Air Pollution: Engineering, Science, and Policy

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Air Pollution: Engineering, Science and Policy

Second Edition

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DEDICATION

This book is dedicated to Jean and Leo – thanks for always believing in me; to Margaret – thanks for always being there for me; and Joseph, Regina, and Eleanor – for keeping me motivated to make the world a better place.

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First Edition: I would like to thank all my undergraduate students for letting me use the initial drafts of this text in class and for all their feedback on how to make it better. I would especially like to thank Emily (Bell) Anderson, Sarah Anderson, Aaron Boothe, Justin Boucher, Kayla Brown, Ryan Clark, Luke Dahlin, Doug Eli, Justin Finke, Caitlin Leach, Marcus Thompson, and Josie Wise for the detailed critiques, creation of figures and tables, the well thought out example problems, and the detailed case studies. I would also like to thank all my other students who provided proof reading and worked-through the examples and homework problems.

Second Edition: Many students and instructors have helped me find errors and typos in the textbook and the solution manual. I would especially like to thank the following people for their assistance: Sydney Costello, Matthew Fulton, Tristan Williams, Kayla Ness, Daniel Schacht, Zachary Czerniak, Maria and Pam Onnen, Wendy Gomez, Madeleine Ogren, Tyler Adricula, Cyrus Muehlberg, and Tori Johnson. I also appreciate the enthusiasm the text generated and the encouragement for continuing with the new edition.

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Rationale

Air Pollution: Engineering, Science, and Policy. This textbook explores the sources and sinks, health effects, regulatory methodologies, history, and control technologies for air pollutants. Chapters are organized by the physical and chemical nature of the pollutants, which determines the technologies useful for their control. The book includes chapters on each of the Clean Air Act criteria air pollutants (particulate matter, sulfur oxides, nitrogen oxides, ozone, carbon monoxide, and lead). Additional topics include mercury, reactive carbon (methane, volatile organic compounds), indoor air quality, hazardous air pollutants, mobile sources, stratospheric ozone depletion, and carbon dioxide induced climate change. Each section also explores the impacts of control technologies on society, industry, and the local, regional, and global atmosphere.

The text is aimed at upper level undergraduates in the sciences and engineering who have completed courses in general chemistry, general physics, and calculus. It provides the background (or review) information needed to help students that have not had (or have forgotten) courses in: problem solving calculations, mass and energy balances, particle technology, fluid mechanics, meteorology, dispersion modeling, and green engineering. These chapters provide the necessary background so any student in a science or engineering discipline can understand and use this book.

The book discusses the *science* of what is known about each pollutant – the natural and anthropogenic sources; what happens to it once it is released into the environment; and the ultimate fate of the release. *Policy* issues include: how humans have organized systems to minimize harm, and the effects of these systems. *Engineering* issues include: control methodologies and technologies, such as controlling inputs, changing processes, and emission removal equipment. Many chapters include case studies from particular industries and situations which may describe the relevant air pollutant issues; provide short and relevant science summaries; describe the current practices for pollutant removal; and explain why some alternative technology is not chosen.

Highlights

- Include global issues and potential solutions for global problem pollutants (carbon dioxide, mercury, stratospheric ozone depletion). These problems are the most relevant, significant, and contemporary issues in air pollution.
- The successes and remaining problems surrounding the criteria pollutants (SOx, NOx, PM, VOC's, Pb, and tropospheric ozone). Readers new to the field of air pollution will want to learn about these past victories, but will also need to know what the current issues are that they may be expected to address.
- Explore issues on the scale of each problem. Scales range from the personal scale, to buildings (indoor air quality) to cities (particulate matter) to regions (acid rain and smog) to global (CFCs, methane, and carbon dioxide). A scale based hierarchy or categorization helps readers move beyond the traditional command and control of point source solutions and see that other solutions can be viable.

