

Aerosol Science

Technology and Applications

IAN COLBECK

*School of Biological Sciences,
University of Essex, UK*

MIHALIS LAZARIDIS

*Department of Environmental Engineering,
Technical University of Crete, Greece*

WILEY

Contents

<i>List of Contributors</i>	xiii
<i>Preface</i>	xv
1. Introduction	1
<i>Mihalis Lazaridis and Ian Colbeck</i>	
1.1 Introduction	1
1.2 Size and Shape	5
1.3 Size Distribution	6
1.4 Chemical Composition	10
1.5 Measurements and Sampling	11
References	12
2. Aerosol Dynamics	15
<i>Mihalis Lazaridis and Yannis Drossinos</i>	
2.1 Introduction	15
2.2 General Dynamic Equation	17
2.2.1 Discrete Particle Size Distribution	18
2.2.2 Continuous Particle Size Distribution	19
2.3 Nucleation: New Particle Formation	19
2.3.1 Classical Nucleation Theory	20
2.3.2 Multicomponent Nucleation	22
2.3.3 Heterogeneous Nucleation	23
2.3.4 Atmospheric Nucleation	24
2.4 Growth by Condensation	26
2.5 Coagulation and Agglomeration	27
2.5.1 Brownian Coagulation	28
2.5.2 Agglomeration	28
2.6 Deposition Mechanisms	32
2.6.1 Stokes Law	32
2.6.2 Gravitational Settling	32
2.6.3 Deposition by Diffusion	34
2.6.4 Deposition by Impaction	34
2.6.5 Phoretic Effects	34
2.6.6 Atmospheric Aerosol Deposition	35
2.6.7 Deposition in the Human Respiratory Tract	36

2.7	Resuspension	38
2.7.1	Monolayer Resuspension	38
2.7.2	Multilayer Resuspension	39
	References	41
3.	Recommendations for Aerosol Sampling	45
	<i>Alfred Wiedensohler, Wolfram Birmili, Jean-Philippe Putaud, and John Ogren</i>	
3.1	Introduction	45
3.2	Guidelines for Standardized Aerosol Sampling	46
3.2.1	General Recommendations	46
3.2.2	Standardization of Aerosol Inlets	47
3.2.3	Humidity Control	49
3.3	Concrete Sampling Configurations	53
3.3.1	General Aspects of Particle Motion	53
3.3.2	Laminar Flow Sampling Configuration	54
3.3.3	Turbulent Flow Sampling Configuration	55
3.4	Artifact-Free Sampling for Organic Carbon Analysis	57
	Acknowledgements	59
	References	59
4.	Aerosol Instrumentation	61
	<i>Da-Ren Chen and David Y. H. Pui</i>	
4.1	Introduction	61
4.2	General Strategy	62
4.3	Aerosol Sampling Inlets and Transport	63
4.4	Integral Moment Measurement	64
4.4.1	Total Number Concentration Measurement: Condensation Particle Counter (CPC)	65
4.4.2	Total Mass Concentration Measurement: Quartz-Crystal Microbalance (QCM) and Tapered-Element Oscillating Microbalance (TEOM)	66
4.4.3	Light-Scattering Photometers and Nephelometers	67
4.5	Particle Surface Area Measurement	68
4.6	Size-Distribution Measurement	70
4.6.1	Techniques based on Particle–Light Interaction	70
4.6.2	Techniques based on Particle Inertia	71
4.6.3	Techniques based on Particle Electrical Mobility	74
4.6.4	Techniques based on Particle Diffusion	77
4.7	Chemical Composition Measurement	78
4.8	Conclusion	80
	References	82
5.	Filtration Mechanisms	89
	<i>Sarah Dunnett</i>	
5.1	Introduction	89

5.2	Deposition Mechanisms	91
5.2.1	Flow Models	92
5.2.2	Diffusional Deposition	96
5.2.3	Deposition by Interception	98
5.2.4	Deposition due to Inertial Impaction	99
5.2.5	Gravitational Deposition	100
5.2.6	Electrostatic Deposition	100
5.3	Factors Affecting Efficiency	104
5.3.1	Particle Rebound	104
5.3.2	Particle Loading	106
5.4	Filter Randomness	109
5.5	Applications	109
5.6	Conclusions	110
	Nomenclature	110
	References	113
6.	Remote Sensing of Atmospheric Aerosols	119
	<i>Sagnik Dey and Sachchida Nand Tripathi</i>	
6.1	Introduction	119
6.2	Surface-Based Remote Sensing	120
6.2.1	Passive Remote Sensing	120
6.2.2	Active Remote Sensing	126
6.3	Satellite-Based Remote Sensing	126
6.3.1	Passive Remote Sensing	127
6.3.2	Active Spaceborne Lidar	135
6.3.3	Applications of Satellite-Based Aerosol Products	136
6.4	Summary and Future Requirements	141
	Acknowledgements	142
	References	142
7.	Atmospheric Particle Nucleation	153
	<i>Mikko Sipilä, Katrianne Lehtipalo, and Markku Kulmala</i>	
7.1	General Relevance	153
7.2	Detection of Atmospheric Nanoparticles	156
7.2.1	Condensation Particle Counting	156
7.2.2	Electrostatic Methods	158
7.2.3	Mass Spectrometric Methods for Cluster Detection	160
7.3	Atmospheric Observations of New Particle Formation	163
7.3.1	Nucleation	163
7.3.2	Growth	165
7.4	Laboratory Experiments	166
7.4.1	Sulfuric Acid Nucleation	166
7.4.2	Hunt for Compound X	168
7.5	Concluding Remarks and Future Challenges	169
	References	170

