Air Pollution: Engineering, Science, and Policy

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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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I would like to thank all of 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.

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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 US 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 that 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 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 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 8. Particulate matter
    - o Chapter 9. Sulfur
    - o Chapter 10. Nitrogen
    - o Chapter 12. Ozone
    - o Chapter 14. Carbon Dioxide

Other chapters either provide review information or expand the types of pollutants and control technologies.

I have taught courses in air pollution for over 20 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, and state government.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Chapter 1

AQI	Air Quality Index
CFC	chlorofluorocarbons
CO_2	carbon dioxide
CO	carbon monoxide
EPA	Environmental Protection Agency
HAP	hazardous air pollutant
NO_x	nitrogen oxide compounds
OSHA	Occupational Health and Safety Administration
PM	particulate matter
SO_x	sulfur oxide compounds
TEL	tetraethyl lead
VOC	volatile organic compounds

Chapter 3

AQA	Air Quality Analysis
BACM	Best Available Control Measures
BACT	Best Available Control Technology
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAFE	Corporate Average Fuel Economy
CFR	Code of Federal Regulations
EPA	Environmental Protection Agency
FIP	Federal Implementation Plan
GPO	Government Printing Office
HAP	Hazardous Air Pollutants
ISO	International Standards Organization
LAER	Lowest Achievable Emission Rate
MACT	Maximum Achievable Control Technology
NAAQS	National Ambient Air Quality Standards
NHTSA	National Highway Traffic Safety Administration
NSPS	New Source Performance Standards
NSR	New Source Review
OTC	Ozone Transport Commission

PSD	Prevention of Significant Deterioration
RACM	Reasonably Available Control Measures
RACT	Reasonable Available Control Technology
RCRA	Resource Conservation and Recovery Act
SIP	State Implementation Plan
TIP	Tribal Implementation Plans
USC	United States Code

Chapter 4

cP	centi-Poise, a unit for viscosity
F	friction
M	mass flow [mass/time]
m	mass
mw	molecular weight
n	number of moles
P	pressure
Q	volumetric flow [volume/time]
R	ideal gas constant (several values are given in appendix 1)
Re	Reynolds number
T	temperature
V	volume
W	work

Chapter *5*

MMD	maximum mixing depth
RH	relative humidity
VP	vapor pressure
Γ	dry adiabatic lapse rate
Λ	actual or environmental lapse rate

Chapter *6*

ADE	advection dispersion equation
C	concentration
CO	carbon monoxide
H	effective stack height
HAP	hazardous air pollutant
ISC3	industrial source complex (an EPA dispersion model)

NO_x	nitrogen oxides
PM	particulate matter
Q	emission rate [mass/time],
SO_x	sulfur oxides
u	wind speed
VOC	volatile organic compound
σ_y and σ_z	mixing lengths

Chapter 7

D_{eff}	effective diameter
f	probability function
K_c	Cunningham correction factor
PM	particulate matter

Chapter 8

ESP	electrostatic precipitators
PM	particulate matter, any size
$PM_{0.1}$	particulate matter with a diameter of less than 0.1 μm
$PM_{2.5}$	particulate matter with a diameter of less than 2.5 μm
PM_{10}	particulate matter with diameters of less than 10 μm
TSP	total suspended particles

Chapter 9

ARP	Acid Rain Program
CAIR	Clean Air Interstate Rule
CCN	cloud condensation nuclei
EU	European Union
FGD	flue gas desulfurization
NAAQS	National Ambient Air Quality Standards
NAPAP	National Acid Precipitation Assessment Program
NSPS	New Source performance Standards
NO_x	nitrogen oxides
PM	particulate matter
SO_x	sulfur oxides
UK	United Kingdom

Chapter 10

ARP	Acid Rain Program
BOOS	burners-out-of-service
CAIR	Clean Air Interstate Rule
FGR	flue gas recirculation
FIR	fuel induced recirculation
HNO_3	nitric acid
HONO	nitrous acid
LEA	low-excess air
LNB	low NO_x burners
NBP	NO_x Budget Trading Program
NH_3	ammonia
NH_4+	ammonium
N_2	molecular nitrogen
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxide compounds (NO and NO_2)
NO_{3-}	nitrate
NO_{2-}	nitrite
N_2O	nitrous oxide
N_2O_5	dinitrogen pentoxide
OFA	over-fire-air
OTC	Ozone Transport Commission
RACT	Reasonably Available Control Technology
SC	staged combustion
SCA	staged combustion air
SCR	selective catalytic reduction
SIP	state implementation plan
SNCR	selective non-catalytic reduction

