# AIR POLLUTION

DR. HOMER W. PARKER, P. E.

# *AIR POLLUTION*

**DR. HOMER W. PARKER, P. E.**

*Consulting Engineer*

Prentice-Hall, Inc., *Englewood Cliffs, New Jersey 07632*

*Library of Congress Cataloging in Publication Data*

PARKER, HOMER W 1921–
Air pollution.

Includes bibliographical references.
1. Air—Pollution. 2. Air quality management.
I. Title.
TD883.P37 628.5'3 76–54689
ISBN 0–13–021006–4



Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

PRENTICE-HALL INTERNATIONAL, INC., *London*
PRENTICE-HALL OF AUSTRALIA, PTY. LTD., *Sydney*
PRENTICE-HALL OF CANADA, LTD., *Toronto*
PRENTICE-HALL OF INDIA PRIVATE LIMITED, *New Delhi*
PRENTICE-HALL OF JAPAN, INC., *Tokyo*
PRENTICE-HALL OF SOUTHEAST ASIA PTE. LTD., *Singapore*
WHITEHALL BOOKS LIMITED, *Wellington, New Zealand*

# PREFACE

This book identifies and discusses air pollutants of frequent concern to municipal and industrial organizations. The presentation is directed toward the practical solution of existing air pollution problems. Tables and other data that are often difficult to find in other sources are provided in this text.

Commercially available air pollution control devices and auxiliary equipment are described or shown in the illustrations. Design equations and procedures are given where appropriate; however, air pollution control devices are mostly proprietary items that are frequently sized by the individual manufacturer. Information required by the manufacturer is stated where pertinent. Design suggestions are included for both unit processes and systems design. Despite the limited number of practical design equations, this book contains sufficient application and tabular data to lead the resourceful engineer to one or more methods on how to solve over 98% of the common air pollution problems that do not require process modification. Even where such modifications are necessary this book will be of value.

Wastewater and solid waste resulting from air pollution equipment are discussed in the most significant cases.

Lists of air pollution equipment manufacturers were found in many cases to be inaccurate. Over 1,500 letters were written seeking to identify viable and responsive sources. Therefore, sufficient identification is given in the text or in the courtesy source notations on figures and tables so that by combining this information with Appendix A the book is a valuable guide to viable equipment sources. Unfortunately the responses of several firms included in Appendix A arrived too late to include their material in the text.

Acknowledgments include the liberal use of information from the U.S. Public Health Service, the Environmental Protection Agency and the manufacturers listed in Appendix A.

DR. HOMER W. PARKER, P. E.

# CONTENTS

# INTRODUCTION 1

In its broadest sense air pollution is any substance (or combination of substances) present in the atmosphere that is detrimental to the health of man or lower life forms; offensive or objectionable to man either internally or externally; or which by its presence will directly or indirectly adversely affect the welfare of man.

Air pollution may be divided into particulate matter and vapors. Practically, an engineer engaged in air pollution work is concerned with the measurement and analysis of particulate matter and vapors in the atmosphere. He also designs control measures to maintain air pollution emissions below specified emission levels. Equipment and processes that create air pollution and are of most concern to air pollution engineers are: fluid flow; heat transfer; evaporation; humidification and dehumidification; gas absorption; solvent extraction; adsorption; distillation and sublimation; dryers or roasters; mixing; classification of materials; sedimentation and decantation; filtration; screening; crystallization; centrifugation; disintegration; materials handling; process areas; and metal melting.

***1–1. Particulate Matter.*** Particulate matter is any material, except uncombined water, that exists as a solid or liquid in the atmosphere or in a gas stream at standard conditions. Particles of this material range in size from 200 $\mu$ (microns) to less than 0.1 $\mu$ in diameter. In common terminology particulate matter consists of dust, aerosols, fly ash, fog, fume, mist, particles, smoke, soot, and sprays. Some common types of particulate matter are indicated in Table 1–1.