- Encourage readers to think about air quality issues in terms of their life as a citizen and consumer, not just as a scientist or engineer. When these problems are explored at the personal scale, it provides additional motivation to learn about the subject.
- Explore engineering and non-engineering solutions to air quality problems. Sometimes the best solution is to not make the mess in the first place rather than looking for ways to clean up the mess. This aspect of the text is blended in as green chemistry, green engineering, and pollution prevention. It has a place in each section of the text.
- Includes some international perspectives. Other countries have similar goals and regulations to the USA, yet they solve the problems in other ways. This information is included in many chapters and in the discussion of specific problem areas and solutions.
- The text contains more information than could be completed in a typical 15 week course. This gives the instructor some choices as to what to cover. The basic core chapters are
    - o Chapter 1. Introduction
    - o Chapter 3. Laws and Regulations
    - o Chapter 5. Meteorology
    - o Chapter 6. Dispersion
    - o Chapter 7. Particulate Matter
    - o Chapter 8. Sulfur
    - o Chapter 9. Nitrogen
    - o Chapter 10. Reactive Carbon Compounds
    - o Chapter 11. Ozone
    - o Chapter 13. Carbon Dioxide and Climate Change

Chapter 2 provides review information and select portions of it should be covered based on the background of your students. The remaining chapters should be considered by the interests of the instructor and students. Other chapters expand on other types of pollutants and control technologies.

I have taught courses in air pollution for over 25 years. Students are mostly undergraduate engineers and environmental scientists, however students from every science and engineering discipline have taken the course and found it useful. Many had not ever considered the topic as an area for their career until taking this course. They have then gone on to successful careers in air pollution control with industrial facilities, power companies, consulting firms, state government, and advanced degrees.

2nd Edition

I am honored to be able to revise this textbook. I appreciate all the comments from students and teachers that took a risk and tried a new book. I have tried to make it as useful and relevant as possible. My goal has been to help prepare the student to start a career that improves air quality and the environment.

Changes:

Corrections from the first edition have been included. Undoubtedly additional errors have found their way in. Please contact the author (ssternbe@d.umn.edu) or the publisher with any questions or corrections.

Many data sets (tables and figures) have been **updated** to reflect changes since the first edition.

Added discussion of **epidemiology**. Within chapter 2 to introduce terms and ideas, then sprinkled throughout other chapters as relevant. Note especially the addition of table 2-9 which shows the strength of various associations between air pollution exposure and adverse health outcomes.

Condense background knowledge into one chapter. 1st edition chapters 2 and 4 were combined into a single chapter (2), allowing removal of redundant information.

Combine the particulate matter chapters. 1st edition chapters 7 and 8 were combined into a single chapter (7), again allowing removal of redundant information. This was the most common suggestion for improvement from students.

Information on the **regulations has been updated** within every chapter. The rules on ozone and carbon dioxide were unsettled when the 1st edition went to print. Ozone rules are more settled. Currently the rules on mobile source fuel efficiencies are undergoing change and are not settled as this book goes to print. Unfortunately, the regulatory uncertainty on carbon dioxide has not abated, even as the science becomes clearer and more consistent.

Addition of learning objectives to the beginning of each chapter may prepare students for the material in a chapter and help instructors to better focus their assessment of student understanding.

Addition of a summary at the end of each chapter. The intention is to help students better organize their understanding of each chapter's material.

CONTENTS

LIST OF ABBREVIATIONS

General

A/F	Air to Fuel ratio
ADE	advection dispersion equation
AQG	air quality guidelines
AQI	air quality index
ARP	Acid Rain Program
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	All-Terrain Vehicles
BACT	Best Available Control Technology
BTR	Budget Trading Program
C_p	heat capacity (constant pressure)
C_v	heat capacity (constant volume)
CAA	Clean Air Act
CAAA	Clean Air Act and Amendments
CAIR	Clean Air Interstate Rule
CARB	California Air Resources Board
CASAC	Clean Air Scientific Advisory Committee
CCN	cloud condensation nuclei
CCS	carbon capture and sequestration
CDC	Center for Disease Control and Prevention
CEMS	continuous emissions monitoring system
CFC	chlorofluorocarbons
CFR	Code of Federal Regulations
CH4	methane
CI	compression ignition
CMAQ	Community Multi-scale Air Quality
CMAS	Community Modeling and Analysis System
CO	carbon monoxide
CO2	carbon dioxide
CSAPR	Cross State Air Pollution Rule
DOE	Department of Energy
DU	Dobson Unit
EEA	European Environment Agency
EGU	electricity generating unit
EIA	Energy Information Agency
EIA	environmental impact assessment
EIS	environmental impact statement

