

Contents

List of Contributors XIII

List of Symbols XVII

Introduction XXIX

1	Introduction to Aerosols	1
	<i>Alexey A. Lushnikov</i>	
1.1	Introduction	1
1.2	Aerosol Phenomenology	2
1.2.1	Basic Dimensionless Criteria	2
1.2.1.1	Reynolds Number	2
1.2.1.2	Stokes Number	2
1.2.1.3	Knudsen Number	3
1.2.1.4	Peclet Number	3
1.2.1.5	Mie Number	3
1.2.1.6	Coulomb Number	3
1.2.2	Particle Size Distributions	4
1.2.2.1	The Log-Normal Distribution	4
1.2.2.2	Generalized Gamma Distribution	5
1.3	Drag Force and Diffusivity	6
1.4	Diffusion Charging of Aerosol Particles	7
1.4.1	Flux Matching Exactly	8
1.4.2	Flux Matching Approximately	9
1.4.3	Charging of a Neutral Particle	9
1.4.4	Recombination	10
1.5	Fractal Aggregates	11
1.5.1	Introduction	12
1.5.2	Phenomenology of Fractals	13
1.5.2.1	Fractal Dimension	13
1.5.2.2	Correlation Function	14
1.5.2.3	Distribution of Voids	14
1.5.2.4	Phenomenology of Atmospheric FA	14
1.5.3	Possible Sources of Fractal Particles	15
1.5.3.1	Natural Sources	15

1.5.3.2	Anthropogenic Sources	15
1.5.4	Formation of Fractal Aggregates	16
1.5.4.1	Growth by Condensation	16
1.5.4.2	Growth by Coagulation	17
1.5.4.3	Aerosol–Aerogel Transition	18
1.5.5	Optics of Fractals	18
1.5.6	Are Atmospheric Fractals Long-Lived?	20
1.5.7	Concluding Remarks	21
1.6	Coagulation	21
1.6.1	Asymptotic Distributions in Coagulating Systems	23
1.6.2	Gelation in Coagulating Systems	26
1.7	Laser-Induced Aerosols	33
1.7.1	Formation of Plasma Cloud	33
1.7.1.1	Nucleation plus Condensational Growth	34
1.7.1.2	Coagulation	34
1.7.2	Laser-Induced Gelation	34
1.8	Conclusion	36
	References	37
Part I	Aerosol Formation	43
2	High-Temperature Aerosol Systems	45
	<i>Arkadi Maisels</i>	
2.1	Introduction	45
2.2	Main High-Temperature Processes for Aerosol Formation	45
2.2.1	Flame Processes	47
2.2.2	Hot-Wall Processes	49
2.2.3	Plasma Processes	49
2.2.4	Laser-Induced Processes	50
2.2.5	Gas Dynamically Induced Particle Formation	50
2.3	Basic Dynamic Processes in High-Temperature Aerosol Systems	50
2.3.1	Nucleation	52
2.3.2	Coagulation/Aggregation	52
2.3.3	Surface Growth Due to Condensation	55
2.3.4	Sintering	55
2.3.5	Charging	57
2.4	Particle Tailoring in High-Temperature Processes	59
	References	61
3	Aerosol Synthesis of Single-Walled Carbon Nanotubes	65
	<i>Albert G. Nasibulin and Sergey D. Shandakov</i>	
3.1	Introduction	65
3.1.1	Carbon Nanotubes as Unique Aerosol Particles	65
3.1.2	History and Perspectives of CNT Synthesis	68
3.2	Aerosol-Unsupported Chemical Vapor Deposition Methods	70

