
Contents

| | |
|----------------------|-------|
| Preface..... | xxi |
| Acknowledgments..... | xxiii |
| Authors..... | xxv |

Chapter 1 Historical Overview of the Development of Clean Air Regulations.... 1

| | |
|--|----|
| 1.1 A Brief History of the Air Pollution Problem | 1 |
| 1.2 Federal Involvement in Air Pollution Control | 3 |
| 1.3 Characterizing the Atmosphere..... | 4 |
| 1.4 Recipe for an Air Pollution Problem | 6 |
| 1.4.1 Sources of Air Pollution | 8 |
| 1.4.2 Meteorological Parameters Affecting Transport of Pollutants..... | 8 |
| 1.4.3 Effects of Air Pollution—A Comparison of London Smog and Los Angeles Smog | 10 |

Chapter 2 Clean Air Act 13

| | |
|--|----|
| 2.1 History of the Clean Air Act | 13 |
| 2.1.1 1970 Clean Air Act Amendments | 13 |
| 2.1.1.1 National Ambient Air Quality Standards... 14 | 14 |
| 2.1.1.2 New Source Performance Standards..... 14 | 14 |
| 2.1.1.3 Hazardous Air Pollutants..... 14 | 14 |
| 2.1.1.4 Citizen Suits..... 15 | 15 |
| 2.1.2 1977 Clean Air Act Amendments | 15 |
| 2.1.2.1 Prevention of Significant Deterioration 16 | 16 |
| 2.1.2.2 Offsets in Nonattainment Areas | 16 |
| 2.2 1990 Clean Air Act Amendments | 17 |
| 2.2.1 Title I: Provisions for Attainment and Maintenance of NAAQS | 18 |
| 2.2.1.1 NAAQS Revisions | 19 |
| 2.2.2 Title II: Mobile Sources | 21 |
| 2.2.3 Title III: Hazardous Air Pollutant Program | 22 |
| 2.2.3.1 Source Categories | 22 |
| 2.2.3.2 Establishing MACT Standards | 24 |
| 2.2.3.3 Risk Management Plans | 34 |
| 2.2.4 Title IV: Acid Deposition Control | 34 |
| 2.2.5 Title V: Operating Permits | 36 |
| 2.2.6 Title VI: Stratospheric Ozone and Global Climate Protection | 36 |
| 2.2.7 Title VII: Enforcement | 36 |
| 2.2.8 Title VIII: Miscellaneous Provisions | 37 |

| | | |
|------------------|---|----|
| 2.2.9 | Title IX: Research | 37 |
| 2.2.10 | Title X: Disadvantaged Business | 37 |
| 2.2.11 | Title XI: Employment Transition Assistance | 37 |
| Chapter 3 | Air Permits for New Source | 39 |
| 3.1 | Elements of a Permit Application..... | 39 |
| 3.1.1 | Applicability | 40 |
| 3.1.1.1 | Potential to Emit | 41 |
| 3.1.1.2 | Fugitive Emissions | 41 |
| 3.1.1.3 | Secondary Emissions | 41 |
| 3.1.2 | Significant Emission Rates | 41 |
| 3.1.3 | Modification | 42 |
| 3.1.4 | Emissions Netting | 43 |
| 3.1.4.1 | Netting Example | 44 |
| 3.2 | Best Available Control Technology | 44 |
| 3.2.1 | Step 1: Identify Control Technologies | 45 |
| 3.2.2 | Step 2: Eliminate Technically Infeasible Options ... | 46 |
| 3.2.3 | Step 3: Rank Remaining Options by Control Effectiveness..... | 46 |
| 3.2.4 | Step 4: Evaluate Control Technologies in Order of Control Effectiveness | 47 |
| 3.2.4.1 | Energy Impacts | 47 |
| 3.2.4.2 | Environmental Impacts..... | 47 |
| 3.2.4.3 | Economic Impacts and Cost-Effectiveness... | 48 |
| 3.2.5 | Step 5: Select BACT | 48 |
| 3.3 | Air Quality Analysis | 48 |
| 3.3.1 | Preliminary Analysis | 49 |
| 3.3.2 | Full Analysis | 50 |
| 3.4 | NSR Reform | 50 |
| Chapter 4 | Atmospheric Diffusion Modeling for Prevention of Significant Deterioration Permit Regulations and Regional Haze | 51 |
| 4.1 | Introduction—Meteorological Background | 51 |
| 4.1.1 | Inversions | 51 |
| 4.1.1.1 | Surface or Radiation Inversions..... | 51 |
| 4.1.1.2 | Evaporation Inversion | 52 |
| 4.1.1.3 | Advection Inversion | 52 |
| 4.1.1.4 | Subsidence Inversion..... | 52 |
| 4.1.2 | Diurnal Cycle | 52 |
| 4.1.3 | Principal Smoke-Plume Models | 53 |
| 4.2 | Tall Stack | 54 |
| 4.3 | Classifying Sources by Method of Emission | 55 |
| 4.3.1 | Definition of Tall Stacks | 56 |
| 4.3.2 | Process Stacks..... | 57 |