Chapter 11

CAFE	Corporate Average Fuel Efficiency
CH_4	methane
CMM	coal mine methane
CO	carbon monoxide
LFG	landfill gas
NHTSA	National Highway and Traffic Safety Administration

NMTOC	non-methane total organic carbon
NMVOC	non-methane volatile organic compounds
VOC	volatile organic compounds
VRU	vapor recovery units

Chapter 12

CAIR	clean air interstate rule
CFC	chlorofluorocarbons
CH4	methane
CMAQ	community multi-scale air quality
CMAS	community modeling and analysis system
CO	carbon monoxide
DU	Dobson units
EKMA	empirical kinetic modeling approach
GWP	global warming potential
HFC	hydrofluorocarbons
HCFC	hydrochlorofluorocarbon
NMVOC	non-methane volatile organic compounds
ODP	ozone depletion potential
ODS	ozone-destroying substance
PAN	peroxyacetyl nitrate
PSC	polar stratospheric clouds
VOC	volatile organic compounds

Chapter 13

BACT	best available control technology
CAA	clean air act
EGU	electricity generating unit
HAP	hazardous air pollutants
MACT	maximum achievable control technology
MATS	mercury and air toxics standards
MSAT	mobile source air toxics
NATA	national air toxic assessment
NESHAP	national emissions standards for hazardous air pollutants
PAC	powdered activated carbon
VOC	volatile organic compounds

Chapter 14

CAFE	corporate averaged fleet efficiency
CCS	carbon capture and sequestration
CFC	chlorofluorocarbons
CFL	compact fluorescent lights
CO_2	carbon dioxide
CT	combustion turbine
EGU	electricity generating unit
GCC	global climate change
GHG	greenhouse gases
GtC	gigaton carbon
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
LCO_2	liquid carbon dioxide
LED	light emitting diodes
NGO	non-government organizations
PC	pulverized coal
PSD	prevention of significant deterioration
SCO_2	supercritical fluid carbon dioxide

Chapter 15

ATSDR	Agency for Toxic Substances and Disease Registry
FSP	fan static pressure
HVAC	heating, ventilating, and air conditioning
IAQ	indoor air quality
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
Re	Reynolds number
TSCA	Toxic Substances Control Act

Chapter 16

A/F	air to fuel
ALVW	adjusted loaded vehicle weight
ATDC	after top dead center
BDC	bottom dead center
BTDC	before top dead center
CARB	California Air Resources Board
CO	carbon monoxide
CO_2	carbon dioxide

CR	compression ratio
DOC	diesel oxidation catalyst
DPF	diesel particle filter
ECA	emission control areas
EGR	exhaust gas recirculation
EVAP	evaporative emission control
FAA	Federal Aviation Administration
GVWR	gross vehicle weight rating
HAP	hazardous air pollutant
HC	hydrocarbon
HDV	heavy duty vehicles
HFO	heavy fuel oil
HLDT	heavy light-duty truck
ICAO	International Civil Aviation Organization
ILEV	inherently low emission vehicles
I/M	inspection and maintenance
IMO	International Maritime Organization's
LLDT	light light-duty truck
LDT	light-duty truck
LDV	light duty vehicles
LEV	low emission vehicles
LPG	liquefied petroleum gas
LTO	landing/take-off
MDPV	medium-duty passenger vehicle
MIL	malfunction indicator lamp
MOVES	Motor Vehicle Emission Simulator
NMOG	non-methane organic gas
NO_x	nitrogen oxide compounds
OBDII	onboard diagnostic system
PCV	positive crankcase ventilation
PM	particulate matter
RFG	reformulated gasoline
RPM	revolutions per minute
SCR	selective catalytic reduction
SI	spark ignition
SO_x	sulfur oxide compounds
SUV	sport utility vehicles
TDC	top dead center

UEGO	universal exhaust gas sensor
ULEV	ultra-low emission vehicles
VOC	volatile organic compounds
ZEV	zero emission vehicles

Chapter 17

CDC	Center for Disease Control and Prevention
COL	conservation of life
EIA	environmental impact assessment
GE	green engineering
HAZOP	hazard and operability analysis
LCA	life cycle analysis
MSDS	material safety data sheets
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limits
PI	process integration
REL	recommended exposure limits