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CONTROL OF AIR POLLUTION SOURCES

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PREFACE

The control of air pollution sources has become a matter of vital importance in our society. This book is directed toward preparing students of science and engineering to practice in the field of air pollution control. It is intended for use in a one or two semester course for advanced undergraduates or beginning graduate students.

The subject matter of the text may be used in courses in several ways depending upon the intent of the course and the preparation of the students. For example, at the University of Maryland we have a complete academic program in air pollution control. The material of Chapters I and III and Appendix A is covered in depth in other courses and is presented here only for completeness and for those students who may only take my course as an elective.

For complete coverage the material of this book is best handled in a two semester course. As an introductory one semester course coverage may be focused on Chapters I, III, VI, VII, and VIII. On the other hand for advanced students in a one semester course coverage may be confined to Chapters II, III, IV, V, and VIII. Similarly for short courses and continuing education programs the instructor may wish to deal in depth with only one or two chapters.

I would like to acknowledge with thanks the many students and colleagues who have contributed to the lectures, reference material, and practical aspects of my course over the past seven years. This text is the culmination of our combined effort. It is offered to you in the hope that it will be of assistance in your efforts to understand and practice the control of air pollution sources.

J. M. Marchello

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Chapter I
AIR QUALITY MANAGEMENT

A. INTRODUCTION

During the beginning of the industrial revolution manufacturers had little concern about the atmospheric discharge of noxious effluents. In Great Britain, the discharge of HCl to the atmosphere from the saltcake process and the inefficient operation of sulfuric acid chamber plants led to the first regulation, the Alkali and Chemical Works Regulations Act of 1863.

Nationwide concern in the United States resulted in the organization of the Air Pollution Control Association in 1907. In many instances, its efforts have resulted in cleaner air for communities. Over the years industry has not been entirely remiss in its responsibility. Millions of dollars have been spent to eliminate visible as well as odorous pollutants from the air. However, modern industrialization, growth of cities, increased vehicular traffic on the roads, crowded living conditions, and waste problems have joined together in recent years to magnify the air pollution problem.

In 1947 the state of California adopted a law permitting formation of county air pollution control districts. By 1966 similar laws had been adopted in 30 additional states. In 1955 the Public Health Service of the U.S. Department of Health, Education and Welfare established programs of technical assistance, training, and research on the control of air pollutants and on their effects on health. The Air Quality Act of 1967 and amendments in 1970 (P.L. 91-604) authorized the formation of the U.S. Environmental Protection Agency (EPA) to direct a concerted program for the control of air pollution.

In the United States the period from 1967 to 1972 was one of organization and preparation to develop the nationwide attack on air quality problems. The 1967 national legislation set in motion the development of regulations by state and local governments that may have needed to enact new codes or to extend existing ones. Under the 1970 amendments the states developed implementation plans to control and reduce pollution emissions so that the national ambient air standards could be met. Monitoring systems were installed, emission inventories developed, and polluters required to develop compliance plans for the control of their emissions (1,2).

This period was also marked by increased public concern for environmental quality as exemplified by the Earth Day activities first held on April 22, 1970. Much of this concern has since been organized into citizen groups that actively participate in public hearings and other regulatory, planning, and decision-making procedures.

Air-quality-control regulatory activities are coordinated through government levels and jurisdictions by various working agreements, regional plans, governing boards, and the nationwide activities of the Environmental Protection Agency. Traditionally, air quality management is the responsibility of the department of health of state, county, and city governments. Frequently a separate division or bureau of air quality control has been created within the department.

The management of air quality (3) in a region requires the following elements:

1. Public policy on air conservation.
2. Organizational framework and staff.
3. Delineation of ambient air quality goals.
4. Continual assessment of existing air quality and estimates of the future levels.
5. Continual assessment of emissions from existing sources and proposed sources.
6. Information about factors that influence the transport of air pollutants.

7. Information on the effects of air quality on man and his environment.
8. Integration with community plans for land use, resource management, and growth.
9. Public information and education programs.

To provide these elements, state and local programs are generally divided into activities such as: air monitoring; compliance engineering, program planning, and evaluation; and public information. Effective management requires maintenance of an air monitoring network, source registration and testing, and an inventory of pollutant emissions.