8. Atmospheric Aerosols and Climate Impacts	181
<i>Maria Kanakidou</i>	
8.1 Introduction	181
8.2 Global Aerosol Distributions	181
8.3 Aerosol Climate Impacts	182
8.4 Simulations of Global Aerosol Distributions	186
8.5 Extinction of Radiation by Aerosols (Direct Effect)	190
8.5.1 Aerosol Optical Depth and Direct Radiative Forcing of Aerosol Components	193
8.6 Aerosols and Clouds (Indirect Effect)	194
8.6.1 How Aerosols Become CCNs and Grow into Cloud Droplets	195
8.7 Radiative Forcing Estimates	200
8.8 The Way Forward	203
References	203
9. Air Pollution and Health and the Role of Aerosols	207
<i>Pat Goodman and Otto Hänninen</i>	
9.1 Background	207
9.2 Size Fractions	208
9.3 Which Pollution Particle Sizes Are Important?	209
9.4 What Health Outcomes Are Associated with Exposure to Air Pollution?	209
9.5 Sources of Atmospheric Aerosols	210
9.6 Particle Deposition in the Lungs	210
9.7 Aerosol Interaction Mechanisms in the Human Body	211
9.8 Human Respiratory Outcomes and Aerosol Exposure	215
9.9 Cardiovascular Outcomes and Aerosol Exposure	215
9.10 Conclusions and Recommendations	216
References	216
10. Pharmaceutical Aerosols and Pulmonary Drug Delivery	221
<i>Darragh Murnane, Victoria Hutter, and Marie Harang</i>	
10.1 Introduction	221
10.2 Pharmaceutical Aerosols in Disease Treatment	223
10.2.1 Asthma	223
10.2.2 Chronic Obstructive Pulmonary Disease	224
10.2.3 Cystic Fibrosis	224
10.2.4 Respiratory Tract Infection	225
10.2.5 Beyond the Lung: Systemic Drug Delivery	225
10.3 Aerosol Physicochemical Properties of Importance in Lung Deposition	226
10.4 The Fate of Inhaled Aerosol Particles in the Lung	228
10.4.1 Paracellular Transport	229
10.4.2 Transcellular Transport	229
10.4.3 Carrier-Mediated Transport	230
10.4.4 Models for Determining the Fate of Inhaled Aerosols	231

10.5	Production of Inhalable Particles	233
10.5.1	Particle Attrition and Milling	233
10.5.2	Constructive Particle Production	235
10.6	Aerosol Generation and Delivery Systems for Pulmonary Therapy	237
10.6.1	Nebulised Disease Therapies	237
10.6.2	Pressurised Metered-Dose Inhaler Systems	241
10.6.3	Dry-Powder Inhalation	248
10.6.4	Advancing Drug-Delivery Strategies	252
10.7	Product Performance Testing	253
10.7.1	Total-Emitted-Dose Testing	253
10.7.2	Aerodynamic Particle Size Determination: Inertial Impaction Analysis	253
10.8	Conclusion and Outlook	255
	References	255
11.	Bioaerosols and Hospital Infections	271
	<i>Ka man Lai, Zaheer Ahmad Nasir, and Jonathon Taylor</i>	
11.1	The Importance of Bioaerosols and Infections	271
11.2	Bioaerosol-Related Infections in Hospitals	272
11.3	Bioaerosol Properties and Deposition in Human Respiratory Systems	275
11.4	Chain of Infection and Infection Control in Hospitals	275
11.5	Application of Aerosol Science and Technology in Infection Control	277
11.5.1	Understanding Hospital Aerobiology and Infection Control	277
11.5.2	Bioaerosol Experiments and Models	280
11.5.3	Numerical Analysis of Particle Dispersion in Hospitals	281
11.5.4	Air-Cleaning Technologies	282
11.6	Conclusion	285
	References	285
12.	Nanostructured Material Synthesis in the Gas Phase	291
	<i>Peter V. Pikhitsa and Mansoo Choi</i>	
12.1	Introduction	291
12.2	Aerosol-Based Synthesis	292
12.3	Flame Synthesis	292
12.4	Flame and Laser Synthesis	299
12.5	Laser-Induced Synthesis	302
12.6	Metal-Powder Combustion	309
12.7	Spark Discharge	313
12.8	Assembling Useful Nanostructures	314
12.9	Conclusions	322
	References	323

