

Index

a

- abrasion resistance, particle strength 281
- active transponders, in primary-drying
 - monitoring 98
- additives, enzyme stabilization 275
- ADH. *see* alcohol dehydrogenase
- adhesion
 - low molecular weight 239
 - mechanisms 299–315
 - powders 260–261
- adhesion bridges 299
- adhesion force, spray fluidized beds 296, 302–305
- adsorption
 - nitrogen 166–168
 - stress 270–271
- aerogels
 - SAXS spectra 164
 - supercritically dried 159
 - vacuum drying 198
- aged gels, shrinkage 200
- agglomerates
 - adhesion mechanisms and mechanical strength 299–315
 - breakage 314, 315–321
 - material structure 300–301
 - mechanical properties 312
 - mechanical strength 299–315, 308–315
 - preparation scheme 310
- agglomeration
 - dextrose sirup 307
 - discrete modeling 363–372
 - glass particles 370
 - particle formulation 296
 - particles properties 298
 - primary particle properties 321–324
 - spray fluidized bed processes 297
 - stochastic discrete modeling 363–372
 - tensile strength 308–310
 - triggering 370
- aging
 - cracks 199–201
 - effects on shrinkage 209
 - RF gels 208–209
 - shrinkage 200
- agricultural products, textured by drying 3
- alcohol dehydrogenase (ADH), activity retention 274–277
- alcohol dehydrogenase (ADH) powder, outer surface morphology 248
- alumina carrier particles 331
- alumina gels
 - crack patterns 175
 - diffusion models 213
- alumina monoliths 201
- amorphous glass state 261
 - vibrational motions 261
- amorphous particles
 - surface tension 305
 - viscous forces in sinter bridges 304–308
 - volume diffusion 305
- amorphous water-soluble materials 302
- anhydrous sugars, glass transition temperature 13
- annealing, influence on ice morphology 67–69
- anthocyanins, changes in drying process 7
- apparatus design, influence on product quality 332–338
- aroma compounds, retention of 9–10
- aromatic oils, spray fluidized bed encapsulation 358
- artificial neural network 359
- ascorbic acid, as a quality index in drying process 6
- attrition, particles strength 281–282

b

- balances, for freeze-dryers 104–105
- band dryer, food industry 2
- barometric temperature measurement (BTM)
 - primary-drying monitoring 115
 - shelf-temperature control 128–129
- BaSO₄-suspension 243
- batch granulation
 - dispersive growth 344–349
 - dispersive growth in 344–349
 - growth 344–349
- batch monitoring
 - endpoint detection of primary drying 106–113
 - freeze-drying 106–125
 - using sublimation-flux measurement 113–114
- bed material, number density
 - distribution 326
- belt dryer, food industry 2
- binder content, sprayed solution 325–326
- biochemical reactions, induced by drying 5–9
- bovine serum albumin (BSA)
 - primary-drying process 127
 - spray-dried particle morphology 250
- breakage behavior
 - agglomerates 315–321
 - cylindrical agglomerates 314
 - elastic-brittle 316–317
 - elastic-plastic 317–318
 - granules with layered structure 320–321
 - plastic 318–320
- breakage probability
 - binder contents 314
 - γ -Al₂O₃ agglomerates 315
 - granulation time dependence 325
 - retention effect 327
- breakage ratios, comparison of visual inspection and image analysis 32
- bridges
 - adhesion 299
 - liquid 303–304
 - sinter 304–308
- brown rice, obtainment of 22
- browning reaction, in drying process 8
- BSA. *see* bovine serum albumin
- BTM. *see* barometric temperature measurement
- buckling pressure, suspensions 242
- bulk modulus, drying methods 176

c

- calorimetric measurements, single-vial monitoring 101

- capillary forces
 - adhesion 299
 - liquid bridges between particles 303–304
 - pore sizes 167
- capillary pressure 175, 304
- capsule wall materials 257
- caramelization, in drying process 8
- carbohydrate polymers, glass transition temperature 13
- carbon aerogels, dry gels 161
- carbon cryogels, quality preservation 192
- cargo rice, obtainment of 22
- carotenoids, changes in drying process 6–7
- carrier materials, particle creation 247–251
- carrier matrices collapse 268
- carrier particles, loading with catalytic active components 329
- CCD camera, fissure formation in rice 28–29
- centrifugal rotary disk atomizer, spray drying 231
- CFD. *see* computational fluid dynamics
- chamber pressure. *see also* sublimation chamber
 - calculated by CFD 140–142
 - primary-drying control 93, 125–135
 - chamber temperature. *see also* temperature
 - vial batch monitoring 118
- cherenkov detectors 161
- chlorophylls, changes in drying process 6
- chromatography 161
- Clausius-Clapeyron equation, low molecular weight substances 236
- CLSM. *see* confocal laser scanning microscopy
- CO₂, low-temperature gel drying 187–189
- coating 296–297
- cold chamber optical microscopy, freeze-drying 55–57
- cold plasma ionization, vial batch monitoring 110–111
- collapse temperature, freeze-drying 54–55
- colloidal gel networks 157
- color, as a quality index in drying process 6
- complex dispersions 244–251
- compression tests 310–311
- computational fluid dynamics (CFD)
 - calculation of local moisture content 12
 - design parameters 139–142
- confocal laser scanning microscopy (CLSM) 234, 247
- constant rate period (CRP) 236
- consumer products, gained by drying 3–4

