Index

Note: Page numbers followed by "f" denote figures; "t" tables.

A

Acting masses law, 45
Activation energy, 60–61, 75–76, 78
Active power, 146
Activity, 42–45
Activity coefficient, 42–45
Agglomeration, 127–129
  briquetting. *See* Briquetting
  of manganese, 234–238
  pelletizing. *See* Pelletizing
  sintered pellets production, 128–129
  sintering. *See* Sintering
Alabandine, 233t
Al-Ba alloys, smelting of, 491
Alkali-earth metals (AEM), 471–494
  barium, 488–491
    Al-Ba alloys, smelting of, 491
    ferrosilicobarium, smelting of, 490–491
    properties of, 488–490
  calcium, 472–480
    properties of, 472–475
  calcium carbide, smelting of, 475–477, 476f
  calcium-silicon alloy, smelting of, 477–480
    reduction by calcium carbide, method of, 480
    reduction by carbon, method of, 477–478
    reduction by silicon, method of, 478–479
  magnesium, 480–485
    production of, 483–485
    properties of, 480–483
  metallurgical lime, 491–494
  strontium, 485–487
    alloys, smelting of, 487
    properties of, 485–487
Alloying, 9–10
Alloy tapping, 350–351
Al_2O_3, 459–460
Alsimin. *See* Ferrosilicon-aluminum
Alternating current (AC), 140–143
  circuits, impedance and power in, 145–146
  furnaces. *See* Alternating current furnaces
  sinusoidal, 141–142
Alternating current (AC) furnaces, 87, 140, 148–153, 320
  electrical supply to, 108–109
  one-phase circuit, 149–150, 149f
  submerged arc
    closed, 335–340, 336f, 337f, 338f
    open, 331–333, 333f, 334f
    semiclosed, 331–333, 333f
    smelting, 340–344
  three-phase circuit, 151–153, 151f, 153f
Aluminothermal processes, 32–33
Aluminum, 195, 198, 214–215
  ferrotungsten reduction by, 385
  ferrovanadium reduction by, 407
  master alloys, composition of, 500t
  reduction, smelting with
    boric anhydrite, 455t
    ferroboron, 454t
    ferrotitanium, 429–432, 431t
    nickelboron, 456t
Anorthite, 205–206, 214–215
Apparent power, for real circuit, 146, 147f
Argon oxygen decarburization (AOD), 14–15, 318, 326
Arrhenius equation, 60–61, 62t
Ascharite, 452
Ash, 194–195, 205, 214
Atomizing, of silicon, 213t
Automatic furnace control, 121–122

B

Baddeleite, 441–442, 446
Bag filter plant, 96–97, 100–101, 104, 128–129, 357–358
Barite, 488–490
Barium, 488–491
  Al-Ba alloys, smelting of, 491
  ferrosilicobarium, smelting of, 490–491
  properties of, 488–490
Bastnesite, 466, 466t
Batch ferroalloy process, 33–35
Bessemer process, 10

Best available technology (BAT), 24–25
Bixbyite, 229–231, 233t
Black-box models, 158
Bøckmann compensation, 168–169, 169f
Boracite, 452
Borax, 452
Boric acid, 453t
Boric anhydrite, 453t
  smelting with aluminum reduction
    heat and energy balance of, 455t
    material balance of, 455t
Boron carbide, 452, 456
Boron ferroalloys, 449–458
  properties of, 449–451
  reduction of, 452–453
  sources of, 452–453
  types of, 453, 453t
Braunite, 229–231
Bravoite, 402t
Briquetting, 34, 128
  chromites, 228–289
  of manganese, 236
Brown condensate, 203–204
Bulat steel, 12
Bulk ferroalloys, 31t
Bus bar, 85, 88, 100, 107, 109, 125