EJ	environmental justice
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
EU	European Union
exp[…]	a mathematics function, aka exponential function, anti-natural-log, or e^x
FAA	Federal Aviation Administration
FGD	flue gas desulfurization
FIP	Federal Implementation Plan
GCC	global climate change
GDP	Gross Domestic Production
GE	green engineering
GHG	greenhouse gas
GWP	global warming potential, also CO2-equivalence
HAP	hazardous air pollutant
HAZOP	hazard and operability analysis
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HDV	Heavy Duty Vehicles
Hg	mercury
HVAC	Heating, Ventilation, and Air Conditioning
IAP	Indoor Air Pollutant
IAQ	Indoor Air Quality
ICAO	International Civil Aviation Organization
IDLH	immediately dangerous to life or health
IGCC	integrated gasification combined cycle
IMO	International Maritime Organization
IPCC	Inter-Governmental Panel on Climate Change
IR	infrared
ISC 3	Industrial Source Complex
ISO	International Standards Organization
IUPAC	International Union of Pure and Applied Chemistry
LAER	Lowest Achievable Emission Rate
LCA	life cycle analysis
LDT	Light Duty Truck
LDV	Light Duty Vehicles
LEED	Leadership in Energy and Environmental Design
LEL	lower explosive limit
MACT	Maximum Achievable Control Technology
MATS	Mercury and Air Toxics Standards
MMD	maximum mixing depth (also mean mixing depth)
MSAT	mobile source air toxics
MSDS	Material Safety Data Sheets
MW	molecular weight

NAAQS	National Ambient Air Quality Standards
NADP	National Acid Deposition Program
NATA	National Air Toxic Assessment
NEI	National Emission Inventory
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NHTSA	National Highway Traffic Safety Administration
NIOSH	National Institute for Occupational Safety and Health
NMHC	non-methane hydrocarbon
NMOG	non-methane organic gas
NMTOC	non-methane total organic carbon
NMVOC	non-methane volatile organic compounds
NOAA	National Oceanic and Atmospheric Administration
NOx	nitrogen oxides
NSPS	New Source Performance Standard
NSR	New Source Review
O3	ozone
ODP	ozone depletion potential
ODS	ozone depleting substance
OMB	Office of Management and Budget
OSHA	Occupational Health and Safety Administration
PAN	peroxyacetyl nitrate
Pb	lead
PEL	Permissible Exposure Limits
PM	particulate matter
PM0.1	particulate matter 0.1 micron and smaller
PM2.5	particulate matter 2.5 micron and smaller
PM10	particulate matter 10 micron and smaller
PSD	Prevention of Significant Deterioration
PSD	particle size distribution
RACT	Reasonably Available Control Technology
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
RFG	reformulated gasoline
RH	relative humidity
S-O3	stratospheric ozone
SCR	selective catalytic reduction
SI	spark ignition
SIP	State Implementation Plan
SNCR	selective non-catalytic reduction
SO_x	sulfur oxides
STP	Standard Temperature and Pressure (298K and 1 atm)
T-O3	tropospheric ozone

TDF	tire derived fuel
TEL	tetraethyl lead
TIP	Tribal Implementation Plan
TSCA	Toxic Substances Control Act
TSP	total suspended particulates
TVOC	total volatile organic compounds
TWA	time weighted average
UEL	upper explosive limit
Units – L	Length
Units – M	Mass
Units – t	time
Units – T	Temperature
USC	United States Code
USGS	United States Geological Survey
UV	ultraviolet
VOC	volatile organic compounds
VSL	value of a statistical life
WHO	World Health Organization