AIR POLLUTION

Second Edition

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and

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WILEY-INTERSCIENCE

a division of John Wiley and Sons, Inc.

New York London Sydney Toronto

Library of Congress Cataloging in Publication Data

Faith, William Lawrence, 1907–
Air pollution.

(Environmental science and technology)
1959 ed. published under title: Air pollution control.
Includes bibliographies.
1. Air—Pollution. I. Atkisson, Arthur A., joint author. II. Title.
TD883.F23 1972 628.5'3 72–4225
ISBN 0–471–25320–0

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

SERIES PREFACE
Environmental Science and Technology

The Environmental Science and Technology Series of Monographs, Textbooks, and Advances is devoted to the study of the quality of the environment and to the technology of its conservation. Environmental science therefore relates to the chemical, physical, and biological changes in the environment through contamination or modification, to the physical nature and biological behavior of air, water, soil, food, and waste as they are affected by man's agricultural, industrial, and social activities, and to the application of science and technology to the control and improvement of environmental quality.

The deterioration of environmental quality, which began when man first collected into villages and utilized fire, has existed as a serious problem under the ever-increasing impacts of exponentially increasing population and of industrializing society. Environmental contamination of air, water, soil, and food has become a threat to the continued existence of many plant and animal communities of the ecosystem and many ultimately threaten the very survival of the human race.

It seems clear that if we are to preserve for future generations some semblance of the biological order of the world of the past and hope to improve on the deteriorating standards of urban public health, environmental science and technology must quickly come to play a dominant role in designing our social and industrial structure for tomorrow. Scientifically rigorous criteria of environmental quality must be developed. Based in part on these criteria, realistic standards must be established and our technological progress must be tailored to meet them. It is obvious that civilization will continue to require increasing amounts of fuel, transportation, industrial chemicals, fertilizers, pesticides, and countless other products and that it will continue to produce waste products of all descriptions. What is urgently needed is a total systems approach to modern civilization through which the pooled talents of scientists and engineers, in cooperation with social scientists and the medical profession, can be focused on the development of order and equilibrium to the presently disparate segments of the human environment. Most of the skills and tools that are needed are already in existence. Surely a technology that has created such manifold environmental problems is also capable of solving them. It is our hope that this Series in Environmental Sciences and Technology will not only serve to make this challenge more explicit to the established professional, but that it also will help to stimulate the student toward the career opportunities in this vital area.

ROBERT L. METCALF
JAMES N. PITTS, JR.

PREFACE

Since the publication of the first edition of this book in 1959, the pollution of man's environment has escalated in public importance and become an issue at the highest levels of government. New programs for control of air pollution sources have been organized, and countless citizens, legislators, engineers, scientists, planners, administrators, technicians, and law enforcement officials have become involved in the multidisciplinary field of air quality management.

This second edition has been prepared to meet the needs of these groups and also to serve the function of the first edition as a textbook for college air pollution courses. Like the first edition, it aims to give the reader an understanding of the types, origin, sources, atmospheric movement, and effects of air pollutants, and of the basic concepts and methods of air pollution control. Discussion of the socio-economic and legal constraints on community control programs has been expanded and new material has been included on the nature and components of effective air quality management programs.

The basic organization of the second edition is essentially the same as the first edition. Some chapters have been expanded, some rearranged for clarity, others redirected in their goals. All have been rewritten.

Chapter 2, "Meteorology" now places major emphasis on design and evaluation of tall stacks for air quality control. The chapters "Dusts, Fumes, and Mists," and "Gases" have been augmented by consideration of current air quality standards and suggested emission regulations. The chapter on "Automobile Exhaust" in the first edition has been updated and expanded into a chapter on "Transportation Sources." A parallel chapter on "Stationary Sources" has been added. This chapter describes the problems of specific industries and the state of the art with regard to means of control.

The treatment of photochemical smog has been removed from the transportation chapter and presented in a new chapter on "Photochemical Air Pollution." The treatment of radioactive pollutants has also been expanded.