C

Calcia (CaO), 472, 474f
Calcining, 372–373
Calcium, 179–180, 472–480
  properties of, 472–475
Calcium carbide (CaC_2), 472
  smelting of, 475–477, 476f
Calcium cyanamide ($CaCN_2$), 472
Calcium diborate, 453t
Calcium manganese silicon (SiMnCa), 472
Calcium silicon (SiCa), 472
  smelting of, 477–480
    reduction by calcium carbide, method of, 480
    reduction by carbon, method of, 477–478
    reduction by silicon, method of, 478–479
CALPHAD (CALculation of PHAse Diagrams) method, 54
$CaO\text{-}SiO_2$, 474f
Capacitance, electric, 144
Capital investment, for high carbon ferrochrome production, 330–331
Carbon
  ferrotungsten reduction by, 382–385
  interaction with manganese, 222–229
  monoxide, 122–123
  reductants, 191–195
    for ferroalloys processing, 79–81, 80t
Carbothermal processes, 30–32
Carnotite, 401–402, 402t, 404
Casting, 4, 133–135
  of ferronickel, 373–374
  of high-carbon ferrochrome, 348, 352
  of manganese ferroalloys, 259–260
  net shape, 260
  of silicon, 211–212, 213t
Cavity, 202–207, 210
Celestine ($SrSO_4$), 486–487
Cerium, 464–465
Chalcopyrite, 392
Channel arc models (CAM), 158–159, 159f
Charcoal, 193–194
Charge (electrical), 78
Charge chrome, 320
  defined, 318
  specification of, 319t
Chemical potentials, 39, 42–43, 45
Chemical reactions, thermodynamics of, 45–53
Chromeboron, 457
Chrome direct reduction (CDR) process, 341
Chromite, production of, 323t
Chromite ores
  briquetting of, 228–289
  classification of, 283t
  pelletizing of, 287–288, 288t
  processing of, 285–289
    general requirements for, 286t
  sintering of, 287, 287t
Chromium, 11, 267–316
  -containing systems, phase equilibria with, 268–276, 372t
  environmental issues of, 312–314
    dust and wastewaters treatment, 313–314
    fire and explosion hazards, 314
    human health hazards, 312–313
  ferroalloys technology, 289–307
    low-carbon ferrochrome, 289–297
  hexavalent, 360–362, 313–314
  minerals, 280–283
  processing of, 285–289
  properties of, 268–280
  resources of, 283–285
  spinel, 278, 280–281, 287–288, 303
  spinelides, 280–282, 282t, 283–285
    composition of, 282t
Chromium carbide, 367–368
Chromium oxide, 368
  phase equilibria with, 276–280

Circuit(s)
AC
impedance and power in, 145–146
one-phase, 149–150, 149f
three-phase, 151–153, 151f, 153f
reactance, 143–145
resistive, 143
Clausius-Clapeyron equation, 43–44
Clinopyroxene, 236–237
Closed roof, 94, 94f
Closed submerged arc AC furnaces, 335–340, 336f, 337f, 338f
Coal, 193
Coal tar pitch volatiles (CTPVs), 363
Cobalt, 367, 371
CO_2 emissions, from ferroalloys production, 22–25, 23t, 24t
CO gas reticulation and utilization, 358–360, 359f, 361f
Coke, 320, 335–336, 338–339, 341–344, 287–288, 299–300
bed, 242–245, 249
metallurgical, 193
petroleum, 194
Colemanite, 452
Columbite, 415–416
Columbium, 411
Complex ferroalloys, 495–499
development, relevancy of, 495–496
Composite electrode, 118–119
Conduction, 37
heat transfer by, 65–66
Continuous ferroalloy process, 33–35
Convection, 37
heat transfer by, 66–67
Convective mass transfer, 71–72
Convective momentum transfer, 71–72
Converting, 372, 374
Crater, 201, 204, 206–207
Creusot-Loire Uddeholm (CLU) refining process, 326
Cristobalite, 181, 189–190, 189t, 207
Cr-O-C Systems, Equilibria in, 372t
Crushing, of manganese ferroalloys, 260
Cryptomelane, 233t
Culsonite, 402t
Cuprodescloizite, 402t

D

Damascus steel, 12
Davidite, 402t
Dead-band regulation, 166–168, 168f
Decarburization, of high-carbon ferromanganese, 257–258, 258t
Dephosphoration, 240, 374
Descloizite, 402t
Desulfuration, 372–373
Differential scanning calorimetry (DSC), 61–62
Differential thermal analysis (DTA), 61–62
Diffusion, 59–60
Diffusive emissions, 219t
Diffusive mass transfer, 70–71
Direct current (DC), 140–143
furnaces, 104–107, 140, 147–148, 148f, 320
electrical supply to, 109
open arc, 344–348, 346f, 349f
Disintegrators, 355–357, 356f
Doloma, 10
Dolomite, 483–484, 492
Donpeacorite, 236–237
Dust, 162, 170–172, 190, 200–201, 217–219
chemical composition, 173, 173t
from chromium ferroalloys processing, 313–314
hexavalent chromium, 362–363

E

Electrical energy efficiency, of high carbon ferrochrome, 329–330
Electric arc, 153–155, 154f, 156f, 157f
models, 156–160
black-box models, 158
channel arc models, 158–159, 159f
magneto-hydrodynamic model, 159–160, 160f
momentum source models, 158
Electric capacitance, 144
Electric circuit theory, 140–146
AC circuits, impedance and power in, 145–146
alternating current, 140–143
direct current, 140–143
reactance circuits, 143–145
resistive circuits, 143
voltage, 140–143
Electric conductivity, of slags, 76–78
Electric current, 141
Electric resistance, 143
Electrodes, 109–119
composite, 118–119
control of, 166–169
graphite, 116–118, 118f
prebaked, 116–118, 117t
regulating, 109–110

