

# Contents

## PART 1 Particle Characterization and Standard Powder

<b>Chapter 1.1</b> Particle Size .....	3
<i>JunIchiro Tsubaki</i>	
1.1.1 Definition of Particle Diameter .....	3
1.1.2 Particle Size Distribution.....	3
1.1.3 Average Particle Size.....	5
References .....	7
<b>Chapter 1.2</b> Size Measurement .....	9
<i>Yasushige Mori</i>	
1.2.1 Introduction .....	9
1.2.2 Classification of Particle Size Analysis Methods.....	10
1.2.3 Counting Analysis .....	10
1.2.4 Fractionation Analysis.....	13
1.2.5 Ensemble Analysis .....	16
1.2.6 Others .....	18
1.2.7 Summary .....	18
References .....	18
<b>Chapter 1.3</b> Particle Shape Characterization .....	19
<i>Shigehisa Endoh</i>	
1.3.1 Introduction .....	19
1.3.2 Representative Size .....	19
1.3.3 Geometrical Shape Descriptors.....	20
1.3.4 Dynamic Equivalent Shape .....	24
1.3.5 Concluding Remarks .....	25
References .....	25
<b>Chapter 1.4</b> Particle Density .....	27
<i>Yoshiyuki Endo</i>	
1.4.1 Definition of Particle Density.....	27
1.4.2 Measurement Method of Particle Density.....	27
1.4.3 Measurement Method of Bulk Density .....	30
References .....	31
<b>Chapter 1.5</b> Hardness, Stiffness and Toughness of Particles.....	33
<i>Mojtaba Ghadiri, Mehrdad Pasha, and Umair Zafar</i>	
1.5.1 Indentation Hardness.....	33
1.5.2 Measurement of Hardness .....	34
1.5.3 Measurement of Stiffness .....	37

1.5.4 Measurement of Toughness.....	37
References .....	40
<b>Chapter 1.6</b> Surface Properties and Analysis .....	41
<i>Masayoshi Fuji and Chika Takai</i>	
1.6.1 Surface Structures and Properties.....	41
1.6.2 Surface Characterization .....	45
References .....	51
<b>Chapter 1.7</b> Characterization by Atomic Force Microscope .....	53
<i>Naoyuki Ishida and Vincent S. J. Craig</i>	
1.7.1 Principle of AFM.....	53
1.7.2 Surface Characterization by AFM.....	54
1.7.3 Measurements of Interaction Forces by AFM.....	55
References .....	58
<b>Chapter 1.8</b> Specific Properties of Nanoparticles .....	59
<i>Wolfgang Peukert and Johannes Walter</i>	
1.8.1 Property Function and Disperse Properties.....	59
1.8.2 Transport Properties .....	60
1.8.3 Particle Interactions .....	60
1.8.4 Thermophysical Properties.....	61
1.8.5 Mechanical Properties .....	62
1.8.6 Optical Properties .....	63
1.8.7 Electrical Properties .....	63
1.8.8 Magnetic Properties.....	64
1.8.9 Catalytic Particles.....	65
References .....	67
<b>Chapter 1.9</b> Standard Powders and Particles .....	69
<i>Hideto Yoshida</i>	
References .....	72
<b>PART 2 Fundamental Properties of Particles</b>	
<b>Chapter 2.1</b> Optical Properties.....	75
<i>Yasushige Mori</i>	
2.1.1 Definitions .....	75
2.1.2 Light Scattering .....	75
2.1.3 Light Extinction.....	77
2.1.4 Dynamic Light Scattering .....	77
2.1.5 Photophoresis .....	78
References .....	78
<b>Chapter 2.2</b> Electrification and Electrophoresis .....	81
<i>Shuji Matsusaka and Hiroaki Masuda (2.2.1)</i>	
<i>Hiroyuki Shinto and Tomonori Fukasawa (2.2.2)</i>	
2.2.1 In Gaseous State .....	81

