

VOLUME 2
HANDBOOK OF ENVIRONMENTAL ENGINEERING

Advanced Air and Noise Pollution Control

Edited by

Lawrence K. Wang, PhD, PE, DEE

Zorex Corporation, Newtonville, NY

Lenox Institute of Water Technology, Lenox, MA

Krofta Engineering Corp., Lenox, MA

Norman C. Pereira, PhD

Monsanto Corporation (Retired), St. Louis, MO

Yung-Tse Hung, PhD, PE, DEE

Department of Civil and Environmental Engineering

Cleveland State University, Cleveland, OH

Consulting Editor

Kathleen Hung Li, ms

HUMANA PRESS  TOTOWA, NEW JERSEY

Contents

Preface	v
Contributors	xvii

1 Atmospheric Modeling and Dispersion

<i>Lawrence K. Wang and Chein-Chi Chang</i>	1
1. Air Quality Management	1
2. Air Quality Indices	4
2.1. US EPA Air Quality Index	4
2.2. The Mitre Air Quality Index (MAQI)	5
2.3. Extreme Value Index (EVI)	6
2.4. Oak Ridge Air Quality Index (ORAQI)	8
2.5. Allowable Emission Rates	9
2.6. Effective Stack Height	10
2.7. Examples	11
3. Dispersion of Airborne Effluents	16
3.1. Wind Speed Correction	16
3.2. Wind Direction Standard Deviations	17
3.3. Plume Standard Deviations	17
3.4. Effective Stack Height	17
3.5. Maximum Ground-Level Concentration	18
3.6. Steady-State Dispersion Model (Crosswind Pollutant Concentrations)	19
3.7. Centerline Pollutant Concentrations	19
3.8. Short-Term Pollutant Concentrations	20
3.9. Long-Term Pollutant Concentrations	20
3.10. Stability and Environmental Conditions	21
3.11. Air Dispersion Applications	23
Nomenclature	29
References	33

2 Desulfurization and Emissions Control

<i>Lawrence K. Wang, Clint Williford, and Wei-Yin Chen</i>	35
1. Introduction	35
1.1. Sulfur Oxides and Hydrogen Sulfide Emissions	36
1.2. SO _x Emissions Control Technologies	36
2. Sulfur Oxides and Hydrogen Sulfide Pollution	37
2.1. Acid Rain	37
2.2. Public Health Effects	38
2.3. Materials Deterioration	38
2.4. Visibility Restriction	38
3. US Air Quality Act and SO _x Emission Control Plan	38
4. Desulfurization Through Coal Cleaning	40

4.1. Conventional Coal Cleaning Technologies	40
4.2. Advanced Coal Cleaning Technologies	41
4.3. Innovative Hydrothermal Desulfurization for Coal Cleaning	44
5. Desulfurization Through Vehicular Fuel Cleaning	45
6. Desulfurization Through Coal Liquefaction, Gasification, and Pyrolysis.....	46
6.1. Coal Gasification	46
6.2. Coal Liquefaction	48
6.3. Pyrolysis	49
7. Desulfurization Through Coal-Limestone Combustion	50
7.1. Fluidized-Bed Combustion	50
7.2. Lime-Coal Pellets	51
8. Hydrogen Sulfide Reduction by Emerging Technologies	52
8.1. Innovative Wet Scrubbing Using a Nontoxic Chelated Iron Catalyst.....	52
8.2. Conventional Wet Scrubbing Using Alkaline and Oxidative Scrubbing Solution	53
8.3. Scavenger Adsorption	53
8.4. Selective Oxidation of Hydrogen Sulfide in Gasifier Synthesis Gas	54
8.5. Biological Oxidation of Hydrogen Sulfide	54
9. "Wet" Flue Gas Desulfurization Using Lime and Limestone	54
9.1. FGD Process Description	55
9.2. FGD Process Chemistry	55
9.3. FGD Process Design and Operation Considerations	58
9.4. FGD Process Modifications and Additives	62
9.5. Technologies for Smelters	64
9.6. FGD Process Design Configurations	65
9.7. FGD Process O&M Practices	74
10. Emerging "Wet" Sulfur Oxide Reduction Technologies	76
10.1. Advanced Flue Gas Desulfurization Process	77
10.2. CT-121 FGD Process	77
10.3. Milliken Clean Coal Technology Demonstration Project	78
11. Emerging "Dry" Sulfur Oxides Reduction Technologies and Others	79
11.1 Dry Scrubbing Using Lime or Sodium Carbonate	79
11.2. LIMB and Coolside Technologies	79
11.3. Integration of Processes for Combined SO _x and NO _x Reduction	80
11.4. Gas Suspension Absorbent Process	81
11.5 Specialized Processes for Smelter Emissions: Advanced Calcium Silicate Injection Technology	82
12. Practical Examples	82
13. Summary	91
Nomenclature	92
References	92
3 Carbon Sequestration	
<i>Robert L. Kane and Daniel E. Klein</i>	97
1. Introduction	97
1.1. General Description	97
1.2. Carbon Sequestration Process Description	98

