I. INTRODUCTION

1. Ceramic Processing and Ceramic Products

- 1.1 A Brief History of Ceramic Technology 3
- 1.2 Industrial Ceramic Processing 12
- 1.3 Science in Ceramic Processing 12 Summary 15 Suggested Reading 15 Problems 16

2. Surface Chemistry

- 2.1 The Atomic Structure of the Surface Differs from That in the Interior of the Particle 17
- 2.2 Surface Energy Causes a Pressure Difference across a Curved Surface 19
- 2.3 Weak Van der Waals Forces or Chemical Bonding Causes Solid Surfaces to Adsorb Molecules from Gases and Liquid Solutions 20
- 2.4 The Wetting and Spreading of a Liquid on a Solid Surface Depends on Short-Range Molecular Forces That Can Be Significantly Modified by a Monolayer Coating 22
- 2.5 Wetting May Cause Compressive Forces between Particles and Liquid Migration 23
- 2.6 Weak Intermolecular Forces Can Cause the Adherence of Molecules on a Surface and the Agglomeration of Small Particles 25

3

Summary 26 Suggested Reading 26 Problems 26

II. CERAMIC RAW MATERIALS

3. Common Raw Materials

- 3.1 Crude Materials 31
- 3.2 Industrial Minerals 32
- 3.3 Industrial Inorganic Chemicals 36
 Summary 44
 Suggested Reading 44
 Problems 45

4. Special Inorganic Chemicals

- 4.1 Powders from Chemical Solution Techniques 47
- 4.2 Powders from Vapor Phase Reactions 54
- 4.3 Other Techniques 55
 Summary 56
 Suggested Reading 56
 Problems 57

III. MATERIAL CHARACTERIZATION

. .

. .

~

э.	Cna	racteristics and Specifications of Ceramic Materia	IS	01
	5.1	Particles, Powders, Colloids, and Agglomerates	61	
	5.2	Raw-Material Specifications 62		
		Summary 66		
		Suggested Reading 67		
		Problems 67		
6.	Che	mical and Phase Composition		68
	6.1	Bulk Chemical Analysis 68		
	6.2	Phase Analysis 73		
	6.3	Surface Analysis 75		
	6.4	Thermochemical and Thermophysical Analyses	76	
-		Summary 80		

• ~

31

47

Suggested Reading 80 Problems 81

	7. I	7. Particle Size and Shape		82	
	7	7.1	Analysis Techniques 83		
			Selecting a Technique 91		
			Presentation of Particle Size Data 94		
			Calculating a Mean Particle Size 96		
	7	7.5 1	Particle Size Distribution Functions 98		
		9	Summary 101		
			Suggested Reading 102		
		J	Problems 103		
	8. I	8. Density, Pore Structure, and Specific Surface Area			
	8	3.1 I	Density 105		
	8	3.2 I	Porosity and Pore Structure 110		
	8	3.3 9	Specific Surface Area 113		
		9	Summary 117		
		5	Suggested Reading 117		
		1	Problems 118		
IV.	V. PROCESSING ADDITIVES 9. Liquids and Wetting Agents			123	
		-		145	
	-		Vater 123		
			Organic Liquids 126 John Liquids Near Orida Surfaces 127		
			Polar Liquids Near Oxide Surfaces 127 Surfactants 128		
	9				
			ummary 130		
			uggested Reading 131 Problems 131		
		r	Iobenis 151		
10. Deflocculants and Coagulants			132		
		10.1	Particle Charging in Liquid Suspensions 132		
		10.2	Development of an Electrical Double Layer 139		
		10.3	Electrokinetic Properties 141		
		10.4	Deflocculation and the Stability of Suspensions 143		
		10.5	Coagulation and Flocculation 146		

Summary 149 Suggested Reading 149 Problems 150

11. Flocculants, Binders, and Bonds

- 11.1 Binder Compositions 153
- 11.2 Clay Binders 154
- 11.3 Molecular Binders 155
- 11.4 Dissolving and Admixing Binders 159
- 11.5 Molecular Weight and Binder Grade 159
- 11.6 Gelation 161
- 11.7 General Effect of Binders 163
- 11.8 Polymer Resins 165
- 11.9 Reaction Bonds 166
- 11.10 Hydraulic Cements 168
 Summary 171
 Suggested Reading 172
 Problems 172

12. Plasticizers, Foaming and Antifoaming Agents, Lubricants, and Preservatives 174

- 12.1 Plasticizers 174
- 12.2 Foaming and Antifoaming Agents 179
- 12.3 Lubricants 180
- 12.4 Preservatives 181 Summary 181 Suggested Reading 181 Problems 182

V. PARTICLE MECHANICS AND RHEOLOGY

13. Particle Packing Characteristics

- 13.1 Characteristics of Packings of Uniform Spheres 186
- 13.2 Packing in Interstices Among Coarser Particles 188
- 13.3 Packing of Continuous Size Distributions 191
- 13.4 Hindered Packing 195
 Summary 197
 Suggested Reading 197
 Problems 198

