

INDEX

- Access areas, sodium hypochlorite facilities design, 517
- Acid-chlorite solution, chlorine dioxide chemistry, 714–717
- Acid chrome violet potassium (ACVK) method, chlorine dioxide analysis, oxychlorine by-products, 751–752
- Acid ionization constant:
 - chlorine dissolution and hydrolysis, 70–74
 - hypochlorous acid dissociation, 74–77
- Acidity, chlorine, 142–144
- Activation energy, sodium hypochlorite degradation, 468–469
- Activity coefficients, hypochlorous acid dissociation, ionic effects, 78–80
- Administrative controls, ultraviolet light systems, 969
- Advanced oxidation processes (AOPs):
 - chemistry, 977–982
 - equipment and generation, 995–997
 - Fenton reaction, 980, 992–993
 - historical background, 976–977
 - hydroxyl radical generation, ultraviolet light, 979–980, 992
 - overview, 976
 - ozone decomposition:
 - hydrogen peroxide, 979, 990–991
 - hydroxide initiation, 978–979
 - ultraviolet photolysis, 979, 991–992
 - photo-Fenton reaction, 980–981, 992–993
 - potable water/wastewater treatment, 982–990
 - degreasers and solvents, 983
 - disinfection by-product precursor oxidation, 989–990
 - fuel oxygenates, 984–985
 - pesticide oxidation, 985–988
 - petroleum products, 984
 - taste and odor compound oxidation, 988–989
 - volatile organic carbon oxidation, 982–985
 - regulatory issues, 994–995
 - system classification, 977
 - system performance factors, 990–994
 - titanium dioxide:
 - hydrogen peroxide-ultraviolet reaction, 981–982
 - ultraviolet reaction, 981, 993–994
- Aeration systems, wastewater chlorination, odor control, 332–333
- Aerochlorination, wastewater chlorination, oil and gas removal, 349
- Aftercooler, ozone generation, 811
- Air-based systems, ozone generation, 800–804
 - cryogenic air separation, 809
 - preparation systems, 809–810
 - supplemental air, 829
- Air control devices, gaseous chlorine systems, 682–684
- Air pollution, wastewater chlorination, foul air scrubbing systems, 333–338

- Air requirement calculations, on-site sodium hypochlorite generation, 551
- Air stripping, hydrogen sulfide removal, 147
- Alachlor, oxidation, 987–988
- Alarm systems, on-site sodium hypochlorite generation, hydrogen formation, separation, and safety, 551–553
- Albuminoid nitrogen, defined, 118
- Aldehydes, ozone disinfection by-products, 795
- Algae and actinomycetes:
 - chlorine dioxide control of, 740
 - taste and odor from, 286–288
- Alkalinity:
 - aqueous chlorine, 142–144
 - cyanide wastes, industrial wastewater chlorination, 355–358
 - potable water chloramination and nitrification, 258
 - sodium hypochlorite degradation, 475
 - wastewater chlorination, ammonia removal, 351–352
- Alternative release analyses, risk management programs, chlorine storage, 46–47
- Alum, liquid waste processing, 361
- Amaranth method, chlorine dioxide analysis, oxychlorine by-products, 751
- Ambient temperature, ozone gas sources, 802
- American Water Works Association (AWWA):
 - available chlorine formation, 89–91
 - chlorine demand assessment, 245–247
 - chlorine impurities standards, 21–22
- Amines, chlorine-organic nitrogen reactions, 119–120
- Ammonia. *See also* Chloramines (chloramination)
 - breakpoint reaction and, 103–109
 - chlorination and chloramine formation, 94–103
 - dichloroamine/trichloroamine, 97–103
 - germicidal efficiency, 158–161
 - monochloramine, 95–97
 - organic nitrogen, 117–122
 - chlorine chemistry in seawater:
 - bromamine formation and decay, 127–129
 - ionic strength effects, 126–127
 - potable water chloramination, N reactions, 251
 - wastewater chlorination:
 - chemistry, 328
 - chlorine reactions, 379–382
 - dechlorination, 396–397
 - foul air scrubbing systems, 337–338
 - nitrified effluents, 385–390
 - removal, 349–352
- Ammonia-chlorine process:
 - potable water chloramination, 250–251
- Ammonia nitrogen. *See* Ammonia
- Ammonia-oxidizing bacteria (AOB), potable water chloramination, nitrification, 257–258
- Amperometric titration:
 - bromine residual compounds, 873
 - chlorination/dechlorination process controls:
 - history, 596–598
 - maintenance, 672–673
 - online analytical measurements, 598–599
 - chlorine dioxide analysis, oxychlorine by-products, 743
 - equivalence point, 744–747
 - Standard Methods* 4500-ClO₂-C, method I, 743–744
 - Standard Methods* 4500-ClO₂-C, method II, 744

- dissolved ozone in water
 - measurement, 841–842
- gaseous chlorine detection and
 - emergency scrubber, 686–687
- residual compound analysis:
 - back titration procedure, 202–204
 - Baker's alternative procedure, 208
 - chemical mechanisms, 194–195
 - development of, 176
 - dual-indicator-electrode titrator, 191–193
 - iodine solution monitoring, 204–205
 - low-level techniques, 200
 - measurement techniques, 187–208
 - nitrite interference, 205–208
 - nitrogen trichloride measurement, 204–205
 - operating principles, 188
 - single-indicator-electrode titrator, 188–190
- sulfur dioxide residuals, dechlorination
 - control systems, 656–657
- wastewater disinfection, chlorine
 - reaction with, 379–382
- Analytic Technology, Inc. chlorine
 - residual analyzers, chlorination/dechlorination process controls, 608–611
- Analyzer-detectors:
 - chlorination/dechlorination process controls, 594–596
 - dechlorination process, sulfur dioxide
 - leak detection, 589–591
 - residual analyzer maintenance and calibration, 681–682
- Aquatic life:
 - dechlorination toxicity, 573–574
 - potable water chloramination, 260–261
- Aqueous chlorine. *See also* Liquid chlorine
 - chlorine demand, 149–151
 - chlorine dioxide, 703–704
 - constituent reactions, 141–149
 - alkalinity, 142–144
 - arsenic, 145
 - carbon, 145–146
 - cyanide, 146
 - hydrogen sulfide, 146–147
 - iron and manganese, 147–148
 - methane, 148
 - nitrite, 148–149
 - free, combined, and available chlorine, 87–91
 - gas dissolution and hydrolysis, 68–74
 - germicidal significance, 151–161
 - chloramines, 155–161
 - hypochlorite ion, 154–155
 - hypochlorous acid, 153–154
 - inactivation mechanisms, 152–153
 - hypochlorite solutions, 82–85
 - hypochlorous acid dissociation, 74–80
 - ionic strength effects, 77–80
 - pH/temperature effects, 74–77
 - nitrogenous compounds, 91–122
 - ammonia chlorination and chloramine formation, 94–103
 - dichloroamine/trichloroamine, 97–103
 - monochloramine, 95–97
 - breakpoint reaction, 103–116
 - breakpoint curve, 105–109
 - chemistry and kinetics, 109–115
 - decomposition products, 115–116
 - historical background, 103–105
 - organic nitrogen, 116–122
 - breakpoint curve, 120–122
 - reaction mechanisms, 118–120
 - in water and wastewater, 92–94
 - oxidation-reduction reactions:
 - basic principles, 129–135
 - measurements, 135–141
 - oxidation states, 85–87
 - seawater chemistry, 122–129
 - bromamine formation and decay, 127–129
 - bromide effect, 123–126
 - ionic strength effects, 126–127
 - sodium hypochlorite, 454–455
 - solubility, 68–74, 1007
 - speciation in concentrated solutions, 81–82
 - wastewater treatment chemistry, 327–329
- Aquifer plugging, well restoration, 304–305

- Aquifer recharge, 299
- Arsenic, aqueous chlorine, 145
- Asbestos, chlorine electrolysis, diaphragm cells, 10–11
- Aspirating turbine mixers, ozone transfer, 821
- Assimilable organic carbon (AOC):
 - chlorine demand assessment, 246–247
 - ozone oxidation, 780
 - regrowth management, 270–271
- Atrazine, oxidation, 987–988
- Available chlorine solutions:
 - basic properties, 87–91
 - bromine residual measurement, 873
 - sodium hypochlorite concentrations, 455–457
 - feed system calculations, 456
 - wastewater disinfection, 376
- Bacillus anthracis*:
 - chlorine dioxide disinfection, 737–738
 - chlorine disinfection, 158
 - ozone disinfection, 790–792
- Bacillus subtilis*, ozone disinfection, 790–792
- Back amperometric titration
 - procedure, residual chlorine, 202–203
 - iodometric method II, 217–218
- Bacteria inactivation:
 - chlorination/dechlorination process
 - controls, oxidation-reduction potential, 605–606
 - chlorine dioxide, 706–711
 - bioterrorism applications, 737–738
 - chlorine disinfectants, mechanisms of, 152–153
 - dechlorination process, 576
 - potable water chloramination, 255–257
 - sulfate-reducing bacteria, 300–303
 - wastewater chlorination,
 - sludge bulking control, 342–343
- Baffled basin contactors, ozone transfer, 821–824
- Baker's procedure, residual chlorine analysis, amperometric titration, 208
- Ballasts, ultraviolet light systems, 924–925
- Ball valves, sodium hypochlorite storage and handling, 508–510
- Batch processing:
 - chlorine dioxide, design criteria, 723
 - sodium hypochlorite, 455
- Bayer MaterialScience Process, hydrochloric acid electrolysis, 20
- Beer-Lambert UV monitors, ozone concentrations in gas, 837–838
- Bell-jar chlorinator, chlorine impurities removal, 21
- Bench-scale generation, chlorine dioxide, 724
- Benzoic peroxide/dimethylaniline (BPO/DMA) cure system, fiberglass-reinforced plastic (FRP), sodium hypochlorite:
 - pipng, 504
 - storage tanks, 480
- Biamperometric titration, residual chlorine analysis, 192–193
- Bias in chlorine control, wastewater chlorination, 333
- Bicarbonate, ozone decomposition, hydroxyl radicals, 978–979
- Biochemical oxygen demand (BOD):
 - wastewater reuse, 399–400
 - wastewater treatment:
 - biological treatment systems, 382
 - chlorine chemistry, 328–329
 - odor control, 332–333
 - reduction, 339–340
 - septicity control, 347–348
 - viral inactivation, 375
- Biocide, chlorine as, 232, 234–235
- Biodosimetry data analysis, ultraviolet light systems, guidelines for, 940–941, 946–947, 952–953
- Biofilm formation, regrowth management, 267–268
- Biologically degradable organic carbon (BDOC), ozone oxidation, 780