| | | |
|------------------|---|-----------|
| 4.4 | Atmospheric-Diffusion Models..... | 57 |
| 4.4.1 | Other Uses of Atmospheric-Diffusion Models | 58 |
| 4.5 | Environmental Protection Agency's Computer Programs for Regulation of Industry | 59 |
| 4.5.1 | Industrial Source Complex Model | 60 |
| 4.5.2 | Screening Models..... | 60 |
| 4.5.3 | New Models..... | 61 |
| 4.6 | Source-Transport-Receptor Problem | 61 |
| 4.6.1 | Source..... | 61 |
| 4.6.2 | Transport | 62 |
| 4.6.2.1 | Effective Emission Height | 62 |
| 4.6.2.2 | Bulk Transport of Pollutants..... | 63 |
| 4.6.2.3 | Dispersion of Pollutants..... | 63 |
| 4.6.3 | Receptor | 63 |
| Chapter 5 | Source Testing | 65 |
| 5.1 | Introduction | 65 |
| 5.2 | <i>Code of Federal Regulations</i> | 65 |
| 5.3 | Representative Sampling Techniques..... | 65 |
| 5.3.1 | Gaseous Pollutants | 65 |
| 5.3.2 | Velocity and Particulate Traverses | 68 |
| 5.3.3 | Isokinetic Sampling..... | 70 |
| Chapter 6 | Ambient Air Quality and Continuous Emissions Monitoring | 73 |
| 6.1 | Ambient Air-Quality Sampling Program..... | 73 |
| 6.2 | Objectives of a Sampling Program..... | 73 |
| 6.3 | Monitoring Systems..... | 73 |
| 6.3.1 | Fixed versus Mobile Sampling | 74 |
| 6.3.2 | Continuous versus Integrated Sampling..... | 74 |
| 6.3.3 | Selection of Instrumentation and Methods | 75 |
| 6.4 | Federal Reference Methods and Continuous Monitoring | 75 |
| 6.5 | <i>Complete Environmental Surveillance and Control</i> System | 78 |
| 6.6 | Typical Air Sampling Train..... | 78 |
| 6.7 | Integrated Sampling Devices for Suspended Particulate Matter | 80 |
| 6.8 | Continuous Air-Quality Monitors | 81 |
| 6.8.1 | Electroconductivity Analyzer for SO ₂ | 82 |
| 6.8.2 | Coulometric Analyzer for SO ₂ | 83 |
| 6.8.3 | Nondispersive Infrared Method for CO | 84 |
| 6.8.4 | Flame Photometric Detection of Total Sulfur and SO ₂ | 85 |
| 6.8.5 | Hydrocarbons by Flame Ionization..... | 86 |
| 6.8.6 | Fluorescent SO ₂ Monitor..... | 86 |

