Index

A

acid-alkali modeling, 154–156
acid rain, 141
active layer thickness, 59–60, 88–90
active layer velocity, 83–87, 90, 99–100
aggregate, lightweight (LWA), 3, 285–294
aggregate kilns, 43*f*
air
  composition, 299
  infiltration, 34, 43, 47, 56, 259
  at low pressure (dry), 303–304
  water percentage calculations, 256
air-fuel ratio, 136–137
air requirements for combustion
  acid-alkali modeling, 154–156
  determining, 135–136
  pulverized coal or coke, 145, 146–147, 170
  sources of, 34
air velocities, typical values of, 43*f*
annular shift kiln, 5*f*
Arrhenius equation, 41, 153
Ash Grove Cement Plant, 51
Aspdin, Joseph, 2
atmosphere
  international standard measurements, 312–313
  units of conversion, 301
atmospheric discharge, 34
atomization, 149–152
axial motion, 26–28
axial segregation, 102

B

Bac, N., 196
Bagnold, R. A., 53–54, 63
banding, 102
Barr, P. V., 67, 68, 197, 200–201
Becher process, 283–284
Becker, H. A., 47
bed. *See also specific types*
  depth, determining, 29–30
  heat transfer
    flame to bed, 195–196
    introduction, 173–174
    paths, 17*f*
    rotating bed mode, 214–215
    wall to bed, 198–199, 207–211
  segregation model, 106–110
  thermal model, 218–224
bed behavior diagram, 23–24
bed motion, modes of, 20*f*
bed phenomenon, 15–18
Blasius, H., 39
Blasius problem, 80
bloating, 233, 286, 288–292
Boateng, A. A., 67, 68, 69, 197
boiler and industrial furnace act (EPA), 130, 141

Boudouard reaction, 281–282
Boynton, R. S., 272
Brimacombe, J. K., 282

C

calcination, 246–247, 261, 266–272
calcination calculation, 251, 255
calciners, fluidized-bed, 6*f*
Campbell, C. S., 70
carbon black, 142
carbon dioxide (CO2), 133, 138, 289
carbon monoxide (CO), 133, 163
carbothermic reduction, 280–284
Carnot cycle, 240
cascading bed, 19–21
cataracting bed, 20*f*
cement, history of, 1–2
cement kilns
  air infiltration, 47
  air velocities, 43*f*
  Craya-Curtet parameter, 47, 156
  energy usage, 278–280
  fuel types used, 141
  history of, 1–2
  schematic, 276
cement process chemistry, 275–278
cenosphere, 149
centrifuging bed, 19–21
CFD. *See* computational fluid dynamics (CFD)
char combustion, 147–149
clay, 287, 289–294
coal
  combustion chemistry, 133
  combustion requirements, 170–171
  conveying air, 248, 259
  delivery and firing systems, 145–146
  firing in kilns, 143–144, 156
  heat transfer, 196
  sensible heat calculations, 258
  tires combined with, 142
  types of, 139–140
Cohen, E. S., 196
coke, 140–141, 143–146, 170–171
combustion. *See also specific types, e.g.* char combustion
  air requirements for
    acid-alkali modeling, 154–156
    determining, 135–136
    pulverized coal or coke, 145, 146–147, 170
    sources of, 34
  CFD modeling, 156–158
  heat release calculations, 261
  introduction, 129–131
  mass and energy balance, 255
  mole and mass fractions of intended fule, 131–133
  practical stoichiometry, 135–136
  radiative effect of combustion gases, 195–196
combustion chemistry, 133–135
combustion efficiency, 34, 46, 48, 50
combustion modeling
  acid-alkali, 154–156
  Hawthrone method, 154
  overview, 152–154
computational fluid dynamics (CFD)
  modeling rotary kiln processes, 156–160
  pulverized fuel burner evaluation, 163–169
concentration transport equation, 41, 153
concrete, 3, 287*f*
concrete ships, 286
confined flame theory, 47

confined jet-free jet relation, 46–47
confined jets, 34, 43–44, 46–48, 155
continuity equation, 40, 153
conversion factors, SI to British, 298, 302
coolers, 10, 12*f*
Couette flow, 35–37
countercurrent flow rotary kiln, 4*f*
cracking, 51, 140
Craya, A., 47
Craya-Curtet parameter, 47–48, 155–156
Curtet, R., 47

D

Damkohler I and II, 42, 46
Davies, T. R. H., 61
dirty fans, 56
dolomite, 267–268
dryers, 10
dry kilns, 9–10
dumbell-type rotary kiln, 7*f*
dust, site survey, 249
dust constituents, 260
dust entrainment, 34, 40, 53–56. *See also* entrainment; saltation

