

CONTENTS

1	INTRODUCTION	1
1.1	Overview of Particulate Matter (PM) Control / 1	
1.2	PM / 2	
1.3	PM ₁₀ / 4	
1.4	PM _{2.5} / 10	
1.4.1	PM _{2.5} Monitoring Goals / 10	
1.4.2	PM _{2.5} Program Objectives / 10	
1.4.3	PM _{2.5} Data Uses / 10	
1.4.4	Trends in PM _{2.5} / 11	
1.4.5	Nanoparticles / 19	
1.5	The Scientific Basis for Ambient Air Quality Standards / 19	
1.6	Primary Standards vs. Secondary Standards / 20	
1.7	PM Effects of Concern / 20	
1.7.1	Secondary Effects / 21	
1.8	Who Is Most at Risk? / 21	
1.9	Current Legislation / 22	
1.9.1	Federal Legislation / 22	
1.9.1.1	<i>Form of the Standard / 22</i>	
1.9.1.2	<i>Standard Level / 22</i>	
1.9.1.3	<i>Averaging Times / 23</i>	
1.9.2	State Legislation / 23	
1.9.2.1	<i>Enforcement Responsibilities / 23</i>	
1.9.2.2	<i>Enforcement Flexibility / 24</i>	

1.9.2.3	<i>Staffing and Other Practical Concerns / 24</i>	
1.9.2.4	<i>National Variations in Enforcement / 24</i>	
1.9.2.5	<i>Permitting—A Tool Used to Achieve Early Enforcement / 24</i>	
1.10	References / 25	
2	HEALTH EFFECTS	26
2.1	Results of Recent Studies / 29	
2.1.1	PM _{2.5} vs. PM _{10-2.5} , PM ₁₀ , and Coarser Particles / 30	
2.1.2	Air Pollution Species and Health Effects / 33	
2.2	EPA Position on Certain Health Effects / 33	
2.2.1	Premature Deaths / 34	
2.2.2	Respiratory Illness in Children / 34	
2.2.3	Cardiovascular Illness / 37	
2.3	References / 38	
3	AIR MONITORING	41
3.1	AMBIENT AIR MONITORING METHODS	43
3.1.1	Introduction and Scope / 43	
3.1.2	Terminology / 44	
3.1.3	Summary of Test Method / 48	
3.1.4	Apparatus / 49	
3.1.5	Procedures / 55	
3.1.6	PM _{2.5} Test Procedures / 55	
3.1.7	PM _{2.5} Measurement Range / 58	
3.1.8	Calculations / 58	
3.1.9	Calibration and Maintenance / 59	
3.1.10	Precision and Bias / 59	
3.1.11	Endnotes / 60	
3.1.12	References / 60	
3.2	EMISSION MEASUREMENT METHODS	62
3.2.1	List of EPA PM Mass Measurement Test Methods / 63	
3.2.2	EPA Stationary (Point) Source PM Mass Measurement Test Methods / 64	
3.2.2.1	EPA Test Method 5 for Total PM Mass / 64	
3.2.2.2	EPA Test Method 5 Variations: 5A–5H / 68	

- 3.2.3 EPA Test Methods for PM₁₀ from Stationary Sources / 72
 - 3.2.3.1 Method 201: Determination of PM₁₀ Emissions—Exhaust Gas Recycle Procedure / 72
 - 3.2.3.2 Methods 201A: Determination of PM₁₀ Emissions—Constant Sampling Rate Procedure / 75
- 3.2.4 EPA Test Method 17: Determination of PM Emissions from Stationary Sources—In-Stack Filtration Method / 75
- 3.2.5 Method 202 for Condensable PM (CPM) Measurement / 78
- 3.2.6 CPM Issues / 79
- 3.2.7 Summary of CTM 39 / 80
- 3.2.8 Summary of CTM 40 / 84
- 3.2.9 Endnotes / 86
- 3.2.10 References / 87

4 EMISSION CONTROL METHODS 91

4.1 FABRIC FILTER/BAGHOUSES 93

- 4.1.1 Fabric Filters—Introduction and Theory / 93
 - 4.1.1.1 Particle Collection and Penetration Mechanisms / 95
 - 4.1.1.2 Pressure Drop / 97
 - 4.1.1.3 Experimental Measurements of K_2 —Specific Cake Coefficient / 98
 - 4.1.1.4 Pressure Drop in Multicompartment Baghouses / 100
 - 4.1.1.5 Gas-to-Cloth (G/C) Ratio / 101
- 4.1.2 Types of Fabric Filters / 101
 - 4.1.2.1 Cleaning Techniques / 101
 - 4.1.2.2 Filtration Fabrics and Fiber Types / 102
 - 4.1.2.2.1 *Filtration Fabrics* / 104
 - 4.1.2.2.2 *Important Fiber Characteristics* / 104
 - 4.1.2.2.3 *Fabric Types* / 105
 - 4.1.2.2.3.1 *Woven Fabric* / 105
 - 4.1.2.2.3.2 *Nonwoven Fabrics* / 106
 - 4.1.2.3 Shaker-Cleaned Fabric Filters / 107
 - 4.1.2.4 Reverse-Air Cleaned Fabric Filter / 110
 - 4.1.2.4.1 *Reverse Air* / 110
 - 4.1.2.5 Pulse-Jet Cleaned Fabric Filter / 113
 - 4.1.2.5.1 *Pulse Jet* / 113