| | | |
|------------------|---|------------|
| 6.8.7 | Chemiluminescence for Detection of Ozone and Nitrogen Oxides..... | 86 |
| 6.8.8 | Calibration of Continuous Monitors | 88 |
| 6.8.8.1 | Specifications for Continuous Air-Quality Monitors..... | 88 |
| 6.8.8.2 | Steady-State Calibrations | 88 |
| Chapter 7 | Cost Estimating | 91 |
| 7.1 | Time Value of Money | 91 |
| 7.1.1 | Annualized Capital Cost | 93 |
| 7.1.2 | Escalation Factors | 93 |
| 7.2 | Types of Cost Estimates | 94 |
| 7.3 | Air Pollution Control Equipment Cost | 95 |
| 7.3.1 | <i>OAQPS Control Cost Manual</i> | 95 |
| 7.3.2 | Other Cost-Estimating Resources | 95 |
| Chapter 8 | Process Design and the Strategy of Process Design | 97 |
| 8.1 | Introduction to Process Design | 97 |
| 8.2 | Strategy of Process Design..... | 97 |
| 8.2.1 | Process Flowsheets..... | 99 |
| 8.3 | Mass and Energy Balances..... | 99 |
| 8.3.1 | Mass-Balance Example | 101 |
| 8.3.2 | Energy-Balance Example | 102 |
| 8.4 | Systems-Based Approaches to Design | 104 |
| Chapter 9 | Profitability and Engineering Economics | 109 |
| 9.1 | Introduction—Profit Goal | 109 |
| 9.2 | Profitability Analysis..... | 109 |
| 9.2.1 | Mathematical Methods for Profitability Evaluation..... | 109 |
| 9.2.2 | Incremental Rate of Return on Investments as a Measure of Profitability | 110 |
| 9.2.2.1 | Example of IROI Comparing Two Cases | 111 |
| 9.2.2.2 | Example of IROI with Four Cases..... | 112 |
| 9.3 | Effect of Depreciation | 113 |
| 9.3.1 | Example..... | 114 |
| 9.4 | Capital Investment and Total Product Cost..... | 115 |
| 9.4.1 | Design Development | 116 |

| | | |
|-------------------|---|-----|
| Chapter 10 | Introduction to Control of Gaseous Pollutants | 119 |
| 10.1 | Absorption and Adsorption | 121 |
| 10.1.1 | Fluid Mechanics Terminology..... | 123 |
| 10.1.2 | Removal of Hazardous Air Pollutants and Volatile Organic Compounds by Absorption and Adsorption..... | 124 |
| 10.2 | Process Synthesis Technology for the Design of Volatile Organic Compounds Recovery Systems..... | 125 |
| Chapter 11 | Absorption for Hazardous Air Pollutants and Volatile Organic Compounds Control | 127 |
| 11.1 | Introduction | 127 |
| 11.1.1 | Description | 127 |
| 11.1.2 | Advantages | 128 |
| 11.1.3 | Disadvantages..... | 128 |
| 11.2 | Aqueous Systems..... | 128 |
| 11.3 | Nonaqueous Systems | 129 |
| 11.4 | Types and Arrangements of Absorption Equipment | 129 |
| 11.5 | Design Techniques for Countercurrent Absorption Columns..... | 132 |
| 11.5.1 | Equilibrium Relationships..... | 135 |
| 11.5.2 | Ideal Solutions—Henry's Law | 136 |
| 11.5.3 | Countercurrent Absorption Tower Design Equations | 138 |
| 11.5.4 | Origin of Volume-Based Mass-Transfer Coefficients..... | 140 |
| 11.5.4.1 | Steady-State Molecular Diffusion ... | 140 |
| 11.5.5 | Whitman Two-Film Theory | 142 |
| 11.5.6 | Overall Mass-Transfer Coefficients | 143 |
| 11.5.7 | Volume-Based Mass-Transfer Coefficients | 144 |
| 11.5.8 | Determining Height of Packing in the Tower: Height of a Transfer Unit Method..... | 145 |
| 11.5.9 | Dilute Solution Case | 146 |
| 11.5.10 | Using Mass Exchange Network Concepts to Simultaneously Evaluate Multiple Mass Separating Agent (Absorbent) Options..... | 147 |
| 11.6 | Countercurrent Flow Packed Absorption Tower Design.... | 151 |
| 11.6.1 | General Considerations | 151 |
| 11.6.2 | Operations of Packed Towers | 151 |
| 11.6.3 | Tower Packings | 153 |
| 11.6.3.1 | Random or Dumped Packing..... | 153 |
| 11.6.3.2 | Types of Random Packing | 154 |
| 11.6.3.3 | Structured Packing..... | 156 |