New chapters have been added to deal with "The Social Origins of Air

Pollution" and the "Organization and Operations of Air Pollution Agencies." The first edition chapter on "Legal Aspects of Air Pollution Control" has been expanded and is presented here under the title, "Air Quality Management." The reader will find, however, that the legal aspects of air pollution control are discussed also in other sections of the book when appropriate to understanding of the focal subject.

Finally, pertinent tabular material and lists of literature citations have been revised and expanded so that the second edition may serve as a desktop reference for professionals in the field of air pollution control.

Because of its expanded coverage of the field and its broader focus on the many community factors that lead to the development of air pollution problems, we think this second edition will be of interest to students and professionals in the field of urban planning and design and to those with an interest in the management of urban affairs.

W. L. FAITH
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THE AIR POLLUTION PROBLEM

The first incidence of air pollution is lost in unrecorded history, but it certainly goes back to the discovery of fire. Undoubtedly, restricted meteorological conditions have occurred from time to time somewhere on the face of the earth since the beginning. Sooner or later, a brush or forest fire must have occurred in an area of restricted ventilation, with subsequent contamination of the air by a thick pall of smoke. Similarly, heavy fogs and sandstorms preceded the dawn of history. The worldwide polluted atmosphere that resulted from Krakatao's "blowing its top" in 1883 was the best known of similar explosions. Sulfide-laden gases emitted from hot springs or fissures in the earth have made life unbearable in restricted localities at one time or another. Although all these examples are of natural origin, they still produced polluted air.

When we think of the *air pollution problem,* however, we associate its source with some activity of man, whether it be farming, manufacturing, or just moving about in this world of ours. Practically all air is contaminated to some extent or other, so some reasonable definition of the term "air pollution" is a prerequisite to an orderly discussion.

Basically, air pollution is the presence of foreign substances in the air. An air pollution problem arises when the concentration of these substances interferes with the well-being of people. A more specific definition of air pollution has been developed by the Engineers Joint Council [9]:

> Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odor, smoke, or vapor, in quantities, of characteristics, and of duration such as to be injurious to human, plant or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property.

These interferences have been classified and are discussed later in this chapter.

The public has chosen the word *smog* to define objectionable air pollution. Originally the word was a contraction of *smoke* and *fog,* but recently it has become descriptive of any air pollution event accompanied by a decrease in visibility. In some cases it has been used to describe malodorous or vegetation-damaging conditions where visibility was no problem. To all intents and purposes, then, the words *smog* and *air pollution* may be considered synonymous.

NOTABLE AIR POLLUTION EPISODES

The London Smog

Historically, the longest record of intermittent air pollution problems belongs to the city of London, England. The notorious pea-soup fogs become particularly offensive when mixed with coal smoke. The word *smog* (smoke and fog) was coined to describe this foul condition.

Sir Hugh E. C. Beaver, Chairman of the Government Committee of Enquiry into the Nature, Causes, and Effects of Air Pollution, says in his review of the growth of public opinion [32]:

> It strikes a sympathetic chord, I think, to learn that 700 years ago almost to a year the then Queen of England moved out of the city to Nottingham where she was residing because of the insufferable smoke; and that some 300 years later the brewers of Westminster offered to use wood instead of coal because of Queen Elizabeth's allergy to coal smoke. But it was only about the end of her reign that feeling began to lead to action; and then there was a prohibition—probably ineffective—of the use of coal in London while Parliament was sitting.

In 1661, John Evelyn published his well-known pamphlet, *"Fumifugium: or The Inconvenience of the Aer and Smoake of London Dissipated."* His major recommendation was the removal of all smoke-producing plants from London. But London did little about it until the famous London smog of December 1952, truly a major air pollution disaster. The smog lasted 5 days (December 5 through 9) and caused 4000 deaths (principally among the old, the infirm, and those with respiratory diseases). The onset of the fog was followed by acute respiratory symptoms in a number of cattle at the Smithfield Club's livestock show; about 60 required major veterinary treatment, 12 of the more serious cases were slaughtered, and one died. Just what the lethal agent was is still a matter of conjecture [8].