2. Development of a Carbon Sequestration Road Map	100
3. Terrestrial Sequestration	101
4. CO ₂ Separation and Capture.....	102
5. Geologic Sequestration Options	105
6. Ocean Sequestration	107
7. Chemical and Biological Fixation and Reuse.....	108
8. Concluding Thoughts	110
Nomenclature	110
Acknowledgment	110
References	110

4 Control of NO_x During Stationary Combustion

<i>James T. Yeh and Wei-Yin Chen</i>	113
1. Introduction	113
2. The 1990 Clean Air Act	114
3. NO _x Control Technologies	115
3.1. In-Furnace NO _x Control	115
3.2. Postcombustion NO _x Control	119
3.3. Hybrid Control Systems	120
3.4. Simultaneous SO ₂ and NO _x Control	120
4. Results of Recent Demonstration Plants on NO _x Control	121
5. Future Regulation Considerations	123
6. Future Technology Developments in Multipollutant Control	123
References	124

5 Control of Heavy Metals in Emission Streams

<i>L. Yu Lin and Thomas C. Ho</i>	127
1. Introduction	127
2. Principle and Theory	128
2.1. Reactions in the Incinerator	128
2.2. Control of Metal Emissions	132
3. Control Device of Heavy Metals	139
3.1. Gravity Settling Chamber	139
3.2. Cyclone	140
3.3. Electrostatic Precipitator	140
3.4. Quench	140
3.5. Scrubber	141
3.6. Fabric Filters	141
3.7. Vitrification	141
3.8. Solidification	142
3.9. Chemical Stabilization and Fixation	142
3.10. Extraction	143
3.11. Fluidized-Bed Metal Capture	143
4. Metal Emission Control Examples.....	145
4.1. Municipal Solid-Waste Incineration	145
4.2. Asphalt-Treatment Plants	145
4.3. Hazardous Waste Incinerator Operation at Low-to-Moderate Temperature	147
Nomenclature	148
References	148

6 Ventilation and Air Conditioning

<i>Zucheng Wu and Lawrence K. Wang</i>	151
1. Air Ventilation and Circulation	151
1.1. General Discussion	151
1.2. Typical Applications	153
2. Ventilation Requirements	157
2.1. Rate of Air Change	158
2.2. Rate of Minimum Air Velocity	159
2.3. Volumetric Airflow Rate per Unit Floor Area	159
2.4. Heat Removal	160
3. Ventilation Fans	160
3.1. Type	160
3.2. Fan Laws	163
3.3. Fan Selection to Meet a Specific Sound Limit	166
4. Hood and Duct Design	167
4.1. Theoretical Considerations	167
4.2. Hoods for Cold Processes	171
4.3. Hoods for Hot Processes	174
4.4. Ducts	180
5. Air Conditioning	186
5.1. General Discussion and Considerations	186
5.2. Typical Applications	190
6. Design Examples	193
7. Health Concern and Indoor Pollution Control	206
7.1. Health Effects and Standards	206
7.2. Indoor Air Quality	207
7.3. Pollution Control in Future Air Conditioned Environments	209
8. Heating, Ventilating, and Air Conditioning	210
8.1. Energy and Ventilation	210
8.2. HVAC Recent Approach	213
8.3. HVAC and Indoor Air Quality Control	217
Nomenclature	219
Acknowledgments	220
References	221
Appendix A: Recommended Threshold Limit Values of Hazardous Substances	223
Appendix B: Tentative Threshold Limit Values of Hazardous Substances	229
Appendix C: Respirable Dusts Evaluated by Count	230
Appendix D: Converting from Round to Rectangular Ductwork	231
Appendix E: Procedure for Fan Selection to Meet a Specific Sound Level Limit	231
Appendix F: Method for Determination of Room Attenuation Effect (RAE)	233
Appendix G: Calculation of a Single-Number Sound-Power Level Adjusted to "A" Weighted Network (LwA)	234
Appendix H: Determination of Composite Sound Level.....	234
Appendix I: Noise Absorption Coefficients of General Building Materials	235