152

14. Consistency, Particle Mechanics, and Deformation Behavior 200

- 14.1 Change in Consistency on Admixing a Liquid 200
- 14.2 Concept of Effective Stress 202
- 14.3 Particle Interactions 203
- 14.4 Interparticle Friction 204
- 14.5 Lubrication 206
- 14.6 Average Stresses in a Powder Mass 208
- 14.7 Shear Resistance of Granular Materials and Powders 209
- 14.8 Stress-Strain Behavior During Compression 212
- 14.9 Strength of Agglomerates 215
- 14.10 Shear Resistance of Nearly Saturated Powders and Plastic Bodies 218
 Summary 223
 Suggested Reading 224
 Problems 224

15. Rheological Behavior of Slurries and Pastes

- 15.1 Effective Stress and Shear Resistance in a Saturated System 227
- 15.2 Rheological Properties 229
- 15.3 Determination of Viscosity 231
- 15.4 Viscosity of Liquids 236
- 15.5 Viscosity of Binder Solutions 237
- 15.6 Viscosity of Suspensions of Dispersed Colloidal Particles 239
- 15.7 Viscosity of Slurries of Dispersed Powders and Powder-Colloid Mixtures 242
- 15.8 Rheology of Coagulated Systems 244
- 15.9 Rheology of Suspensions and Slurries Containing Binders 247
 Summary 249
 Suggested Reading 250
 Problems 250

VI. BENEFICIATION PROCESS

16. Comminution

- 16.1 Comminution Equipment 255
- 16.2 Loading and Fracture of Particles 260

- 16.3 Milling Performance 265 16.4
- Milling Practice 268
- 16.5 Particle Size Distributions 270
- 16.6 Milling Efficiency 272 Summary 274 Suggested Reading 274 Problems 275

17. Batching and Mixing

- 17.1 Bulk Solids Transport and Batching 277
- 17.2 Mixing and Mixedness 280
- 17.3 Mixing Mechanisms 285
- 17.4 Mixing Equipment and Practice 286
- 17.5 Mixing Performance 292 Summary 295 Suggested Reading 295 Problems 296

18. Particle Separation, Concentration, and Washing Processes 298

- 18.1 Particle Sizing 298
- 18.2 Filtration and Washing Processes 302
- 18.3 Other Particle Concentration Processes 310 Summary 311 Suggested Reading 311 Problems 311

19. Granulation

- 19.1 **Direct Granulation** 313
- 19.2 Spray-Drying 317 Summary 324 Suggested Reading 324 Problems 325

VII. FORMING PROCESSES

- 20. Pressing
 - 20.1 Process Variables In Dry-Pressing 329
 - 20.2 Powder Flow and Die Filling 333

277

- 20.3 Compaction Behavior 336
- 20.4 Ejection and Transfer 342
- 20.5 Die Wall Effects 345
- 20.6 Control of Compact Defects 348
- 20.7 Isostatic Compaction 349
- 20.8 Combination Pressing 351
- 20.9 Roll Pressing 351 Summary 352 Suggested Reading 352 Problems 353

21. Plastic-Forming Processes

- 21.1 Equipment and Material Variables in Extrusion 356
- 21.2 Extrusion Mechanics 360
- 21.3 Control of Extrusion Defects 368
- 21.4 Plastic Transfer Pressing and Jiggering 371
- 21.5 Injection Molding 373 Summary 376 Suggested Reading 377 Problems 378

22. Casting Processes

- 22.1 Slip-Casting in a Permeable Mold 381
- 22.2 Slip-Casting Mechanics and Behavior 386
- 22.3 Nontraditional Casting 393
- 22.4 Control of Cast Defects 395
- 22.5 Tape Casting 395
- 22.6 Casting of Monosize, Spherical Colloids 399
 Summary 400
 Suggested Reading 400
 Problems 401

23. Molecular Polymerization Forming

- 23.1 Sol-Gel Processing 403
- 23.2 Chemical Vapor Deposition 405 Summary 407 Suggested Reading 407 Problems 407

380

403

VIII. DRYING, SURFACE PROCESSING, AND FIRING

- 24. Drying
 - 24.1 Drying Systems 411
 - 24.2 Mechanisms in Drying 413
 - 24.3 The Drying Process 415
 - 24.4 Drying Shrinkage and Defects 417
 - 24.5 Modes of Drying 420 Summary 423 Suggested Reading 423 Problems 424

25. Shaping, Surface Finishing, Film Printing, and Glazing Processes

- 25.1 Trimming, Smoothing, and Grinding 426
- 25.2 Blanking, Punching, and Laminating 429
- 25.3 Printing Processes 429
- 25.4 Coating Processes 434 Summary 438 Suggested Reading 438 Problems 439

26. Firing Processes

- 26.1 Firing Systems 440
- 26.2 Presintering Processes 445
- 26.3 Solid-State Sintering 449
- 26.4 Sintering of Glass Particles 461
- 26.5 Sintering in the Presence of a Small Amount of a Wetting Liquid 463
- 26.6 Sintering of Whiteware Bodies (Vitrification) 464
- 26.7 Sintering of Glazes and Glassy Thick Films 466
- 26.8 Cooling 469
- 26.9 Hot Pressing 470 Summary 471 Suggested Reading 472 Problems 473

411

440

APPENDIX 1	Aperture Size of U.S. Standard Sieves	475
	Density of Ceramic Materials	476
	Viscosity and Density Values of Water and Air	478
	Conversion from Metric to English/American Units	479
	_	

INDEX