contact stiffness 312
 continuous freeze-drying 142–143
 continuously operated stirred tank reactors (CSTR) 339
 control algorithms, primary freeze drying 125–135
 controlled nucleation
 – and physical quality 70–73
 – by ultrasound sonication 70–72
 convective drying
 – advanced modeling 211–220
 – contact angle 199
 – diffusion model 211–217
 – gels 174–182
 – hydrogel 175
 – quality preservation 198–210
 – RF gels 206
 convective hot air drying, and mechanical transformations 15
 cooling rate. *see* freezing rate
 – influence on dried layer permeability 66
 crack formation. *see also* fissured rice
 – convective gel drying 174–175, 180–182
 – critical drying rate 214
 – density change 183
 – during drying 16
 – initiation 181
 – in rice 26–27
 – shells 320
 – supercritical drying 188
 – surface and internal 25
 crack-free monoliths 190
 crack patterns 175
 crack propagation 316
 cracking, video acquisition 29
 cracks. *see also* fissured rice
 – from aging 199–201
 – surface and internal 25
 critical drying rate, crack formation 214
 cross-sectional structures, spray-dried powders 248
 CRP. *see* constant rate period
 crust formation, during annealing process 69
 cryogel flakes 191
 cryogels 159
 crystal nucleation. *see* nucleation
 crystalline substances, water-soluble 304
 crystallization
 – in drying process 10
 – low molecular weight substances 238
 – during storage 16–17
 CSTR. *see* continuously operated stirred tank reactors

d

D-limonene
 – flavor solubility 259
 – oxidation reaction 267
 – release kinetics 264
 – retention 258
 Darcy's law
 – differential shrinkage 177
 – freeze-dried layer permeability 76
 – PRT 60
 deep bed dryer, food industry 2
 dehydration stress 271–272
 depressurization, supercritical drying 186
 dewatering. *see also* drying
 dextrose sirup, fluidized bed agglomeration 307
 diametral compression test, rice grains 37
 dielectric measurements, single-vial monitoring 100–101
 differential scanning calorimetry (DSC)
 – freeze-drying 55
 – gel drying 164
 differential shrinkage
 – diffusion equation 178
 – and stress 177–180
 dihedral dryer, food industry 2
 discrete particle modeling (DPM)
 – agglomeration 363–372
 – principles 350–351
 – simulation parameters 351–352
 – Wurster coater 349–357
 distributor plates, apparatus design 337
 DPE. *see* dynamic parameters estimation
 DPM. *see* discrete particle modeling; drying process monitoring
 dried layer. *see* freeze-dried layer
 dried particles
 – lipids oxidation 279–280
 – porosity 280–281
 dried powder
 – flavor release 262–267
 – stickiness 260–261
 droplet drying 273–274
 droplet shrinkage 232
 droplet size, feed emulsion 258
 drugs. *see* pharmaceuticals
 drum dryer, food industry 2
 dry coating process 298
 dry gels
 – applications 160–162
 – catalysis 161
 – characterization 166–172, 166–174
 – conductivity 159
 – density 159

- dielectric constant 160
- elastic behavior 160
- hydrophobicity 160
- insulation 160
- optical coatings 161
- optical transparency 159
- other methods 171–172
- properties 158–160
- refractive index 160
- sound insulation 161
- sound speed 160
- surface area 159
- thermal conductivity 159
- thermal insulation 160
- transparency 159
- water treatment 161
- drying. *see also* dewatering; freeze-drying; gel drying
 - advanced modeling 211–220
 - convective 174–182, 198–210
 - encapsulation and microencapsulation of enzymes and oil by 269–280
 - gel characterization 172–174
 - gels 155–230
 - microencapsulation 269–270
 - microwave 210–211
 - oil emulsions 278–279
 - particle creation 251–253
 - preserving quality 189–211
 - process variables effect on the stabilization of enzymes 275–278
 - protein encapsulation theory 272–273
 - protein solutions 273
 - quality loss 174–189
 - retention of emulsified hydrophobic flavors 257–260
 - single suspended droplet 273–274
 - stress on proteins 270–272
 - subcritical 189–190
 - vacuum 197–198
- drying chamber. *see also* sublimation chamber
 - fluid dynamics in 139–142
 - water vapor pressure 62
- drying equipment, food industry 2
- drying modes
 - combined 17–18
 - in foods 14
- drying process
 - as a controlled texturing operation 3
 - impact on mechanical properties and crack formation in rice 21–45
 - quality changes in food materials 1–18
- drying process monitoring (DPM), single vials 101
- drying process severity, and food quality 5
- Drying3000 simulator 39
- DSC. *see* differential scanning calorimetry
- dynamic parameters estimation (DPE)
 - algorithm
 - primary-drying control 129, 132
 - vial batch monitoring 115–116
- e**
- easy-to-use products, gained by drying 3
- ebullition, as drying mode 14
- effective contact stiffness 312
- elastic-brittle breakage behavior 316–317
- elastic-plastic breakage behavior 317–318
- elastoplastic material, stress-strain relationship 36
- empirical curve fitting, modeling of rice quality 39
- emulsified hydrophobic flavors
 - retention 257–260
 - spray drying 256–257
- emulsions
 - complex dispersions 244–251
 - drop size 258
 - microencapsulated flavor powders 245–247
 - spray drying 278–279
- encapsulated flavor
 - glass temperature influence 261–262
 - oxidation 267
 - release and oxidation during storage 261–269
- encapsulated flavor droplets, CLSM pictures 246–247
- encapsulated lipids, oxidation 279–280
- encapsulation
 - enzymes and oil 269–280
 - neural networks 357–363
- endpoint detection, vial batch monitoring 106–113, 121–122
- enzymatic activity, and water activity 8
- enzyme activity retention 275
- enzyme stabilization
 - effect of process variables 275–278
 - effects of formulation composition 274–275
- enzymes
 - encapsulation and microencapsulation 269–280
 - particle creation 247–251
 - spray drying microencapsulation 269–270
 - thermal stress 271–272
- ethanol retention 256
- ethyl-*n*-butyrate powder