Electrodes (*Continued*)
self-baking, 110f, 111–116
slipping, 110–111, 113–114
Söderberg, 109, 110f, 111–116, 112f, 113t, 115f
Electrometallurgy, 6
Electrostatic precipitators, 358
Ellingham diagram, 30, 45–46
Emissions, 4, 66, 67t
control, 168–169
gaseous, 173–174
heat, 174
particulate, 170–173
in silicon production plant, 219t
control of, 217–219
Energy, 4
demand, for ferroalloys making, 22, 23t
recovery, in silicon production plant, 215–217
Enthalpy, 38–40
Entropy, 37–39
Environmental control, 217–219
Environmental impact, of high carbon ferrochrome production, 354–360
Environmental issues
associated with chromium, 312–314
dust and wastewaters treatment, 313–314
fire and explosion hazards, 314
human health hazards, 312–313
associated with furnaces, 170–174
gaseous emissions, 173–174
particulate emissions, 170–173
associated with silicon production, 215–219
emissions control, 217–219
energy recovery, 215–217
Equilibrium phase diagrams, 53–58
eutectoid system, 55, 56t
peritectic system, 56t, 57
Equipment
ferroalloy processing, 83–138
for furnace feed processing, 127–133
agglomeration, 127–129
manganese ore, sintering of, 129–130
preheating, 131–132
prereduction, 132–133
Excess free energy, 41–42
Exhaust gas, 85, 94, 96–97, 100, 103–104, 120, 128–129, 131–133
Exothermic ferroalloys, 503–504, 273f
Explosions, 93–94, 123, 125, 134–135
hazards, of chromium ferroalloys, 314

F

FactSage, 53
FactSage 6.2, 6, 52
Fans, 115–116, 128–130
Faraday number, 71
Fe-Cr-Mn-Si Alloys, composition of, 500t
$FeCr_2O_4$ spinel structure, 281f
Feed bins, 84, 95–96, 104, 129
Feralsit. *See* Ferrosilicon-aluminum
Ferroalloys, 3–4
basics of, 9–28
classification of, 4, 31t
defined, 29–30
development and production of, 9–12
major, 4
minor, 4
processing, theory of, 29–82
smelter, 84f
types of, 31t
Ferroaluminum (FeAlN), 496, 499t
Ferro-alumo-zirconium (FeAlZr), 443, 446–447, 446t
Ferroboral (FeBAl), 452, 456
Ferroboron, 453–456
chemical composition of, 454t
smelting with aluminum reduction, charge composition of, 454t
Ferrocerium, 467
Ferrochrome-aluminum (Fe-Cr-Al), 498
Ferrochrome (FeCr) furnaces, 92–98, 92f, 94f, 95f, 98f
tapping of, 134f
Ferrochrome-manganese (FeCrMn), 498
Ferrochrome preheating system, 131f
Ferrochromium
high-carbon, 287–297, 290t, 291t
low carbon, 294t
medium-carbon, 287, 291t, 297–299
nitrided, 305–312, 305t
ultra-low carbon, 303–305, 304f
Ferromanganese (FeMn)
furnaces, 92–98, 127
high-carbon, 246–250, 249t, 257–258, 258t
post–tap hole processing for, 252–253
Ferromanganese-aluminum (FMA), 496–497, 499t
Ferromanganese-vanadium, composition of, 408t
Ferromolybdenum, 387–388
production of, 393–395, 394t
smelting of, 137, 137f
Ferronickel, 367–376
alloys, composition of, 372t