| | | |
|-------------------|---|------------|
| 11.6.3.4 | Types of Structured Packing | 158 |
| 11.6.3.5 | Grid-Type Packing | 161 |
| 11.6.4 | Packed Tower Internals | 162 |
| 11.6.4.1 | Packing Support Plate | 162 |
| 11.6.4.2 | Liquid Distributors | 162 |
| 11.6.4.3 | Liquid Redistributors | 163 |
| 11.6.4.4 | Bed Limiter | 163 |
| 11.6.5 | Choosing a Liquid–Gas Flow Ratio | 164 |
| 11.6.6 | Determining Tower Diameter—Random Dumped Packing | 165 |
| 11.6.7 | Determining Tower Diameter—Structured Packing | 168 |
| 11.6.8 | Controlling Film Concept | 169 |
| 11.6.9 | Correlation for the Effect of L/G Ratio on the Packing Height | 169 |
| 11.6.10 | Henry's Law Constants and Mass-Transfer Information | 171 |
| 11.6.11 | Using Henry's Law for Multicomponent Solutions | 174 |
| 11.7 | Sample Design Calculation | 174 |
| 11.7.1 | Dumped Packing | 174 |
| 11.7.2 | Flooding | 179 |
| 11.7.3 | Structured Packing | 180 |
| 11.7.3.1 | Flooding | 182 |
| Chapter 12 | Adsorption for Hazardous Air Pollutants and Volatile Organic Compounds Control | 185 |
| 12.1 | Introduction to Adsorption Operations | 185 |
| 12.1.1 | Description | 185 |
| 12.1.2 | Advantages | 187 |
| 12.1.3 | Disadvantages | 187 |
| 12.2 | Adsorption Phenomenon | 187 |
| 12.3 | Adsorption Processes | 187 |
| 12.3.1 | Stagewise Process | 188 |
| 12.3.2 | Continuous Contact, Steady-State, Moving-Bed Adsorbers | 188 |
| 12.3.3 | Unsteady-State, Fixed-Bed Adsorbers | 188 |
| 12.3.4 | Newer Technologies | 189 |
| 12.3.4.1 | Rotary Wheel Adsorber | 189 |
| 12.3.4.2 | Chromatographic Adsorption | 189 |
| 12.3.4.3 | Pressure Swing Adsorption | 190 |
| 12.4 | Nature of Adsorbents | 190 |
| 12.4.1 | Adsorption Design with Activated Carbon | 192 |
| 12.4.1.1 | Pore Structure | 192 |
| 12.4.1.2 | Effect of Relative Humidity | 192 |