- 4.1.2.6 Other Fabric Filter Designs / 117
 - 4.1.2.6.1 *Sonic Horns* / 118
 - 4.1.2.6.2 *Cartridge Collectors* / 118
- 4.1.3 Fabric Characteristics / 119
 - 4.1.3.1 Case Study / 121
- 4.1.4 Collection Efficiency / 122
- 4.1.5 Applicability / 123
- 4.1.6 Energy and Other Secondary Environmental Impacts of Fabric Filter Baghouses / 124
 - 4.1.6.1 Filtration Processes / 124
 - 4.1.6.2 Example / 125
 - 4.1.6.3 Treatments and Finishes / 125
- 4.1.7 Records of Routine Baghouse Operation and Baghouse Maintenance / 129
 - 4.1.7.1 Why Keep Records? / 129
 - 4.1.7.2 What Records to Keep? / 129
 - 4.1.7.3 Baghouse Maintenance / 130
- 4.1.8 References / 132

4.2 ELECTROSTATIC PRECIPITATORS

135

- 4.2.1 Particle Collection / 135
 - 4.2.1.1 Electric Field / 137
 - 4.2.1.2 Corona Generation / 137
 - 4.2.1.3 Particle Charging / 138
 - 4.2.1.4 Particle Collection / 139
- 4.2.2 Penetration Mechanisms / 141
 - 4.2.2.1 Back Corona / 141
 - 4.2.2.2 Dust Reentrainment / 141
 - 4.2.2.3 Dust Sneakage / 142
- 4.2.3 Types of ESPs / 142
 - 4.2.3.1 Dry ESPs / 142
 - 4.2.3.2 Specific Collecting Area (SCA) / 143
 - 4.2.3.3 SCA Procedure with Known Migration Velocity / 143
 - 4.2.3.4 Full SCA Procedure / 144
 - 4.2.3.5 SCA for Tubular Precipitators / 150
 - 4.2.3.6 Flow Velocity / 150
 - 4.2.3.7 Pressure Drop Calculations / 151
 - 4.2.3.8 Particle Characteristics / 152

- 4.2.3.9 Gas Characteristics / 153
- 4.2.3.10 Cleaning / 154
- 4.2.3.11 Construction Features / 155
- 4.2.3.12 Problems and Test Methods Associated with Dry ESPs / 155
- 4.2.3.13 Wet Electrostatic Precipitator (Wet ESP) / 157
 - 4.2.3.13.1 *Designs, Configurations, Materials, and Operational Aspects / 157*
 - 4.2.3.13.2 *Common Elements of Wet ESPs / 160*
 - 4.2.3.13.3 *Parallel Plate Designs / 160*
 - 4.2.3.13.4 *Tubular Designs / 161*
 - 4.2.3.13.5 *Advantages Associated with Wet ESPs / 161*
 - 4.2.3.13.6 *Operational Issues / 161*
 - 4.2.3.13.6.1 *Pre-Scrubbing / 162*
 - 4.2.3.13.6.2 *Washdown Sprays and Weirs / 162*
 - 4.2.3.13.6.3 *Wet/dry Interface / 162*
 - 4.2.3.13.6.4 *Current Suppression / 162*
 - 4.2.3.13.6.5 *Sparking / 162*
 - 4.2.3.13.6.6 *Tracking / 162*
 - 4.2.3.13.6.7 *Mist Elimination / 162*
 - 4.2.3.13.7 *Various Other Issues / 163*
 - 4.2.3.13.8 *Efficiencies and Power Requirements / 163*
 - 4.2.3.13.9 *Design Factors Affecting Efficiency / 163*
 - 4.2.3.13.9.1 *SCA / 163*
 - 4.2.3.13.9.2 *Electrode Designs—Collecting Surfaces / 163*
 - 4.2.3.13.9.3 *Electrode Designs—Discharge Surfaces / 164*
 - 4.2.3.13.10 *Materials of Construction / 164*
 - 4.2.3.13.11 *Wet ESP Verdict / 164*
- 4.2.3.14 Wire-Plate ESPs / 165
- 4.2.3.15 Wire-Pipe ESPs / 165
- 4.2.3.16 Other ESP Designs / 165
- 4.2.4 Collection Efficiency / 167
- 4.2.5 Applicability / 168
- 4.2.6 ESP Performance Models / 168