- Biological phosphorus removal,
 - wastewater chlorination and odor control, 332–333
- Biological slime removal, wastewater chlorination, septicity control, 347–348
- Biological treatment:
 - wastewater chlorination, 338–345
 - BOD reduction, 339–340
 - sludge bulking control, 340–345
 - trickling filters, 338–339
 - wastewater disinfection, chlorine reaction with, 382
- Biologic filtration, ozone, 780–781
- Bioterrorism, chlorine dioxide disinfection, 737–738
- Bleach liquor, hypochlorite formation and, 453
- Bordon, Tomiyasu, and Fukutomi mechanism, ozone reaction, 770–771
- Bottled water, superchlor-dechlor processing of, 573–574
- Breakpoint curve:
 - aqueous chlorine, 105–109
 - organic nitrogen-chlorine reactions, 120–122
- Breakpoint reaction:
 - bromine chemistry, 851
 - chlorination/dechlorination process controls, 595–596
 - chemistry of, 664–670
 - chlorine chemistry in seawater,
 - bromamine formation and decay, 128–129
 - cyanide wastes, industrial
 - wastewater chlorination, 355–358
 - nitrogenous compounds, aqueous chlorine, 103–116
 - breakpoint curve, 105–109
 - chemistry and kinetics, 109–115
 - decomposition products, 115–116
 - historical background, 103–105
 - residual formation and, 175–179
 - wastewater chlorination, ammonia removal, 349–352
 - wastewater disinfection, nitrified effluents, 386–390
- Breakthrough phenomenon, regrowth management, 268
- Brine systems:
 - iodine production, 877
 - on-site sodium hypochlorite generation:
 - dilution appurtenances, 545
 - electrolytic formation, 531–534
 - layout and design, 560–565
 - metering pumps, 542
 - overview, 530
 - saturator tank, 537–539
- Briquette system, calcium hypochlorite, 519–520, 523–524
- Bromamine:
 - chemistry of, 851
 - chlorine chemistry in seawater,
 - formation and decay, 127–129
- Bromate:
 - as disinfection by-product, 245
 - on-site sodium hypochlorite generation, 530–531
 - ozone treatment, 777
 - disinfection by-products, 793–795
- Bromide:
 - chlorine chemistry in seawater, 123–126
- Bromimide, chlorine chemistry in seawater, 127–129
- Bromine:
 - chlorine chemistry, 852
 - in seawater, 122–129
 - broamine formation and decay, 127–129
 - bromide effect, 123–126
 - ionic strength effects, 126–127
 - in cooling water, 854
 - facility design, 854–855
 - germicidal efficiency, 869–870
 - health and safety aspects, 874–875
 - occurrence, 849
 - on-site generation:
 - advantages and disadvantages, 857–858
 - basic principles, 855–857
 - current U.S. practices, 857

- Bromine:** (*cont'd*)
 physical and chemical properties, 848, 887–888
 potable water treatment, 851–853
 production processes, 849–850
 residual compound measurement, 872–875
 in swimming pools, 854
 wastewater disinfection, 376–377
 chemical reactions, 851, 853
- Bromine chloride:**
 advantages and disadvantages, 865
 chemistry in water, 860–861
 cost issues, 865
 facilities layout, 861–865
 automatic controls, 864
 construction materials, 865
 current practices, 861–862
 evaporators, 864–865
 injector systems, 864
 metering and control equipment, 863–865
 safety equipment, 865
 solution lines and diffusers, 864
 storage and handling, 864
 system evaluation, 862–863
 germicidal efficiency, 869–870
 physical and chemical properties, 858–859, 888
 preparation, 859–860
- 1-Bromo-3-chloro-5,5-dimethylhydantoin (BCDMH):**
 application and production, 866
 chlorination vs., 867–869
 physical and chemical properties, 866, 888
 potable water treatment, 866
 wastewater disinfection, 377, 866–867
- Bromochloro-dimethyl hydantoin,**
 swimming pool systems, 854
- Bromoform,** wastewater disinfection
 by-product, 390–391
- Bromo-organic compounds,** 871–872
- Brush fires,** chlorine leaks, 59
- Bulkhead fittings,** high-density
 polyethylene storage tanks,
 sodium hypochlorite,
 481–483
- Buna N rubber (BNR),** sodium
 hypochlorite storage and
 handling, gaskets, seals, and
 o-rings, 506
- Butterfly valves,** chlorine feeders, 449
- Calcium:**
 on-site sodium hypochlorite
 generation, water softening
 systems, 532–535
- Calcium carbonate,** on-site sodium
 hypochlorite generation,
 water softening systems,
 534–535
- Calcium hypochlorite:**
 applicable standards, 524
 aqueous chlorine solutions,
 82–85
 basic properties, 518–522
 chlorine dissolution and hydrolysis,
 68–74
 disinfection, 521–522
 hazard analysis, 463, 523
 history of, 453, 518–519
 manufacturing process, 520–521
 solubility, 522–523
 stability, 523
 tablet and briquette systems,
 523–524
 wastewater disinfection, 376
- Calculated dose approach,** ultraviolet
 light systems, dose
 calculations, 937
- Capital Controls online analyzers:**
 chlorination/dechlorination process
 controls, 614–619
 dechlorination process control,
 662–663
- carbofuran,** oxidation, 987–988
- Carbon.** *See also* Assimilable organic
 carbon; Granular activated
 carbon
 aqueous chlorine and, 145–146
 bromine chemistry, 872
 wastewater treatment, viral
 inactivation and adsorption
 of, 373–375
- Carbonate,** ozone decomposition,
 hydroxyl radicals, 978–979

- Carbon dioxide:
 - chlorine dissolution and hydrolysis, 74
 - wastewater chlorination and hydrogen sulfide, 335–338
 - well restoration, 306
- Carbon tetrachloride:
 - chlorine impurities and, 21
 - wastewater disinfection by-product, 393–394
- Carboxylic acids, ozone disinfection by-products, 795
- Carelessness, chlorine leaks, 60–61
- Catalytic agents, sodium hypochlorite degradation, 467–469
- Caustic-and-chlorine scrubber:
 - gaseous chlorine detection and emergency scrubber, 686–687
 - wastewater chlorination, foul air scrubbing systems, 334–338
- Central European validation protocols, ultraviolet light system guidelines, 947–948
- Chemical metering pumps, sodium hypochlorite transfer, 488–489
- Chemical oxygen demand (COD):
 - biological solids, ozone treatment, 786
 - wastewater chlorination:
 - biological treatment systems, 381
 - viral inactivation, 375
- Chemical Transportation Emergency Center (CHEMTREC), chlorine emergencies, 64–65
- Chemistry of chlorination, process control systems, 663–670
- Chile saltpeter, iodine production, 876
- Chlor-alkali plant, chlorine electrolysis, process diagram, 15–17
- Chloramines (chloramination):
 - ammonia chlorination, 94–103
 - dichloroamine/trichloroamine, 97–103
 - monochloramine, 95–97
 - bromine reactions, 852
 - chlorine demand and, 150–151
 - combined chlorine formation of, 87–91
 - defined, 94–95
 - germicidal efficiency, 155–161
 - organic nitrogen and formation of, 182–184
 - organic nitrogen reactions, 118–120
- potable water disinfection, 248–263
 - ammonia-chlorine process, 250–251
 - ammonia N reaction chemistry, 251
 - aquatic life and, 260–261
 - efficiency concerns, 255–256
 - free chlorine residuals, 253–255
 - historical background, 248–250
 - kidney dialysis patients, 260
 - lead concentrations, 261
 - limitations, 253
 - nitrification, 256–260
 - shock-chlorination, 260
- residual compound testing, 185–186
- wastewater chlorination:
 - chemistry, 328–329
 - disinfection by-products, 393–394
- wastewater disinfection, chlorine reaction with, 381–382
- Chlorate ions:
 - chlorine dioxide disinfection, 731–734
 - regulatory guidelines, 755
 - sodium hypochlorite:
 - degradation, 85, 463–464
 - processing, 455
 - sodium hypochlorite degradation, 476
- Chlorate systems, chlorine dioxide electrochemistry, 722
- Chlor-A-Vac™, chlorine contact systems design, 408–409
- Chlorinated lime:
 - chlorine dissolution and hydrolysis, 68–74
 - wastewater treatment, 326–327
- Chlorinated polyvinyl chloride (CPVC)
 - pipe, sodium hypochlorite:
 - basic properties, 501–502
 - storage tank linings, 478
 - valves, 505–506
- Chlorinate polyvinyl chloride (CPVC)
 - pipe, sodium hypochlorite:
 - chemical properties, 460
 - failure of, 460
 - pressure rating, 499
 - thermofusion welding, 499
 - threaded connections, 501–502

- Chlorination-dechlorination process:
 chlorine contact system design, dose levels, 405
 disinfection by-products, 247–248
- Chlorination systems. *See also* Potable water treatment; Wastewater treatment
- 1-bromo-3-chloro-5,5-dimethylhydantoin vs., 867–869
- chlorine leaks in, 55–57
- historical background, 174–175
- iodination vs., 884
- oxidation-reduction, chlorine compounds, 139–141
- ozone by-products control, 779–780
- residual compound analysis, 185
- seawater chlorination, bromine in, 874
- Chlorine compounds. *See also* Aqueous chlorine; Gaseous chlorine; Liquid chlorine
- annual production, 62–63
- available chlorine content, 90–91
- bromine reactions with, 852
- consumer accidents, 52–62
- dissolution and hydrolysis, 68–74
- end uses, 62–64
- gas, 1–2
- health and safety requirements, 753
- leaks, 33–41
 brush fires, 59
 definitions, 33–34
 emergency guidelines for, 64–65
 fire and building codes, 34
 flash-off phenomenon, 34–35
 frequency and magnitude, 59–62
 fusible plug blowout, 40
 fusible plug corrosion, 39–40
 PVC header failure, 38–39
 rate calculations, 35–36
 tanker truck unloading, 36
 ton containers:
 flexible connection failure, 39
 guillotine pipeline break, 36–38
- liquid, 2
- manufacturing processes, 2–4
 electrolytic cells, 3–17
 cell design and maintenance, 5
 cell development, 4–5
 chlor-alkali plant, 15–17
 diaphragm cells, 8–11
 history, 3–4
 hydrochloric acid solutions, 20
 membrane cells, 5–8
 mercury cells, 11–15
 hydrochloric acid oxidation, 18–20
 impurities:
 consequences of, 22
 historical background, 20–22
 nitrogen trichloride, 23
 silica contamination, 24
 salt process, 18
 organic nitrogen reactions, 118–120
 ozone treatment, 776–777
 physical and chemical properties, 24–30
 chemical reactions, 29–30
 compressibility coefficient, 25–26
 critical properties, 24–25
 latent heat of vaporization, 27
 vapor density, 27
 vapor pressure, 27
 volume-temperature relationship, 26
 specific heat, 27
 taste and odor, 289–290
 toxic effects, 30–31
 first aid, 31–32
 intentional chlorine release, 32–33
 intentional release, 32
 physiological response, 32
 transport accidents, 47–52
 highway transportation, 51–52
 railroad transportation, 47–51
- Chlorine demand. *See also* Biochemical oxygen demand (BOD)
- aqueous chlorine, 149–151
- chlorination/dechlorination process
 controls, 667–670
 disinfection by-products, 245–247
 feedback control systems, 644–647
 wastewater chlorination:
 chemistry, 328–329
 foul air scrubbing systems, 334–338
 prechlorination and odor control, 331–333
- Chlorine dioxide:
 advantages and disadvantages, 755–756
 basic properties, 700