B. AMBIENT AIR QUALITY

National primary and secondary ambient air quality standards have been set by the EPA (2). Primary ambient air quality standards define levels of air quality judged to allow an adequate margin of safety to protect the public health. National secondary ambient air quality standards define levels judged to protect the public welfare from adverse effects associated with the presence of air pollutants in the ambient air.

Part 410, Chapter IV, Title 42, Code of Federal Regulations contains the standards for air pollutants and the reference methods for their measurement. Similarly, the maximum permissible levels of radioactive materials have been set by the Atomic Energy Commission and are published in Parts 20 and 100, Title 10, Code of Federal Regulations. The national ambient air standards are given in Table I-1.

Water vapor at about 1 to 3% by volume is normally present in air. Dry air contains 78% nitrogen and 21% oxygen. The remaining 1% consists of argon (0.93%), carbon dioxide (0.03%), and traces of the other noble gases and various substances, most of which are classified as air pollutants. The most common unit for both partic-

TABLE I-1

National Ambient Air Quality Standards (2)

Sulfur oxides

Primary standard

(a) 80 $\mu g/m^3$ (0.03 ppm) Annual arithmetic mean

(b) 365 $\mu g/m^3$ (0.14 ppm) Max 24-hr conc not to be exceeded more than once per year

Secondary standard

1,300 $\mu g/m^3$ (0.5 ppm) Max 3-hr conc not to be exceeded more than once per year

Particulate matter

Primary standard

(a) 75 $\mu g/m^3$ Annual arithmetic mean

(b) 260 $\mu g/m^3$ Max 24-hr conc not to be exceeded more than once per year

Secondary standard

(a) 60 $\mu g/m^3$ Annual geometric mean

(b) 150 $\mu g/m^3$ Max 24-hr conc not to be exceeded more than once per year

Carbon monoxide

Primary and secondary standards

(a) 10 mg/m^3 (9 ppm) Max 8-hr conc not to be exceeded more than once per year

(b) 40 mg/m^3 (35 ppm) Max 1-hr conc not to be exceeded more than once per year

Photochemical oxidants

Primary and secondary standards

160 $\mu g/m^3$ (0.08 ppm) Max 1-hr conc not to be exceeded more than once per year

Hydrocarbons

Primary and secondary standards

160 $\mu g/m^3$ (0.24 ppm) Max 3-hr conc (6 to 9 a.m.) not to be exceeded more than once per year

TABLE I-1 (continued)

Nitrogen dioxide

Primary and secondary standards

100 $\mu g/m^3$ (0.05 ppm) Annual arithmetic mean

Radionuclides			
Tritium		2×10^{-6}	Max permissible conc (4) (microcuries per cubic centimeter), Section VI-C-5
Argon-41		4×10^{-7}	
Krypton-85		3×10^{-6}	
Iodine-131,	soluble	3×10^{-9}	
	insoluble	1×10^{-7}	
Strontium-90		1×10^{-11}	
Xenon-133		3×10^{-6}	

ulate and gaseous air pollutants is micrograms per cubic meter, $\mu g/m^3$. At 25°C and 760 mm Hg pressure for gases, the conversion of $\mu g/m^3$ to parts per million by volume is ppm = 0.244 ($\mu g/m^3$)/(molecular weight).

Trace substances entering the environment may pose a health hazard. While the physiological effects of trace concentrations of specific substances are not known, significant amounts of potentially hazardous elements are emitted into the air from smelting, refining, incineration, and the burning of coal and oil (5,6). The concentrations are low and are not generally detected and reported in measurements such as those in Appendix B. The general approach of reducing and controlling emissions to meet the national ambient air standards should have the effect of indirectly reducing the potential hazard from trace substances until more health information becomes available.

The national ambient standards are continually under review and may be changed and extended to include other substances. Under the Clean Air Act Amendments of 1970 the states were required to submit plans for implementation, maintenance, and enforcement of these standards. Plans for control of particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide were approved for all 50 states during 1972 with implementation procedures for achieving ambient standards by 1977.

The preparation and implementation of plans to meet the national standards are covered in Part 420, Chapter IV of the Code of Federal Regulations. It provides for a statewide system of permits for construction and operation of stationary sources, a strategy to attain and maintain ambient air standards, and emergency procedures during episodes, to reduce emissions. The emergency procedures provide for three levels of action: Alert, Warning, and Emergency.

