FUNDAMENTALS OF AIR POLLUTION ENGINEERING

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Preface

Analysis and abatement of air pollution involve a variety of technical disciplines. Formation of the most prevalent pollutants occurs during the combustion process, a tightly coupled system involving fluid flow, mass and energy transport, and chemical kinetics. Its complexity is exemplified by the fact that, in many respects, the simplest hydrocarbon combustion, the methane–oxygen flame, has been quantitatively modeled only within the last several years. Nonetheless, the development of combustion modifications aimed at minimizing the formation of the unwanted by-products of burning fuels requires an understanding of the combustion process. Fuel may be available in solid, liquid, or gaseous form; it may be mixed with the air ahead of time or only within the combustion chamber; the chamber itself may vary from the piston and cylinder arrangement in an automobile engine to a 10-story-high boiler in the largest power plant; the unwanted by-products may remain as gases, or they may, upon cooling, form small particles.

The only effective way to control air pollution is to prevent the release of pollutants at the source. Where pollutants are generated in combustion, modifications to the combustion process itself, for example in the manner in which the fuel and air are mixed, can be quite effective in reducing their formation. Most situations, whether a combustion or an industrial process, however, require some degree of treatment of the exhaust gases before they are released to the atmosphere. Such treatment can involve intimately contacting the effluent gases with liquids or solids capable of selectively removing gaseous pollutants or, in the case of particulate pollutants, directing the effluent flow through a device in which the particles are captured on surfaces.

The study of the generation and control of air pollutants can be termed *air pollution engineering* and is the subject of this book. Our goal here is to present a rigorous and fundamental analysis of the production of air pollutants and their control. The book is

intended for use at the senior or first-year graduate level in chemical, civil, environmental, and mechanical engineering curricula. We assume that the student has had basic first courses in thermodynamics, fluid mechanics, and heat transfer. The material treated in the book can serve as the subject of either a full-year or a one-term course, depending on the choice of topics covered.

In the first chapter we introduce the concept of air pollution engineering and summarize those species classified as air pollutants. Chapter 1 also contains four appendices that present certain basic material that will be called upon later in the book. This material includes chemical kinetics, the basic equations of heat and mass transfer, and some elementary ideas from probability and turbulence.

Chapter 2 is a basic treatment of combustion, including its chemistry and the role of mixing processes and flame structure. Building on the foundation laid in Chapter 2, we present in Chapter 3 a comprehensive analysis of the formation of gaseous pollutants in combustion. Continuing in this vein, Chapter 4 contains a thorough treatment of the internal combustion engine, including its principles of operation and the mechanisms of formation of pollutants therein. Control methods based on combustion modification are discussed in both Chapters 3 and 4.

Particulate matter (aerosols) constitutes the second major category of air pollutants when classified on the basis of physical state. Chapter 5 is devoted to an introduction to aerosols and principles of aerosol behavior, including the mechanics of particles in flowing fluids, the migration of particles in external force fields, Brownian motion of small particles, size distributions, coagulation, and formation of new particles from the vapor by homogeneous nucleation. Chapter 6 then treats the formation of particles in combustion processes.

Chapters 7 and 8 present the basic theories of the removal of particulate and gaseous pollutants, respectively, from effluent streams. We cover all the major air pollution control operations, such as gravitational and centrifugal deposition, electrostatic precipitation, filtration, wet scrubbing, gas absorption and adsorption, and chemical reaction methods. Our goal in these two chapters, above all, is to carefully derive the basic equations governing the design of the control methods. Limited attention is given to actual equipment specification, although with the material in Chapters 7 and 8 serving as a basis, one will be able to proceed to design handbooks for such specifications.

Chapters 2 through 8 treat air pollution engineering from a process-by-process point of view. Chapter 9 views the air pollution control problem for an entire region or airshed. To comply with national ambient air quality standards that prescribe, on the basis of health effects, the maximum atmospheric concentration level to be attained in a region, it is necessary for the relevant governmental authority to specify the degree to which the emissions from each of the sources in the region must be controlled. Thus it is generally necessary to choose among many alternatives that may lead to the same total quantity of emission over the region. Chapter 9 establishes a framework by which an optimal air pollution control plan for an airshed may be determined. In short, we seek the least-cost combination of abatement measures that meets the necessary constraint that the total emissions not exceed those required to meet an ambient air quality standard.

Once pollutants are released into the atmosphere, they are acted on by a variety of

chemical and physical phenomena. The atmospheric chemistry and physics of air pollution is indeed a rich arena, encompassing the disciplines of chemistry, meteorology, fluid mechanics, and aerosol science. As noted above, the subject matter of the present book ends at the stack (or the tailpipe); those readers desiring a treatment of the atmospheric behavior of air pollutants are referred to J. H. Seinfeld, *Atmospheric Chemistry and Physics of Air Pollution* (Wiley-Interscience, New York, 1986).

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