| | | |
|-------------------|---|------------|
| 12.5 | Theories of Adsorption | 192 |
| 12.6 | Data of Adsorption..... | 194 |
| 12.7 | Adsorption Isotherms..... | 195 |
| 12.7.1 | Freundlich's Equation | 195 |
| 12.7.2 | Langmuir's Equation..... | 196 |
| 12.7.3 | Brunauer, Emmett, Teller, or BET Isotherm.... | 196 |
| 12.7.3.1 | Adsorption without Capillary Condensation | 196 |
| 12.7.3.2 | Adsorption with Capillary Condensation | 197 |
| 12.8 | Polanyi Potential Theory..... | 198 |
| 12.8.1 | Hexane Example of the Polanyi Potential Theory | 198 |
| 12.9 | Unsteady-State, Fixed-Bed Adsorbers | 200 |
| 12.10 | Fixed-Bed Adsorber Design Considerations..... | 201 |
| 12.10.1 | Safety Considerations | 202 |
| 12.11 | Pressure Drop through Adsorbers..... | 203 |
| 12.11.1 | Pressure Drop Example | 203 |
| 12.12 | Adsorber Effectiveness, Regeneration, and Reactivation | 204 |
| 12.12.1 | Steam Regeneration | 205 |
| 12.12.2 | Hot Air or Gas Regeneration | 205 |
| 12.12.3 | Reactivation | 208 |
| 12.13 | Breakthrough Model | 208 |
| 12.13.1 | Mass Transfer..... | 209 |
| 12.13.2 | Breakthrough Curve Example | 211 |
| 12.13.3 | Second Breakthrough Curve Example: Hexane Problem..... | 213 |
| 12.14 | Regeneration Modeling | 218 |
| 12.14.1 | Steam Regeneration Example | 218 |
| 12.15 | Using Mass Exchange Network Concepts to Simultaneously Evaluate Multiple Mass-Separating Agent (Absorbent and Adsorbent) Options | 219 |
| Chapter 13 | Thermal Oxidation for Volatile Organic Compounds Control | 221 |
| 13.1 | Combustion Basics | 221 |
| 13.2 | Flares..... | 223 |
| 13.2.1 | Elevated, Open Flare | 224 |
| 13.2.2 | Smokeless Flare Assist..... | 225 |
| 13.2.3 | Flare Height | 226 |
| 13.2.4 | Ground Flare | 227 |
| 13.2.5 | Safety Features..... | 228 |
| 13.3 | Incineration | 229 |
| 13.3.1 | Direct Flame Incineration..... | 230 |
| 13.3.2 | Thermal Incineration | 231 |

| | | |
|-------------------|---|-----|
| 13.3.3 | Catalytic Incineration..... | 235 |
| 13.3.4 | Energy Recuperation in Incineration | 237 |
| Chapter 14 | Control of Volatile Organic Compounds and Hazardous Air Pollutants by Condensation | 239 |
| 14.1 | Introduction | 239 |
| 14.1.1 | Description | 240 |
| 14.1.2 | Advantages | 240 |
| 14.1.3 | Disadvantages..... | 240 |
| 14.2 | Volatile Organic Compounds Condensers | 240 |
| 14.2.1 | Contact Condensers..... | 241 |
| 14.2.2 | Surface Condensers | 241 |
| 14.2.2.1 | Example—Design Condensation Temperature to Achieve Desired Volatile Organic Compounds Recovery..... | 243 |
| 14.3 | Coolant and Heat Exchanger Type | 244 |
| 14.3.1 | Example—Heat Exchanger Area and Coolant Flow Rate..... | 244 |
| 14.4 | Mixtures of Organic Vapors..... | 247 |
| 14.4.1 | Example—Condensation of a Binary Mixture.... | 248 |
| 14.5 | Air as a Noncondensable | 251 |
| 14.6 | Systems-Based Approach for Designing Condensation Systems for Volatile Organic Compounds Recovery from Gaseous Emission Streams | 252 |
| Appendix 14A: | Derivation of the Area Model for a Mixture Condensing from a Gas | 256 |
| Appendix 14B: | Algorithm for the Area Model for a Mixture Condensing from a Gas..... | 257 |
| Chapter 15 | Control of Volatile Organic Compounds and Hazardous Air Pollutants by Biofiltration..... | 259 |
| 15.1 | Introduction | 259 |
| 15.2 | Theory of Biofilter Operation..... | 260 |
| 15.3 | Design Parameters and Conditions | 261 |
| 15.3.1 | Depth and Media of Biofilter Bed | 262 |
| 15.3.2 | Microorganisms..... | 262 |
| 15.3.3 | Oxygen Supply | 263 |
| 15.3.4 | Inorganic Nutrient Supply | 263 |
| 15.3.5 | Moisture Content..... | 263 |
| 15.3.6 | Temperature..... | 264 |
| 15.3.7 | pH of the Biofilter..... | 264 |