calcining, 372–373
casting of, 373–374
converting, 372, 374
furnaces, 101–104
oxidative roasting of, 372–373
refining of, 373–374
smelting of, 371–373
Ferroniobium (FeNb), 412, 416–419, 499
Ferrophosphorus, 501–502, 502f
Ferroselenium, 503
Ferrosilicobarium, smelting of, 490–491
Ferrosilicoboral (FeSiBAl), 452
Ferrosilicochrome (FeSiCr)
charge materials for, 302t
chemical composition of, 299t
technology of, 299–303
Ferrosilicon (FeSi)
compositions of, 195–198, 197t
equilibrium diagram, 188f
furnaces, 92–98
smelting technology, 198–210
basic principles of, 198–201
costs of, 209–210
energy demand for, 207t, 209–210
materials of, 207t
parameters of, 207t
peculiarities of, 205–207
reactions in furnace, 201–205
Ferrosilicon-aluminum (FSA), 497
Ferro-silicon-calcium (FeSiCa). *See* Calcium-silicon alloy
Ferrosiliconiobium, 416–417, 419
Ferro-silicon-magnesium (FeSiMg), 483–485
Ferrosiliconmanganese (FeSiMn), production of, 250–252
Ferrosiliconmanganese-aluminum alloys (FAMS), 497
Ferrosilicostrontium, 487
Ferrosilicovanadium, composition of, 408t
Ferrosilicozirconium (FeSiZr), 442–446
Ferrosulfur, 502
Ferrotellurium, 503
Ferrotitanium
composition of, 430t
smelting of, charge composition of, 431t
Ferrotungsten, production of, 382–385
reduction by aluminum, 385
reduction by carbon, 382–385
reduction by silicon, 382–385
Ferrovanadium, 405–407
composition of, 406t
nitrided, 408–409
reduction by aluminium, 407
reduction by silicon, 405–407, 406t
FeSiREM alloys, composition of, 467t
Fick's law of diffusion, 70–71
Fines, 189–190, 200–201, 211–212, 217
Fire hazards, of chromium ferroalloys, 314
Flotation method, 286
Flux, 444–445
Flux ferroalloy process, 33–35, 243, 248
Flux-less ferroalloy process, 33–35, 243, 248, 252, 256
Fourier's law, 65–66
Fourier transform infrared spectrometry (FTIR), 61–63
Free energy
excess, 41–42
Gibbs, 45
Freeze lining, 102–103
Friability index, 190
Fumes, 200, 202, 217–218, 219t
hexavalent chromium, 362–363
Furnace(s)
alternating current, 87, 140, 320
closed submerged arc, 335–340, 336f, 337f, 338f
one-phase circuit, 149–150, 149f
open submerged arc, 331–333, 333f, 334f
semiclosed submerged arc, 331–333, 333f
smelting submerged arc, 340–344
three-phase circuit, 151–153, 151f, 153f
control, 121–122, 165–169
crucible, 93–94
design of, 85–92
parameters for, 90t
direct current, 104–107, 140, 147–148, 148f, 320
open arc, 344–348, 346f, 349f
downstream processing, 133–135
casting, 133–135
refining, 133
electrical supply to, 107–119
AC furnaces, 108–109
DC furnaces, 109
electrodes, 109–119
environmental issues of, 170–174
gaseous emissions, 173–174
particulate emissions, 170–173
feed processing, equipment for, 127–133
agglomeration, 127–129
manganese ore, sintering of, 129–130
preheating, 131–132
prereduction, 132–133
ferrochrome, 92–98
ferromanganese, 92–98
ferronickel, 101–104

Furnace(s) (*Continued*)
ferrosilicon, 92–98
heat dissipation in, modes of, 153–165
current paths of, 162–163
distribution of, 163–165
electric arc, 153–155, 154f, 156f, 157f
electric arc models, 156–160
resistive heating, 160–161, 161t
linings, 119–120
operations, for ferroalloys processing, 85–92, 139–140
parameters, 87t
principal operating stages of, 120–121
processing hazards and risk management of, 122–126
hazardous gases, 122–124
high current, 125
high voltage, 125
molten metal, 124–125
repairs and maintenance, 125–126
slag, 124–125
water, 125
refractory lining, 92–93, 93f
resistance and electrode parameter, relationship between, 87–88
roof, 94, 94f, 95f
silicomanganese, 92–98
silicon metal, 98–101
silicon reactions in, 201–205
slag cleaning, 237–238
submerged arc, 234, 242–243, 245–247, 250, 256
tensioning springs on, 120f
Future outlook, for ferroalloys industry, 26–27

G

Gas cleaning plant, 96–97, 104
Gas cleaning systems, 354–358
bag filter plants, 357–358
disintegrators, 355–357, 356f
electrostatic precipitators, 358
Venturi-type scrubbers, 354–355, 355f
Gaseous emissions, 173–174
Gauerite, 233t
Gehlenite, 205–206
Gibbs-Duhem equation, 41, 44
Gibbs energy, 30, 37–40, 45–52
Gibbs minimization method, 6
Gladkih *et al.* method, 89–92
Granshot granulation, 353
Granulation
Granshot, 353
of high carbon ferrochrome, 352–353
of manganese ferroalloys, 260
Showa Denko, 352
Graphite electrode, 116–118
column, 118f
Grashof number, 68t
Gravity concentration method, 286
Greynal, 457

H

Hausmannite, 229–231, 233t
Hazards, in smelting manganese ferroalloys, 263–265
Hazards management of furnaces, 122–126
hazardous gases, 122–124
high current, 125
high voltage, 125
molten metal, 124–125
repairs and maintenance, 125–126
slag, 124–125
water, 125
Heat capacity, 38–39
Heat dissipation in furnaces, modes of, 153–165
current paths of, 162–163
distribution of, 163–165
electric arc, 153–155, 154f, 156f, 157f
electric arc models, 156–160
Heat emissions, 174
Heat generation, 69–70
Heat losses, 174
Heat recovery systems, 174
Heat transfer, in ferroalloys processing
by conduction, 65–66
by convection, 66–67
by equation, 67–69
heat generation, 69–70
by radiation, 66
Helmholtz energy, 37–39
Henrian reference state, 43
Hexavalent chromium, 360–362, 313–314
High-carbon ferrochrome (HGFeCr), 317–364
applications of, 326
mass and energy balance of, 327t
nominal composition of, 289, 290t
production of, 318–326, 321t, 323t
alloy tapping, 350–351
environmental impact of, 354–360
occupational health hazards of, 360–363
product types, 351–353
slag handling and utilization, 353
slag tapping, 350–351