- biocidal applications, 702–703
- chemical properties, 703–704
- disinfection applications, 727–738
 - algae growth control, 740
 - chlorate, 731–734
 - chlorite, 729–731
 - combined sewer overflow, 735–736
 - contactor design criteria, 728
 - diffusers and injectors, 728
 - disinfection by-products, 729, 740
 - food processing, 736–737
 - iron and manganese oxidation, 739–740
 - medical devices, 736
 - pathogen detection, 737–738
 - potable water treatment, 727–728
 - secondary disinfection, 734
 - taste and odor control, 734–735, 738–739
 - taste and odor formation, 734–735
 - TTHMs and HAAs, 734
 - ultraviolet exposure, 728–729
 - wastewater effluent, 735
 - zebra mussels control, 740
- encrusted parasites, 711–712
- European practices, 701–702
- generation and equipment, 712–726
 - acid-chlorite solution, 714–717
 - batch-scale generation, 724
 - batch tank, 723
 - chlorate-based systems, 722
 - chlorine-chlorite solution, 717–718
 - commercial methods, 713–714
 - electrochemical methods, 720–722
 - feed design criteria, 722–723
 - gaseous chloride-chlorite solution, 719
 - gaseous chloride-solid chlorite, 720, 726
 - hydrochloric acid, 717
 - hypochlorite electrochemistry, 722
 - potassium persulfate-chlorite solution, 724–725
 - purity, 713, 723–724
 - sodium hypochlorite-hydrochloric acid-chlorite solution, 725–726
 - storage, 723
 - sulfuric acid-chlorite solution, 725
 - three-chemical systems, 718–719
 - germicidal efficiency, 705–706
 - health and safety issues, 752–754
 - historical background, 700–701
 - oxidant selectivity, 705
 - oxychlorine by-products analysis, 740–752
 - amperometric titration, 743–747
 - colorimetry, 751–752
 - diethyl-*p*-phenylenediamine titration, 747–748
 - flow injection analysis, 750
 - iodometry, 742
 - ion chromatography, 749
 - Lissamine Green B dye, 748
 - spectrophotometry, 749–750
 - ozone treatment, 776–777
 - disinfection by-products, 794–795
 - potable water treatment chemistry, 704–705
 - regulatory issues, 754–755
 - viral/bacterial inactivation, 706–711
 - wastewater disinfection, 376

Chlorine impurities, 20–22

Chlorine pressure-reducing valve (CPRV), gaseous chlorine system operations, 682–684

Chlorine solution-chlorite solution, chlorine dioxide chemistry, 717–718

Chlorine-sulfide reaction, wastewater chlorination, prechlorination, 331–333

Chlorine-to-ammonia ratio, oxidation-reduction, 137–141

Chlorine-to-nitrogen ratio:

 - breakpoint reaction, 103–109
 - chlorine-organic nitrogen reactions, 120–122
 - dichloramine/trichloramine formation, 98–103
 - monochloramine formation, 96–97

Chlorite ions:

 - chlorine dioxide, viral and bacterial inactivation, 708–711
 - chlorine dioxide by-products, 729–731
 - regulatory guidelines, 755

Chlorobutyl rubber linings, sodium hypochlorite storage tanks, 479

- Chloroform, wastewater disinfection by-product, 390–391
- 4-Chloro-2 nitrophenol, oxidation of, 988
- Chloro-oxidation, phenolic wastes, industrial wastewater chlorination, 359–360
- Chlorophenol red (CPR) method, chlorine dioxide analysis, oxychlorine by-products, 751
- Chloropicrin, potable water chloramination, 262
- Class A biosolids, ozone treatment, 786
- Cleaning systems, ultraviolet light systems, 927–928
- Clortec on-site sodium hypochlorite generation systems, 565–566
- Closed vessel reactors, ultraviolet light systems, 921–924
- Clostridium botulinum*, ozone disinfection, 790–792
- Coagulation:
 - potable water chlorination, 293
 - surface water disinfection, 310–311
- Coliform bacteria:
 - chlorine dioxide inactivation, 709–711
 - ozone treatment, 787–792
 - regrowth management, 269–270
 - wastewater treatment standard for, 363–368
 - chlorine dose and effluent quality, 383–384
- Collimated beam analysis, ultraviolet light systems, guidelines for, 938–940, 945–946, 952
- Colorimetric methods:
 - chlorination/dechlorination process controls:
 - history, 596–598
 - online analytical measurements, 606–607
 - chlorine dioxide analysis, oxychlorine by-products, 751
 - vs. titrimetric methods, 180
 - amperometric titration, 193–194
 - diethyl-*p*-phenylenediamine (DPD) colorimetric method, 210–211
- Color removal:
 - ozone, 782
 - potable water treatment, 303
- Combined chlorine solutions:
 - basic properties, 87–91
 - breakpoint curve chemistry and kinetics, 111–115
 - bromine residual compound measurement, 873
 - chlorine demand and, 150–151
 - dechlorination process, 576–577
 - germicidal efficiency, 155–161
 - residual chlorine analysis:
 - amperometric techniques, 197–199
 - DPD method, 208–214
 - iodometric method I, 215–217
- Combined cyanides, industrial wastewater chlorination, 352–358
- Combined sewer overflow (CSO), chlorine dioxide, 735–736
- Compound loop control:
 - dechlorination control systems, 654–655
 - online chlorination analyzers, 647–653
- Compressibility coefficient, chlorine, 25–26
- Compressor systems, ozone generation, 810–811
- Computational fluid dynamics:
 - ozone drinking water treatment, 787–789
 - ultraviolet light systems, 959–960
- Concave head design, ton containers, chlorine feed systems, 424–427
- Concentrated chlorine solutions:
 - sodium hypochlorite, 455–457
 - speciation, 81–82
- Concentration effects, sodium hypochlorite:
 - basic chemistry, 455–457
 - degradation, 466–467
- Concrete storage tanks, sodium hypochlorite, 483
- Consensus indicator organisms:
 - chlorine disinfectants, 236
 - coliform standard, wastewater treatment, 366–368

- Constituent reactions:
 - aqueous chlorine, 141–149
 - alkalinity, 142–144
 - arsenic, 145
 - carbon, 145–146
 - cyanide, 146
 - hydrogen sulfide, 146–147
 - iron and manganese, 147–148
 - methane, 148
 - nitrite, 148–149
 - wastewater disinfection, 379–382
- Construction materials, bromine chloride facilities, 865
- Contact systems:
 - chlorine processing:
 - automated process control, 638
 - chlorine dioxide, potable water treatment, 728
 - dechlorination process:
 - sulfite compounds, 582–583
 - sulfur dioxide, 580–581
 - design criteria:
 - chamber sizing, 411–413
 - chlorination/dechlorination doses, 405
 - construction guidelines, 417
 - disinfection by-products, 417
 - dispersion process, 405–406
 - mixing technologies, 406–411
 - no-tracer test design, 416
 - overview, 404
 - potable water, 414–416
 - reuse water, 413
 - sampling and reporting, 417
 - wastewater flow, 413
 - wet weather wastewater disinfection, 416–417
 - ozone transfer:
 - baffled basins, 822–824
 - design criteria, 821–826
 - layout, 819
 - pipeline systems, 824–826
- Container failures, chlorine leaks, 61–62
- Container-mounted vacuum regulator,
 - gas chlorine feed system, 440–442
- Continuously stirred tank reactor (CSTR) method, ozone disinfection process, 789
- Continuous processing, sodium hypochlorite, 455
- Contour plates, sodium hypochlorite transfer, 491
- Control systems:
 - bromine chloride facilities, 863–864
 - chlorination/dechlorination:
 - amperometry, 598–599
 - basic principles and applications, 594–596
 - chemistry/process control combination, 663–670
 - colorimetry, 606–607
 - compound loop control, 647–655
 - dechlorination process control, 653–657
 - feedback control, 644–647, 654
 - flow pacing, 641–645, 654
 - historical background, 596–598
 - manual control, 638–639
 - membrane cell, 600
 - online chlorination analyzers, 607–633
 - Analytical Technology, Inc., 608–611
 - Capital Controls, 614–619, 662–663
 - dechlorination analysis, 657–663
 - field comparisons of, 629–633
 - GLI International, 619–620
 - Hach CL17 analyzer, 611–614
 - Orion Research, Inc., 620–621
 - process review, 633–637
 - selection criteria, 631–633
 - Stranco HRR, 657–658
 - Stranco Products, 622–629
 - Wallace & Tiernan, 621–622, 658–662
 - operation and maintenance, 670–673
 - oxidation-reduction potential, 602–606
 - polarography, 599–600
 - potentiometry, 600–602
 - process control, 634–653
 - record keeping and regulatory issues, 673–676
 - voltametry, 599
 - zero residual control, 655–657

- Control systems: (*cont'd*)
 gaseous chlorine system operations, 682–684
 sodium hypochlorite facilities design, 518
 ultraviolet light systems, 965–966
 health and safety issues, 967–970
- Conversion factors table, 1008
- Cooling water:
 bromine chloride chemistry, 861
 bromine treatment, 854
 ozone generation, 829–831
- Copper:
 chlorine corrosion, pipe line leaks, 60
 cyanide wastes, industrial wastewater chlorination, 357–358
 sodium hypochlorite impurities and degradation, 472
- Copperas, textile wastes, industrial wastewater chlorination, 360–361
- Corona discharge generators, ozone generation, 799–800
- Corrosion:
 chlorine, aqueous solutions, 30
 chlorine leaks, fusible plug failure, 39–40
 ozone, 768
 potable water chlorination, regrowth management and, 271–272
 sulfur dioxide, dechlorination process, 578–579
- Cost studies:
 bromine chloride facilities, 865
 iodine production, 885–886
 ozone generation, 831–832
- Countercurrent packed tower design, wastewater chlorination, foul air scrubbing systems, 333–338
- Countercurrent transfer cells, ozone disinfection process, 788–789
- Critical density, chlorine, 24–25
- Critical temperature, chlorine, 24–25
- Cross-linked polyethylene, high-density polyethylene storage tanks, sodium hypochlorite, 481–483
- Cryogenic air separation, ozone generation, 809
- Cryptosporidium* pathogens:
 advanced oxidation processes, 994–995
 chlorine dioxide inactivation, 711–712
 chlorine disinfectants, 235–241
 ozone treatment, 787–792
 baffled basin contactors, 823–824
 ultraviolet light systems, potable water treatment, 896
- CT criteria. *See also* Selleck-Collins wastewater disinfection model
 advanced oxidation processes, 994–995
 chlorination/dechlorination process controls, 638
 chemistry and, 666–670
 chlorine contact system design, 404
 chlorine dioxide, 728
 chlorine dioxide:
 contact system design, 728
 encrusted parasites, 711–712
 chlorine disinfectants:
 biocidal properties of chlorine, 234–235
 Interim Enhanced Surface Water Treatment Rule, 238–239
 mechanisms of, 153, 157–161
 protozoa inactivation, 235
 virucidal properties, 235
 ozone disinfection process, 787–792
 baffled basin contactors, 823–824
 potable water chloramination, 255–257
 Surface Water Treatment Rule and, 236–238
 wastewater treatment, chlorine dose and effluent quality, 382–384
- Cyanate:
 aqueous chlorine, 146
 cyanide wastes, industrial wastewater chlorination, 354–358
- Cyanide, aqueous chlorine, 146
- Cyanides, industrial wastewater chlorination, 352–358
- Cyanogen chloride:
 cyanide wastes, industrial wastewater chlorination, 353–358
 formation of, 146
 potable water chloramination, 262