Almost exactly ten years later, December 3 to 7, 1962, London experienced another black fog, with 340 excess deaths. The improvement over the 1952 episode was laid to smoke reduction brought about by the Clean Air Act and public awareness of the harmful effects of smog which restrained many respiratory cripples from going outdoors [33].

The Donora Smog

Donora, Pennsylvania (1950 population—12,186), is an industrial town on the banks of the Monongahela River about 30 miles south of the heart of Pittsburgh. The major industrial installations were a steel and wire mill, a zinc smelter, and a sulfuric acid plant. During a particularly calm and meteorologically stable period from October 27 to 31, 1948, air pollutants accumulated, and as a result many persons were hospitalized and 20 died. Illnesses of several thousand persons were blamed on the episode, and over 130 separate lawsuits were filed.

As in the London smog of 1952, the causative agent of the deaths and illnesses was never determined incontrovertibly, but in both instances sulfur compounds (SO_2, SO_3, H_2SO_4, inorganic sulfates) were present in the air in abnormally high quantities [7, 44].

Meuse Valley, Belgium

A strong atmospheric inversion settled over the Meuse Valley on December 1, 1930, and remained until December 5. Effluents from the several factories in the Valley, chiefly oxides of sulfur, various inorganic acids, metallic oxides, and soot, were then trapped in the stable atmosphere. Sixty-three persons (generally the old and infirm) died, and several hundred others became ill. Although sulfur oxides and hydrofluoric acid are suspected by many, the actual lethal substance was never proved [30].

Ducktown, Tennessee

In the early 1900's, gases from short stacks at two copper smelters near the Georgian 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 by-product sulfur dioxide recovery plant [46].

Trail, British Columbia

Two decades later, a similar case involved the lead and zinc smelter of the Consolidated Mining and Smelting Company of Canada at Trail, B.C. 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 United States side of the border, a damage suit, finally settled by an international tribunal, was instigated. 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 [18].

Pittsburgh (Allegheny County), Pennsylvania

Prior to 1948 the nickname, "Smoky City," was appropriate for Pittsburgh. A black pall of smoke and soot often turned day into night, blackened the brightest buildings in a few months, and made washday a nightmare. Finally, the activity of the civic-minded Allegheny Conference on Community Development brought about a smoke-control ordinance that dramatically changed the condition of the atmosphere. The change resulted largely from regulations prohibiting the sale, transportation, and use of high-volatile solid fuels except where adequate mechanical stoking equipment is available. The dieselization of locomotives and the extinguishing of burning gobpiles also helped. Smoke reduction between 1945 and 1953 was estimated at 70% by the Department of Public Health [31].

St. Louis, Missouri

Actually, the first effective control of solid-fuel quality for the prevention of air pollution was initiated in St. Louis. Prior to 1940, when the law went into effect, the need for street lamps and automobile headlights at midday in the winter was not at all unusual. Strict enforcement of the law resulted in a 75% reduction in smoke and a consequent economic boon in reduced dry cleaning, lighting bills, building maintenance, and vegetation damage [31]. More recent regulations in both Pittsburgh and St. Louis have further improved air quality.

Los Angeles, California

Probably the most publicized smog problem in the United States is that of Los Angeles. Meteorological conditions in the 1600-square-mile Los Angeles Basin are conducive to stable atmospheric conditions. In 1542 Juan Rodriguez Cabrillo, after observing the smoke made by Indians burning brush, called the San Pedro Bay the "Bay of Smokes." The tremendous increase in population of the Los Angeles Basin (from less than 1 million in 1920 to 2.86 million in 1940 and more than 6 million in January 1958) and concurrent increases in industrial and human activity brought about an intolerable atmospheric condition. In 1947 the Los Angeles County Air Pollution Control District was organized and appropriate regulations restricting emissions of smoke and sulfur dioxide were passed. Only slight relief resulted. Eye irritation, damage to vegetation, restricted visibility, and the peculiarly high oxidant content of the air continued to increase. In the early 1950's it was shown that these conditions resulted largely from a reaction between organic compounds and nitrogen dioxide activated by sunlight. Both reactants are emitted in large quantities in the exhaust gases from internal-combustion engines. As a consequence, the state of California passed its first motor vehicle pollution control law in 1959 and has strengthened it several times. Smog in Los Angeles has improved somewhat since then but would have been intolerable had controls on new motor vehicles not been required.