2.2.2 In Liquid State .....	83
References .....	89
<b>Chapter 2.3 Magnetic Properties .....</b>	<b>91</b>
<i>Toyohisa Fujita</i>	
2.3.1 Magnetic Force on a Particle.....	91
2.3.2 Ferromagnetic Properties of a Small Particle.....	93
2.3.3 Magnetism of Various Materials .....	94
References .....	96
<b>Chapter 2.4 Diffusion of Particles .....</b>	<b>97</b>
<i>Toshiyuki Fujimoto and Kikuo Okuyama (2.4.1)</i>	
<i>Shinichi Yuu (2.4.2)</i>	
2.4.1 Thermal Diffusion .....	97
2.4.2 Turbulent Diffusion .....	100
References .....	103
<b>Chapter 2.5 Particle Motion in Fluid .....</b>	<b>105</b>
<i>Shinichi Yuu</i>	
2.5.1 Introduction .....	105
2.5.2 Motion of a Single Particle.....	105
2.5.3 PARTICLE Motion in Shear Flow .....	107
References .....	107
<b>Chapter 2.6 Particle Sedimentation .....</b>	<b>109</b>
<i>Shinichi Yuu</i>	
2.6.1 Introduction .....	109
2.6.2 Terminal Settling Velocity .....	109
2.6.3 Settling of Two Spherical Particles .....	111
2.6.4 Rate of Sedimentation in Concentrated Suspension.....	111
References .....	112
<b>Chapter 2.7 Adhesive Force of Single Particle .....</b>	<b>113</b>
<i>Kuniaki Gotoh (2.7.1)</i>	
<i>Naoyuki Ishida (2.7.2)</i>	
<i>Shuji Matsusaka (2.7.3)</i>	
2.7.1 In Gaseous State .....	113
2.7.2 In Liquid State .....	116
2.7.3 Measurement of Adhesive Force .....	117
References .....	119
<b>Chapter 2.8 Particle Deposition and Reentrainment.....</b>	<b>121</b>
<i>Manabu Shimada (2.8.1)</i>	
<i>Shuji Matsusaka and Hiroaki Masuda (2.8.2)</i>	
2.8.1 Particle Deposition .....	121
2.8.2 Particle Reentrainment .....	124
References .....	127

<b>Chapter 2.9</b> Agglomeration (Coagulation) .....	129
<i>Takafumi Seto and Kikuo Okuyama (2.9.1)</i>	
<i>Ko Higashitani (2.9.2)</i>	
2.9.1 In Gaseous State .....	129
2.9.2 In Liquid State .....	133
References .....	137
<b>Chapter 2.10</b> Viscosity of Slurry .....	139
<i>Yoshiyuki Komoda</i>	
2.10.1 Introduction .....	139
2.10.2 Basic Flow Characteristics .....	139
2.10.3 Time-Dependent Flow Characteristics .....	139
2.10.4 Viscosity Equations for Suspensions of Spherical Particles of Narrow Particle Size Distribution .....	140
2.10.5 Effect of Particle Size Distribution on Slurry Viscosity .....	141
2.10.6 Shear Thinning or Thickening Behavior of Slurry .....	141
2.10.7 Measurement of Slurry Viscosity by a Capillary Viscometer .....	141
2.10.8 Measurement of Slurry Viscosity by a Rotating Viscometer .....	142
References .....	142
<b>Chapter 2.11</b> Particle Impact Breakage .....	145
<i>Mojtaba Ghadiri</i>	
2.11.1 Impact Force .....	145
2.11.2 Mode of Breakage .....	146
2.11.3 Analysis of Breakage for the Brittle Failure Mode .....	146
2.11.4 Analysis of Breakage for the Semi-Brittle Failure Mode .....	147
2.11.5 Analysis of Breakage of Agglomerates .....	148
References .....	148
<b>Chapter 2.12</b> Sintering .....	151
<i>Takafumi Seto and Kikuo Okuyama</i>	
2.12.1 Mechanisms of Solid-Phase Sintering .....	151
2.12.2 Modeling of Sintering of Agglomerates .....	151
2.12.3 Sintering Process of Nanoparticles .....	152
2.12.4 Sintering Process of Packed Powder .....	153
References .....	154
<b>Chapter 2.13</b> Mechanochemistry .....	155
<i>Qiwu Zhang and Fumio Saito</i>	
2.13.1 Introduction .....	155
2.13.2 Phase Transformation .....	155
2.13.3 Solid State Reaction .....	155
2.13.4 Mechanochemical Doping .....	160
2.13.5 Mechanical Synthesis of Hydrated Compounds .....	160
2.13.6 Decomposition of Halogenated Polymers .....	161
2.13.7 Material Processing with Mechanical Activation Followed by Chemical or Physical Treatment .....	162
References .....	164