production of, technology routes for, 328–350, 332t
capital investment, 330–331
closed submerged arc AC furnaces, 335–340, 336f, 337f, 338f
economy of scale, 330
electrical energy efficiency, 329–330
metallurgical efficiency, 328–329
occupational health, 331
open arc DC furnaces, 344–348, 346f, 349f
open submerged arc AC furnaces, 331–333, 333f, 334f
prereduction, 340–344
semiclosed submerged arc AC furnaces, 331–333, 333f
submerged arc AC furnaces smelting, 340–344
Tecnored process, 348–350
specification of, 318, 319t
uses of, 326
High-carbon ferromanganese
decarburization of, 257–258, 258t
production, 246–250, 249t
High current, risk management of, 125
High voltage, risk management of, 125
History of ferroalloys, 9–12
Hollandite, 233t
HSC Chemistry, 53
HSC Chemistry 7.1, 6
Human health hazards, of chromium, 312–313
Hyperoxide (CaO_4), 472

I

Ilmenite, 424–425, 428–432, 428t, 431t
Impedance, of AC circuits, 145–146
Inductance, 143
Internal energy, 37–38
Iron-titanate, 428t

J

Jacobsite, 233t

K

Kanoite, 236–237
Katana swords, 12
Kelly factor, 87–88, 88t, 91
Kelly's method, 87–88
Kernite, 452
Kinetics, of pyrometallurgical processes, 58–65

L

Ladle, 97–100, 104, 121, 124–125, 133–135
Lanthanum, 462–464
Laterite, 371–373
Lime, 491–494
Limestone, 480, 484, 492–494
Loparite, 415–416, 466
Low-carbon ferrochrome
nominal composition of, 294t
production, by aluminum reduction, 311t
slag compositions, 312t
technology of, 298–297
furnace method, 294t
off-furnace technology, 294–295
Low-carbon silicomanganese, production of, 258–259
Lump size distribution, 189–190

M

Magneli phases, 424
Magnesium, 480–485
production of, 483–485
properties of, 480–483
Magnesium-ferrosilicon (FeSiMg), 483–484
Magnetic concentration method, 286
Magnetite, titaniferrous, 401–405, 402t
Magneto-hydrodynamic (MHD) model, 159–160, 160f
Manganese, 10–11, 221–266
agglomeration of, 234–238
background of, 222
history of, 222
interaction with carbon, 223–225
interaction with other elements, 225–228
interaction with oxygen, 223–225
metal, production of, 253–256
minerals, 233t
ores, 229–234
compositions of, 235t, 237t
particle size distribution of, 236t
in oxide systems, 228–229
properties of, 222–223
in slags, 228–229
Manganese ferroalloys, 238–240
casting of, 259–260
composition of, 239t
crushing of, 260
high-carbon, 227
impurities in, 240, 241t
low-carbon, 227, 238–240, 246–247, 256–259
medium-carbon, 227, 238–240, 246–247
nitrided, 261–262

Manganese ferroalloys (*Continued*)
processing
energy use in, 262–263
operational hazards of, 263–265
sieving of, 261–262
smelting technologies for, 240–246
industrial practice, 242–246
reduction processes, 240–242
specifications of, 238–240. *See also* Ferromanganese
Manganese ore, sintering of, 129–130
Manganese oxide, 222–223, 237, 242–244, 250–253, 262
Manganese oxygen refining (MOR), 257–258
Manganite, 233t
Manganocalcite, 233t
Markets of ferroalloys, 17–22
Mass spectrometry (MS), 61–62
Mass transfer
convective, 71–72
diffusive, 70–71
Master alloys, 447
with aluminum, 496–498
composition of, 500t
boron, 454t
niobium-contained complex, 501t
tungsten, 377–378, 385
MatCalc, 53
Materials production, ferroalloy processes in, 35, 36f, 36t
Maxwell-Ampere law, 69–70
Maxwell-Stefan equation, 70–71
Medium-carbon ferrochrome
nominal composition of, 289, 291t
technology of, 297–299
Metallic chromium
nominal composition of, 308t
production, by aluminum reduction, 307–312
Metallic manganese, smelting of, 136, 136f
Metallic melts, 72–74
Metallurgical coke, 193
Metallurgical efficiency, of high carbon ferrochrome, 328–329
Metallurgical lime, 491–494
Metal tapping, 97–98
Meyer-Neldel rule, 76
Micro-alloying, 13
Minerals, 465–466
Minor ferroalloys, 31t
Mischmetal, 467
Mixing method, 294–295
Molten metal, hazardous and risk management of, 124–125
Molybdenite, 388–390, 392
concentrates, oxidative roasting of, 392–393
Molybdenum
concentrates of, 392
oxidative roasting, 392–393
ferromolybdenum, production of, 393–395, 394t
minerals of, 392
ores of, 392
properties of, 387–390
Molybdenum carbide, 388
Molybdenum oxide, 390
Molybdite, 392
Momentum source models, 158
Momentum transfer, convective, 71–72
Monazite, 466, 466t