13. The Safety of Emerging Inorganic and Carbon Nanomaterials	327
<i>L. Reijnders</i>	
13.1 Introduction	327
13.2 Human Health and Inhaled Persistent Engineered Inorganic and Carbon Nanomaterials	330
13.3 Human Health Hazards and Risks Linked to the Ingestion of Persistent Inorganic Nanomaterials	333
13.4 Ecotoxicity of Persistent Inorganic and Carbon Nanomaterials	335
13.5 Conclusion	336
References	336
14. Environmental Health in Built Environments	345
<i>Zaheer Ahmad Nasir</i>	
14.1 Environmental Hazards and Built Environments	345
14.2 Particulate Contaminants	348
14.2.1 Transport and Behaviour of Particles in Built Environments	349
14.3 Gas Contaminants	351
14.3.1 Biological Hazards	351
14.3.2 Physical Hazards	357
14.3.3 Ergonomic Hazards	358
14.3.4 Ventilation and Environmental Hazards	359
14.3.5 Energy-Efficient Built Environments, Climate Change and Environmental Health	361
References	362
15. Particle Emissions from Vehicles	369
<i>Jonathan Symonds</i>	
15.1 Introduction	369
15.2 Engine Concepts and Technologies	370
15.2.1 Air–Fuel Mixture	370
15.2.2 Spark-Ignition Engines	371
15.2.3 Compression-Ignition Engines	372
15.2.4 Two-Stroke Engines	372
15.2.5 Gas-Turbine Engines	373
15.3 Particle Formation	373
15.3.1 In-Cylinder Formation	373
15.3.2 Evolution in the Exhaust and Aftertreatment Systems	375
15.3.3 Noncombustion Particle Sources	375
15.3.4 Evolution in the Environment	376
15.4 Impact of Vehicle Particle Emissions	376
15.4.1 Health and Environmental Effects	376
15.4.2 Legislation	376

15.5	Sampling and Measurement Techniques	378
15.5.1	Sample Handling	378
15.5.2	Mass Measurement	379
15.5.3	Solid-Particle-Number Measurement	380
15.5.4	Sizing Techniques	382
15.5.5	Morphology Determination	382
15.6	Amelioration Techniques	385
15.6.1	Fuel Composition	385
15.6.2	Control by Engine Design and Calibration	385
15.6.3	Particulate Filters	386
	Acknowledgements	388
	References	388
16.	Movement of Bioaerosols in the Atmosphere and the Consequences for Climate and Microbial Evolution	393
	<i>Cindy E. Morris, Christel Leyronas, and Philippe C. Nicot</i>	
16.1	Introduction	393
16.2	Emission: Launch into the Atmosphere	395
16.2.1	Active Release	397
16.2.2	Passive Release	397
16.2.3	Quantifying Emissions	398
16.3	Transport in the Earth's Boundary Layer	399
16.3.1	Motors of Transport	399
16.3.2	Quantifying Near-Surface Flux	400
16.4	Long-Distance Transport: From the Boundary Layer into the Free Troposphere	404
16.4.1	Scale of Horizontal Long-Distance Transport	404
16.4.2	Altitude of Long-Distance Transport	405
16.5	Interaction of Microbial Aerosols with Atmospheric Processes	406
16.6	Implications of Aerial Transport for Microbial Evolutionary History	407
	References	410
17.	Disinfection of Airborne Organisms by Ultraviolet-C Radiation and Sunlight	417
	<i>Jana S. Kesavan and Jose-Luis Sagripanti</i>	
17.1	Introduction	417
17.2	UV Radiation	418
17.3	Sunlight	419
17.4	Selected Organisms	421
17.4.1	Bacterial Endospores	421
17.4.2	Vegetative Bacteria	422
17.4.3	Viruses	423

17.5	Effects of UV Light on Aerosolized Organisms	423
17.5.1	Cell Damage Caused By UV Radiation	423
17.5.2	Photorepair	424
17.5.3	Typical Survival Curve for UV Exposure	425
17.5.4	The UV Rate Constant	427
17.5.5	RH and Temperature Effects	428
17.5.6	Bacterial Clusters	429
17.6	Disinfection of Rooms Using UV-C Radiation	429
17.7	Sunlight Exposure Studies	430
17.8	Testing Considerations	431
17.8.1	Test Methodology in Our Laboratory	432
17.9	Discussion	435
	References	435
18.	Radioactive Aerosols: Tracers of Atmospheric Processes	441
	<i>Katsumi Hirose</i>	
18.1	Introduction	441
18.2	Origin of Radioactive Aerosols	442
18.2.1	Natural Radionuclides	442
18.2.2	Anthropogenic Radionuclides	444
18.3	Tracers of Atmospheric Processes	446
18.3.1	Transport of Radioactive Aerosols	446
18.3.2	Dry Deposition	448
18.3.3	Wet Deposition	449
18.3.4	Resuspension	450
18.3.5	Other Processes	452
18.3.6	Application of Multitracers	452
18.3.7	Atmospheric Residence Time of Radioactive Aerosols	454
18.4	Tracer of Environmental Change	457
18.5	Conclusion	460
	References	461
	<i>Index</i>	469