- flavor powders 246
 - flavor release 262
 - flavor solubility 259
 - explosion puffing, combined with drying 18
 - extended Kalman filter, single-vial monitoring 102
- f**
- failure strength, rice grains 36–39
 - feed liquid, spray drying 231
 - feedback controlling, primary-drying 134–135
 - filling height, freeze-drying 66–67
 - film thinning effect, low molecular weight substances 238
 - fine glass filament suspension 272
 - finite element modeling, modeling of rice quality 39
 - finite strain tensor 218
 - fish oil, oxidation kinetics 264
 - fissure formation
 - characterization by image analysis techniques 28–33
 - count algorithm 31
 - segmentation method for characterization 30–31
 - fissure ratios, comparison of visual inspection and image analysis 33
 - fissured rice
 - definition 23–24
 - and relative humidity 24–28
 - flash spray drying, suspensions 242
 - flavor compounds, retention of 9–10
 - flavor droplets, encapsulated 247
 - flavor encapsulation, theory and mechanism 255
 - flavor powders, microencapsulated 245–247
 - flavor release
 - analysis by PTR-MS 266
 - humidities and temperatures 264, 266
 - mathematical modeling 262
 - and oxidation 261–269
 - flavor retention, spray-dried food products 253–269
 - flavor solubility 259
 - flavor solution, spray-drying scheme 257
 - flavors
 - emulsified 257–260
 - glass temperature influence 261–262
 - microencapsulation 254–256
 - oxidation 267
 - spray drying 256–257
 - flaxseed, water activity effect 279
 - fluorescein sodium salt, protein particles 248
 - fluid dynamics, as quality parameter 139–142
 - fluid temperature, primary-drying control 130
 - fluidized bed agglomeration, dextrose sirup 307
 - fluidized bed coating, process conditions 346
 - fluidized bed dryer, food industry 2
 - fluidized beds
 - catalyst impregnation 329–332
 - particle formulation 253, 295–378
 - food industry, drying equipment 2
 - food materials
 - biochemical reactions induced by drying 5–9
 - drying-process-influenced quality changes in 1–18
 - mechanical transformations induced by drying 14–16
 - physical transformations during drying 9–14
 - storage and rehydration of 16–17
 - food particle bridges, capillary forces 303–304
 - food particles
 - relaxation 302
 - viscoelastic deformation 302
 - viscous forces in sinter bridges 304–308
 - food products
 - flavor retention 253–269
 - spray-dried 233
 - food quality also quality
 - and drying process severity 5
 - gained by drying 4
 - and nutritional and sensory properties 4
 - formulation. *see also* liquid formulation; particle formulation
 - complex dispersions 244–251
 - enzyme stabilization 274–275
 - fractal drying front, crack formation 182
 - fracture morphology, dry gels 160
 - fracture surface
 - γ -Al₂O₃ agglomerates 316–317
 - sodium benzoate granules 321
 - zeolite agglomerate 319
 - freeze-dried cake morphology
 - and physical quality 74–78
 - and water vapor mass transfer resistance 74–76
 - freeze-dried cake permeability
 - PRT 59–61
 - theoretical 77
 - freeze-dried layer permeability
 - experimental 77
 - influence of cooling rate 66
 - and water vapor mass transfer resistance 76–78

- freeze-dried matrix, moisture gradients in 52
 - freeze-dryer, food industry 2
 - freeze-dryer balances 104–105
 - freeze-drying. *see also* drying; primary-drying control; primary-drying monitoring
 - chamber pressure 93
 - cold chamber optical microscopy 55–57
 - collapse temperature 54–55
 - continuous 142–143
 - control of freezing step 94–96
 - control of primary drying 125–135
 - DSC 55
 - estimation of mean product temperature 61–63
 - gels 182–185
 - and glass transition 11
 - heat flux heterogeneity 57–59
 - ice structure and morphology 55–57
 - in-line product quality control 91–144
 - key quality factors 52–63
 - and mechanical transformations 14
 - melting curves 54–55
 - monitoring and control of secondary drying 135–138
 - MTM 59
 - of pharmaceuticals 51–86
 - PRA 59–61
 - principal basic phenomena 51–52
 - product quality during drying and storage 83–85
 - product-temperature maintenance 91
 - quality parameters 139–142
 - quality preservation 190
 - residual water content 91–92
 - RF and carbon cryogels 192–193
 - shelf temperature 93
 - state diagram 54–55
 - vitreous transition 54–55
 - freeze-drying microscopy 55
 - freeze-drying parameters, influence on physical quality factors 63–82
 - freeze-drying process, different steps 52, 91
 - freeze spray drying, particle creation 251–253
 - freezing process, and tensile stress 184
 - freezing protocol, influence on ice morphology 63–69
 - freezing rate, influence on ice morphology 55–56, 64–66
 - freezing step. *see also* nucleation
 - control of 94–96
 - full milk particle, agglomerated 253
 - functional oils 278
 - functionalities, of food materials 1
- g**
- γ -Al₂O₃ agglomerates
 - breakage probability 315
 - fracture surface 316–317
 - γ -Al₂O₃ particles
 - elastic-brittle breakage behavior 316
 - used to produce agglomerates 310
 - gap distance, Wurster coater 355–357
 - gas distributor, apparatus design 333
 - gas recycling, apparatus design 332
 - gas temperature, in chamber. *see* chamber temperature; temperature
 - Gaussian blobs 322
 - gel applications, quality aspects 156–162
 - gel drying 155–230
 - cracking 180–182
 - differential shrinkage 176–180
 - freezing 182–185
 - low-temperature process 187–189
 - methods 174–189
 - phase diagram 174
 - supercritical 159, 185–189
 - X-ray tomography 172
 - gel networks 157
 - gel structure
 - changes 155–230
 - characterization 162
 - destruction 183
 - during drying 155
 - resorcinol-formaldehyde gels 158
 - gel synthesis, optimization 194
 - gelatinization 245
 - gelation
 - quality aspects 156
 - ultrasonic irradiation 195
 - gelinization, starch 245
 - gels
 - aging 208–209
 - applications 160–162
 - characterization during drying 172–174
 - characterization of dry 166–172
 - characterization of wet 162–166
 - crack patterns 175
 - diffusion models 213
 - ice templating 195–197
 - polymer crosslinking 201
 - preparation 156–157
 - properties 158–160
 - quality aspects 156–162
 - resorcinol-formaldehyde 157–158, 204–208
 - RF aging 208–209
 - RF convective drying 206
 - RF freeze drying 191
 - RF linear shrinkage 209