- Cyanotoxins, ozone treatment, 785–786
- Cylinders:
 - chlorine feed systems, 420–424
 - gas chlorine storage, operation and maintenance, 693–694
- Daily microscopic evaluation,
 - wastewater chlorination, sludge bulking control, 342–345
- Dark repair mechanism, UV-inactivated microorganism repair, 902
- Data recording guidelines, ultraviolet light systems, 937–938, 945, 951–952
 - collection systems, 965
- Davies equation, hypochlorous acid dissociation, ionic effects, 78–80
- Deacon process, chlorine manufacturing:
 - early history, 3
 - hydrochloric acid oxidation, 19
- Dead-end area surveillance, potable water treatment and distribution, 275
- Deamination, organic nitrogen reactions, 118–120
- Decay coefficient, chlorine demand, 151
- Dechlorination:
 - activated carbon, 583–585
 - carbon and, 146
 - chlorine contact systems design, chlorination/dechlorination doses, 405
 - chlorine speciation, 576–577
 - defined, 572
 - facility design, 585–593
 - gaseous system sulfur dioxide, 586–589
 - sulfite liquid system design, 592–593
 - sulfur dioxide leak detectors, 589–591
 - gas system operation and maintenance, 690–692
 - history, 572–574
 - hydrogen peroxide, 583
 - liquid system operation and maintenance, 692–693
 - process control systems, 653–657
 - Capital Control, 662–663
 - online analyzers, 657–663
 - Stranco HRR system, 657–658
 - Wallace & Tiernan, 658–662
 - sulfite compounds, 581–583
 - chemical properties, 581–582
 - contactor design, 582–583
 - dose calculations, 583
 - facility design, 592–593
 - sulfur dioxide:
 - chemical properties, 577–581
 - contactor design, 580–581
 - dose calculations, 581
 - facility design, 586–591
 - trichoramine formation, 102–103
 - wastewater disinfection, 396–397
- Decomposer tower, mercury cells, chlorine electrolysis, 14
- Decomposition products:
 - breakpoint reaction, 115–116
 - chlorine demand, 151
 - sodium hypochlorite, 459–460
- Degas separation, ozone transfer, sidestream injectors, 818–820
- Degradation mechanisms, sodium hypochlorite, 463–477
 - concentration effects, 466–468
 - impurities, 471–475
 - pH effects, 469–470
 - rate estimation, 464–466
 - recommendations and guidelines, 476–477
 - settled particulates, 473–474
 - sodium bromate, 475
 - sodium carbonate, 474
 - suspended solids, 473
 - temperature effects, 468–469
 - ultraviolet light effects, 470–471
- Degreasers, advanced oxidation, water treatment systems, 983
- Density, chlorine, 27
- Desalination, water chlorination, 303–304

- Design Manual for Municipal Wastewater Disinfection*, ultraviolet light systems guidelines, 908–909, 950–953
- nonbiological, mathematical-based modeling, 955–958
- Dessicant dryer, ozone generation, 811
- Destruction equipment, ozone discharge, 826–829
- off-gas reuse, 828–829
- thermal catalytic destruction, 826–828
- thermal destruction, 828
- Detection limits, residual chlorine analysis:
- amperometric techniques, 200
 - comparison of methods, 181
- Diaphragm cell, chlorine electrolysis, 8–11
- Diaphragm metering pumps, sodium hypochlorite transfer, 486–493
- Diaphragm valves:
- chlorine feeders, valve systems and, 448–449
 - sodium hypochlorite storage and handling, 510–513
- Dibromamine:
- chlorine chemistry in seawater, 127–129
 - germicidal efficiency, 869–870
 - residual chlorine measurement, 872–875
- Dichloramine:
- ammonia chlorination, 97–103
 - breakpoint curve, 106–115
 - chemistry and kinetics, 109–115
 - combined chlorine formation of, 87–91
 - dechlorination process, 576–577
 - germicidal efficiency, 155–161
 - residual chlorine analysis, 186
 - amperometric titration, 198
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate technique, 212
 - wastewater disinfection, nitrified effluents, 385–390
- Diethyl-*p*-phenylenediamine (DPD) titration:
- bromine residual compounds, 873–874
 - chlorination/dechlorination process controls, history, 596–598
 - chlorine dioxide analysis, oxychlorine by-products, 741–742, 747–748
 - dechlorination, 577
 - residual compound analysis, 176–177
 - basic techniques, 208–214
 - breakthrough phenomenon, 213
 - colorimetric method, 210–211
 - combined ferrous ammonium sulfate (DPD-FAS) method, 211–214
 - free chlorine measurement, 178–179, 212
 - manganese interference, 213–214
 - monochloramine/dichloramine, 212
 - nitrogen trichloride, 212
 - spectrophotometric method, 211
 - total residual chlorine, 212–213
 - wastewater disinfection, chlorine reaction with, 381
- Differential transmitters, gaseous chlorine system operations, 683–684
- Diffusers:
- bromine chloride facilities, 864
 - chlorine dioxide systems, 728
 - chlorine feeder systems, 444–445
- Dihaloacetic acids, potable water chloramination, 262
- Dilution blower systems, on-site sodium hypochlorite generation, 553–556
- Dimensionally stable anodes (DSA), chlorine electrolytic process, 5
- Direct filtration systems, wastewater chlorination, viral inactivation, 372–375
- Disinfectants/Disinfection By-Products Rule (DBPR), chlorine disinfectants, 238–239
- Disinfection by-products (DBPs):
- advanced oxidation processes, precursor oxidation, 989–990, 995
 - bromo-organic compounds, 871–872
 - chloramine residual analysis, 186

- chlorination/dechlorination process
 - controls, overview, 594–598
- chlorine contact system design, 417
- chlorine dioxide, 729–736
 - chlorate, 731–734
 - chlorite, 729–731
 - combined sewer overflow, 735–736
 - organic compounds, 734
 - preoxidation control, 740
 - regulatory guidelines, 755
 - taste and odor formation, 734–735
 - wastewater effluents, 735
- ozone:
 - aldehydes, carboxylic acids, and ketones, 795
 - bromate control, 793–795
 - control using, 779–780
 - generation of, 792–795
- potable water treatment, 243–248, 261–262
 - bromate, 245
 - chloramination, 261–262
 - chlorination-dechlorination, 247–248
 - chlorine demand, 245–247
 - chlorine dioxide, 729
 - haloacetic acids, 244
 - long-term effects, 232–234
 - total organic halides, 244–245
 - trihalomethanes, 243–244
- trichloramine formation, 103
- wastewater treatment, 390–394
 - water quality, 340–341
- Disinfection process:
 - calcium hypochlorite, 521–522
- chlorine contact systems design:
 - potable water, 414–416
 - wastewater, 413
- chlorine dioxide:
 - food processing, 736–737
 - medical devices, 736
 - pathogen attacks (bioterrorism), 737–738
 - potable water treatment, 727–728
 - secondary disinfection, 734
 - viral and bacterial inactivation, 706–711
- feed systems, 279–280
- free chlorine chemistry, 279
- ozone:
 - potable water treatment, 787–789
 - wastewater treatment, 790–792
- potable water treatment, 240–248
 - application points, 242–243
 - biocidal properties, 232, 234
 - bromate, 245
 - building disinfection, 283
 - by-products, 243–248, 261–262
 - chloramination, 248–263
 - ammonia-chlorine process, 250–251
 - ammonia N reaction chemistry, 251
 - aquatic life and, 260–261
 - efficiency concerns, 255–256
 - free chlorine residuals, 253–255
 - historical background, 248–250
 - kidney dialysis patients, 260
 - lead concentrations, 261
 - limitations, 253
 - nitrification, 256–260
 - shock-chlorination, 260
- chlorination-dechlorination, 247–248
- chlorine contact systems design, 414–416
- chlorine demand, 245–247
- chlorine dioxide, 727–728
- consensus indicator organism, 236
- Disinfectants/Disinfection
 - Byproducts Rule, 239
- gas and liquid chlorine, 243
- gaseous and liquid chlorine, 243
- Ground Water Rule, 240
- haloacetic acids, 244
- historical background, 241–242
- Interim Enhanced Surface Water Treatment Rule, 238–239
- Long-Term 1 and 2 Enhanced Surface Water Treatment Rules, 239–240
- protozoa inactivation, 235
- regrowth management and, 271
- Safe Drinking Water Act
 - requirements, 236
- secondary disinfectants, 275–276
- Surface Water Treatment Rule, 236–238
- total organic halides, 244–245