TABLE 1-1. Typical Particulate Particle Size

| *Substance* | *Normal Maximum Size, Microns* | *Normal Minimum Size, Microns* |
|---|---|---|
| Water wapor mists | 500 | 40 |
| Pulverized coal | 250 | 25 |
| Dust | 200 | 20 |
| Foundry shakeout dust | 200 | 1 |
| Cement dust | 150 | 10 |
| Fly ash | 110 | 3 |
| Plant pollens | 60 | 20 |
| Fog (nature) | 40 | 1.5 |
| Plant spores | 30 | 10 |
| Bacteria | 15 | 1 |
| Insecticide dust | 10 | 0.4 |
| Paint pigment spray | 4 | 0.1 |
| Smog | 2 | 0.001 |
| Tobacco smoke | 1 | 0.01 |
| Oil smoke | 1 | 0.03 |
| Zine oxide fume | 0.3 | 0.01 |
| Coal smoke | 0.2 | 0.01 |
| Viruses | 0.05 | 0.003 |

Dust consists of solid particles larger than colloidal size and capable of temporary suspension in air and other gases.

An aerosol consists of a dispersion in a gaseous media of solid or liquid particles of microscopic size, such as smoke, fog, or mist. In some difinitions aerosols are considered to include anything from particles of 100 $\mu$ to 0.1 $\mu$ or less (1). Particles 5 $\mu$ or smaller tend to form stable suspensions. Particles larger than 5 $\mu$ tend to settle out as dustfall.

Fly ash consists of finely divided particles of ash entrained in flue gases arising from the combustion of fuel. The particles of ash may contain unburned fuel and minerals.

Fog consists of visible aerosols in which the dispersed phase is liquid. In meteorology, fog is a dispersion of water or ice.

Fume consists of particles formed by condensation, sublimation, or chemical reaction, of which the predominate part, by weight, consists of particles smaller than 1 $\mu$. Tobacco smoke and condensed metal oxides are examples of fume. Fume may flocculate or coalasce.

Mist is a low-concentration dispersion of relatively small liquid droplets. In meteorology, the term mist applies to a light dispersion of water droplets big enough to fall from the air. Mists may result from the condensation of gases or vapors to the liquid state. Mists can also be generated by breaking up a liquid through splashing, spraying, or foaming. Sprays are liquid droplets formed by mechanical action.

A *particle* is a small, discrete mass of solid or liquid matter. *Smoke* is made up of small gas-borne particles resulting from incomplete combustion. Such particles consist predominately of carbon and other combustible material which are present in sufficient quantity to be observable independently of other solids. *Soot* is an agglomeration of carbon particles impregnated with "tar." It is formed in the incomplete combustion of carbonaceous material.

Plain dry grinding does not usually produce particles less than a few microns in size. Very small particles (0.1 $\mu$ to 1 $\mu$) may be produced by heat-vaporizing material that later condenses.

Large size particulate matter tends to settle under the influence of gravity and is reported as dustfall measured in tons per square mile per month. Particles less than 5 $\mu$ tend to form stable suspensions, and particulate matter smaller than 0.1 $\mu$ will not settle. Concentrations of airborne particulates are commonly expressed in milligrams or micrograms per cubic meter. Filters are used to catch particulate matter for analysis. The organic portion is often reported as benzene-soluble matter.

***1–2. Vapors.*** Vapors includes gases and compounds that in general have a boiling point below 200°C. The terms *vapor* and *gas* are often used interchangeably. In a strict sense a vapor is a substance which, though present in the gaseous phase, generally exists as a liquid or solid at room temperature and sea level barometric pressure. A gas normally exists in the gaseous phase at room temperature.