- RF quality preservation 204–208
 - RF SAXS spectra 164
 - RF synthesis 157–158
 - shrinkage 200
 - shrinkage prevention and cracks
 - by aging 199–201
 - shrinkage reversion 201–204
 - silica 156–157
 - structural characterization 162
 - technical 158
 - transmission electron microscopy 171
 - wet 156–158
 - glass encapsulation 254
 - glass particles
 - agglomeration 370
 - growth 368
 - glass transition curve, in drying
 - process 10–11
 - glass transition temperature
 - of anhydrous sugars and carbohydrate polymers 13
 - low molecular weight substances 238
 - relaxation process correlation 267–269
 - spray-dried powder stickiness 260
 - and storage stability of encapsulated flavor 261–262
 - glassy particles
 - lactose 238
 - surface of 261
 - Gordon-Taylor constant 300
 - grains, rice. *see* rice grains
 - granulated particles, mechanical
 - strength 324–329
 - granulated products, breakage 315–321
 - granulation
 - dispersive growth 344–349
 - particle formulation 296
 - particles properties 298
 - spray fluidized bed processes 297
 - granulator, radial particle distribution 353
 - granule shapes 327
 - granules, breakage behavior 320–321
 - gray level histograms, rice grains 29
 - growth rates
 - low molecular weight substances 238
 - total 346
 - Guidance for Industry PAT (Process Analytical Technology) 92, 143
 - Guinier regime 163
- h**
- hard shell particles 244–245
 - head rice yield (HRY)
 - definition 23
 - kinetics 43–44
 - heat flux heterogeneity, freeze-drying 57–59
 - heat transfer coefficient, for tubing
 - vials 58–59
 - hexamethyldisiloxane (HMDSO) 203
 - hierarchical pore collapse 169
 - high gain observers, single-vial
 - monitoring 102
 - high-porosity particles, morphology 235
 - highly hydrated agricultural products, textured
 - by drying 3
 - highly insulating and light transmitting (HILIT) aerogel 189
 - HMDSO. *see* hexamethyldisiloxane
 - hollow particles
 - morphology 235
 - outlet temperature 251, 252
 - SBS-latex 241
 - Hooke's law, rice grains 34
 - horizontal fluidized bed unit 337
 - hot air drying
 - freeze drying replacement 195
 - RF and carbon cryogels 192
 - hot melt coating 299
 - HRY. *see* head rice yield
 - human recombinant interferon, ultrasound
 - triggered nucleation 96–97
 - hybrid gels 204
 - hydrogels
 - convective drying 175
 - vacuum drying 197
 - hydrolysis, silica gelation 156
 - hydrophilic flavors,
 - microencapsulation 255–256
 - hydrophobic flavors
 - retention of emulsified 257–260
 - spray drying 256–257
 - hydrophobic silica xerogel 203
 - hydrophobicity, dry gels 160
 - hygrocapacity, material structure 300
 - hygrosensitivity 300
- i**
- ice crystal size, distribution of 65, 67–68
 - ice crystal structure
 - observation methods 57
 - on vertical cross-sections 73
 - ice fog method, controlled nucleation 70
 - ice morphology
 - influence by annealing 67–69
 - influence by freezing protocol 63–69
 - influence by freezing rate 55–56, 64–66
 - influence by supercooling 55, 63

- influence by vial type and filling height 66–67
 - and physical quality factors 63–69
 - ice penetration, pores 165
 - ice structure, freeze-drying material 55–57
 - ice sublimation front temperature 62
 - ice templating 195–197
 - ICP-AES. *see* inductively coupled plasma/atomic emission spectroscopy
 - image analysis techniques
 - compared to visual inspection 32–33
 - fissure formation in rice 28–33
 - IMC. *see* internal model control
 - impregnation, catalyst 329–332
 - in-line product quality control, pharmaceuticals 91–144
 - inductively coupled plasma/atomic emission (ICP-AES) spectroscopy, vial batch monitoring 110–111
 - industrial products, textured by drying 3
 - integral square error (ISE), primary-drying control 131, 134
 - integrated fluidized beds, particle creation 253
 - intermediate industrial products, textured by drying 3
 - internal cracks, rice 25
 - internal model control (IMC), primary-drying control 133
 - ISE. *see* integral square error
- k**
- Kalman filter, single-vial monitoring 102
 - kernel structure, rice grain 22
 - Knudsen regime, molecular diffusion in 75
 - Kohlraush-Williams-Watts equation 263
- l**
- lactose-based materials, spray-drying 11–12
 - lactose particles, low molecular weight substances 238
 - large primary suspension particles 244
 - large solid particles, suspensions 244
 - layered structured granules, breakage behavior 320–321
 - layering
 - solidified shells 296
 - spray fluidized bed processes 297
 - linear materials, stress-strain relationships 34–36
 - linoleic acid, emulsion size 280
 - lipid amount, oil emulsions 278
 - lipid oxidation, in drying process 7
 - lipids oxidation 279–280
 - liquid bridges 303–304
 - capillary forces 303–304
 - forces 303–304
 - particle formulation 296
 - tensile strength 309
 - liquid distribution, open-pore particle network 220
 - liquid drainage 183
 - liquid encapsulation, neural networks 357
 - liquid flow rate, stochastic discrete modeling 367
 - liquid formulation
 - composition of 83–84
 - of pharmaceuticals 53
 - liquid/gas interface 175
 - liquid penetration time 283
 - liquid pressure, drying methods 176
 - liquid transport models 212
 - local moisture content, calculated by CFD 12
 - low hydrated agricultural products, textured by drying 3
 - low molecular weight substances
 - solutions 236–240
 - transfer coefficients 237
 - vapor pressure 236
 - low-temperature process, CO₂ 187–189
 - LyoDriver, primary-drying control algorithm 129–132
 - LyoMonitor system, vial batch monitoring 123–124
 - lyophilization. *see* freeze-drying
 - LYOTRACK sensor, vial batch monitoring 111–112
- m**
- macropore size, tuning 196
 - macroscopic models, convective drying 211–218
 - Maillard reactions, in drying process 8
 - maltodextrin (MD)
 - investigations by CLSM 247–248
 - mint oil particle size 360
 - orange oil particle size 360
 - pergamot oil particle size 361
 - plasticized surface 305
 - mannitol particles 240
 - manometric temperature measurement (MTM)
 - and PRA 59
 - primary-drying control 129, 133
 - vial batch monitoring 115, 119–120
 - mass balance equation 218
 - mass flow rate of water, secondary drying 135–136