- Disinfection process: (*cont'd*)
 trihalomethanes, 243–244
 virucide applications, 235
 storage tanks, 282
 ultraviolet light systems:
 chemical and biological properties, 897–898
 in Europe, 893–894
 in North America, 895–896
 in United Kingdom, 308–309
 wastewater treatment:
 by-product formation, 390–394
 chlorination, basic principles, 328–329
 chlorine chemistry, 379–390
 constituent reactions, 379–382
 dose and effluent quality, 382–384
 nitrified effluent chlorination, 384–390
 chlorine contact systems design, 413
 coliform standard, 364–368
 dechlorination indications, 396–397
 history, 363–364
 methods and techniques, 357–378
 organism regrowth, 394–395
 residual chlorine toxicity, 395–396
 viruses, 368–375
 water mains, 281
 water treatment plants, 282–283
- Dispersion:
 chlorine contact systems design, 405–406
 risk management programs, chlorine storage, 47
 ultraviolet light systems guidelines, nonbiological, mathematical-based modeling, 956–958
- Disproportionation reaction:
 breakpoint curve chemistry and kinetics, 110–111
 chlorine demand, 150–151
 chlorine gas dissolution and hydrolysis, 70–74
- Dissolved organic carbon (DOC), ozone removal, 780–782
- Dissolved oxygen (DO) concentrations:
 dechlorination process, 576
 sulfur dioxide, 580
 hydrogen sulfide control, 301–303
 potable water chloramination and nitrification, 258
 wastewater chlorination and biological treatment, 338–339
- Dissolved ozone decay, 772–773
 quench chemicals, 836
 residual measurement in water, 839–842
- Distribution system, potable water treatment, 263–279
 flushing, 278
 monitoring, 273–275
 operation, 272–273
 regrowth management, 266–272
 bacterial growth, 268
 biofilm formation, 267–268
 breakthrough, 268
 coliforms, 269–270
 corrosion and sediment accumulation, 271–272
 disinfectant residuals, 271
 environmental factors, 270
 nutrient availability, 270–271
 regulatory compliance, 264–265
 secondary disinfectant residuals, 275–276
 treatment plant performance and water quality, 279
 water age control, 275–276
- Dose calculations:
 chlorine contact systems design, 405
 dechlorination process:
 sulfite compounds, 583
 sulfur dioxide, 581
 ozone generation, 835
 ultraviolet light systems:
 challenge microorganisms, dosing guidelines for, 933–935, 943–944, 951
 collimated beam analysis, 938–940
 dose-monitoring methods and validation test conditions, 936–937, 945–946, 951
 microorganism inactivation, 902–904
 wastewater disinfection, effluent quality and, 382–384
- Drinking water. *See* Potable water treatment

- Drinking Water Systems Center, ultraviolet light system guidelines, 948–949
- Drop dilution method, residual chlorine analysis, 222–223
- Dry sensors, ultraviolet light systems, 926–927
- Dual-indicator-electrode titrator, amperometric titration, residual chlorine analysis, 191–193
- Duplex water-softening systems, on-site sodium hypochlorite generation, 536–537
- Dyed microspheres, ultraviolet light systems, 960–961
- E. coli* bacteria:
 - coliform standard, wastewater treatment, 365–368
 - ozone treatment, 787–792
- Economic issues, wastewater chlorination, septicity control, 347–348
- Eductors, and chlorine feed systems, 442–451
 - diffusers, 444–445
 - pipe and valve systems, 445–449
 - scrubbers, 450–451
- Efficiency criteria:
 - ozone generation, 834–835
 - ozone transfer, sidestream injectors, 818
 - potable water chloramination, 255–256
- Effluent standards:
 - chlorination/dechlorination process controls:
 - chemistry and, 665–670
 - history, 596–598
 - coliform standard, wastewater treatment, 365–368
 - wastewater chlorination:
 - biochemical oxygen demand reduction, 339–340
 - dose and, 382–384
 - nitrified effluents, 384–390
- EFV valves, chlorine storage and leak prevention, 58
- Electrical system modification, ultraviolet light systems, 965–966
- Electrochemistry:
 - bromine production, 849–850
 - chlorine dioxide, 720–722
 - ozone concentrations in gas, 838
- Electrode design:
 - amperometric titration, residual chlorine analysis, 193
 - chlorination/dechlorination
 - process controls, oxidation-reduction potential, 603–606
 - oxidation-reduction potential measurement, 135–141
- Electrodeless mercury vapor lamps, ultraviolet light systems, 914–917
- Electrolysis:
 - bromine production, 849–850
 - chlorine manufacture:
 - cell design and maintenance, 5
 - cell development, 4–5
 - chlor-alkali plant, 15–17
 - diaphragm cells, 8–11
 - history, 3–4
 - hydrochloric acid solutions, 20
 - membrane cells, 5–8
 - mercury cells, 11–15
 - on-site sodium hypochlorite
 - generation systems, 531–534
 - cell components, 542–544, 563–564
- Electrolyzer, mercury cells, chlorine electrolysis, 14
- Elemental chlorine. *See* Chlorine; Gaseous chlorine; Liquid chlorine
- Elevation differences, sodium hypochlorite facility design, 513–514
- Encrusted parasites, chlorine dioxide inactivation, 711–712
- Endocrine-disrupting compounds (EDCs), ozone treatment, 784–785
- Engineering controls, ultraviolet light systems, 969

- Enteric viruses, wastewater disinfection
 - process, viral inactivation, 369–375
- Enteroviruses, wastewater disinfection
 - process, viral inactivation, 369–375
- Environmental factors, regrowth management, 270
- EPRG-2 values, risk management
 - programs, chlorine storage, 47
- Equipment failure, chlorine leaks, 61
- Equipment sizing:
 - on-site sodium hypochlorite generation layout, 557–558
 - ultraviolet light systems, 932
- Equivalence point, amperometric titration, chlorine dioxide analysis, oxychlorine by-products, 744–747
- Ethylene propylene (EPDM), sodium hypochlorite storage and handling, 506
 - diaphragm valves, 512
- Ethyl *tert*-butyl ether (ETBE),
 - advanced oxidation, water treatment systems, 984–985
- European water treatment systems, chlorine dioxide, 701–702
- Evaporators, bromine chloride facilities, 864–865
- Excimer lamps, ultraviolet light systems, 918–920
- Expansion tanks, chlorine feed systems, 437–438
- Explosions, nitrogen trichloride as cause of, 23
- Facility design:
 - bromine chloride, 861–865
 - automatic controls, 864
 - construction materials, 865
 - current practices, 861–862
 - evaporators, 864–865
 - injector systems, 864
 - metering and control equipment, 863–864
 - safety equipment, 865
 - solution lines and diffusers, 864
 - storage and handling, 864
 - system evaluation, 862–863
 - bromine processing, 854–855
 - dechlorination process, 585–593
 - gaseous system sulfur dioxide, 586–501
 - sulfite liquid system design, 592–593
 - sulfur dioxide leak detectors, 589–591
 - iodine production, 884–886
 - potable water installations, ozone treatment, 796
 - wastewater installations, ozone treatment, 797
- Facility layouts:
 - on-site sodium hypochlorite generation, design criteria, 557–565
 - equipment sizing, 557–558
 - layout, 559–565
 - storage requirements, 559
 - system redundancy, 558–559
 - sodium hypochlorite storage and handling, 513–518
 - access and clearances, 517
 - control panels, 518
 - elevation differences, 513–514
 - tank and pump bases, 515–517
- Faraday efficiency plot, on-site sodium hypochlorite generation, soft-water chiller, 540–541
- Faraday's law, chlorine electrolysis, 3–4, 9–11
- Fecal coliform concentration, coliform standard, wastewater treatment, 365–368
- Feedback controllers:
 - compound loop control, 647–653
 - dechlorination control systems, 654
 - manual systems, 639–641
 - online chlorination analyzers, 633–637, 644–647
- Feed-forward control systems:
 - compound loop control, 647–653
 - dechlorination process, 575
 - flow pacing, 641–644
 - online chlorination analyzers, 633–637
- Feedstock impurities, sodium chlorite, chlorate generation, 733

Feed systems:

- basic principles, 418–420
- 1-bromo-3-chloro-5,5-dimethylhydantoin (BCDMH), 867
- chlorination/dechlorination process
 - controls, manual control systems, 638–639
- chlorine dioxide, design criteria, 722–723
- cylinders, 420–424
- for disinfectants, 279–280
- eductors and, 442–451
 - diffusers, 444–445
 - pipe and valve systems, 445–449
 - scrubbers, 450–451
- expansion tanks, 437–438
- gaseous chlorine, 438–442
- gas filter, 437–438
- liquid chlorine, 431–436
 - vaporizers, 431–436
- pressure-reducing valve, 436–437
- sodium hypochlorite, 486–499
 - calculations for, 455–457
 - contour plates, 491
 - design criteria, 458
 - diaphragm metering pumps, 486–490
 - electric drives, 497
 - hose and tube life, 498
 - hose pumps, 496–497
 - hose replacement, 497–498
 - liquid dosing systems, 498–499
 - on-site sodium hypochlorite generation, 556
 - peristaltic pumps, 493–499
 - specialty pumps, 492–493
 - stroke length limits, 491
 - transfer pumps, 486
 - tube failure, 496
 - tube pumps, 495
 - tubular diaphragms, 491–492
 - turndown/pressure capabilities, 495–496
 - vapor locking problems, 490–493
- storage tanks, 430–431
- tank trucks/cars, 427–430
- ton containers, 424–426

Fenton reaction:

- advanced oxidation processes:
 - historical background, 976–977
 - hydrogen peroxide, 980, 992–993
 - equipment and generation, 997
- Ferric chloride, chlorine impurities and, 22
- Ferric sulfate, textile wastes, industrial wastewater chlorination, 360–361
- Ferrocyanide/ferricyanide, industrial wastewater chlorination, 358
- Ferrous ammonium sulfate (FAS):
 - bromine residual measurement, 873–874
 - dechlorination, 577
 - residual chlorine analysis,
 - diethyl-*p*-phenylenediamine (DPD) titration, 176–177, 211–214
 - wastewater disinfection, chlorine reaction with, 381
- Ferrous metals, chlorine chemical reactions, 29–30
- Fiberglass-reinforced plastic (FRP):
 - brine saturator tanks, on-site sodium hypochlorite generation, 537–539
 - on-site sodium hypochlorite generation, hydrogen dilution blowers, 554–556
 - sodium hypochlorite:
 - pipng, 504
 - storage tanks, 478, 480
 - high-density polyethylene storage tanks vs., 480, 482–483
- Filamentous bacteria, wastewater chlorination, sludge bulking control, 342–345
- Filtration, potable water chlorination, 294–295
- Final volume end point, amperometric titration, chlorine dioxide analysis, oxychlorine by-products, 745–747
- Fine-bubble diffusers, ozone transfer, 816–817
- Fire, chlorine leaks, 59–60