3.2.1	The HiPco Process	70
3.2.2	Ferrocene-Based Method	71
3.2.3	Hot-Wire Generator	73
3.3	Control and Optimization of Aerosol Synthesis	74
3.3.1	On-Line Monitoring of CNT Synthesis	74
3.3.2	Individual CNTs and Bundle Separation	76
3.3.3	CNT Property Control and Nanobud Production	76
3.4	Carbon Nanotube Bundling and Growth Mechanisms	78
3.4.1	Bundle Charging	78
3.4.2	Growth Mechanism	80
3.5	Integration of the Carbon Nanotubes	82
3.6	Summary	84
	Acknowledgements	84
	References	84
4	Condensation, Evaporation, Nucleation	91
	<i>Alexey A. Lushnikov</i>	
4.1	Introduction	91
4.2	Condensation	92
4.2.1	Continuum Transport	93
4.2.2	Free-Molecule Transport	93
4.3	Condensation in the Transition Regime	94
4.3.1	Flux-Matching Theory	95
4.3.2	Approximations	96
4.3.2.1	The Fuchs Approximation	96
4.3.2.2	The Fuchs–Sutugin Approximation	96
4.3.2.3	The Lushnikov–Kulmala Approximation	96
4.3.3	More Sophisticated Approaches	97
4.4	Evaporation	97
4.5	Uptake	99
4.5.1	Getting Started	100
4.5.2	Hierarchy of Times	101
4.5.3	Diffusion in the Gas Phase	101
4.5.4	Crossing the Interface	103
4.5.5	Transport and Reaction in the Liquid Phase	103
4.6	Balancing Fluxes	104
4.6.1	No Chemical Interaction	104
4.6.2	Second-Order Kinetics	106
4.7	Nucleation	108
4.7.1	The Szilard–Farkas Scheme	109
4.7.2	Condensation and Evaporation Rates	110
4.7.3	Thermodynamically Controlled Nucleation	111

4.7.4	Kinetically Controlled Nucleation	111
4.7.5	Fluctuation-Controlled Nucleation	113
4.8	Nucleation-Controlled Processes	114
4.8.1	Nucleation Bursts	114
4.8.2	Nucleation-Controlled Condensation	115
4.8.3	Nucleation-Controlled Growth by Coagulation	117
4.8.4	Nucleation Bursts in the Atmosphere	119
4.9	Conclusion	120
	References	122
5	Combustion-Derived Carbonaceous Aerosols (Soot) in the Atmosphere: Water Interaction and Climate Effects	127
	<i>Olga B. Popovicheva</i>	
5.1	Black Carbon Aerosols in the Atmosphere: Emissions and Climate Effects	127
5.2	Physico-Chemical Properties of Black Carbon Aerosols	132
5.2.1	General Characteristics	133
5.2.2	Key Properties Responsible for Interaction with Water	137
5.3	Water Uptake by Black Carbons	140
5.3.1	Fundamentals of Water Interaction with Black Carbons	140
5.3.2	Concept of Quantification	143
5.3.3	Laboratory Approach for Water Uptake Measurements	144
5.3.4	Quantification of Water Uptake	146
5.3.4.1	Hydrophobic Soot	146
5.3.4.2	Hydrophilic Soot	148
5.3.4.3	Hygroscopic Soot	151
5.4	Conclusions	152
	Acknowledgements	153
	References	153
6	Radioactive Aerosols – Chernobyl Nuclear Power Plant Case Study	159
	<i>Boris I. Ogorodnikov</i>	
6.1	Introduction	159
6.2	Environmental Aerosols	164
6.2.1	Dynamics of Release of Radioactive Aerosols from Chernobyl	164
6.2.2	Transport of Radioactive Clouds in the Northern Hemisphere	166
6.2.3	Observation of Radioactive Aerosols above Chernobyl	168
6.2.4	Observations of Radioactive Aerosols in the Territory around Chernobyl	171
6.2.5	Dispersity of Aerosol Carriers of Radionuclides	183
6.3	Aerosols inside the Vicinity of the “Shelter” Building	185
6.3.1	Devices and Methods to Control Radioactive Aerosols in the “Shelter”	185
6.3.2	Control of Discharge from the “Shelter”	185