<b>Chapter 2.14 Ignition and Combustion Reaction .....</b>	167
<i>Hisao Makino and Ryoichi Kurose</i>	
2.14.1 Combustion Profile.....	167
2.14.2 Devolatilization and Ignition.....	167
2.14.3 Gaseous Combustion.....	168
2.14.4 Solid Combustion.....	169
References .....	169
<b>Chapter 2.15 Solubility and Dissolution Rate .....</b>	171
<i>Hirofumi Takeuchi</i>	
2.15.1 Solubility of a Solid.....	171
2.15.2 Solubility Changes as Properties of Solvent or Solute Change.....	171
2.15.3 Dissolution Rate Analysis: Theory and Methods .....	172
2.15.4 Methods to Improve the Solubilization of Powdered Materials.....	174
References .....	176
<b>PART 3 Properties of Powders and Powder Beds</b>	
<b>Chapter 3.1 Specific Surface Area.....</b>	179
<i>Takashi Takei</i>	
3.1.1 Definition of Specific Surface Area.....	179
3.1.2 Estimation of Surface Area by Gas Adsorption.....	179
3.1.3 Methodology of Gas Adsorption .....	181
3.1.4 Estimation of Surface Area by Gas Flow (Permeametry) .....	182
References .....	183
<b>Chapter 3.2 Adsorption Characteristics.....</b>	185
<i>Takashi Takei</i>	
3.2.1 Introduction .....	185
3.2.2 Adsorption Measurement .....	185
3.2.3 Theory of Adsorption Isotherms.....	186
3.2.4 Estimation of Surface Properties by Adsorption Method.....	188
References .....	190
<b>Chapter 3.3 Moisture Content.....</b>	193
<i>Satoru Watano</i>	
3.3.1 Bound Water and Adhesive Water .....	193
3.3.2 Method to Determine Moisture Content in Particulate System .....	194
References .....	194
<b>Chapter 3.4 Electrical Properties .....</b>	195
<i>Ken-ichiro Tanoue and Hiroaki Masuda (3.4.1)</i>	
<i>Yasufumi Otsubo (3.4.2)</i>	
3.4.1 In Gaseous State .....	195
3.4.2 In Nonaqueous Solutions .....	199
References .....	202

<b>Chapter 3.5</b> Packing Properties .....	203
<i>Michitaka Suzuki</i>	
3.5.1    Packing of Equal-Size Spheres.....	203
3.5.2    Packing of Multi-Size Particles.....	205
3.5.3    Effect of Particle Shape on Void Fraction .....	207
References .....	209
<b>Chapter 3.6</b> Capillarity of Porous Media.....	211
<i>Minoru Miyahara</i>	
3.6.1    Common Phenomenon: Young–Laplace Effect.....	211
3.6.2    Nitrogen Adsorption Method .....	211
3.6.3    Mercury Intrusion Method (Mercury Porosimetry) .....	214
3.6.4    Other Techniques of Interest .....	214
References .....	215
<b>Chapter 3.7</b> Permeation (Flow through Porous Media).....	217
<i>Chikao Kanaoka</i>	
3.7.1    Resistance to Flow Through a Porous Media.....	217
3.7.2    Pressure Drop Across a Fibrous Mat.....	219
References .....	221
<b>Chapter 3.8</b> Mechanical Properties of a Powder Bed .....	223
<i>Michitaka Suzuki</i>	
3.8.1    Shearing Strength of a Powder Bed .....	223
3.8.2    Adhesion of a Powder Bed .....	225
3.8.3    Yielding Characteristics of a Powder Bed .....	226
References .....	229
<b>Chapter 3.9</b> Fluidity of Powder .....	231
<i>Toyokazu Yokoyama</i>	
3.9.1    Definition of Fluidity.....	231
3.9.2    Measurement of Fluidity .....	231
3.9.3    Factors Affecting Fluidity.....	234
3.9.4    Improvement of Fluidity.....	235
References .....	235
<b>Chapter 3.10</b> Blockage in Storage Vessels .....	237
<i>Hiroshi Takahashi and Jun Yoshida</i>	
3.10.1    Typical Phenomena .....	237
3.10.2    Mechanisms and Flow Criteria.....	237
3.10.3    Experimental Study .....	240
3.10.4    Methods of Preventing Blockage .....	241
References .....	241
<b>Chapter 3.11</b> Segregation of Particles .....	243
<i>Kuniaki Gotoh</i>	
3.11.1    Segregation Phenomena and its Factors .....	243
3.11.2    Mechanism of Segregation .....	243