- Fire and building codes:
 - chlorine leaks, 34
 - sodium hypochlorite, 461–462
- First aid procedures:
 - chlorine exposure, 31–32
 - sulfur dioxide exposure,
 - dechlorination process, 579
- Flanged connections, sodium
 - hypochlorite piping, 498–499
 - lined steel piping, 503–504
- Flashlamps, ultraviolet light systems, 917–918
- Flash-off phenomenon, chlorine leaks, 34–35
- Flavor profile analysis (FPA), chlorine
 - dioxide taste and odor control, 738–739
- Flexible connections:
 - chlorine feed systems, ton containers, 427
 - chlorine leaks and failure of:
 - corrosion, 60
 - ton containers, 39
- Floc-forming bacteria, wastewater
 - chlorination, sludge bulking control, 342–345
- Flow injection analysis (FIA), chlorine
 - dioxide analysis, oxychlorine by-products, 750
- Flow pacing:
 - compound loop control, 648–653
 - dechlorination control systems, 654
 - gaseous chlorine system operations, 682–684
 - process control systems, 641–644
 - ultraviolet light systems, 964–965
- Fluid mechanics, chlorine contact
 - systems dispersion, 405–406
- Fluorosilicone (FVMQ), sodium
 - hypochlorite storage and handling, 507
- Flushing operations, water distribution
 - systems, 278
- Foaming, wastewater chlorination,
 - sludge bulking control, 345
- Food processing, chlorine dioxide
 - disinfection, 736–737
- Foul air scrubbing systems, wastewater
 - chlorination, 333–338
- Fouling, ultraviolet light systems, 931–932
- Free available chlorine test using
 - syringaldazine (FACTS):
 - free chlorine measurement, 178–179
 - residual chlorine analysis:
 - basic techniques, 214–215
 - small water supplies, 184–185
- Free chlorine
 - basic properties, 87–91
 - breakpoint curve chemistry and kinetics, 111–115
 - bromine residual measurement, 873
 - chlorination/dechlorination process
 - controls, chemistry of, 666–670
 - chlorine demand and, 150–151
 - dechlorination process, 576–577
 - disinfection applications, 279
 - germicidal efficiency, 155–161
 - monochloramine formation, 96–97
 - residual compound analysis:
 - amperometric techniques, 196–199
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate technique, 212
 - field measurements, 177–179
 - iodometric method I, 215–217
 - potable water chloramination, 253–255
 - short contact times, 201
 - secondary disinfection, chlorine
 - dioxide, taste and odor formation, 734
 - speciation in concentrated solution, 81–82
 - wastewater disinfection,
 - dechlorination, 396–397
- Free cyanides, industrial wastewater
 - chlorination, 352–358
- Free residual chlorine (FRC),
 - wastewater treatment, nitrified effluents, 385–390
- Free sulfur generation, wastewater
 - chlorination and hydrogen sulfide, 335–338
- Freezing point, sodium hypochlorite, 458–459

- Fuel oxygenates, advanced oxidation, water treatment systems, 984–985
- Functional testing, ultraviolet light systems, 964
- Fusible plug failure, chlorine leaks:
 - blowout, 40
 - corrosion, 39–40
- Fuzzy logic, programmable logic controllers, chlorination/dechlorination process controls, 637
- Gaseous chlorine:
 - chemical reactions, 30
 - chlorite solution, 719
 - cylinder storage units, operation and maintenance, 693–694
 - dissolution and hydrolysis, 68–74
 - feed systems, 438–442
 - health and safety requirements, 753
 - historical background, 1–2
 - hypochlorite solutions and, 85
 - leaks:
 - detection systems and emergency scrubber, 686–687
 - equipment failure, 61
 - fusible plug corrosion, 39–40
 - fusible plug failure, 39–40
 - rate calculations, 35–36
 - maintenance guidelines, 684–686
 - on-site sodium hypochlorite generation, process overview, 533
 - operation guidelines, 682–684
 - physical and chemical properties, 25
 - potable water disinfection, 243
 - pressure and density, 1003
 - solid chlorite, 720, 726
 - solubility in water, 27–28, 68–74
 - sulfonator operation and maintenance, 690–692
 - toxic effects, 30–31
 - vacuum density, 1004
 - vaporizer feed systems, 431–436
 - viscosity, 1004
 - wastewater treatment, chemistry, 328
- Gaseous oxygen (GOX), ozone generation, 802–806
 - pressure swing adsorption, 808–809
 - vacuum swing adsorption, 806–808
- Gaseous sulfur dioxide system, dechlorination facility design, 586–591
- Gas filter, chlorine feed systems, 437–438
- Gas flow calculations, ozone processing, 832–834
- Gas impulse devices, well restoration, 306
- Gaskets:
 - chlorine leaks, failure analysis, 61
 - sodium hypochlorite storage and handling, 506–507
- Gas-phase systems, dechlorination facility design, 586–591
- Gas sources, ozone generation, 800–812
 - air-based systems, 800–801
 - concentration monitors, 837–839
 - enriched and high-purity oxygen systems, 801
 - quality controls, 801–806
 - selection criteria, 811–812
- Gas-to-water ratio, ozone transfer, sidestream injectors, 817–820
- Gastroenteritis, wastewater disinfection process, viral inactivation, 368–375
- Generator-originated chlorite, chlorine dioxide by-products, 729
- Generic Verification Protocol for High Rate, Wet-Weather Flow Disinfection Applications*, ultraviolet light systems guidelines, 953–954
- Geometric mean, coliform standard, wastewater treatment, 366–368
- Geosmin:
 - advanced oxidation processes, 988–989
 - chlorine dioxide, 734–735, 738–739
 - ozone treatment, 777–779
- Germany, water chlorination in, 310
- Germicidal efficiency:
 - bromine compounds, 869–870
 - chlorine dioxide, 705–711
 - chlorine residuals, 151–161

- Germicidal efficiency: (*cont'd*)
 chloramines, 155–161
 hypochlorite ion, 154–155
 hypochlorous acid, 153–154
 inactivation mechanisms, 152–153
 dechlorination, process controls, 653–657
 dechlorination process, 576–577
 iodine, 882–883
 oxidation-reduction, chlorine residuals, 137–141
 wastewater disinfection, chlorine reaction with, 381–382
- Giardia* pathogens:
 chlorine dioxide inactivation, 711–712
 chlorine disinfectants, 235–241
 ozone treatment, 787–792
 baffled basin contactors, 823–824
 potable water treatment:
 chloramination, 255–256
 ultraviolet light systems, 896–897
- GLI International AccuChlor2 online analyzer, chlorination/dechlorination process controls, 619–620
- Gold ore refining, cyanide wastes, industrial wastewater chlorination, 353–358
- Granular activated carbon (GAC):
 aqueous chlorine and, 145–146
 chlorine demand assessment, 246–247
 dechlorination process, 583–585
 ozone filtration, 780–781
- Gravel chlorination, well disinfection, 284
- Grosvenor Miller process, chlorine manufacturing, hydrochloric acid oxidation, 19
- Groundwater:
 chlorine residuals in, breakpoint curve calculations, 108–109
 disinfection and treatment, iron and manganese and, 311
 microbes in, 230–231
- Groundwater Rule (GWR):
 chlorine disinfectants, 240
 microbe removal guidelines, 231
- Groundwater under the direct influence (GWUDI):
 chlorine disinfectant requirements, 237
 ultraviolet light system guidelines, 896, 904–906
- Growth mechanisms, regrowth management, 268
- Guillotine break, chlorine leaks, ton container pipeline, 36–38
- Hach CL17 online analyzer, chlorination/dechlorination process controls, 611–614
- Half-reactions, oxidation-reduction, 129–135
 oxidation-reduction potential measurement, 136–141
- Haloacetic acids (HAA5):
 chlorine disinfection requirements, 239
 as disinfection by-product, 244
 ozone control, 779–780
 potable water chloramination, 262
 water age control, 275–276
- Hardness values, on-site sodium hypochlorite generation, water softening systems, 534–535
- Hastelloy C steel:
 chlorine storage, 57–58
 sodium hypochlorite piping, 506
 storage tank linings, 478
- Hazard analysis:
 calcium hypochlorite, 463, 523
 sodium hypochlorite, 455–457, 462–463
- Health issues:
 bromine compounds, 874–875
 chlorine dioxide processing and handling, 752
 iodine, 886–887
 ozone treatment, 842–843
 ultraviolet light systems, 966–970
- Heat capacity calculations, on-site sodium hypochlorite generation, soft-water heater, 539–540

- Heated metal oxide semiconductor (HMOS), ozone concentrations in gas, 838–839
- Heat transfer:
 - chlorine feed systems, 419–420
 - ozone generation, 800
 - sodium hypochlorite degradation, 468–469
- Henry's law:
 - chlorine gas dissolution and hydrolysis, 68–74
 - hypochlorous acid dissociation, 74–77
 - ozone solubility, 769
- Herbicides, oxidation of, 986–988
- Heterotrophic plate count (HPC),
 - potable water chloramination, nitrification, 257–260
- Hexachlorobenzene, chlorine
 - impurities and, 22
- Hexachloroethane, chlorine
 - impurities and, 22
- Hexose-monophosphate shunt (HMPS),
 - kidney dialysis, potable water chloramination, 260
- H. H. Dow process, bromine
 - production, 850
- High-density polyethylene (HDPE),
 - sodium hypochlorite storage and handling:
 - pipng, 505
 - storage tanks, 479, 480–483
- Highway transport accidents, chlorine, 51–52
- Hoechst-Uhde process, hydrochloric acid electrolysis, 20
- Hoigne, Staehelin, and Bader
 - mechanism, ozone reaction, 770–771
- Horizontal tube generators, ozone
 - generation, 813–815
- Hydraulic effects:
 - potable water chlorination, 272
 - sulfur dioxide dechlorination facilities, 587–589
- Hydrocarbons, ozone gas sources, 801
- Hydrochloric acid:
 - bromine chloride chemistry, 860–861
 - chlorine dioxide chemistry, 717
 - chlorine gas dissolution and hydrolysis, 72–74
 - chlorine manufacturing:
 - electrolysis, 20
 - membrane cell electrolysis, 7–8
 - oxidation process, 18–19
- Hydrogen dilution blowers, on-site
 - sodium hypochlorite generation, 553–556
 - layout and design, 563–564
- Hydrogen dilution standpipe, on-site
 - sodium hypochlorite generation, 546–553
 - layout and design, 564–565
- Hydrogen formation, on-site sodium
 - hypochlorite generation, separation and safety concerns, 546–553
- Hydrogen peroxide:
 - dechlorination process, 583
 - dissolved ozone in water
 - measurement, 841
 - equipment and generation systems, 995–997
 - ozone decomposition, 979, 990–991
 - Fenton reaction, 980, 992–993
 - photo-Fenton reaction, 980–981, 992–993
 - titanium dioxide-hydrogen peroxide, 981–982
 - ultraviolet photolysis, 979–980, 991–992
 - wastewater disinfection, 379
- Hydrogen production calculations,
 - on-site sodium hypochlorite generation, 551
- Hydrogen sulfide:
 - aqueous chlorine, 146–147
 - ozone treatment, 775–776
 - potable water treatment and, 299–303
 - wastewater chlorination:
 - foul air scrubbing systems, 334–338
 - odor control, 329–338
 - prechlorination, 330–333
 - septicity control, 346–348
- Hydrolysis, chlorine, 68–74
- Hydroxide, ozone decomposition, 978–979