N

Navier-Stokes equation, 71–72, 75
Nernst-Planck equation, 71–72
Net shape casting, 260
Nickel
ferronickel, 367–376
alloys, composition of, 372t
calcining, 372–373
casting of, 373–374
converting, 372, 374
oxidative roasting of, 372–373
refining of, 373–374
smelting of, 371–373
properties of, 367–369
raw materials, 371
Nickelboron, 456–457
smelting with aluminum reduction, charge composition of, 456t
Niobium, 499
-contained complex master alloys, 501t
ferroalloys, 416–419
minerals of, 415–416
properties of, 411–414
reduction of, 416
sources of, 415–416
Niobium oxide, 414, 416
Nitrided ferrochromium, 305
nominal composition of, 305t
Nitrided ferrovanadium, 408–409
Nitrided manganese ferroalloys, 261–262
Nodules, 371
Nondimensional numbers, 68t
Nonmetallic elements, ferroalloys with, 500–503

Nontronite, 371
Nusselt number, 68–69, 68t

O

Occupational health hazards, of high carbon ferrochrome, 331, 360–363
  dust, 362–363
  fumes, 362–363
  hexavalent chromium, 360–362
Ohm's law, 69–70, 166–167
Ohmic (joule) heating, 69–70
Oligonite, 233t
One-phase AC furnace circuit, 149–150, 149f
Open arc DC furnaces, 344–348, 346f, 349f
Open furnace, 92, 96
Open submerged arc AC furnaces, 331–333, 333f, 334f
Ores, 465–466
Orthosilicate, 475
Oxidation, 60–61, 69–70, 73
Oxide melts, 74–78
Oxide systems, manganese in, 228–229
Oxygen interaction with manganese, 222–229
Ozonide (CaO_6), 472

P

Pandat, 53
Particulate emissions, 170–173
Patronite, 402t
Pelletizing, 34, 84, 127–128, 132–133
  chromites, 287, 288t
  of manganese, 234–237
Perovskite, 425, 429, 432
Peroxide (CaO_2), 472
Petroleum coke, 194
Phase coupling, 168
Phase diagrams, equilibrium, 53–58
Phase reactance, 152
Phase resistance, 152
Phase shift, 140, 142, 144–146, 149
Phosphorus, 497–499, 501–502, 502f
Polycrystalline, 392
Polytypes, of silicon carbide, 184f, 193f
Post–tap hole processing, for FeMn/SiMn, 252–253
Povellite, 392
Power, of AC circuits, 145–146
Power control, 166
Power factor, 145–146, 148, 150, 153, 167–168
Prandtl number, 68t
Prebaked electrode, 116–118, 117t
  properties of, 117t
Preexponential factor, 75–76, 78
Preheating, of furnace feed materials, 131–132
Prereduction, 132–133
  of high carbon ferrochrome, 340–344
Production of ferroalloys, 9–12, 17–22
Programmable logic controller (PLC), 121–122, 123f
Pseudobrookite, 424
Psilomelane, 233t
Pyrochlore, 415–416, 418–419, 466
Pyrolusite, 222, 229–231, 233t, 235t
Pyrometallurgical (high-temperature chemical) processes
  kinetics of, 58–65
  thermodynamics of, 37–58
    chemical reactions, 45–53
    equilibrium phase diagrams, 53–58
    general considerations and definitions, 37–40
    solutions, 41–45
Pyroxene, 236–237

Q

Quartz, 186–191
  phase transformations, schematic of, 189t
Quartzite, 186–191
  materials, compositions of, 192t

R

Rabbling, 98–99
Radiation, 37
  heat transfer by, 66
Raoult reference state, 42–43
Rare-earth metals (REM), 459–470
  cerium, 464–465
  concentrates of, 465–466
  ferroalloys with, production of, 466–469
    reduction by aluminum, 468–469
    reduction by carbon, 467–468
  lanthanum, 462–464
  minerals, 465–466
  ores, 465–466
  properties of, 460t
  yttrium, 461–462
Raw materials, 6
Rayleigh number, 68t
Reactance
  circuits, 143–145
  phase, 152
Reaction mechanism, 59–60
Reaction rate, 60–61