3.11.3 Surface Segregation.....	244
3.11.4 Interlayer Segregation .....	246
3.11.5 Method to Prevent Segregation .....	247
References .....	247
<b>Chapter 3.12 Vibrational and Acoustic Characteristics .....</b>	<b>249</b>
<i>Jusuke Hidaka</i>	
3.12.1 Behavior of a Particle on a Vibrating Plate .....	249
3.12.2 Behavior of a Vibrating Powder Bed.....	250
3.12.3 Generating Mechanism of Impact Sound Between Two Particles .....	252
3.12.4 Frictional Sound from a Granular Bed.....	253
3.12.5 Vibration of a Small Particle in a Sound Wave.....	256
3.12.6 Attenuation of Sound in a Suspension of Particles.....	256
References .....	257
<b>PART 4 Particle Generation and Modification</b>	
<b>Chapter 4.1 Aerosol Particle Generation .....</b>	<b>261</b>
<i>Jakub M. Gac and Sotiris E. Pratsinis</i>	
4.1.1 Atomization of Fluids.....	261
4.1.2 Condensation Methods.....	265
4.1.3 Powder Dispersion .....	267
References .....	268
<b>Chapter 4.2 Generation of Particles by Reactions .....</b>	<b>269</b>
<i>Kakeru Fujiwara and Sotiris E. Pratsinis (4.2.1)</i>	
<i>Hisao Suzuki (4.2.2)</i>	
4.2.1 Gas-Phase (Aerosol) Techniques.....	269
4.2.2 Liquid-Phase Techniques.....	273
References .....	277
<b>Chapter 4.3 Crystallization .....</b>	<b>279</b>
<i>Yoshiyuki Shirakawa</i>	
4.3.1 Introduction .....	279
4.3.2 Solid-Liquid Equilibrium and Supersaturated Solution .....	279
4.3.3 Nucleation Rate .....	280
4.3.4 Crystal Growth Rate .....	281
4.3.5 Control of Powder Properties in Crystallization Processes.....	281
4.3.6 Synthesis of Composite Particles .....	282
References .....	284
<b>Chapter 4.4 Design and Formation of Composite Particles.....</b>	<b>285</b>
<i>Hideki Ichikawa, Tooru Andoh, and Fumihiko Fujii</i>	
4.4.1 Typical Structure of Composite Particles .....	285
4.4.2 Process.....	285
4.4.3 Materials.....	286
4.4.4 Examples of Particulate Design and Preparation of Composite Particles .....	287
References .....	296

<b>Chapter 4.5 Electrical Charge Control.....</b>	299
<i>Takashi Ogi and Kikuo Okuyama (4.5.1.1)</i>	
<i>Shuji Matsusaka (4.5.1.2)</i>	
<i>Ko Higashitani (4.5.2.1)</i>	
<i>Hidehiro Kamiya (4.5.2.2)</i>	
4.5.1 In Gaseous State .....	299
4.5.2 In Liquid State .....	305
References .....	309
<b>Chapter 4.6 Surface Modification.....</b>	311
<i>Makio Naito (4.6.1), (4.6.3)</i>	
<i>Hidehiro Kamiya (4.6.2)</i>	
4.6.1 Purpose of Surface Modification and Its Methods .....	311
4.6.2 Chemical Methods.....	311
4.6.3 Physical Methods .....	314
References .....	315
<b>PART 5 Powder Handlings and Simulations</b>	
<b>Chapter 5.1 Crushing and Grinding.....</b>	319
<i>Fumio Saito</i>	
5.1.1 Introduction .....	319
5.1.2 Basic Approach for Understanding Grinding Phenomena .....	319
5.1.3 Comminution of Materials .....	324
References .....	334
<b>Chapter 5.2 Dispersion of Particles.....</b>	337
<i>Kuniaki Gotoh (5.2.1)</i>	
<i>Ko Higashitani (5.2.2)</i>	
5.2.1 In Gaseous State .....	337
5.2.2 Dispersion in Liquids .....	341
References .....	345
<b>Chapter 5.3 Classification .....</b>	347
<i>Hideto Yoshida and Kunihiro Fukui</i>	
5.3.1 Basis of Classification .....	347
5.3.2 Dry Classification .....	348
5.3.3 Wet Classification .....	351
5.3.4 Screening .....	359
References .....	362
<b>Chapter 5.4 Storage (Silo) .....</b>	363
<i>Jun Yoshida</i>	
5.4.1 Storing Bulk Solids .....	363
5.4.2 Basic Structure and Functions.....	363