E

Edison, Thomas A., 2
efficiency, thermal, 243–244
Ehlers, E. G., 289, 290
emissions modeling, 161–163
emissivity, 194–195
energy cost savings, 142, 145
energy savings, maximizing, 135
enthalpy transport equation, 41, 153
entrainment. *See also* dust entrainment
- jet properties and, 43–53
- saltation and, 53–56

environmental sustainability, 145
equation of state, 41, 153

F

Fan, L. T., 106
fans. *See specific types of*
Ferron, J. R., 60, 72, 207–211
field kilns, 2
flame shape and character
- air-fuel ratio in, 137–138
- Craya-Curtet parameters, 47–48, 156
- droplet fuel size and, 151
- heat dissipation and, 130
- heat flux and, 46–47
- luminosity-emissions relation, 51, 195

flame temperature, adiabatic, 136–138
flame theory, 47
flotsam, 109, 114. *See also* percolation
flow behavior, transverse, 24–26
flow visualization modeling, 154–156
flue gases, 134, 260
fluid flow
- laminar and turbulent, 36–39, 154
- in pipes, 33–40
- sources of, 34, 43

forced draft fans, 56
4-nine destruction efficiencies, 138
freeboard aerodynamics
- in dust entrainment, 34, 40, 53–56
- fluid flow in pipes, effect on, 33–40
- introduction, 33–34

freeboard aerodynamics (*Continued*)
mixing and, 43–53
total flow inducement, 56
freeboard phenomenon-bed phenomena synergy, 15–17, 33
freeboard(s)
dimensionless parameters of combustion, 42
heat transfer
among exposed surfaces, 199–203
coefficients for radiation, 196–198
to exposed bed and wall, 3–4, 4*f*, 15, 198–199
introduction, 173–174
to the wall, 187–189
in indirect fired kilns, purging volatiles, 12
thermal model, 218–221
free jet-confined jet relation, 46–47
free jets, 43–45
friction velocity, 40
fuel. *See also specific fuel types*
atomization of liquid, 149–152
combustion and, 129–131
energy calculations, 256
types used in rotary kilns, 130–131, 138–139
fuel-air systems, 135–136, 137*f*
fuel efficiency, 51, 135, 138, 154, 244
fuel heating value, 130, 134–135
fuel NOx, 161–162
fuel oil firing, 149–152

G

gas components, natural and exit gas, 250
gaseous fuels, 130, 137, 138*f*
gases
H, U, S, G, 306–311
radiative effect of combustion, 195–196
specific heats, 304–305
gas flow rate, 34
gas-phase combustion, 158–159
Gauthier, C., 86
Gibbs free energy and entropy, 159, 240–243
grain inertia regime, 63
grain temperature, 66
granular flow
defined, 59
equations of motion, 64–67
kinetic theory application to, 63–64
mechanisms of momentum transfer, 63
modeling, 59–62, 72
observed, in a rotary drum, 25, 68–72
other flow types compared, 61–62, 61*f*
theories governing, 62–63
granular temperature, 66, 87–88, 90
Greek nomenclature, Appendix
green coke, 140
Guruz, H. K., 196
Gyro-Therm, 50

H

Hagen-Poiseuille equation of laminar flow, 37
Hawthrone method, 154
Hayde, Stephen J., 3, 286
hazardous waste incineration, 130, 138, 243
heat balance, 239
heat content, units of conversion, 300–301
heat exchange, cross section, 16*f*
heat flux, 46–47, 175

heat of reaction/heat of
formation, 240
heat recuperators, 8
heat transfer
in the bed, 173–174, 207–215
bed to wall, 198–199, 207–211
combustive gases, radiative
effect, 195–196
conduction, 174, 175–180,
211–215
conduction-convection
problems, 182–184
conduction in the wall,
187–189
convection, 174, 180–182
estimating, 40
exposed surfaces, 198–203
flame to bed, 195–196
in the fluid, 42
methods overview, 174–175
packed beds, 211–214
radiant, 50
radiation, 51, 138, 174,
189–191
radiation exchange, 194–195
radiation shape factors,
192–194
refractory lining materials and,
184–187
rotating bed mode, 214–215
shell losses, 184
wall to bed, 198–199, 207–211
heat transfer, freeboard
among exposed surfaces,
199–203
coefficients for radiation,
196–198
to exposed bed and wall,
198–199
introduction, 173–174
to the wall, 187–189
heat transfer model
results and application,
228–232
single particle for shale
processing, 232–237
solution procedure, 224–227
Henein, H., 67, 69, 113, 119
higher heating value (HHV), 134
horizontal kilns, 4–7
Hottel, H. C., 196