Other Cities

The cities previously mentioned are unique only in that their air pollution problems are notorious. One could add other cities, whose names have been attached to specific diseases peculiar to the locality. Thus "Tokyo-Yokahama asthma" affected many U.S. servicemen stationed there [42]. Periodic outbreaks of "New Orleans asthma" [48] puzzled medical authorities for years, but it is now laid to dust from grain elevators which was held near the earth by stagnant air. Some cities have recognized the seriousness of air pollution episodes only well after their occurrence when statistical studies brought excess mortality and morbidity to light. Thus, Dr. Leonard Greenburg, then New York City's Commissioner of Air Pollution only in 1967 attributed 800 excess deaths to smog during a 1963 episode [24].

Emphasis on urban air pollution problems may be misleading, inasmuch as air is not confined by political boundaries. In recognition of this fact, the U.S. Air Quality Act of 1967 directed the Secretary of Health, Education, and Welfare to designate air quality control regions in which the potential air pollution problem was common to several municipalities, even interstate. Currently designated air quality control regions are listed in Table 1.1.

EFFECTS OF AIR POLLUTION

One of the difficulties in coping with air pollution lies in the variety of its effects on people. A farmer is most interested in its effect on his crops; a housewife will complain that dirt and soot soil clothing and furniture; a

TABLE 1.1
Summary of Air Quality Control Regions

	Interstate AQCRs	Intrastate AQCRs	Remaining area AQCRs	Total AQCRs affecting each state
Alabama	3	4	0	7
Alaska	0	4	0	4
Arizona	3	1	0	4
Arkansas	4	3	0	7
California	0	11	0	11
Colorado	1	7	0	8
Connecticut	2	2	0	4
Delaware	1	1	0	2
District of Columbia	1	0	0	1
Florida	2	4	0	6
Georgia	5	4	0	9
Hawaii	0	1	0	1
Idaho	1	2	1	4
Illinois	7	4	0	11
Indiana	5	5	0	10
Iowa	6	6	0	12
Kansas	1	6	0	7
Kentucky	5	4	0	9
Louisiana	3	0	0	3
Maine	1	4	0	5
Maryland	2	4	0	6
Massachusetts	3	3	0	6
Michigan	2	4	0	6
Minnesota	3	4	0	7
Mississippi	2	2	0	4
Missouri	2	3	0	5
Montana	0	5	0	5
Nebraska	2	1	1	4
Nevada	1	1	1	3
New Hampshire	2	0	1	3
New Jersey	3	0	1	4
New Mexico	3	5	0	8
New York	2	6	0	8
North Carolina	1	7	0	8
North Dakota	1	0	1	2
Ohio	6	8	0	14
Oklahoma	2	6	0	8
Oregon	1	4	0	5
Pennsylvania	3	3	0	6
Rhode Island	1	0	0	1
South Carolina	3	7	0	10

TABLE 1.1 (*continued*)

	Interstate AQCRs	Intrastate AQCRs	Remaining area AQCRs	Total AQCRs affecting each state
South Dakota	2	1	1	4
Tennessee	4	2	0	6
Texas	3	9	0	12
Utah	1	1	1	3
Vermont	1	0	1	2
Virginia	2	5	0	7
Washington	2	4	0	6
West Virginia	4	6	0	10
Wisconsin	4	4	0	8
Wyoming	0	2	1	3
American Samoa	0	0	1	1
Guam	0	0	1	1
Puerto Rico	0	1	0	1
U.S. Virgin Islands	0	1	0	1

traveler may be inconvenienced by low atmospheric visibility; a large segment of the general public is concerned with the possible health effects of polluted air.

The five most common effects of air pollution are visibility reduction, economic damage to property, annoyance to human senses, damage to health, and substantive changes in the ecology of the natural environment.