| | | |
|-------------------|---|------------|
| 15.3.8 | Loading and Removal Rates | 264 |
| 15.3.9 | Pressure Drop..... | 265 |
| 15.3.10 | Pretreatment of Gas Streams | 265 |
| 15.4 | Biofilter Compared to Other Available Control Technology | 265 |
| 15.5 | Successful Case Studies | 266 |
| 15.6 | Further Considerations | 266 |
| Chapter 16 | Membrane Separation | 267 |
| 16.1 | Overview | 267 |
| 16.1.1 | Description..... | 267 |
| 16.1.2 | Advantages..... | 268 |
| 16.1.3 | Disadvantages | 268 |
| 16.2 | Polymeric Membranes..... | 268 |
| 16.3 | Performance..... | 268 |
| 16.4 | Applications..... | 269 |
| 16.5 | Membrane Systems Design | 270 |
| Chapter 17 | NO_x Control..... | 271 |
| 17.1 | NO _x from Combustion | 271 |
| 17.1.1 | Thermal NO _x | 271 |
| 17.1.2 | Prompt NO _x | 274 |
| 17.1.3 | Fuel NO _x | 274 |
| 17.2 | Control Techniques..... | 274 |
| 17.2.1 | Combustion Control Techniques..... | 274 |
| 17.2.1.1 | Low Excess Air Firing..... | 275 |
| 17.2.1.2 | Overfire Air | 275 |
| 17.2.1.3 | Flue Gas Recirculation | 275 |
| 17.2.1.4 | Reduce Air Preheat..... | 275 |
| 17.2.1.5 | Reduce Firing Rate | 275 |
| 17.2.1.6 | Water/Steam Injection | 276 |
| 17.2.1.7 | Burners out of Service | 276 |
| 17.2.1.8 | Reburn | 276 |
| 17.2.1.9 | Low NO _x Burners | 277 |
| 17.2.1.10 | Ultra Low NO _x Burners | 278 |
| 17.2.2 | Flue Gas Treatment Techniques..... | 279 |
| 17.2.2.1 | Selective Noncatalytic Reduction ... | 279 |
| 17.2.2.2 | Selective Catalytic Reduction..... | 280 |
| 17.2.2.3 | Low Temperature Oxidation with Absorption | 281 |
| 17.2.2.4 | Catalytic Absorption..... | 282 |
| 17.2.2.5 | Corona-Induced Plasma..... | 283 |