- 6.3.3 Well-Boring in Search of Remaining Nuclear Fuel 186
- 6.3.4 Clearance of the Turbine Island of the Fourth Power
Generating Unit 188
- 6.3.5 Strengthening of the Seats of Beams on the Roof of the “Shelter” 189
- 6.3.6 Aerosols Generated during Fires in the “Shelter” 191
- 6.3.7 Dust Control System 192
- 6.3.8 Control of the Release of Radioactive Aerosols through the “Bypass”
System 192
- 6.3.9 Radon, Thoron and their Daughter Products in the “Shelter” 195
References 197

Part II Aerosol Measurement and Characterization 203

- 7 Applications of Optical Methods for Micrometer and Submicrometer
Particle Measurements 205**
Aladár Czitrovsky
 - 7.1 Introduction 205
 - 7.2 Optical Methods in Particle Measurements 206
 - 7.3 Short Overview of Light Scattering Theories 208
 - 7.4 Classification of Optical Instruments for Particle Measurements 213
 - 7.4.1 Multi-Particle Instruments 213
 - 7.4.2 Single-Particle Instruments 214
 - 7.5 Development of Airborne and Liquid-borne Particle Counters and
Sizers 215
 - 7.5.1 Development of Airborne Particle Counters 216
 - 7.5.2 Development of Liquid-borne Particle Counters 222
 - 7.6 New Methods Used to Characterize the Electrical Charge and Density
of the Particles 225
 - 7.7 Aerosol Analyzers for Measurement of the Complex Refractive Index
of Aerosol Particles 227
 - 7.8 Comparison of Commercially Available Instruments and Analysis of
the Trends of Further Developments 229
 - 7.8.1 Portable Particle Counters 230
 - 7.8.2 Remote Particle Counters 230
 - 7.8.3 Multi-Particle Counters 233
 - 7.8.4 Handheld Particle Counters 233
 - 7.9 Conclusions 233
References 234
- 8 The Inverse Problem and Aerosol Measurements 241**
Valery A. Zagaynov
 - 8.1 Introduction 241
 - 8.2 Forms of Representation of Particle Size Distribution 243
 - 8.3 Differential and Integral Measurements 245

8.4	Differential Mobility Analysis	246
8.5	Diffusion Aerosol Spectrometry	252
8.5.1	Raw Measurement Results and their Development – Parameterization of Particle Size Distribution	254
8.5.2	Fitting of Penetration Curves	256
8.5.3	Transformation of the Integral Equation into Nonlinear Algebraic Form	257
8.5.4	Effect of Experimental Errors on Reconstruction of Particle Size Distribution	259
8.5.5	Reconstruction of Bimodal Distributions	261
8.5.6	Mathematical Approach to Reconstruct Bimodal Distribution from Particle Penetration Data	264
8.5.7	Solution of the Inverse Problem by Regularization Method	266
8.6	Conclusions	268
	References	269
 Part III Aerosol Removal 273		
 9	History of Development and Present State of Polymeric Fine-Fiber Unwoven Petryanov Filter Materials for Aerosol Entrapment	 275
	<i>Bogdan F. Sadovsky</i>	
	References	282
 10	Deposition of Aerosol Nanoparticles in Model Fibrous Filters	 283
	<i>Vasily A. Kirsch and Alexander A. Kirsch</i>	
10.1	Introduction	283
10.2	Results of Numerical Modeling of Nanoparticle Deposition in Two-Dimensional Model Filters	287
10.2.1	Fiber Collection Efficiency at High Peclet Number: Cell Model Approach	287
10.2.2	Fiber Collection Efficiency at Low Peclet Number: Row of Fibers Approach	289
10.2.3	Deposition of Nanoparticles upon Ultra-Fine Fibers	292
10.2.4	Deposition of Nanoparticles on Fibers with Non-Circular Cross-Section	294
10.2.5	Deposition of Nanoparticles on Porous and Composite Fibers	298
10.3	Penetration of Nanoparticles through Wire Screen Diffusion Batteries	302
10.3.1	Deposition of Nanoparticles in Three-Dimensional Model Filters	302
10.3.2	Theory of Particle Deposition on Screens with Square Mesh	304
10.3.3	Comparison with Experiment	305
10.4	Conclusion	310
	Acknowledgements	311
	References	311