Reactive losses, 30, 62–65, 69–70
Reactivity of silicon monoxide, 191, 194–195, 205, 210
Redlich-Kister-Muggianu polynomial, 54–55
Reductants, 320–326, 341
Reduction
  by aluminum, 32–33. *See also* Aluminum
  by carbon, 30–32. *See also* Carbon
  by silicon, 32. *See also* Silicon
Refining
  Creusot-Loire Uddeholm, 326
  of ferronickel, 373–374
  furnaces, 133, 136–137
  manganese oxygen, 257–258
  of medium-carbon ferrochrome alloys, 299
  operations, for low-carbon manganese ferroalloys, 256–259
    silicothermal reduction, 256–257, 257f
  of silicon, 200–201, 212–215
    trace elements distribution, 212–214
Refractory lining, 92–93, 93f
REM_2O_2S, 459–460
Resistance, phase, 152
Resistance-heating furnaces (RHFs), 139–140, 162
Resistive circuits, 143
Resistive heating, 160–161, 161t
Reynolds number, 68–69, 68t
Rhodochrosite, 229–231, 233t
Rhodonite, 228, 233t, 252
Risk management of furnaces, 122–126
  hazardous gases, 122–124
  high current, 125
  high voltage, 125
  molten metal, 124–125
  repairs and maintenance, 125–126
  slag, 124–125
  water, 125
Roasting, oxidative
  of chromium ferroalloys, 287–288, 314
  of ferromolybdenum, 392–393
  of ferronickel, 372–373
Root mean square (RMS) value, 142–143
Roscoelite, 402t
Rutile, 424–425, 429

S

Scheelite, 380–381, 381t, 383, 385, 392
Scrubber, 96
Segregation coefficient, 211–212, 212t
Selenium, 500, 503
Self-baking electrode, 110f, 111–116
Semiclosed submerged arc AC furnaces, 331–333, 333f
Sensitization phenomenon, 14–15
Shell cooling
  copper coolers, 103
  forced convection, 84–85, 93–94, 99, 102–103, 105
  natural convection, 84–85, 99
  water film, 84–85, 93–94
  water spray, 84–85, 93–94
Showa Denko (SDK) granulation, 352
Sieving of manganese ferroalloys, 261–262
Silica
  fume, 200, 202, 217–218, 219t
  sources of, 186–191
Silicate, 180–181, 205, 215, 217
  network structure, 75t
Silicides, 186, 212
Silicomanganese (SiMn), 250–252
  crude, 238–240, 250, 253–254, 256
  furnaces, 92–98, 127
  low-carbon, 258–259
  nitride, 261–262
  post–tap hole processing for, 252–253
Silicon, 11–12, 179–186
  atomizing of, 213t
  casting of, 211–212, 213t
  compositions of, 195–198, 197t
  equilibrium phase diagram of, 182f
  ferrotungsten reduction by, 382–385
  ferrovanadium reduction by, 405–407, 406t
  interaction with other elements, 181–186
  production, environmental issues associated with, 215–219
    emissions control, 217–219
    energy recovery, 215–217
  properties of, 180–181
  refining of, 200–201, 212–215
    trace elements distribution, 212–214
  smelting technology, 198–210
    basic principles of, 198–201
    costs of, 209–210
    energy demand for, 209–210
    parameters of, 207t
    reactions in furnace, 201–205
  solubuility of impurities in, 184, 185f
  world production of, 196, 196t
  yield, 209–210
Silicon carbide (SiC), 181, 258–259
  equilibrium phase diagram of, 183f
  polytypes, 184f, 193f
Silicon dioxide (SiO_2), 181
Silicon metal furnaces, 98–101