The Alert level is the concentration at which first-stage actions begin. The alert will be declared when any one of the following levels is reached and meteorological conditions are such that the condition can be expected to continue for 12 or more hours:

SO_2: 0.3 ppm, 24-hr av
Particulate: 3.0 COH_s (coefficient of haze), 24-hr av (approx 150 $\mu g/m^3$)
SO_2 and particulate combined: product of SO_2 and COH_s = 0.2, 24-hr basis
CO: 15 ppm, 8-hr av
O_3: 0.1 ppm, 1-hr av
NO_2: 0.6 ppm, 1-hr av; 0.15 ppm, 24-hr av

The Warning level indicates that air quality is continuing to degrade and additional abatement action is necessary. A warning will be declared when any one of the following levels is reached and meteorological conditions indicate that the condition will continue for 12 or more hours:

SO_2: 0.6 ppm, 24-hr av
Particulate: 5.0 COH_s, 24-hr av
Combined SO_2 and COH_s product = 0.8, 24-hr av
CO: 34 ppm, 8-hr av
O_3: 0.4 ppm, 1-hr av
NO_2: 1.2 ppm, 10-hr av; 0.3 ppm, 24-hr av

The Emergency level indicates that air quality is continuing to degrade toward a level of significant harm to the health of persons and that the most stringent control actions are necessary. An emergency will be declared when any one of the following levels is reached at any monitoring site and meteorological conditions are such that this condition can be expected to remain at these levels for 12 or more hours (2).

SO_2: 0.8 ppm, 24-hr av
Particulate: 7.0 COH_s, 24-hr av
Combined SO_2 and COH_s product = 1.2, 24-hr av
CO: 40 ppm, 8-hr av
O_3: 0.6 ppm, 1-hr av
NO_2: 1.6 ppm, 1-hr av; 0.4 ppm, 24-hr av

Emission reduction plans during an episode provide strategies, consistent with good industrial practice and safe operation, for reducing emissions. Preplanned strategies must be approved and published for each source. Their implementation should automatically go into effect when the episode level is announced by the Director.

Example I-1--A city must decide between a sanitary landfill or an incinerator for refuse disposal. Emission estimates for a large incinerator and for refuse-hauling trucks are given in the following table along with the ambient air standards.

Pollutant	Truck emissions (grams/mile)	Incinerator emissions (lb per ton of refuse burned)	National primary ambient air standards ($\mu g/m^3$)
Carbon monoxide	3.40	0.05	10,000
Nitrogen oxides	3.00	0.10	100
Hydrocarbons	0.41	0.05	160
Particulates	0.10	0.05	75

Each truck carries 8 tons of refuse. Use the average emissions for both full and empty trucks.

(a) On the basis of total weight of pollutants emitted how far can the trucks travel beyond the incinerator site to a landfill before their total mass emissions exceed those of the incinerator?

(b) Use the ambient standards (let $NO_x = 1.00$) to weight each pollutant (7) and determine how far the landfill can be beyond the incinerator on an equivalent pollutant-potential basis.

Solution

(a) Using one truck or 8 tons of refuse as the base, the incinerator emissions are $8(0.05 + 0.10 + 0.05 + 0.05) = 2.0$ lb. The truck emissions are $(3.40 + 3.00 + 0.41 + 0.10)(2M/454)$. Where M is the distance between the incinerator and the landfill. The truck emissions are $(3.40 + 3.00 + 0.41 + 0.10)(2M/454)$, where at which the mass of emissions would be equal is $M = (2.0/0.0306) = 65$ miles.

(b) Since NO_x is to be used as the base for weighting the relative potential of each pollutant divide its 100 $\mu g/m^3$ by the standard for each pollutant. The weighting factors are:

Carbon monoxide	$100/10,000 = 0.01$
Nitrogen oxides	$100/100 = 1.00$
Hydrocarbons	$100/160 = 0.62$
Particulates	$100/75 = 1.33$

The weighted incinerator emissions are $8[(0.05)(0.01) + (0.10) + (0.05)(0.62) + (0.05)(1.33)] = 8(0.1978) = 1.58$.

The weighted truck emissions are $(2M/454)[(3.40)(0.01) + (3.00)(1.00) + (0.41)(0.62) + (0.10)(1.33)] = 0.0044M\ (3.411) = 0.015M$.

The distance at which the potential effects are equivalent is $M = (1.58/0.015) = 105$ miles.