4.2.7 Energy and Other Secondary Environmental Impacts of ESPs / 171

4.2.8 References / 173

4.3 WET SCRUBBERS 175

4.3.1 Particle Collection and Penetration Mechanisms / 175

4.3.2 Types of Wet Scrubbers / 177

4.3.2.1 Spray Chambers / 177

4.3.2.2 Packed-Bed Scrubbers / 178

4.3.2.3 Impingement-Plate Scrubbers / 178

4.3.2.4 Mechanically Aided Scrubbers (MAS) / 179

4.3.2.5 Venturi Scrubbers / 179

4.3.2.6 Orifice Scrubbers / 180

4.3.2.7 Condensation Scrubbers / 180

4.3.2.8 Charged Scrubbers / 181

4.3.2.9 Fiber-Bed Scrubbers / 181

4.3.3 Collection Efficiency / 181

4.3.4 Applicability / 182

4.3.5 Energy and Other Secondary Environmental Impacts of Scrubber Systems / 183

4.3.6 References / 184

4.4 ENVIRONMENTAL TECHNOLOGY VERIFICATION AND BAGHOUSE FILTRATION PRODUCTS 185

4.4.1 ETV Program Overview / 185

4.4.2 Air Pollution Control Center (APCT) / 188

4.4.3 BFP / 189

4.4.4 Test Apparatus and Procedure / 190

4.4.5 BFP Published Verifications / 192

4.4.6 Environmental, Health, and Regulatory Background / 195

4.4.6.1 Outcomes / 198

4.4.6.1.1 *Pollutant Reduction Outcomes / 201*

4.4.6.1.2 *Human Health and Environmental Outcomes / 202*

4.4.6.1.3 *Regulatory Compliance Outcomes / 203*

4.4.6.1.4 *Economic and Financial Outcomes / 204*

4.4.6.1.5 *Scientific Advancement Outcomes / 205*

4.4.6.1.6 *Technology Acceptance and Use Outcomes / 205*

	Appendix A: Methods for Baghouse Filtration Productions Outcomes / 206	
4.4.7	References / 210	
4.5	COST CONSIDERATIONS	211
4.5.1	EPA OAQPS Methodology / 211	
4.5.1.1	Costs of Fabric Filters / 211	
	4.5.1.1.1 <i>Capital Costs of Fabric Filters / 212</i>	
	4.5.1.1.2 <i>Annual Costs of Fabric Filters / 214</i>	
4.5.1.2	Costs of Electrostatic Precipitators / 214	
	4.5.1.2.1 <i>Capital Costs of Electrostatic Precipitators / 215</i>	
	4.5.1.2.2 <i>Annual Costs of Electrostatic Precipitators / 216</i>	
4.5.1.3	Costs of PM Wet Scrubbers / 216	
	4.5.1.3.1 <i>Capital Costs of Wet Scrubbers / 216</i>	
	4.5.1.3.2 <i>Annual Costs of Wet Scrubbers / 218</i>	
4.5.2	Edmisten and Bunyard Cost Analysis Methodology / 218	
4.5.2.1	Capital Investment / 218	
4.5.2.2	Maintenance and Operation / 219	
4.5.2.3	Capital Charges / 219	
4.5.2.4	Annualized Cost / 219	
4.5.2.5	Annual Operating Cost for Air Pollution Control Equipment / 220	
4.5.2.6	Annual Baghouse Operating Cost / 220	
4.5.2.7	Baghouse Electrical Costs / 221	
4.5.2.8	Baghouse Annual Operating Cost / 221	
	4.5.2.8.1 <i>Example 1—Baghouse Costs / 221</i>	
	4.5.2.8.1.1 <i>Input Data / 222</i>	
4.5.2.9	Maintenance Cost Input Data / 222	
4.5.2.10	Annual Operating Costs Calculation / 224	
4.5.2.11	Total Annualized Cost / 224	
4.5.3	Example 2—Electrostatic Precipitator (ESP) vs. Baghouse / 225	
4.5.4	References / 227	
5	NANOPARTICULATES	228
5.1	What Is a Nanoparticle? / 229	
5.2	What Is Nanotechnology? / 230	

xii CONTENTS

- 5.3 What Is Nanotoxicology? / 231
- 5.4 Health Concerns/Issues / 232
- 5.5 Ongoing Research / 233
- 5.6 Current Organizations/Research / 236
- 5.7 Diesel Nanoparticulate Matter / 238
- 5.8 Nanofilters/Nanotechnology in the Fabric Filter Industry / 239
- 5.9 Additional Research Concerning Nanofiber Filtration / 242
- 5.10 References / 243

Index

247