5.4.3 Classification of Silos.....	364
5.4.4 Behavior of Bulk Solids in Silos .....	364
5.4.5 Planning Silos.....	365
5.4.6 Structural Design .....	366
5.4.7 Trouble in Silos .....	368
References .....	369
<b>Chapter 5.5 Feeding.....</b>	<b>371</b>
<i>Shuji Matsusaka</i>	
5.5.1 Introduction .....	371
5.5.2 Type of Feeders .....	371
References .....	374
<b>Chapter 5.6 Transportation .....</b>	<b>375</b>
<i>Yuji Tomita (5.6.1)</i>	
<i>Yoshiyuki Komoda (5.6.2)</i>	
5.6.1 Transportation in the Gaseous State .....	375
5.6.2 Transportation in the Liquid State.....	381
References .....	382
<b>Chapter 5.7 Fluidization and Fluidized Bed .....</b>	<b>385</b>
<i>Xinhua Liu and Shanwei Hu (5.7.1)</i>	
<i>Xinhua Liu, Bona Lu, Xizhong Chen and Limin Wang (5.7.2)</i>	
5.7.1 Overview of Fluidization.....	385
5.7.2 Computational Methods for Fluidization .....	389
References .....	398
<b>Chapter 5.8 Mixing .....</b>	<b>401</b>
<i>Satoru Watano</i>	
5.8.1 Introduction .....	401
5.8.2 Mixing Mechanism .....	401
5.8.3 Mixing Indices and Mixing Rate.....	401
5.8.4 Evaluation of Mixing Condition.....	402
5.8.5 Characterization of Mixing Equipment.....	407
References .....	409
<b>Chapter 5.9 Slurry Conditioning.....</b>	<b>411</b>
<i>JunIchiro Tsubaki and Takamasa Mori</i>	
5.9.1 Slurry Characterization.....	411
5.9.2 Slurry Preparation.....	414
References .....	415
<b>Chapter 5.10 Granulation .....</b>	<b>417</b>
<i>Kazuo Murase and Isao Sekiguchi</i>	
5.10.1 Growth Mechanisms of Wet Granulation .....	417
5.10.2 Mechanical Properties of Wet Granules .....	418
5.10.3 Testing Methods for Evaluating the Agglomerate Granulation of Wet Powders.....	420
5.10.4 Granulators .....	423
References .....	426

<b>Chapter 5.11</b>	Kneading and Plastic Forming .....	429
<i>Minoru Takahashi and Masayoshi Fuji</i>		
5.11.1	Kneading .....	429
5.11.2	Plastic Forming.....	430
References .....		432
<b>Chapter 5.12</b>	Drying .....	433
<i>Yuji Tatemoto</i>		
5.12.1	Fundamental of Drying .....	433
5.12.2	Dryer Selection and Design.....	434
References .....		438
<b>Chapter 5.13</b>	Combustion .....	439
<i>Hisao Makino and Kenji Tanno</i>		
5.13.1	Introduction .....	439
5.13.2	Control of the Combustion Process.....	439
5.13.3	Combustion Burner .....	441
5.13.4	Furnace and Kiln .....	442
References .....		443
<b>Chapter 5.14</b>	Dust Collection .....	445
<i>Chikao Kanaoka</i>		
5.14.1	Flow-Through-Type Dust Collectors .....	446
5.14.2	Obstacle-Type Dust Collectors.....	449
5.14.3	Barrier-Type Dust Collectors .....	452
5.14.4	Miscellaneous.....	453
References .....		453
<b>Chapter 5.15</b>	Electrostatic Separation .....	455
<i>Ken-ichiro Tanoue and Hiroaki Masuda</i>		
5.15.1	Separation Mechanism .....	455
5.15.2	Separation Machines .....	457
References .....		460
<b>Chapter 5.16</b>	Magnetic Separation .....	461
<i>Toyohisa Fujita</i>		
5.16.1	Classification of Magnetic Separators.....	461
5.16.2	Static Magnetic Field Separators.....	461
5.16.3	Application of Magnetic Separation.....	466
5.16.4	Magnetohydrostatic Separation.....	469
5.16.5	Electromagnetic-Induction-Type Separation.....	470
References .....		471
<b>Chapter 5.17</b>	Dry Dense Medium Separation .....	473
<i>Jun Oshitani</i>		
5.17.1	Basis of Separation.....	473
5.17.2	Application of Separation.....	475
References .....		475