I

ilmenite, 283
indirect fired kilns, 12–13
induced draft (I.D.) fan, 34,
35, 56
infiltration air, 34, 43, 47,
56, 259
instantaneous jet, 51
irradiation, 192

J

Jenkins, B. G., 154, 205
jets. *See* flame shape and
character; *specific types of*
jetsam, 109. *See also* percolation
jetsam loading-number
concentration, 124–125

K

kerosene, 149
kidney, 107
kiln design, 29–30, 56, 135. *See
also specific types of kilns*
kiln geometry
determining capacity, 28
plug-flow estimations from, 29
residence time relation, 18, 23,
26–27
kiln loading, 21–23
kiln wall
heat transfer
freeboard, 187–189
refractory lining materials
and, 184–187

kiln wall (*Continued*)
shell losses, 184
wall to bed, 198–199, 207–211

L

laminar jets, 45
Lewis number, 152
lightweight aggregate (LWA), 3, 285–294
lime kilns
about, 272–274
active layer, 59
air velocities, 43*f*
Craya-Curtet parameter, 156, 273
history of, 1–2, 266
modern, 10
lime manufacturing, 265–266, 272
lime products, 260
limestone, 248, 259, 266
limestone calcination, 246–247, 261, 266–272
limestone calcination kilns, 47
liquid burnable materials (LBM), 130, 152, 196
long dry kilns, 9–10
long kilns, history of, 2
lower heating value (LHV), 134–135
Luminis Pty. Ltd., 50
Lun, C. K. K., 65, 83, 98
Lunn, 104
Luxton, R. E., 51

M

Mach number, 41
mass, units of conversion, 300
mass and energy balance
calcination calculation, 251, 255
chemical compositions, 246
combustion, 251, 255
energy balance inputs, 246–247
global heat and material, 243–244
introduction, 239
mass balance inputs, 245–246
sensible energy, input and output, 258–260
shell heat loss, 251–254
site survey-measured variables, 247–251
thermal module for chemically reactive system, 244–245
metallurgy, extractive, 280
methane combustion, 133–134
microexplosions, 152
Millen, Thomas, 2
minerals process applications
carbothermic reduction processes, 280–283
cement kilns, 275–280
cement process chemistry, 276–278
introduction, 265
lightweight aggregate, 285–294
lime manufacturing, 265–266
limestone dissociation (calcination), 266–272
ore reduction processes, 280
rotary lime kiln, 272–274
mixing
atomization requirements, 149–152
in carbothermic processes, 282
Hawthrone method, 154
introduction, 101
jet properties and, 43–53
modeling within the bed, 105–106
purpose of, 24
turbulent, 39, 154
Moles, F. D., 154, 196, 205
momentum equation, 153
Mullinger, P. J., 154

N

Nathan, G. J., 51
natural gas, 138, 196, 250, 256, 258
Navier-Stokes, 56, 64, 159
Newby, M. P., 47
Nicholson, T., 26–28
nitric oxide (NOx) emissions, 51, 161–162
nomenclature, Appendix
notation, variables, unit, and description, 297
nozzle tip velocities, 43

O

Owen, P. R., 54
oxy-hemoglobin formation, 133

P

Parker, D. J., 29
particle-laden jets, 52–53, 143
particulate flow behavior in rotary kilns, 67–68, 160
particulate flow model
  active layer
    analytical expression for thickness of the, 88–90
    momentum equation solution, 83–85
    velocity profile in the, 85–87
  application, 94–95
  density and granular temperature profiles, 87–88
  description, 73–74
  introduction, 72–73
  momentum conservation
    governing equations, 75–79
    integral equation, 79–83
  momentum equation
    numerical solution scheme, 90–91
    solution in the active layer, 83–85
  results and validation, 92–94
  simplifying assumptions, 74–75
Peclet number, 42
Peray, K. E., 275
percolation
  defined, 102
  spontaneous, 104, 107–109, 112–113, 120
percolation velocity, 106, 107, 110–112, 114
Pershin, V. F., 59–60
petroleum coke, 140–141
Phillips, E. L., 289
pipes, fluid flow in, 33–40
PJ burner, 51
plug-flow estimations, 29
Polak, S. L., 140
pollution control, 34, 50, 135, 244. *See also specific pollutants*
Portland cement, 2
pot kilns, 2
Prandtl number, 38, 41
precalciners, 10
precessing jets, 49–51
preheaters, 11*f*
pressure, units of conversion, 301
prompt NO, 162
pulverized fuel
  burner evaluation using CFD, 163–169
  combustion systems
    confined jets, 33–34, 46
    particle-laden jets, 52
  delivery and firing systems, 145–146
  reaction kinetics of carbon particles, 147–149
  sources of, 139–144