11	Filtration of Liquid and Solid Aerosols on Liquid-Coated Filters	315
	<i>Igor E. Agranovski</i>	
11.1	Introduction	315
11.2	Wettable Filtration Materials	316
11.2.1	Theoretical Aspects	318
11.2.2	Practical Aspects	320
11.2.3	Inactivation of Bioaerosols on Fibers Coated by a Disinfectant	326
11.3	Non-Wettable Filtration Materials	327
11.3.1	Theoretical Aspects	327
11.3.2	Practical Aspects of Non-Wettable Filter Design	330
11.4	Filtration on a Porous Medium Submerged into a Liquid	330
11.4.1	Theoretical Approach	330
11.4.2	Application of the Technique for Viable Bioaerosol Monitoring	337
	References	340
	Part IV Atmospheric and Biological Aerosols	343
12	Atmospheric Aerosols	345
	<i>Lev S. Ivlev</i>	
12.1	General Concepts	345
12.2	Atmospheric Aerosols of Different Nature	348
12.2.1	Soil Aerosols	348
12.2.2	Marine Aerosols	351
12.2.3	Volcanic Aerosols	354
12.2.4	Aerosols <i>In situ</i> – Secondary Aerosols	358
12.2.4.1	Photochemical Oxidation – Heterogeneous Reactions	359
12.2.4.2	Catalytic Oxidation in the Presence of Heavy Metals	360
12.2.4.3	Reaction of Ammonia with Sulfur Dioxide in the Presence of Water Droplets (Reaction of Cloud Droplets)	360
12.2.5	Biogenic Small Gas Compounds and Aerosols	360
12.3	Temporal and Dimensional Structure of Atmospheric Aerosols	363
12.3.1	Aerosols in the Troposphere	363
12.3.1.1	Terrigenous Elements	363
12.3.1.2	The Group of Ions	363
12.4	Aerosols in the Stratosphere	371
	References	377
13	Biological Aerosols	379
	<i>Sergey A. Grinshpun</i>	
13.1	Introduction	379
13.2	History of Bioaerosol Research	379
13.3	Main Definitions and Types of Bioaerosol Particles	381
13.4	Sources of Biological Particles and their Aerosolization	383
13.5	Sampling and Collection	384
13.5.1	Impaction	386

13.5.2	Collection into Liquid	388
13.5.3	Filter Collection	389
13.5.4	Gravitational Settling	390
13.5.5	Electrostatic Precipitation	390
13.6	Analysis	391
13.7	Real-Time Measurement of Bioaerosols	393
13.8	Purification of Indoor Air Contaminated with Bioaerosol Particles and Respiratory Protection	393
13.8.1	Air Purification	393
13.8.2	Respiratory Protection	396
	References	398
14	Atmospheric Bioaerosols	407
	<i>Aleksandr S. Safatov, Galina A. Buryak, Irina S. Andreeva, Sergei E. Olkin, Irina K. Reznikova, Aleksandr N. Sergeev, Boris D. Belan and Mikhail V. Panchenko</i>	
14.1	Introduction	407
14.2	Methods of Atmospheric Bioaerosol Research	408
14.2.1	Methods and Equipment for Atmospheric Bioaerosol Sampling	409
14.2.2	Methods to Analyze the Chemical Composition of Atmospheric Bioaerosols and their Morphology	411
14.2.3	Methods Used to Detect and Characterize Microorganisms in Atmospheric Bioaerosols	416
14.3	Atmospheric Bioaerosol Studies	421
14.3.1	Time Variation of Concentrations and Composition of Atmospheric Bioaerosol Components	421
14.3.2	Spatial Variation of the Concentrations and Composition of Atmospheric Bioaerosol Components	432
14.3.3	Possible Sources of Atmospheric Bioaerosols and their Transfer in the Atmosphere	436
14.3.4	The Use of Snow Cover Samples to Analyze Atmospheric Bioaerosols	438
14.3.5	Potential Danger of Atmospheric Bioaerosols for Humans and Animals	442
14.4	Conclusion	446
	References	448
	Index	455