| | | |
|-------------------|--|-----|
| Chapter 18 | Control of SO _x | 285 |
| 18.1 | H ₂ S Control | 285 |
| 18.2 | SO ₂ (and HCl) Removal..... | 287 |
| 18.2.1 | Reagents | 287 |
| 18.2.1.1 | Calcium-Based Reactions | 287 |
| 18.2.1.2 | Calcium-Based Reaction Products.... | 288 |
| 18.2.1.3 | Sodium-Based Reactions..... | 289 |
| 18.2.1.4 | Sodium-Based Reaction Products | 290 |
| 18.2.2 | Capital versus Operating Costs..... | 290 |
| 18.2.2.1 | Operating Costs..... | 290 |
| 18.2.3 | SO ₂ Removal Processes | 291 |
| 18.2.3.1 | Wet Limestone..... | 291 |
| 18.2.3.2 | Wet Soda Ash or Caustic Soda..... | 293 |
| 18.2.3.3 | Lime Spray Drying..... | 294 |
| 18.2.3.4 | Circulating Lime Reactor..... | 296 |
| 18.2.3.5 | Sodium Bicarbonate/Sodium Sesquicarbonate Injection | 298 |
| 18.2.3.6 | Other SO ₂ Removal Processes | 300 |
| 18.2.4 | Example Evaluation | 300 |
| 18.3 | SO ₃ and Sulfuric Acid..... | 300 |
| 18.3.1 | SO ₃ and H ₂ SO ₄ Formation | 300 |
| 18.3.2 | Toxic Release Inventory..... | 304 |
| Chapter 19 | Fundamentals of Particulate Control | 305 |
| 19.1 | Particle Size Distribution | 305 |
| 19.2 | Aerodynamic Diameter..... | 310 |
| 19.3 | Cunningham Slip Correction | 310 |
| 19.4 | Collection Mechanisms..... | 311 |
| 19.4.1 | Basic Mechanisms: Impaction, Interception, and Diffusion | 311 |
| 19.4.1.1 | Impaction..... | 312 |
| 19.4.1.2 | Interception..... | 313 |
| 19.4.1.3 | Diffusion..... | 313 |
| 19.4.2 | Other Mechanisms..... | 313 |
| 19.4.2.1 | Electrostatic Attraction | 313 |
| 19.4.2.2 | Gravity..... | 313 |
| 19.4.2.3 | Centrifugal Force | 313 |
| 19.4.2.4 | Thermophoresis..... | 314 |
| 19.4.2.5 | Diffusiophoresis | 314 |

| | | |
|-------------------|--|-----|
| Chapter 20 | Hood and Ductwork Design | 315 |
| 20.1 | Introduction..... | 315 |
| 20.2 | Hood Design..... | 316 |
| 20.2.1 | Flow Relationship for Various Types of Hoods ... | 317 |
| 20.2.1.1 | Enclosing Hoods..... | 317 |
| 20.2.1.2 | Rectangular or Round Hoods..... | 317 |
| 20.2.1.3 | Slot Hoods | 317 |
| 20.2.1.4 | Canopy Hoods | 318 |
| 20.3 | Duct Design..... | 318 |
| 20.3.1 | Selection of Minimum Duct Velocity | 319 |
| 20.3.2 | Mechanical Energy Balance | 320 |
| 20.3.2.1 | Velocity Head..... | 321 |
| 20.3.2.2 | Friction Head | 321 |
| 20.4 | Effect of Entrance into a Hood | 325 |
| 20.5 | Total Energy Loss | 325 |
| 20.6 | Fan Power..... | 325 |
| 20.7 | Hood–Duct Example..... | 326 |
| Chapter 21 | Cyclone Design..... | 329 |
| 21.1 | Collection Efficiency..... | 329 |
| 21.1.1 | Factors Affecting Collection Efficiency | 331 |
| 21.1.2 | Theoretical Collection Efficiency | 333 |
| 21.1.3 | Lapple's Efficiency Correlation | 334 |
| 21.1.4 | Leith and Licht Efficiency Model | 335 |
| 21.1.5 | Comparison of Efficiency Model Results | 336 |
| 21.2 | Pressure Drop..... | 337 |
| 21.3 | Saltation..... | 338 |
| Chapter 22 | Design and Application of Wet Scrubbers | 341 |
| 22.1 | Introduction..... | 341 |
| 22.2 | Collection Mechanisms and Efficiency..... | 342 |
| 22.3 | Collection Mechanisms and Particle Size..... | 342 |
| 22.4 | Selection and Design of Scrubbers | 344 |
| 22.5 | Devices for Wet Scrubbing | 344 |
| 22.6 | Semrau Principle and Collection Efficiency | 344 |
| 22.7 | Model for Countercurrent Spray Chambers..... | 347 |
| 22.7.1 | Application to a Spray Tower..... | 351 |