C. MONITORING AND MODELS

Knowledge of the ambient air quality and the sources of air pollution in a community provides the basic framework for air conservation activities. The results of air monitoring and an emission survey may be used effectively in metropolitan planning, pollution abatement activities, and diffusion models for predicting atmospheric levels of pollutants (3,8).

The assembly, correlation, and evaluation of the many pieces of information needed for an air resource management program have necessitated the development of tools that can speed up these operations and facilitate better understanding of the information. Maps are essential for showing variations in pollutant emission levels and air quality within a metropolitan area. One example of their use is in showing predicted effects of large, new, single sources on the metropolitan area by the method of superposition. For any air pollution control activity of significant size, the compilation and evaluation of the data can be accomplished only with the aid of computer methods. Computation of statistical parameters and correlations that describe cause and effect relations would be impossible without the computer, as would solving the complicated equations that define the diffusion models (Section III-D).

The air resource management data assembled by computer programing constitute an information system that permits calculation of expected air pollution concentrations for adverse meteorological conditions. For the planner, the data system permits a rational analysis

of the air pollution aspects of proposed regional development such as the added effects of new sources due to increased industrialization, added population, and increased transportation activity.

Contemplated land use plans can be analyzed with models on the basis of air quality levels that would be created. In some instances air quality standards and goals may necessitate the modification by zoning of certain activities in specific areas. Such analyses have become an integral part of environmental impact statements.

Perhaps the most advanced facet of air resource management is air quality measurement and monitoring. A wide range of methods and equipment is available for monitoring sulfur dioxide, particulate matter, hydrocarbons, oxidants, and other pollutants. The opacity or Ringlemann number for evaluating visible emission is included in many regulations (Section I-D). With the Ringlemann chart the user matches the appearance of the smoke as it leaves the chimney against the background of the sky to judge the smoke level (Section III-E). Sampling and measurement methods for pollutants are reviewed in Appendix A. Monitoring in a region entails stack-emission sampling, periodic measurements such as monthly dust fall, and real-time monitoring by instrumented systems. Other methods of air quality determination such as citizen complaints and observed effects on health, vegetation, materials, and visibility may also be used for monitoring.

Real-time monitoring of pollutant levels consists of a system of remotely located monitoring stations and a central data-processing control station. A typical system uses a modular configuration with between six and thirty remote stations located on the basis of meteorologic, geographic, population, and land-use considerations. Data processing systems are generally capable of handling 16 sensors at a remote site with interrogation of each sensor once per minute.

Remote stations are often housed in trailers, for ease of relocation, with sampling probes located three feet above the roof. In addition to sensor and telemetry equipment, they should be provided with temperature control, constant voltage regulation, and

storage space. Chart recorders should also be provided as backup in case of telephone failure and for use during instrument servicing.

Measurements and instrumentation at remote stations are usually an adaptation of the Federal Continuous Air Monitoring Project (CAMP) stations. The monitoring instruments included in these stations may provide continuous information directly for eight pollutants. Sulfur dioxide is measured using flame photometry; carbon monoxide, by non-dispersive infrared spectrometry with dehumidification to negate water vapor interference; total hydrocarbons, using flame ionization; methane, also by flame ionization but with precolumn scrubbing; nitrogen dioxide and nitric oxide, using the Saltzman colorimetric in-series technique; photochemical oxidants, by the chemiluminescent method; and soiling index, by use of the in-head light transmission filter paper tape sampler. From these measurements the central computer also may calculate total oxides of nitrogen and nonmethane hydrocarbons.

The data processing centers are equipped with telemetry modules, a minicomputer, a magnetic tape recorder, a digital clock, and a teletype for operator input/output. There also may be a punched-paper-tape reader for processing periodic data. In normal operations the central station interrogates each monitor once per minute, and reads and advances the tape sampler on the hour. The program causes dynamic zero and span instrument calibration once per day. On the hour, three pollutant statistics are printed: the hourly average; the running 24-hour average; and the maximum reading during the hour, except for soiling index.

An important part of air quality management involves the continuous evaluation of abatement control strategy (9). A system of control strategy evaluation provides for: review of achievement and of attainment of goals; response to episodes; and it serves as a basis for assessing emissions from proposed activities. Such systems require the use of several computer programs in an automated computer model of the region. They permit rapid simulation of emis-