- Hydroxylamine, breakpoint curve
chemistry and kinetics,
110–115
- Hydroxyl radicals, advanced oxidation
processes:
chemistry, 977–982
equipment and generation, 995–997
Fenton reaction, 980, 992–993
historical background, 976–977
hydroxyl radical generation,
ultraviolet light, 979–980, 992
overview, 976
ozone decomposition:
hydrogen peroxide, 979, 990–991
hydroxide initiation, 978–979
ultraviolet photolysis, 979,
991–992
photo-Fenton reaction, 980–981,
992–993
potable water/wastewater
treatment, 982–990
degreasers and solvents, 983
disinfection by-product precursor
oxidation, 989–990
fuel oxygenates, 984–985
pesticide oxidation, 985–988
petroleum products, 984
taste and odor compound oxidation,
988–989
volatile organic carbon oxidation,
982–985
regulatory issues, 994–995
system classification, 977
system performance factors, 990–994
titanium dioxide:
hydrogen peroxide-ultraviolet
reaction, 981–982
ultraviolet reaction, 981, 993–994
- Hypobromite ion:
chlorine chemistry in seawater,
123–126
dissociation, 851
hypochlorite formation with, 853
- Hypobromous acid (HOBr):
bromine chloride chemistry, 860–861
chlorine reactions, 852
in seawater, 123–126
bromamine formation and decay,
127–129
cooling water, 854
dissociation, 851
ionic strength effects, 126–127
residual measurement, 182,
872–875
- Hypochlorite. *See also* Calcium
hypochlorite; Lithium
hypochlorite; Sodium
hypochlorite
aqueous chlorine solutions, 82–85
background and history, 452–453
chlorine dioxide electrochemistry,
722
germicidal efficiency, 154–155
hypobromite formation, 852–853
raw wool processing, wastewater
chlorination, 361
wastewater disinfection, 376
constituent reactions, 379–382
- Hypochlorous acid (HOCl):
bromine reactions with, 852
chlorine chemistry in seawater,
126–127
chlorine gas dissolution and
hydrolysis, 68–74
dechlorination process, 574
speciation, 576–577
dissociation, 74–80
ionic strength effects, 77–80
pH/temperature effects, 74–77
germicidal efficiency, 153–154
oxidation-reduction, 132–135
speciation in concentrated solution,
81–82
trichoramine formation, 102–103
wastewater treatment chemistry,
328–329
- Hypoiodous acid:
chemistry, 879–882
germicidal efficiency, 882–883
- Impurity detection:
chlorine dioxide, 713, 723–724
sodium hypochlorite:
chlorate generation, chlorine
dioxide, 734
degradation mechanism,
471–475
processing systems, 455–457

- Inactivation mechanisms:
 - chlorine disinfectants, 152–153
 - ultraviolet light systems guidelines, nonbiological, mathematical-based modeling, 956–958
- Incinerator scrubber water, cyanide waste, industrial wastewater chlorination, 358
- Indigo trisulfonate, dissolved ozone in water measurement, 840–842
- Industrial wastewater:
 - chlorination, 352–361
 - free and combined cyanides, 352–358
 - phenols, 359–360
 - textile wastes, 360–361
 - nitrogenous compounds, 92–94
- Infectious hepatitis, wastewater disinfection process, viral inactivation, 368–375
- Information Collection Rule (ICR), chlorine dioxide analysis, oxychlorine by-products, 741–742
- Injector systems:
 - bromine chloride facilities, 864
 - 1-bromo-3-chloro-5,5-dimethylhydantoin (BCDMH), 867
 - chlorination/dechlorination process controls, 594–596
 - chlorine dioxide, 728
- Inlet/outlet conditions, ultraviolet light system guidelines, 936
- Inorganic compounds:
 - ozone treatment, 773–777
 - chlorine, chlorine dioxide, monochloramine, 776–777
 - iron and manganese, 773–775
 - sulfides, 775–776
 - wastewater chlorination, chemistry, 328–329
- Insulated-gate bipolar transistors (IGBTs), ozone generation, 814
- Intensity set point approach, ultraviolet light systems, dose calculations, 936–937
- Interferences, residual chlorine measurement, 180, 182
- manganese interference, 213–214
- nitrite interference, 205–208
- orthotolidine method, 221–222
- Interim Enhanced Surface Water Treatment Rule (IESWTR), chlorine disinfectants, 238–239
- International Fire Code (IFC), sodium hypochlorite, 461–462
- Iodine:
 - applications, 877–878
 - brine production, 877
 - Chile saltpeter production, 876
 - chlorination comparisons, 884
 - chlorine dioxide analysis, oxychlorine by-products, amperometric titration, 745–747
 - facility layout, 884–885
 - germicidal efficiency, 882–883
 - health and safety aspects, 886–887
 - iodination chemistry, 879–882
 - limitations of, 883
 - normality monitoring, residual compound analysis, 203–204
 - occurrence and production, 876
 - physical and chemical properties, 875, 889
 - regulatory issues, 887
 - residual compounds, 886
 - water treatment, 877–878
- Iodometry:
 - chlorine dioxide analysis, oxychlorine by-products, 742
 - residual chlorine measurement, 179
 - method I, 215–217
 - method II, 217–218
 - potentiometric techniques, 218–219
- Ion chromatography (IC), chlorine dioxide analysis, oxychlorine by-products, 741–742, 749
- Ion exchange mechanisms:
 - bromine reactions, 852–853
 - iodine chemistry, 879–882
 - on-site sodium hypochlorite generation, water softening systems, 535–537

- Ionic strength effects:
 - chlorine chemistry in seawater, 126–127
 - hypochlorite, germicidal efficiency, 154–155
 - hypochlorous acid dissociation, 77–80
 - sodium hypochlorite degradation, 467
 - pH levels and, 469–470
- Iron:
 - aqueous chlorine, 147–148
 - chlorine dioxide oxidation, 739–740
 - chlorite removal and reduction of, 730
 - groundwater disinfection and treatment, 311
 - ozone treatment, 773–775
 - potable water chlorination and, 290–293
 - sodium hypochlorite impurities and degradation, 472
- Irrigation systems, wastewater reuse, 399–400
- Javelle water:
 - early chlorine manufacturing, 2–3
 - hypochlorite formation and, 452–453
- Joule-Thompson effect, vaporizer chlorine feed systems, 433
- Kalrez elastomer, sodium hypochlorite storage and handling, 506–507
- Kel-Chlor process, chlorine manufacturing, hydrochloric acid oxidation, 19–20
- Ketones, ozone disinfection by-products, 795
- Kidney dialysis patients, potable water chloramination, 260
- Klorigen on-site sodium hypochlorite generation systems, 566–567
- Kossuth process, bromine production, 849
- Kubierschky process, bromine production, 850
- LaBlanc soda process, early chlorine manufacturing, 3
- Lagrangian actinometry, ultraviolet light systems, 960–961
- Lag time of bacterial kill, wastewater treatment, chlorine dose and effluent quality, 384
- Lamps, ultraviolet light systems, 910–921
 - elapse time, 964
 - electrodeless mercury vapor lamps, 914–917
 - excimer lamps, 918–920
 - mercury vapor lamps, 910–914
 - metal halide lamps, 917
 - pulsed lamps, 917–918
- Lamp sleeves, ultraviolet light systems, 925–926
- Latent heat of vaporization:
 - chlorine, 27
 - liquid chlorine, 1005
- Lead concentrations, potable water chloramination, 261
- Leaks:
 - chlorine, 33–41
 - definitions, 33–34
 - fire and building codes, 34
 - flash-off phenomenon, 34–35
 - fusible plug blowout, 40
 - fusible plug corrosion, 39–40
 - PVC header failure, 38–39
 - rate calculations, 35–36
 - tanker truck unloading, 36
 - ton containers:
 - flexible connection failure, 39
 - guillotine pipeline break, 36–38
 - dechlorination process, sulfur dioxide leak detection, 589–591
 - Leuco crystal violet (LCV) titration, residual chlorine, 177, 219–220
- Level instrumentation, sodium hypochlorite storage tanks, 483–484
- Light-emitting diodes (LEDs), ultraviolet light systems, 920–921
- Light exposure limits, ultraviolet light systems, 967–970

- Light intensity distribution (LID),
 - ultraviolet light systems,
 - microorganism inactivation, 903–904
- Lime requirements, calcium hypochlorite processing, 521
- Linear polyethylene, high-density polyethylene storage tanks, sodium hypochlorite, 481
- Lined steel, sodium hypochlorite storage:
 - pipng, 503–504
 - tanks, 479–480
- Liquid bleach. *See* Sodium hypochlorite
- Liquid chlorine. *See also* Aqueous chlorine
 - chemical reactions, 29–30
 - compressibility coefficient, 25
 - dechlorination system operation and maintenance, 692–693
 - density, 27
 - feed systems, 431–436
 - historical background, 2
 - latent heat of vaporization, 1005
 - leaks:
 - consumer accidents, 55–56
 - fusible plug corrosion, 39
 - fusible plug failure, 39
 - pipeline guillotine break, ton containers, 36–38
 - rate calculations, 35
 - ton container explosions, 60
 - nitrogen chloride in, 23
 - physical and chemical properties, 25
 - potable water disinfection, 243
 - solubility in water, 28–29
 - storage operations and maintenance, 696–697
 - temperature-density relation, 1005
 - toxic effects, 30–31
 - vapor pressure vs. temperature, 1006
 - viscosity, 1004
 - volume-temperature relationship, 26, 1007
 - wastewater treatment, history, 327
- Liquid dosing systems, sodium hypochlorite, 498–499
- Liquid oxygen (LOX):
 - health and safety guidelines, 843
 - ozone generation, 800–806
 - quality and storage criteria, 802–806
- Liquid system design, sulfite dechlorination process, 592–593
- Liquid wastes, wastewater chlorination, 361
- Lissamine Green B (LGB) process, chlorine dioxide analysis, 741–742, 748
- Lithium hypochlorite, 525–526
- Loading and unloading systems, sodium hypochlorite, 484
- Long-term 1 and 2 Enhanced Surface Water Treatment Rules (LT1ESWTR/LT2ESWTR):
 - advanced oxidation processes, 994–995
 - chlorine dioxide, 754
 - encrusted parasites, 711–712
 - chlorine disinfectants, 239–240
 - ozone disinfection process, 789
 - potable water disinfection:
 - chlorine dioxide, 727–728
 - ultraviolet light systems, 896–897
 - ultraviolet light system guidelines, 904–906
 - challenge microorganisms and dose requirements, 935
- Lower explosive limit (LEL), on-site sodium hypochlorite generation:
 - hydrogen formation, separation and safety, 546–553
 - process overview, 534
- Low-flow area surveillance, potable water treatment and distribution, 275
- Low-level titrations, residual chlorine analysis, amperometric techniques, 200
- Low-pressure-high-output (LPHO) lamps, ultraviolet light systems, 910–914
- Low-pressure (LP) mercury vapor lamps:
 - potable water treatment, 896–897
 - ultraviolet light systems, 910–914
 - wastewater treatment, 895–896