| | | |
|---|--|-----|
| 22.8 | A Model for Venturi Scrubbers..... | 357 |
| 22.9 | Calvert Cut Diameter Design Technique | 357 |
| 22.9.1 | Example Calculation..... | 360 |
| 22.9.2 | Second Example Problem | 361 |
| 22.10 | Cut-Power Relationship..... | 362 |
| | Appendix 22A: Calvert Performance Cut Diameter Data..... | 363 |
| Chapter 23 Filtration and Baghouses..... | | 367 |
| 23.1 | Introduction..... | 367 |
| 23.2 | Design Issues..... | 367 |
| 23.3 | Cleaning Mechanisms..... | 368 |
| 23.3.1 | Shake/Deflate | 368 |
| 23.3.2 | Reverse Air..... | 369 |
| 23.3.3 | Pulse Jet (High Pressure) | 370 |
| 23.3.4 | Pulse Jet (Low Pressure)..... | 372 |
| 23.3.5 | Sonic Horns..... | 372 |
| 23.4 | Fabric Properties | 373 |
| 23.4.1 | Woven Bags..... | 374 |
| 23.4.2 | Felted Fabric | 374 |
| 23.4.3 | Surface Treatment..... | 374 |
| 23.4.4 | Weight | 374 |
| 23.4.5 | Membrane Fabrics | 375 |
| 23.4.6 | Catalytic Membranes..... | 375 |
| 23.4.7 | Pleated Cartridges..... | 375 |
| 23.4.8 | Ceramic Candles..... | 376 |
| 23.5 | Baghouse Size | 376 |
| 23.5.1 | Air-to-Cloth Ratio..... | 376 |
| 23.5.2 | Can Velocity..... | 377 |
| 23.6 | Pressure Drop..... | 377 |
| 23.7 | Bag Life..... | 379 |
| 23.7.1 | Failure Modes | 379 |
| 23.7.2 | Inlet Design..... | 380 |
| 23.7.3 | Startup Seasoning | 380 |
| 23.8 | Baghouse Design Theory | 380 |
| 23.8.1 | Design Considerations | 382 |
| 23.8.2 | Number of Compartments | 383 |
| 23.8.3 | Example Problem for a Baghouse Design | 386 |
| Chapter 24 Electrostatic Precipitators | | 391 |
| 24.1 | Early Development..... | 391 |
| 24.2 | Basic Theory | 391 |
| 24.2.1 | Corona Formation..... | 392 |
| 24.2.2 | Particle Charging | 392 |

| | | |
|-------------------|--|-----|
| 24.2.3 | Particle Migration..... | 394 |
| 24.2.4 | Deutsch Equation..... | 395 |
| 24.2.4.1 | Sneakage | 396 |
| 24.2.4.2 | Rapping Re-Entrainment | 397 |
| 24.2.4.3 | Particulate Resistivity | 397 |
| 24.2.4.4 | Gas-Flow Distribution | 399 |
| 24.3 | Practical Application of Theory..... | 400 |
| 24.3.1 | Effective Migration Velocity | 400 |
| 24.3.2 | Automatic Voltage Controller..... | 400 |
| 24.4 | Flue Gas Conditioning | 401 |
| 24.4.1 | Humidification..... | 401 |
| 24.4.2 | SO ₃ | 401 |
| 24.4.3 | Ammonia..... | 402 |
| 24.4.4 | SO ₃ and Ammonia..... | 403 |
| 24.4.5 | Ammonium Sulfate | 403 |
| 24.4.6 | Proprietary Additives | 403 |
| 24.5 | Using V-I Curves for Troubleshooting | 403 |
| References | | 407 |
| Index | | 419 |