7 Indoor Air Pollution Control

<i>Nguyen Thi Kim Oanh and Yung-Tse Hung</i>	237
1. Indoor Air Quality: Increasing Public Health Concern	237
2. Indoor Air Pollution and Health Effects.....	238
2.1. Sources of Indoor Air Pollution	238
2.2. Health Effects of Indoor Air Pollutants	240
3. Indoor Air Pollution	253
3.1. Identifying Indoor Air Pollution Problems	253
3.2. Monitoring Indoor Air Quality	254
3.3. Mitigation Measures	255
4. Regulatory and Nonregulatory Measures for Indoor Air Quality Management	269
References	271

8 Odor Pollution Control

<i>Toshiaki Yamamoto, Masaaki Okubo, Yung-Tse Hung, and Ruihong Zhang</i>	273
1. Introduction	273
1.1. Sources of Odors	273
1.2. Odor Classification	273
1.3. Regulations	274
1.4. Odor Control Methods	275
2. Nonbiological Method	275
2.1. Emission Control	276
2.2. Air Dilution	284
2.3. Odor Modification	292
2.4. Adsorption Method	295
2.5. Wet Scrubbing or Gas Washing Oxidation.....	299
2.6. Design Example of Wet Scrubbing or Gas Washing Oxidation	304
2.7. Incineration	307
2.8. Nonthermal Plasma Method	310
2.9. Indirect Plasma Method (Ozone or Radicals Injection)	318
2.10. Electrochemical Method	323
3. Biological Method	325
3.1. Introduction.....	325
3.2. Biological Control.....	326
3.3. Working Principles of Biological Treatment Processes	326
3.4. Design of Biofilters	328
Nomenclature	330
References	331

9 Radon Pollution Control

<i>Ali Gökmen, Inci G. Gökmen, and Yung-Tse Hung</i>	335
1. Introduction	335
1.1. Units of Radioactivity	336
1.2. Growth of Radioactive Products in a Decay Series	337
2. Instrumental Methods of Radon Measurement	340
2.1. Radon Gas Measurement Methods	340

2.2. Radon Decay Product Measurement Methods	343
3. Health Effects of Radon	344
4. Radon Mitigation in Domestic Properties	347
4.1. Source Removal	351
4.2. Contaminated Well Water	351
4.3. Building Materials	352
4.4. Types of House and Radon Reduction	352
References	356

10 Cooling of Thermal Discharges

<i>Yung-Tse Hung, James Eldridge, Jerry R. Taricska, and Kathleen Hung Li</i>	359
---	-----

1. Introduction	359
2. Cooling Ponds	360
2.1. Mechanism of Heat Dissipation (Cooling)	360
2.2. Design of Cooling Ponds	361
3. Cooling Towers	370
3.1. Mechanism of Heat Dissipation in Cooling Towers	371
3.2. Types of Towers	371
3.3. Natural Draft Atmospheric Cooling Towers	371
3.4. Natural Draft, Wet Hyperbolic Cooling Towers	373
3.5. Example 1	376
3.6. Hybrid Draft Cooling Towers	376
3.7. Induced (Mechanical) or Forced Draft Wet Cooling Towers	376
3.8. Cooling Tower Performance Problems	380
Nomenclature	381
Glossary	382
Acknowledgment	383
References	383