- mass spectrometers, vial batch monitoring 107–110
- material structure, agglomerates 300–301
- maximum product temperature 126–127, 134
- Maxwell model, viscoelastic gels 217
- MC. *see* Monte Carlo methods
- MDSC. *see* modulated DSC
- mean product temperature, freeze-drying 61–63
- melting curves, freeze-drying 54–55
- mercury porosimetry 168–171
- mercury pycnometry 171
- meridian cracks
- agglomerates 316
 - shells 320
- mesopore sizes, dry RF gels 192, 194
- micro-cracks 181
- microencapsulated flavor powders 245–247
- microencapsulation
- enzymes and oil 269–280
 - general remarks on 253–255
 - hydrophilic flavors 255–256
 - oils 278–280
 - by spray drying 269–270
- microspheres, wet gels 195
- microtomography 172–173
- microwave drying, quality preservation 210–211
- milled rice, obtainment of 22
- mint oil particle size 360
- model predictive control (MPC) algorithm, primary-drying control 133
- modeling
- agglomeration 363–372
 - convective drying 211–220
 - diffusion 211–217
 - of final quality of rice grains 39–45
 - flavor release 262
 - fluid dynamics in drying chamber 141–142
 - macroscopic 211–218
 - pore-scale 218–220
 - of primary-drying process 125–135
 - rigorous 217–218
 - Wurster coater 349–357
- modulated DSC (MDSC), freeze-drying 55
- moisture content. *see also* water content
- residual 137, 282–283
- moisture gradients, in freeze-dried matrix 52
- moisture profiles 208
- moisture sensors, vial batch monitoring 107–113
- molecular diffusion, in Knudsen regime 75
- momentum equation, discrete particle modeling 350
- monitoring. *see* batch monitoring; primary-drying monitoring; single-vial monitoring; vial monitoring
- monolithic carbon aerogels, dry gels 161
- monomer solution, shrinkage prevention 199
- Monte Carlo (MC) methods
- agglomeration 363
 - coalescence 366
- morphology. *see also* ice morphology
- alcohol dehydrogenase (ADH) powder 248
 - bovine serum albumin (BSA) 250
 - fracture 160
 - high-porosity particles 235
 - hollow particles 235
 - spray-dried particles 231–294
 - spray-dried powders 234–236
- MPC. *see* model predictive control
- MTM. *see* manometric temperature measurement
- n**
- NaCl particles 239
- near-infrared (NIR) spectroscopy
- residual moisture 283
 - single-vial monitoring 100
- neural networks
- artificial 359
 - encapsulation 357–363
- nitrogen adsorption 166–168
- NMR. *see* nuclear magnetic resonance
- non-invasive monitoring techniques, primary drying 98–99
- non-invasive sensors, freeze drying of pharmaceuticals 86
- nozzles, spray drying 231
- nuclear magnetic resonance (NMR) 283
- nucleation
- control of 70–73, 94–96
 - freezing process 184
- nucleation temperature
- pharmaceuticals 56
 - spontaneous 71
 - and sublimation rates 73–74
- number density distribution, bed material 326
- nutritional properties, and food quality 4
- o**
- observation methods, of ice crystal structure 57
- oil powders 278

- oils
 - encapsulation and microencapsulation 269–280
 - microencapsulation 278–280
 - orange 359
 - particle size 360–361
 - spray drying 278–279
 - thermal stress 271–272
 - yields 361–362
- open-pore particle network, liquid distribution 220
- operating conditions, and sublimation kinetics 79–82
- orange oil
 - in granules 359
 - particle size 360
 - yields 361–362
- organic-inorganic hybrid gels 204
- organic particle sintering 306
- outlet gas handling, apparatus design 332
- oxidation
 - encapsulated flavors 261–269
 - encapsulated lipids 279–280
- oxidation reaction, *D*-limonene 267

- P**
- paddy. *see also* rice grains
 - HRY 23–28
 - quality kinetics 40–44
- parboiled rice
 - HRY 23–28
 - obtainment of 21
- particle. *see also* specific types of particles
- particle collisions, in DPM 351
- particle formulation
 - carrier materials 247–251
 - material properties 299–324
 - operating conditions 324–332
 - spray fluidized beds 295–378
- particle growth rate, total 346
- particle modeling, Wurster coater 349–357
- particle morphology, skin-forming materials 234
- particle porosity, and agglomeration 369–372
- particle retention time 326–327
- particle size
 - distribution evolution 345
 - spray-dried powders 236
 - two-compartment model 348
- particle strength, spray-dried particles 281–282
- passive transponders, in primary-drying monitoring 98

- PAT. *see* Guidance for Industry Process Analytical Technology
- pharmaceuticals
 - freeze-drying 51–86, 91–144
 - key quality factors of freeze-drying 52–63
 - liquid formulation 53
 - nucleation temperature 56
 - polymorphism 84–85
- phase transitions, dependence on drying speed 12–13
- physical quality factors
 - and controlled nucleation 70–73
 - freeze-dried cake morphology 74–78
 - ice morphology 63–69
 - importance of temperature control 78–79
 - influenced by freeze-drying parameters 63–82
 - nucleation temperatures and sublimation rates 73–74
 - operating conditions and sublimation kinetics 79–82
- PI. *see* proportional-integral compensator
- Pirani gauges, vial batch monitoring 106
- plastic breakage behavior 318–320
- plastic range, drying methods 176
- pneumatic dryer, food industry 2
- polymer crosslinking, silica gels 200
- polymer-like gel networks 157
- polymer solutions, vapor pressure 240
- polymers, solutions 240
- polymorphism, and product quality during freeze-drying 84–85
- population balance equation, dispersive growth 344
- population balance modeling 324
- pore-scale model, convective drying 218–220
- pore sizes
 - distribution 331
 - mercury porosimetry 168
 - tomography 172
 - wet RF gel 166
- porod regime 163
- porosimetry, mercury 168–171
- porosity
 - dry gels 159
 - particles 369–372
 - spray dried particles 280–281
 - xerogels after pyrolysis 205
- porous carrier particles, loading with catalytic active components 329
- porous media, standard characterization techniques 155
- powdered milk products, rubbery state 11
- powders