R

radiosity, 192
Ransome, F., 2
reacting flows, multicomponent, basic equations, 40–43
recirculation, 46–47
recirculation vortex, 48–49, 156
relaxation time, 52–53
residence time, 46, 149, 154
  dimensionless, 28–30
residence time-kiln geometry relation, 18, 23, 26–27
Reynolds number, 36, 41, 46, 150
Reynolds principle, 36, 37, 38
Ricou, F. P., 45–46
rolling bed, 20–22, 73–79, 82
Rosin-Rammler relation, 143–144, 160
rotary kilns. *See also specific types of*
  basics, 3–4, 129
  competitive features, 3, 12, 287
  dams and tumblers, purpose of, 7–8
  design challenges, 56
  efficiency, 51, 56
  evolution of, 1–7
  fuel types used in, 130–131, 138–139
  lifters, energy-savings with, 7–8
  other contact kilns compared, 4–7
  regulation of, 130, 141, 287–288
  sizing, 19
  types of, 7–13
rotary kilns, operation basics
  axial motion, 26–28
  bed phenomenon, 16–19
  dimensionless residence time, 28–30
  freeboard phenomenon, 15–17
  geometrical features and their transport effects, 18–19
  introduction, 15–17
  transverse bed motion, 19–23
  transverse flow behavior, 24–26
rotary reactor, 15
round jets, 45–46
Ruhland, W., 154
rutile, 283

S

saltation, 53–56, 146
Sarofim, A., 196
Savage, S. B., 62, 104, 111
Schlichting, H., 35
Schneider, G. M., 51
scrubbing, 141
seals, 34
Seaman, W. C., 22, 26, 28, 61
segregation
  mechanisms of, 102–104
  reducing, 104
segregation equation solutions
  mixing and segregation, 116–117, 125–127
  radial mixing, 115–116
  strongly segregating system, 114–115
segregation model
  application, 120–121
  within the bed, 106–110
  boundary conditions, 113–114
  governing equations, 110–113
  governing equations numerical solution, 117–119
  introduction, 105–106
  validation, 119–120
segregation rates, 103
sensible heat calculations, 66
sensible heat defined, 240
shaft-type kilns, 4, 6
shale, 3, 232–237, 286, 288–294
shell heat loss, 184, 250, 251–254
ships, concrete, 286
short dry kilns, 10, 11*f*

sieving, inverse, 103
Singh, D. K., 60, 68, 72, 207–211
skin friction coefficient, 40
slate, 286, 289–294
slipping bed, 20
SL/RN kilns, 280–283
slumping bed, 20, 82
Spaulding, D. B., 45–46
squeeze expulsion, 110
stack gases, 134
stationary kilns, 2
Stefan-Boltzmann constant, 300
Strouhal number, 50–51
submerged jets, 43–44
sulfar dioxide (SO2) emissions, 141
surface velocity, deep beds, 26
swirling jets, 48–49
swirl number, 49

T

Tackie, E. N., 56
temperature, formulas for calculating, 300. *See also specific types of temperature*
thermal model
  description, 216–217
  one-dimensional for bed and freeboard, 218–221
  quasi three-dimensional for the bed, 223–224
  of rotary kiln processes, 215–216
  two-dimensional for the bed, 221–223
thermal NO, 162
thermodynamics, chemical, 239–240
thermodynamic tables
  gases, 301
  inorganic materials, 313
Thring, M. W., 47
tire combustion, 141–143
titaniferous materials, 282–285
tongue, 107
trajectory segregation, 102–103
transport phenomenon
  history of, 2
  modeling, 16
Tscheng, S. H., 211
turbulence modeling, 158–159
turbulent diffusion flames, 34, 42, 46
turbulent jets, 43–46, 154
turbulent kinetic energy (TKE), 154
turbulent variable swirl burners, 48, 50

V

van der Hegge Zijnen, 45
vaporization, 134–135, 150–152
vapors
  H, U, S, G, 306–311
  specific heats, 304–305
velocity, units of conversion, 300
Venkateswaran, V., 282
vertical kilns, 4–7
viscosity, 35–36, 98–99
von Karman, T., 79
vortex shedding, 48–49, 156

W

Wang, R. H., 106
waste fuels, 130, 152, 196, 287
Watkinson, A. P., 211
wet kilns, 9

Z

Zhang, Y., 70