**TABLE 1–2.** Typical Examples of Vapors

| *Substance* | *Recommended Limit of Concentration in Atmosphere–ppm** |
|---|---|
| Acetone | 1,000 |
| Ammonia | 50 |
| Benzene | 25 |
| Carbon monoxide | 30 |
| Chlorine | 1 |
| Formaldehyde | 5 |
| Gasolene | 500 |
| Hydrogen chloride | 5 |
| Hydrogen fluoride | 3 |
| Hydrogen sulfide | 20 |
| Methyl acetate | 200 |
| Methyl bromide | 20 |
| Methyl mercaptan | 20 |
| Naphtha (coal tar) | 200 |
| Nitric acid | 10 |
| Nitrogen dioxide | 5 |
| Sulfur dioxide | 5 |
| Turpentine | 100 |

*These should be regarded as the maximum values of exposure for a healthy person at standard atmospheric conditions for a limited period of exposure. Air pollution values in a city atmosphere should be significantly lower than these values. Consult the latest published data from the *American Conference of Governmental Industrial Hygienists* and see Section 2–36.

Many industrial processes as well as the operation of machines such as engines may either raise temperatures or lower the barometric pressure, causing a substance to convert to the gaseous phase. Table 1–2 indicates some of the types of vapors that are of concern in air pollution.

***1–3. Sources.*** This text will limit itself to air pollution emanating from: (1) fuel consumption; (2) industrial activity; (3) refuse burning; and, (4) motor vehicle emissions. Industrial activity would include such processes as combustion (releasing, for example, sulfur dioxide, carbon monoxide, benzene vapor, hydrogen chloride, and nitrous oxide); roasting and heating (sulfur dioxide, hydrogen sulphide, hydrogen flouride); chemical processes (hydrogen fluoride, hydrogen sulphide, nitrous dioxide, sulfur dioxides, sulfur trioxide, and hydrogen chloride); and the generating of noxious odors.

***1–4. Control Devices.*** Control devices may be separated into vapor control equipment and particulate matter control equipment. Vapor control equipment consists of control by combustion, adsorbers, and absorbers. Particulate matter and liquid mist control equipment may be divided into dry separators and filters, wet collectors, electrical precipitators, and special equipment. Dry separators might include settling chambers; cyclones (low-pressure or high-efficiency type); fabric-type (bag) collectors (filters) of intermittent, periodic, or continual cleaning type. Wet collectors include a number of different types of scrubbers.

***1–5. Mixtures.*** If two hazardous substances are mixed, the result may not be additive if each produces local effects on different organs of the body. However, in most cases the additive effects must be considered. In the absence of reliable information to the contrary always assume that the effect of all harmful substances present will be additive:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n} \tag{1–1}$$

where $C_1$ = observed concentration of substance No. 1
$C_2$ = observed concentration of substance No. 2
$T_1$ = threshold limit of substance No. 1
$T_2$ = threshold limit of substance No. 2
$C_n$ = equivalent concentration of all substances combined
$T_n$ = equivalent threshold limit of all substances combined

***1–6. Interaction of Substances.*** Chemical substances can react with each other in the atmosphere. Natural phenomena such as solar radiation and/or meteorological conditions can be part of this reaction. Smog is considered to be a product of motor vehicle contamination, solar radiation, and meterological conditions. According to the Haagen-Smit theory (2) sulfur dioxide, nitrogen dioxide, and aldehydes may absorb ultraviolet radiation and react with molecular oxygen to produce first atomic oxygen and then ozone ($O_3$). Aldehydes reacting with sulfur dioxide are irreversible; however, the ultraviolet light causes nitrogen dioxide ($NO_2$)

to form atomic oxygen and NO, which reacts first with molecular oxygen ($O_2$) to form $NO_3$ and then with additional oxygen to form $NO_2$ and $O_3$. The nitrogen dioxide is thus regenerated and continues the reaction. A somewhat similar but less effective reaction occurs as a result of ultraviolet irradiation of sulfur dioxide to form sulfur trioxide and ozone (3). In the presence of water vapor, sulfuric acid will result.

*1–7. Temperature Inversion.* The earth radiates heat energy into space at a relatively constant rate that is a function of the absolute temperature. Incoming radiation at night is less than outgoing radiation, and the temperature of the earth's surface and the air immediately above it decreases. This surface cooling sometimes leads to an increase of temperature with altitude, known as a *temperature inversion* in the lower layer (4). An inversion may be formed by an offshore wind (5) when air that has attained a definite temperature distribution while passing over heated land comes in contact with the sea. The temperature profile in the air mass is given as a function of its height and the time that has elapsed since the air mass came in contact with the sea. In winter a mountain peak may occasionally experience higher temperatures than a valley station in the same area (6). This state is also an example of a temperature inversion.