- flavor release 262–267
 - layering 298
 - microencapsulated flavor 245–247
 - particle formation 231
 - silica aerogels 191
 - spray drying 234–236
 - stickiness 260–261
 - PRA. *see* pressure rise analysis
 - pressure gradient, differential shrinkage 178
 - pressure rise analysis (PRA)
 - key quality factors 59–61
 - vial batch monitoring 115, 119–120
 - pressure rise test (PRT)
 - primary-drying control 131–132
 - secondary drying 135–136
 - vial batch monitoring 114–125
 - pressure sensors, vial batch monitoring 106
 - primary-drying control
 - chamber pressure 125–135
 - DPE algorithm 129, 132
 - feedback logic 134–135
 - IMC 133
 - in-line 125–135
 - ISE 131, 134
 - LyoDriver 129–132
 - MPC 133
 - MTM 129, 133
 - PI 134
 - PRT 131–132
 - shelf temperature 125–135
 - primary-drying monitoring. *see also* single-vial monitoring
 - active transponders 98
 - BTM 115
 - detection of endpoint 106–113
 - DPE algorithm 115
 - group of vials 103–105
 - in-line 96–125
 - MTM 115, 119–120
 - non-invasive techniques 98–99
 - passive transponders 98
 - RTD 97–99
 - single vials 99–103
 - thermocouples 97–99
 - using measurement of sublimation flux 113–114
 - using methods based on PRT 114–125
 - vial batch 106–125
 - primary particle properties, agglomeration 321–324
 - ProCell units, apparatus design 334–335
 - process analytical technology (PAT), guidance for, in industry 92, 143
 - process chamber, apparatus design 333
 - process temperature, spray fluidized beds 327–329
 - process variables 275–278
 - product flowability, spray dried particles 282
 - product quality. *see also* quality
 - apparatus design 332–338
 - during drying and storage 83–85
 - and formulation 83–84
 - gained by drying 4
 - and polymorphism 84–85
 - product quality control
 - continuous freeze-drying 142–143
 - control of freezing step 94–96
 - control of primary drying 125–135
 - in-line 91–144
 - monitoring and control of secondary drying 135–138
 - monitoring of primary drying 96–125
 - quality by design 139–142
 - product stability, during drying and storage 83–85
 - proportional-integral (PI) compensator, primary-drying control 134
 - protein addition, enzyme stabilization 275
 - protein encapsulation theory 272–273
 - protein loss, surface adsorption 270
 - protein solutions
 - aqueous 51
 - spray drying 273
 - proteins
 - particle creation 247–251
 - stress during the spray drying processes 270–272
 - stresses 271
 - proton transfer reaction mass spectrometry (PTR-MS), flavor release 266
 - PRT. *see* pressure rise test
 - PTR-MS. *see* proton transfer reaction mass spectrometry
- q**
- QMS. *see* quadrupole mass spectrometer
 - quadrupole mass spectrometer (QMS), vial batch monitoring 107–110
 - quality *also* food quality; product quality
 - modeling of convective drying 211–220
 - quality assessment, gels 162
 - quality by design 139–142
 - quality considerations, drying food materials 1–18
 - quality control, in-line 91–144
 - quality factors. *see also* physical quality factors
 - interactions with transport phenomena 53
 - quality loss, gel drying methods 174–189

- quality preservation
 - advanced drying techniques 189–211
 - carbon cryogels 192
 - convective drying 198–210
 - cracks from aging 199–201
 - ice templating 195–197
 - microwave drying 210–211
 - RF gels 192, 204–209
 - shrinkage reversion 201–204
 - silica gels 195–197
 - vacuum drying 197–198

- r**
- radiation from surrounding, as quality parameter 139
- re-agglomeration 284
- reconstitution behavior, spray dried particles 283–284
- rehydration, during storage 16–17
- relative humidity (RH)
 - flavor release rate 264
 - lipid oxidation 279
 - and rice fissuring 24–25
- relaxation function 216
- relaxation process correlation
 - glass transition temperature 267–269
 - temperatures 267–269
- residence time distribution 338–344
- residual moisture content
 - infrared irradiation 282
 - spray dried particles 282–283
- residual water content, monitoring of 91–92, 137–139
- resistance thermal detector (RTD), in primary-drying monitoring 97–99
- resorcinol-formaldehyde (RF) gels
 - aging 208–209
 - convective drying 206
 - freeze drying 191
 - linear shrinkage 209
 - preparation 156–158
 - quality preservation 192, 204–208
 - saxs spectra 164
 - synthesis 158
- restitution coefficient 351
- retention
 - emulsified hydrophobic flavors during spray drying 257–260
 - enzyme activity 275
- retention phenomenon, at microscopic level 10
- retention time, particles 326–327
- RF gels. *see* resorcinol-formaldehyde gels
- RH. *see* relative humidity

- rice
 - characterization of mechanical properties 33–39
 - HRY 23–28
 - image analysis techniques 28–33
 - mechanical properties and crack formation 21–45
 - tempering time 27–28
- rice bran, obtainment of 22
- rice grains. *see also* paddy
 - dehulling 22
 - diametral compression test 37
 - failure strength 36–39
 - glass transition 34
 - gray level histograms 29
 - harvesting 21
 - Hooke’s law 34
 - kernel structure 22
 - moisture content 21–22
 - stress-strain relationships 34–36
 - Young’s modulus 35
- rice kernels
 - cracks in 23
 - fissured 23–24
 - possible states for 24
 - shrinkage and cracking 29
 - stress cracks 39
 - structure 22
 - tension tests 37–38
- rice processing yield, definition 23
- rice quality
 - kinetics 40–44
 - modeling of 39–45
- rolling agglomeration 318
- rotary dryer, food industry 2
- rotational motions, amorphous glass state 261
- rough rice. *see* rice grains
- rubbery state, of freeze-dried materials 11