<b>Chapter 5.18 Gravity Thickening .....</b>	477
<i>Eiji Iritani</i>	
5.18.1 Pretreatment.....	477
5.18.2 Ideal Settling Basin .....	477
5.18.3 Settling Curve.....	477
5.18.4 Kynch Theory .....	478
5.18.5 Design of Continuous Thickener.....	479
References .....	480
<b>Chapter 5.19 Filtration.....</b>	481
<i>Eiji Iritani</i>	
5.19.1 Basis of Cake Filtration Theory .....	481
5.19.2 Constant-Pressure and Constant-Rate Filtration .....	484
5.19.3 Internal Structure of Compressible Filter Cake.....	485
5.19.4 Filtration of Non-Newtonian Fluid–Solid Mixtures.....	486
5.19.5 Filtration Equipment .....	486
References .....	488
<b>Chapter 5.20 Expression.....</b>	489
<i>Eiji Iritani</i>	
5.20.1 Basis of Expression .....	489
5.20.2 Modified Terzaghi Model.....	489
5.20.3 Secondary Consolidation.....	491
5.20.4 Simplified Analysis .....	492
5.20.5 Expression Equipment.....	492
References .....	493
<b>Chapter 5.21 Flotation .....</b>	495
<i>Wei Sung Ng, George Vincent Franks, Elizaveta Forbes, Luke Andrew Connal and Hiroki Yotsumoto</i>	
5.21.1 Fundamentals of Flotation.....	495
5.21.2 Minerals Separation.....	498
5.21.3 Flotation Reagents.....	499
5.21.4 Flotation Equipment.....	500
5.21.5 Plant Practice.....	503
5.21.6 Challenges in Flotation.....	505
5.21.7 Emerging Technologies .....	505
References .....	506
<b>Chapter 5.22 Electrostatic Powder Coating.....</b>	509
<i>Ken-ichiro Tanoue</i>	
5.22.1 Coating Machines.....	509
5.22.2 Powder Feeding Machine .....	510
5.22.3 Powder Coating Booth .....	510
5.22.4 Numerical Simulation for Electrostatic Powder Coating .....	511
References .....	512

<b>Chapter 5.23</b> Multipurpose Equipment .....	515
<i>Hisao Makino and Hiromi Shirai (5.23.1, 5.23.2)</i>	
<i>Junichi Tatami (5.23.3)</i>	
5.23.1 Fixed Beds.....	515
5.23.2 Moving Beds .....	516
5.23.3 Rotary Kiln .....	518
References .....	519
<b>Chapter 5.24</b> Nanoparticle Handling and Formulation .....	521
<i>Wolfgang Peukert and Stefan Romeis</i>	
5.24.1 Introduction and Overview.....	521
5.24.2 Formation of Nanoparticles.....	522
5.24.3 Dispersion of Nanoparticles .....	522
5.24.4 Nanoparticle Stabilization .....	523
5.24.5 From Surfaces to Properties – The Effect of Surface Modification .....	527
5.24.6 Nanoparticle Handling in Classical Unit Operations of Powder Processing .....	529
5.24.7 Processing of Functional Thin Films from Liquids.....	531
5.24.8 Conclusions .....	532
References .....	532
<b>Chapter 5.25</b> Simulation of Powders and Particles in Dry and Wet Phases.....	535
<i>Junya Kano and Jusuke Hidaka (5.25.1)</i>	
<i>Mikio Sakai (5.25.2)</i>	
<i>Yutaka Tsuji (5.25.3)</i>	
<i>Mojtaba Ghadiri, Tina Bonakdar and Sadegh Nadimi (5.25.4)</i>	
<i>Kenji Iimura and Ko Higashitani (5.25.5)</i>	
<i>Ryoichi Yamamoto (5.25.6)</i>	
5.25.1 Powder Simulation Using Discrete Element Method (DEM) .....	535
5.25.2 Recent Advances in DEM Simulations for Industrial Applications .....	542
5.25.3 Particle Motion in Fluid .....	543
5.25.4 Breakage of Particles in Gas Phase .....	545
5.25.5 Breakage of Aggregates in Liquid Phase .....	549
5.25.6 Direct Numerical Simulations of Colloidal Particles in a Liquid .....	551
References .....	557
<b>PART 6 Process Instrumentation</b>	
<b>Chapter 6.1</b> Powder Sampling.....	563
<i>Hiroaki Masuda</i>	
6.1.1 Sampling Equipment .....	563
6.1.2 Analysis of Sampling .....	564
References .....	566
<b>Chapter 6.2</b> Particle Sampling in Gas Flow.....	567
<i>Hideto Yoshida (6.2.1, 6.2.2)</i>	
<i>Hisao Makino (6.2.3)</i>	
6.2.1 Anisokinetic Sampling Error .....	567
6.2.2 Sampling in Stationary Air.....	568