11 Performance and Costs of Air Pollution Control Technologies

<i>Lawrence K. Wang, Jiann-Long Chen, and Yung-Tse Hung.....</i>	385
--	-----

1. Introduction	385
1.1. Air Emission Sources and Control	385
1.2. Air Pollution Control Devices Selection	386
2. Technical Considerations	386
2.1. Point Source VOC Controls	386
2.2. Point Source PM Controls	388
2.3. Area Source VOC and PM Controls	388
2.4. Pressure Drops Across Various APCDs	391
3. Energy and Cost Considerations for Minor Point Source Controls	391
3.1. Sizing and Selection of Cyclones, Gas Precoolers, and Gas Preheaters	391
3.2. Sizing and Selection of Fans, Ductworks, Stacks, Dampers, and Hoods	393
3.3. Cyclone Purchase Costs	396
3.4. Fan Purchase Cost	397
3.5. Ductwork Purchase Cost	400

3.6. Stack Purchase Cost	400
3.7. Damper Purchase Cost	403
4. Energy and Cost Considerations for Major Point Source Controls	404
4.1. Introduction	404
4.2. Sizing and Selection of Major Add-on Air Pollution Control Devices	404
4.3. Purchased Equipment Costs of Major Add-on Air Pollution Control Devices	404
5. Energy and Cost Considerations for Area Source Controls	412
5.1. Introduction	412
5.2. Cover Cost	414
5.3. Foam Cost	415
5.4. Wind Screen Cost	415
5.5. Water Spray Cost	415
5.6. Water Additives Costs	416
5.7. Enclosure Costs	416
5.8. Hood Costs	416
5.9. Operational Control Costs	416
6. Capital Costs in Current Dollars	417
7. Annualized Operating Costs	421
7.1. Introduction	421
7.2. Direct Operating Costs	421
7.3. Indirect Operating Costs	426
8. Cost Adjustments and Considerations	428
8.1. Calculation of Current and Future Costs	428
8.2. Cost Locality Factors	428
8.3. Energy Conversion and Representative Heat Values	429
8.4. Construction Costs, O&M Costs, Replacement Costs, and Salvage Values	430
9. Practice Examples	431
Nomenclature	436
References	438
Appendix: Conversion Factors	440

12 Noise Pollution

<i>James P. Chambers</i>	441
1. Introduction	441
2. Characteristics of Noise	442
3. Standards	443
4. Sources	445
5. Effects	446
6. Measurement	446
7. Control	450
References	452

13 Noise Control

<i>James P. Chambers and Paul Jensen</i>	453
1. Introduction	453
2. The Physics of Sound	454

2.1. Sound	454
2.2. Speed of Sound	454
2.3. Sound Pressure	455
2.4. Frequency	456
2.5. Wavelength	456
2.6. rms Sound Pressure	458
2.7. Sound Level Meter	458
2.8. Sound Pressure Level	458
2.9. Loudness	459
2.10. Sound Power Level	461
2.11. Sound Energy Density	461
3. Indoor Sound	462
3.1. Introduction.....	462
3.2. Sound Buildup and Sound Decay	464
3.3. Diffuse Sound Field	467
3.4. Reverberation Time	468
3.5. Optimum Reverberation Time	469
3.6. Energy Density and Reverberation Time	469
3.7. Relationship Between Direct and Reflected Sound	470
4. Sound Out-of-Doors	471
4.1. Sound Propagation	471
4.2. Wind and Temperature Gradients	471
4.3. Barriers	472
5. Noise Reduction	473
5.1. Absorptive Materials	473
5.2. Nonacoustical Parameters of Absorptive Materials	479
5.3. Absorption Coefficients	480
6. Sound Isolation	480
6.1. Introduction.....	480
6.2. Transmission Loss	481
6.3. Noise Reduction	486
6.4. Noise Isolation Class (NIC)	487
7. Vibrations	488
7.1. Introduction.....	488
7.2. Vibration Isolation	489
8. Active Noise Control	491
9. Design Examples	491
9.1. Indoor Situation.....	491
9.2. Outdoor Situation	495
Glossary	503
Nomenclature	507
References	508
Index	511