- s**
- safety, and food quality 4
- Sauter mean diameter, reconstitution behavior 283
- SAXS. *see* small angle X-ray scattering
- SBS. *see* styrene-butadiene-styrene
- scanning electron microscopy (SEM), spray-dried particles 234
- secondary drying, monitoring and control 93, 135–138
- segmentation method, image analysis techniques 30–31
- selective diffusion, in drying process 10

- selective diffusion theory, hydrophilic flavors 255
- self-assembly techniques, gelation 156
- SEM. *see* Scanning electron microscopy
- sensors
 - LYOTRACK 111–112
 - for mean-product-temperature measurements 61–63
 - moisture 107–113
 - non-invasive 86
 - pressure 106
 - soft 101–102
- sensory properties, and food quality 4
- SEP function, sublimation endpoint detection 112
- series-of-tanks model 340
- shear stress 271–272
- shelf temperature. *see also* temperature
 - BTM control 128–129
 - influence on drying curve 79–80, 82
 - primary-drying control 93, 125–135
 - as quality parameter 139
- shrinkage
 - aged gels 200
 - aging effects 209
 - by convective hot air drying 15
 - differential 177–180
 - diffusion models 213
 - drying methods 177
 - freezing process 184
 - gels 175–177
 - irreversible 169
 - isotropic 206
 - linear 209
 - pore sizes 168
 - prevention 199–201
 - reversion 201–204
 - video acquisition 29
- silica gelation, condensation 156
- silica gels
 - ice templating 195–197
 - polymer crosslinking 201
 - preparation 156–157
 - shrinkage prevention and cracks by aging 199–201
 - shrinkage reversion 201–204
- silylation agents 203
- Si₃N₄-suspensions, spray-dried particles 243
- single suspended droplet, drying 273–274
- single-vial monitoring
 - extended Kalman filter 102
 - high gain observers 102
 - in-line 99–103
 - soft-sensors 101–102
- sinter bridges 304–308
 - forces 304–308
 - viscous forces 304–308
- sintering
 - mechanisms 305
 - organic particle 306
- skeletal density
 - RF gels 191
 - shrinkage prevention 199
- skin-forming materials, particle morphology 234
- small angle X-ray scattering (SAXS), drying of gels 162–164
- small solid particles, suspensions 240–244
- smart-vial concept 98, 103
- SMART™ Freeze-Dryer 129
- sodium benzoate granules
 - breakage 320–321
 - force-displacement curves 320
- soft-sensors, single-vial monitoring 101–102
- solid network stress, drying methods 176
- solid particles
 - suspensions of large 244
 - suspensions of small 240–244
- solid pharmaceutical substances, preparation 269
- solid phase, diffusion models 212
- solids, diffusion rate 241
- solids handling, apparatus design 332
- solutions
 - binder content 325–326
 - low molecular weight substances 236–240
 - polymers 240
 - spray drying 273
- solvent exchanges
 - RF and carbon cryogels 193
 - TMCS surface modification 203
- solvents, supercritical drying 185–187
- sound insulation, dry gels 161
- sound speed, dry gels 160
- space science, dry gels 162
- specific surface area, dry gels 159
- spectroscopy methods, single-vial monitoring 100
- spontaneous nucleation temperatures 71
- spout velocity 352–355
- spray-dried food products
 - flavor retention 253–269
 - ingredients 233
- spray-dried particles
 - β-lactoglobulin effects 250
 - BSA effects 250
 - bulk density 282
 - compression 311

- emulsions 246
- freeze spray drying 251–253
- hard shell 244–245
- integrated fluidized beds 253
- lipids oxidation 279–280
- morphology and properties 231–294
- porosity 280–281
- proteins, enzymes and carrier materials 247–251
- quality aspects 280
- schematic view 269
- spray-dried 231–294
- structures 246
- surface structure 239
- suspensions of large solid 244
- suspensions of small solid 240–244
- spray-dried powders
 - cross-sectional structures 248
 - flavor release 262–267
 - morphological characteristics 233
 - morphology 249
 - morphology classification 234–236
 - outer structural changes 266
 - stickiness 260–261
- spray dryer, food industry 2
- spray drying
 - emulsified hydrophobic flavors 256–257
 - encapsulation and microencapsulation of enzymes and oil by 269–280
 - enzyme stabilization 274–275
 - flavor encapsulation 255
 - of lactose-based materials 11–12
 - microencapsulation 269–270
 - oil emulsions 278–279
 - particle creation 251–253
 - process variables effect on the stabilization of enzymes 275–278
 - protein encapsulation theory 272–273
 - protein solutions 273
 - retention 257–260
 - stress on proteins 270–272
- spray-drying system
 - scheme of 232
 - stresses 271
- spray fluidized bed encapsulation, aromatic oils 358
- spray fluidized bed processes 297
- spray fluidized beds
 - apparatus design 332–357
 - particle formulation 295–378
 - periphery 332
- spray system, apparatus design 333
- sprayed solutions, binder content 325–326
- springback, convective drying 204
- stability, during drying and storage 83–85
- stability diagram, of foods 2
- stabilizer, role of 83
- starch
 - gelinization 245
 - mint oil particle size 360
 - orange oil particle size 360
 - pergamot oil particle size 361
- state diagram, freeze-drying 54–55
- stickiness, spray-dried powder 260–261
- stochastic discrete modeling 364–367
 - agglomeration 363–372
- storage
 - of food materials 16–17
 - product quality and stability during 83–85
 - release and oxidation of encapsulated flavor 261–269
- storage stability, glass temperature influence 261–262
- strain difference, diffusion models 213
- strength
 - agglomerates 299–315
 - particles 281–282
- stress
 - and differential shrinkage 177–180
 - diffusion models 213
 - on proteins during drying 270–272
 - simulations 215
- stress cracks, in rice kernels 39
- stress-strain relationships, rice grains 34–36
- styrene-butadiene-styrene (SBS) latex 241
- subcritical drying, quality preservation 189–190
- sublimation chamber. *see also* drying chamber
 - gas pressure and drying curve 79–81
 - heat flux heterogeneity in 57–59
 - total gas pressure 117–118
- sublimation endpoint detection, vial batch monitoring 106–113, 121–122
- sublimation flux measurement, vial batch monitoring 113–114
- sublimation front temperature 62
- sublimation kinetics, and operating conditions 79–82
- sublimation rates, and nucleation temperatures 73–74
- sudden expansion, combined with drying 18
- sun-cracks, rice 24
- supercapacitors, dry gels 161
- supercooling, and ice morphology 55, 63
- supercritical drying
 - gels 159, 185–189
 - heating rate 185
 - initial solvent 185–187