6.2.3 Practical Applications of Particle Sampling .....	570
References .....	573
<b>Chapter 6.3 Concentration and Flow Rate Measurement .....</b>	<b>575</b>
<i>Shuji Matsusaka</i>	
6.3.1 Particle Concentration in Suspensions .....	575
6.3.2 Powder Flow Rate .....	577
References .....	579
<b>Chapter 6.4 Level Measurement of Powder Bed.....</b>	<b>581</b>
<i>Shuji Matsusaka</i>	
6.4.1 Level Meters and Level Switches.....	581
6.4.2 Mechanical Methods .....	581
6.4.3 Electrical Methods.....	582
6.4.4 Ultrasonic Wave Level Meters .....	583
6.4.5 Radiometric Method.....	583
6.4.6 Pneumatic and Other Methods .....	583
References .....	584
<b>Chapter 6.5 Temperature Measurement of Powder.....</b>	<b>585</b>
<i>Koichi Nakaso and Kuniaki Gotoh</i>	
6.5.1 Temperature Measurement by Contact-Type Thermometers .....	585
6.5.2 Temperature Measurement by Non-Contact-Type Thermometers .....	586
References .....	588
<b>Chapter 6.6 On-Line Measurement of Moisture Content .....</b>	<b>589</b>
<i>Satoru Watano</i>	
6.6.1 Introduction .....	589
6.6.2 Electric Methods.....	589
6.6.3 Optical Moisture Sensor.....	591
6.6.4 Continuous Monitoring and Control of Moisture Content.....	593
References .....	594
<b>Chapter 6.7 Tomography .....</b>	<b>595</b>
<i>Richard A. Williams</i>	
6.7.1 Introduction .....	595
6.7.2 Sensor Selection and Specification.....	596
6.7.3 Examples of Powder and Slurry Processing Applications .....	597
References .....	600

## PART 7 *Working Atmospheres-Risks, Hazards and Protection*

<b>Chapter 7.1 Health Effects Due to Particle Matter .....</b>	<b>603</b>
<i>Yasuo Morimoto and Toshihiko Myojo</i>	
7.1.1 Introduction .....	603
7.1.2 Respiratory System .....	603

7.1.3 Penetration and Deposition of Particles in the Respiratory Tract .....	603
7.1.4 Rate of Deposited Particles .....	604
7.1.5 Health Effects of Inhaled Particles .....	604
7.1.6 Threshold Limit Value .....	605
References .....	606
<b>Chapter 7.2 Risks of Nanoparticles .....</b>	<b>607</b>
<i>Toshihiko Myojo (7.2.1–7.2.3)</i>	
<i>Hidehiro Kamiya (7.2.4)</i>	
7.2.1 Introduction .....	607
7.2.2 Concept of Risk Assessment and Management of Nanomaterials .....	607
7.2.3 Risk Management Using Control Banding of Nanomaterials.....	608
7.2.4 Specific Risk and Measurement of PM2.5 .....	609
References .....	611
<b>Chapter 7.3 Respiratory Protective Devices for Particulate Matter .....</b>	<b>613</b>
<i>Toshihiko Myojo</i>	
7.3.1 Introduction .....	613
7.3.2 Types of Respirators .....	613
7.3.3 Protection Factor .....	615
7.3.4 Fit Check and Fit Test of Respirators .....	615
7.3.5 Selection, Use, and Maintenance of Respirators .....	616
References .....	616
<b>Chapter 7.4 Dust Explosion .....</b>	<b>617</b>
<i>Ritsu Dobashi and Wei Gao</i>	
7.4.1 What is Dust Explosion? .....	617
7.4.2 Flame Propagation Mechanism in Dust Explosion .....	617
7.4.3 Risk of Dust Explosion .....	621
7.4.4 Prevention and Mitigation of Accidental Dust .....	627
References .....	632
<b>Index.....</b>	<b>633</b>