Silicon monoxide (SiO), 181
Silicothermal processes, 30, 32
Simultaneous thermal analysis (STA), 61–62
SINTEF reactivity test, 194
Sintered pellets production, 128–129
Sintering, 34
  chromites, 287, 287t
  of manganese, 129–130, 236–237
Slags, 74–78, 394–395
  electric conductivity of, 76–78
  ferroalloy process, 33
  granulation, 135
  handling of, 353
  hazardous and risk management of, 124–125
  -less ferroalloy process, 33
  manganese in, 228–229
  process, charge materials for, 302t
  silicate network structure formation in, 75t
  tapping, 97–98, 350–351
  utilization of, 353
  viscous properties of, 75–76
Smelting, 4, 12, 20–22, 34–35, 37, 74–75, 84–86
  of calcium carbide, 475–477
  of calcium-silicon alloy, 477–480
    reduction by calcium carbide, method of, 480
    reduction by carbon, method of, 477–478
    reduction by silicon, method of, 478–479
  electric, 11
  of ferromolybdenum, 393–395, 394t
  of ferronickel, 371–373
  of ferrosilicobarium, 490–491
  ferrosilicon, 198–210
    basic principles of, 198–201
    costs of, 209–210
    energy demand for, 207t, 209–210
    materials of, 207t
    parameters of, 207t
    peculiarities of, 205–207
    reactions in furnace, 201–205
  of low-carbon ferrochrome, 294t
  of manganese ferroalloys, 240–246
    industrial practice, 242–246
    reduction processes, 240–242
  silicon, 194, 198–210
    basic principles of, 198–201
    costs of, 209–210
    energy demand for, 209–210
    parameters of, 207t
    reactions in furnace, 201–205
  of strontium alloys, 487
  submerged arc AC furnaces, 340–344
Soda, 404
  treatment, 373
Söderberg electrode, 109, 110f, 111–116, 115f
  column, 115f
  paste, properties of, 113t
  zonal structure of, 112f
Sodium octaborate, 453t
Solid state reduction with carbon (SRC) process, 341
Specific heat, 66–68
Sphene, 424–425, 431
Spiegeleisen, 10–11
Steel development, ferroalloys in, 12–17
Steelmaking, 3–4, 6, 10
Stefan-Boltzmann law, 66
Stoking, 98–99
Strontianite ($SrCO_3$), 486–487
Strontium, 485–487
  alloys, smelting of, 487
  properties of, 485–487
Submerged arc, 86
  AC furnaces smelting, 340–344
  furnace (SAF), 12, 18, 22, 25, 139–140, 149, 152, 154–155, 160–162, 234, 242–243, 245–247, 250, 256
  operations, Kelly factors for, 88t
Sulfur, 502
Sulvanite, 402t
Supervisory control and data acquisition (SCADA) system, 121–122

T

Tantalum, 415–416
Tapping, 4
  alloy, 350–351
  of ferromolybdenum, 395
  of manganese ferroalloys, 252–253
  of silicon, 181–184, 201, 205, 218–219
  slag, 350–351
Tecnored process, 348–350
Tellurium, 503
Tephroite, 228, 233t
Theisen disintegrator, 355–356
Thermal analysis, 61–62
  differential, 61–62
Thermal conductivity, 65–66, 68–69
ThermoCalc, 53
  ThermoCalc R, 6
Thermodynamics, of pyrometallurgical (high-temperature chemical) processes, 37–58
  chemical reactions, 45–53

Thermodynamics, of pyrometallurgical (high-temperature chemical) processes (*Continued*)
equilibrium phase diagrams, 53–58
general considerations and definitions, 37–40
solutions, 41–45
Thermogravimetry (TG), 61–62
Thermo-mechanical controlled rolling process, 12
Three-phase AC furnace circuit, 151–153, 151f, 153f
Titaniferous magnetite, 401–405, 402t
Titanium
concentrates, chemical composition of, 428t
ferroalloys, 429–432
from oxides, reduction of, 429
properties of, 421–424
raw materials, 425–429
sources of, 425–429
Titanium carbide, 422, 429
Titanium oxide, 422, 428–430
Titanomagnetite, 425, 428t
Todorokite, 233t
Trace elements distribution, 212–214
Transformer power, 89, 91–92
Transformer-rectifier, 104–105, 107
Traveling grate technology, 237
Tridymite, 181, 189, 189t
Tungsten
concentrates of, 380–381
ferrotungsten, production of, 382–385
reduction by aluminum, 385
reduction by carbon, 382–385
reduction by silicon, 382–385
minerals of, 380–381
ores of, 380–381
properties of, 377–380
Tungsten carbide, 378–381, 383–384

U

Ulexite, 452
Ultra-low carbon ferrochrome, technology of, 303–305, 304f
Ulvospinel, 424

V

Vacuum argon decarburization (VOD), 326
Vacuum treatment, 296, 307
Vanadates, 400
Vanadiferous phosphate rock, 402t
Vanadinite, 402t
Vanadium
ferrovanadium, 405–407
composition of, 406t
nitrided, 408–409
reduction by aluminum, 407
reduction by silicon, 405–407, 406t
minerals of, 402t
properties of, 397–400
raw materials, treatment of, 402–405
chemical treatment, 404
metallurgical processing, 404–405
reduction from oxides, 405
sources of, 401–402
Vanadium pentoxide, 400, 404–407
Venturi-type scrubbers, 354–355, 355f
Vernadite, 233t
Viscosity, of slags, 75–76
Voltage, 140–143

W

Wastewater treatment, from chromium ferroalloys processing, 313–314
Water, hazardous and risk management of, 125
Westly's heat distribution coefficient, 165
Westly's method, 88–89
White condensate, 204
Wolframite, 380–381, 381t, 383, 392
Wulfenite, 392

X

Xenotime, 466
Xstrata Premus process, 341–344, 343f

Y

Yttrium, 461–462

Z

Zircon, 441–442, 444–446
Zirconia, 438–439, 441, 446
Zirconium
ferroalloys, 443–447
ferro-alumo-zirconium, 446–447, 446t
ferrosilicozirconium, 443–446
properties of, 435–441
reduction of, 441–443
sources of, 441–443
Zirconium carbide, 435–436, 442