Limited Visibility

Restriction of visibility is the most widely noticed and probably least understood of all effects of air pollution. Smoke and dust clouds that are sufficiently dense to darken the sky will obviously limit visibility, but there are many other times when horizontal visibility is restricted and the sky overhead is bright. The most noteworthy case of this type is the so-called "Los Angeles smog." The sun shines brilliantly with horizontal visibility less than a quarter of a mile on many occasions (Fig. 1.1). The effect is similar to the low horizontal visibility in a ground-hugging fog, except that the relative humidity is very low. Another familiar example of limited visibility with little or no sky-darkening is the white or blue smoke from burning brush or leaves in open fires, or from the wigwam-type incinerators used for burning wood waste.

The difficult problem with respect to visibility restriction is the determination of whether or not it is independent of natural phenomena, i.e., fog and desert or mountain haze. Combination effects like London's smog (smoke and fog) Denver's smaze (smoke and haze), El Paso's smust (smoke and dust) confound the issue.

FIGURE 1.1
Sunshine and limited visibility in Los Angeles; low inversion. (*Courtesy Los Angeles County Air Pollution Control District.*)

Restricted visibility is actually caused by the forward scattering of light by minute solid or liquid particles (aerosols) in the size range of 0.4 μ to 0.9 μ. Smoke, fog, and industrial fumes all contain particles in this range and thus restrict visibility in proportion to the number of particles present in this size range. Much smaller particles, which are emitted from various sources, may also grow sufficiently in the open atmosphere to become important in light-scattering. Thus, minute salt nuclei in an ocean breeze may absorb moisture under proper conditions (usually above 70% relative humidity) to produce fog. Chemical condensation of the reaction products of pollutants in the air may undergo similar growth. In fact, it is believed that the formation of smog particles in Los Angeles is a phenomenon of this type (see Chapter 8). Under suitable conditions sulfur dioxide may be oxidized atmospherically to sulfur trioxide and then condensed with moisture to yield droplets of sulfuric acid (H_2SO_4). The resulting blue haze is a familiar sight in the plumes from many industrial stacks.

Measurement of the particulate matter and aerosols in the atmosphere is a complex problem and is described in Chapter 4. Measurement of the *effect* of these solid or liquid particles, i.e., visibility, is simpler. At United

States Weather Bureau stations, visibility is commonly estimated by an observer by viewing prominent landmarks at known distances from the point of observation. This method is not useful at night or where landmarks are few.

Numerous attempts have been made to relate visibility quantitatively to the concentration of particles in the atmosphere. Obvious drawbacks are the vast range in size of atmospheric particles and measurement of concentration at only one site and often over too long a period of time. Nevertheless, Charlson et al [15] and Noll et al [40] have proposed generalized formulas relating visibility with atmospheric dust concentration measured by high-volume samplers (see Chapter 4) over a 24-hour period. The several formulas are each in the form

$$L_v \times M = K$$

where L_v = visual range in kilometers
M = mass concentration in micrograms per cubic meter
K = a constant

In his most recent publication, Charlson [14] suggests 1800 as the value of the constant, K, when relative humidity is less than 70%. As mentioned previously, the equation has obvious limitations and should be used only as a general guide.

A similar formula, corrected for relative humidity, has been proposed for sulfuric acid mist [39].

Public objection to reduced visibility stems from two factors, transportation hazards and delays, and aesthetic considerations. Aircraft landing hazards at two Kansas City airports led federal authorities, in 1967, to recommend curtailment of open burning and further control of industrial process dust emissions which were said to be responsible for low visibility at the airports. The hazard to motor vehicle traffic caused by a smoke or dust plume dipping across a highway is well known.

Only recently have aesthetic considerations been taken seriously by control agencies. The blotting of the horizon in a smoke-filled valley can well discourage tourist trade and reduce the land value of spectacular-view sites. Obviously, aesthetics have an economic value in this case. A truly aesthetic consideration receiving more attention is public objection to visible plumes. Eventually the problem must be faced on a cost-benefit basis.

ECONOMIC DAMAGE TO PROPERTY

Air pollution damage to property includes damage to materials, vegetation, and animals, as well as interference with production and services.