Air pollution tends to be concentrated below such inversion layers. A high-pressure area also may descend, resulting in the compression and heating of air to form a dense, warm layer. If such a layer of air drops lower, it may force the concentration of contaminants in the atmosphere surrounding the inhabitants below. Thus meteorological conditions can be the cause of sudden severe concentrations of air pollution. The consequences can be serious, particularly if the mass of polluted air is trapped in an industrial valley where pollutants are continuously being generated.

*1–8. Air Pollution as a Hazard to Man.* Students of history have found indications that certain diseases recorded in the past were linked to specific occupations. For hundreds of years air pollution in confined areas such as mines resulted in disease that shortened the miner's lifespan. The burning of coal in London caused air pollution on a large scale long ago. Nature has occasionally made significant contributions to pollution through the eruptions of volcanoes, major forest fires, etc.

Some of the papers documenting the health aspects of air pollution to man and animals have been listed in the references at the end of this chapter (10 through 50). Included in this collection are accounts of the Meuse Valley disaster in 1930 in which at least 60 persons died and a larger number of persons became seriously ill. An atmospheric inversion lasted for several days in the valley, where there were a number of industrial establishments. The inversion trapped the air pollution products in the valley, and the concentrations built up until people became ill on a mass basis (41, 42).

Another well-known air pollution disaster took place at Donora, Pennsylvania, between October 27 and October 31, 1948. At least 20 persons died and over 6,000 became ill (43).

An incident in Poza Rica, Mexico, on November 24, 1950, resulted in 22 persons dead and 320 made seriously ill (44). In this case the cause was a malfunction in a single plant where unburned hydrogen sulfide was emitted into the atmosphere.

There have been a number of air pollution incidents in London. The December 5–8, 1952 case resulted in approximately 4,000 deaths (45 through 50). Heavy pollution is often accompanied by climatic factors, such as temperature inversions, that tend to trap and hold the air pollution being emitted. Such major disasters are a preview of what will happen to man if air pollution levels are permitted to continue to increase.

Man is not going do dispense with his industrial development, his personal vehicles that provide such rapid transportation, nor will he otherwise attempt to go back to nature. Current world population growth and the way man has developed would not permit a true return to a nonindustrialized and nonmechanized way of life. It is therefore necessary to find engineering solutions to these problems.

Based on a study of over 250 papers, 40 of which are listed at the end of this chapter (10 through 50), the following conclusions were drawn:

1. Adequate evidence exists to establish beyond all reasonable doubt that air pollution is a serious health hazard to man, other animals, and plant life.
2. Particulate matter is a significant air pollution health hazard. The presence of particulates complicates the establishment of threshold limits on vapors and gases.
3. The products of combustion, especially the sulfur oxides and the interaction products they create, are particularly significanct health hazards.
4. It will probably be established beyond all reasonable doubt that certain air pollutants, or combinations of air pollutants, results in carcinogenesis. Already there is the adequate evidence to warrant strong control measures on certain products.
5. Studies on the threshold limits of tolerance are usually conducted on healthy adult specimens under limited-duration, controlled conditions, using only one or a small number of pollutants. In the real world a large segment of the population suffers from health deficiences that tend to make them more susceptible to damage from air pollution.
6. In actual practice the emission level of all pollutants present may be below the established maximum threshold limits, but either the cumulative effect of the contaminants and/or their intereaction, caused by climatic conditions such as sunlight, may present a health hazard to the residents.
7. The fact that significant problems may not have been experienced in a particular industrialized urban area is no insurance against a disaster occurring. A natural fog on a cool day accompanied by a stationary temperature inversion and winds under six miles per hour will tend to establish conditions leading to such a disaster. Cool ground tempera-