection groups were more frequently the plaintiffs in cases brought to court seeking interpretation of the law. Today, industry has become more active in this role. Forum shopping, the process of finding a court that is more likely to be sympathetic to the plaintiffs' point of view, continues to be an important tool in this area of environmental regulation. Many environmental cases have been heard by the Circuit Court of the District of Columbia.

Enforcement approaches for environmental regulations are environmental management–oriented in that they seek to remedy environmental harm, not simply a specific infraction of a given regulation. All laws in a legal system may be used in enforcement to prevent damage or threats of damage to the environment or human health and safety. Tax laws (e.g., tax incentives) and business regulatory laws (e.g., product claims, liability disclosures) are examples of laws not directly focused on environmental protection, but that may also be used to encourage compliance and discourage noncompliance with environmental regulations.

Common law also plays an important role in environmental management. Common law is the set of rules and principles relating to the government and security of persons and property. Common law authority is derived from the usages and customs that are