- RF and carbon cryogels 192
- washing step 187
- surface cracking, during drying 16
- surface cracks, rice 25
- surface modification
 - quality preservation 201–204
 - TMCS 203
- surfactants, enzyme activity retention 275
- suspension droplets
 - drying 273–274
 - glass deposition 245
- suspensions
 - fine glass filament 272
 - flash spray drying 242
 - large solid particles 244
 - small solid particles 240–244
- syneresis, silica gelation 157

t

- TDLAS. *see* tunable diode laser absorption spectroscopy
- temperature. *see also* chamber temperature; shelf temperature
 - influence on crack formation in rice 26–27
- temperature control, and physical quality 78–79
- temperature increase, and biochemical reactions in foods 5–9
- temperature remote interrogation system (TEMPRIS) 98
- tempering time, rice 27–28
- tension tests, rice kernels 37–38
- TEOS. *see* tetraethoxysilane
- tert-butanol, microwave drying 210
- tert-butanol (CH₃)₃COH, freeze drying 191
- tetraalkoxysilane Si(OR)₄ 156
- tetraethoxysilane (TEOS) 156
- tetramethoxysilane (TMOS) 156
- thermal conductivity gauges, vial batch monitoring 106
- thermal effects, stochastic discrete modeling 367–369
- thermal stress, enzymes and oil 271–272
- thermocouples
 - insertion in vials 61
 - in primary-drying monitoring 97–99
- thermograms, with ultrasound triggered nucleation 71
- thermoporometry 164–166
- three-layer artificial neural network 359
- time step length, MC methods 364
- TMCS. *see* trimethylchlorosilane
- TMOS. *see* tetramethoxysilane

- total gas pressure, sublimation chamber 79–81, 117–118
- transmission electron microscopy, characterization of gels 171
- transport phenomena, interactions with quality factors 53
- trimethylchlorosilane (TMCS)
 - shrinkage reversion 202
 - solvent exchanges 203
- tunable diode laser absorption spectroscopy (TDLAS), vial batch monitoring 113–114
- tunnel conveyor dryer, food industry 2
- two-compartment model
 - fluidized bed 347
 - particle size distributions 348
- two population balance equations 348

u

- ultrasonic atomizers, spray drying 231
- ultrasonic irradiation, gelation 195
- ultrasound, effect on structural and morphological properties 72–73
- ultrasound triggered nucleation
 - controlled 70–72, 95–96
 - human recombinant interferon 96–97
 - thermograms 71
- undercooling 165

v

- vacuum drying
 - gels 184
 - quality preservation 197–198
 - RF and carbon cryogels 192
- van der Waals forces
 - adhesion 299
 - agglomerates 301–303
- ventilated cabinets drying, food industry 2
- vial monitoring
 - single vials 99–103
 - vial batches 106–125
 - vial groups 103–105
- vial type, influence on ice morphology 66–67
- vials
 - for freeze-drying of pharmaceuticals 51–86
 - heat transfer coefficient 58–59
- video acquisition, of shrinkage and cracking of rice kernels 29
- viscoelastic gels, Maxwell model 217
- viscosity
 - shift factor 301
 - stochastic discrete modeling 367
- viscous forces
 - adhesion 299
 - between amorphous particles 304–308

- viscous solid network, differential shrinkage 179
- visual inspection, compared to image analysis 32–33
- vitamin C. *see also* ascorbic acid
 - as a quality index in drying process 6
- vitreous transition, freeze-drying 54–55
- vitrification concept, product stabilization 83
- volatile flavors 255
- volume-averaged liquid density, transport models 212
- VPO precursors 244

- W**
- Washburn equation 168
- water activity
 - decreasing 1
 - and enzymatic activity 8
 - and stability diagram of foods 2
- water concentration, time evolution
 - measurements 107–113, 136–137
- water content. *see also* moisture content
 - residual 91–92, 137–139
- water flow rate, secondary drying 135–136
- water layer hypothesis, protein encapsulation 271
- water replacement hypothesis, protein encapsulation 271–273
- water-soluble crystalline substances 304
- water substitute concept, product stabilization 83
- water vapor mass transfer resistance
 - and freeze-dried cake morphology 74–76
 - and freeze-dried layer thickness 69, 76
- water vapor pressure, in drying chamber 62
- wet gels
 - characterization 162–166
 - preparation 156–158
- white rice, obtainment of 22
- whole-batch monitoring, freeze-drying 106–125
- Williams, Landel and Ferry (WLF) equation 267, 301
- wireless probes, in primary-drying monitoring 98
- Wurster coater
 - discrete particle modeling 349–357
 - gap distance 355–357
 - geometry 352
 - particle positions 353–356
 - schematic representation of 334
 - velocity distributions 353–356

- X**
- X-ray tomography, drying gels 172
- xerogels
 - definition 159
 - mercury porosimetry 170
 - vacuum drying 198

- Y**
- Young's modulus
 - rice grains 35
 - time-dependent 36

- Z**
- zeolite agglomerates 317–319