- Magnesium:**
 on-site sodium hypochlorite
 generation, water softening
 systems, 535–535
 sodium hypochlorite degradation, 475
- Maintenance issues:**
 chlorination/dechlorination process
 controls, 670–673
 chlorination systems:
 overview, 678–679
 planning guidelines, 680
 standard operating procedures,
 679–680
 dechlorination gas systems, 690–692
 dechlorination liquid systems,
 692–693
 electrolytic cell design, 5
 gaseous chlorine systems, 682–687
 chlorine detection systems and
 emergency scrubber, 686–687
 operation guidelines, 682–686
 operator training and safety, 693
 ozone transfer, sidestream injectors,
 818–820
 regulatory requirements, 697–699
 risk management plan, 697–698
 SDWA and state testing and
 reporting, 698
 wastewater chlorine use and
 facilities reporting, 699
 residual analyzers, calibration and,
 681–682
 sodium hypochlorite systems,
 687–690
 storage systems, 693–697
 gas cylinders, 693–694
 liquid chemicals, 696–697
 rail cars, 695–696
 ton containers, 694–695
 ultraviolet light systems, 961–965
- Manganese:**
 aqueous chlorine, 147–148
 chlorine dioxide oxidation,
 739–740
 groundwater disinfection and
 treatment, 311
 ozone treatment, 773–775
 destruction catalyst, 826–828
 potable water chlorination and, 290
 residual chlorine analysis, interference
 reactions, 213–214
- Manual control systems:**
 chlorination/dechlorination process
 controls, 638–639
 gaseous chlorine system operations,
 682–684
- Maximum contaminant levels (MCLs),
 chlorine disinfectants
 requirements, 239**
- Mean cell residence time (MCRT),
 wastewater chlorination,
 sludge bulking control,
 343–345**
- Mechanical mixing intensity:**
 chlorine contact systems design, 406
 wastewater chlorination, ammonia
 removal, 351
- Mechanical system modifications,
 ultraviolet light systems, 966**
- Medical applications:**
 chlorine dioxide disinfection, 736
 iodine, 877–878
- Medium-pressure (MP) ultraviolet
 lamps:**
 potable water treatment, 896
 ultraviolet light systems, 910–914
- Membrane cell:**
 chlorination/dechlorination process
 controls, online analytical
 measurements, 600
 chlorine electrolysis, 5–8
- Mercury cells, chlorine electrolysis,
 11–15**
- Metal catalysts, sodium hypochlorite
 impurities and degradation,
 471–472**
- Metal halide lamps, ultraviolet light
 systems, 917**
- Metal plating, cyanide wastes, industrial
 wastewater chlorination,
 353–358**
- Metering equipment:**
 bromine chloride facilities, 863–864
 hydrogen peroxide, 996–997
- Methane, aqueous chlorine, 148**
- Methylene blue stability test, wastewater
 chlorination, septicity control,
 346–348**

- 2-Methylisoborneol (MIB):
 - advanced oxidation processes, 988–989
 - chlorine dioxide, 734–735, 738–739
 - ozone treatment, 777–779
- Methyl orange (MO) method, residual chlorine, 177, 220–221
- Methyl *tert*-butyl ether (MTBE),
 - advanced oxidation, water treatment systems, 984–985
- MicrOclor systems, 568, 570–571
- Microorganisms:
 - chlorine disinfection, mechanisms of, 152–153
 - nitrite oxidation, 148–149
 - oxidation-reduction, chlorine compounds, 139–141
 - potable water chloramination, 254–258
 - nitrification, 257–258
 - potable water supply, 230–231
 - regrowth management, 266–272
 - ultraviolet light systems:
 - dose calculations for inactivation, 902–904, 935, 943–944, 951
 - inactivation mechanisms, 152–153, 898–900
 - repair mechanisms, 899–901
 - sensitivity, 899, 901
 - validation and dose requirements, 933–935
 - wastewater chlorination:
 - regrowth problems, 394–395
 - sludge bulking control, 342–345
- Miniamprometric titration, residual chlorine measurement, 179
- MIOX on-site sodium hypochlorite generation systems, 567, 569
- Mixed liquor total suspended solids (MLSS), wastewater
 - chlorination, sludge bulking control, 343–345
- Mixed liquor volatile suspended solids (MLVSS), wastewater
 - chlorination, sludge bulking control, 343–345
- Mixing technologies, chlorine contact systems, 406–411
- Mixing zone standards, wastewater disinfection by-products, 392–394
- Modified orthotolidine-arsenite (MOTA), free chlorine measurement, 177–178
- Moisture, chlorine impurities and, 22
- Molecular chlorine:
 - alkalinity, 142–144
 - chlorine gas dissolution and hydrolysis, 72–74
- Molecular weight:
 - calcium hypochlorite, 520–521
 - sodium hypochlorite:
 - basic chemistry, 454
 - concentrations, 457
- Mollusca control, in seawater, 295–299
- Monel alloy, bromine storage containers, 848
- Monitoring procedures:
 - chlorination/dechlorination process controls, 670–673
 - chlorine dioxide, 753–754
 - ozone concentrations, 837–839
 - potable water chlorination, 273
 - ultraviolet light systems:
 - dose-monitoring approaches, 936–937, 945–946, 951–952
 - online monitors, 928
- Monobromamine (bromamide):
 - chlorine chemistry in seawater, 127–129
 - residual measurement, 872–875
- Monochloramine:
 - ammonia chlorination, 95–97
 - breakpoint curve, 106–115
 - chemistry and kinetics, 109–115
 - combined chlorine formation of, 87–91
 - dechlorination process, 576–577
 - germicidal efficiency, 155–161
 - residual chlorine analysis:
 - amperometric techniques, 197–198
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate procedure, 213
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate technique, 212

- Monochloramine: (*cont'd*)
wastewater disinfection, formation of,
380–381
nitrified effluents, 385–390
- Morris's best-fit formula, hypochlorous
acid dissociation, 75–77
- Most probable number (MPN)
procedure:
coliform standard, wastewater
treatment, 363–368
residual chlorine analysis, 186
- National Pollutant Discharge
Elimination System (NPDES):
chlorination/dechlorination process
controls compliance, 675–676
coliform standard, wastewater
treatment, 366–368
ultraviolet wastewater treatment
systems, historical background,
895–896
- National Water Research Institute/
American Water Works
Association Research
Foundation (NWRI/AwwaRF)
*Ultraviolet Disinfection
Guidelines for Drinking Water
and Water Reuse*, ultraviolet
light system guidelines, 904,
907–908
- biodosimetry data analysis, 946–947,
950
- challenge microorganisms and dose
requirements, 943–944,
949–950
- collimated beam analysis, 945–946
- dose-monitoring approaches and test
conditions, 944–945
- sampling and data recording, 945
- validation location and test stand
considerations, 944, 949–950
- water reuse validation guidelines,
949–950
- Natural organic matter (NOM):
chlorine demand assessment,
243–247
chlorine dioxide control, 734, 740
disinfection by-products formation,
243–248
ozone decomposition, hydroxide,
978–979
ozone treatment, 776–777
- Nernst equation, oxidation-reduction,
132–135
oxidation-reduction potential
measurement, 136–141
- New building systems, disinfection
process, 283
- Nickel plating, cyanide wastes, industrial
wastewater chlorination,
357–358
- Nickle alloys, bromine storage
containers, 848
- Nitrate:
breakpoint curve chemistry and
kinetics, 113–115
chlorine demand and formation of,
150–151
potable water chloramination and
nitrification, 258
wastewater chlorination, ammonia
removal, 350–352
- Nitric acid, ozone gas sources, 802
- Nitrification:
chlorination/dechlorination process
controls, 670–673
potable water chloramination, 256–260
control procedures, 273–274
wastewater treatment:
disinfection by-products, 392–394
effluent chlorination, 384–390
- Nitrified effluents, residual chlorine
analysis, 187
- Nitrile, sodium hypochlorite storage and
handling, gaskets, seals, and
o-rings, 506
- Nitrite:
aqueous chlorine, 148–149
dechlorination process, 574
residual chlorine analysis:
amperometric techniques,
205–208
iodometric method I, 216–217
- Nitrite-oxidizing bacteria (NOB),
potable water chloramination,
nitrification, 257–258
- Nitrogen cycle, nitrogenous compounds,
92–94

- Nitrogen dioxide, ozone gas sources, 801–802
- Nitrogenous compounds:
 - aqueous chlorine and, 91–122
 - ammonia chlorination and
 - chloramine formation, 94–103
 - dichloroamine/trichloroamine, 97–103
 - monochloramine, 95–97
 - breakpoint reaction, 103–116
 - breakpoint curve, 105–109
 - chemistry and kinetics, 109–115
 - decomposition products, 115–116
 - historical background, 103–105
 - organic nitrogen, 116–122
 - breakpoint curve, 120–122
 - reaction mechanisms, 118–120
 - in water and wastewater, 92–94
 - wastewater disinfection, chlorine reactions, 379–382
- Nitrogen padding, dechlorination facility design, 586–589
- Nitrogen pentoxide, ozone gas sources, 801–802
- Nitrogen tribromide:
 - chlorine chemistry in seawater, 127–129
 - germicidal efficiency, 159
- Nitrogen trichloride:
 - ammonia chlorination, 97–103
 - breakpoint curve chemistry and kinetics, 113–115
 - combined chlorine formation of, 87–91
 - cyanide wastes, industrial wastewater chlorination, 355–358
 - dechlorination process, 573–574
 - speciation, 577
 - liquid chlorine, 23
 - ton container explosions, 60
 - odor generation, 262–263
 - potable water chloramination,
 - N reactions, 251
 - residual chlorine analysis:
 - amperometric techniques, 199, 204–205
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate technique, 212
 - wastewater chlorination, ammonia removal, 350–352
- Nitrous oxide, cyanide wastes, industrial wastewater chlorination, 355–358
- Nitroxyl formation, breakpoint curve chemistry and kinetics, 112–115
- N*-nitrosodimethylamine (NDMA),
 - potable water chloramination, 262
- Nonbiological, mathematical-based modeling, ultraviolet light systems, 955–958
- No-tracer test design, chlorine contact systems, 416
- Nucleic acid absorption spectrum,
 - ultraviolet light systems, microbial inactivation, 898–900
- Nutrient availability, regrowth management, 270–271
- Occupational Safety and Health Administration (OSHA):
 - chlorine dioxide guidelines, 753–754
 - chlorine electrolysis, mercury cells, 14–15
 - Process Safety Management regulations, 45–46
- Occupational safety and health issues:
 - chlorine dioxide guidelines, 753–754
 - mercury cells, chlorine electrolysis, 14–15
- Odor control:
 - advanced oxidation processes, 988–989
 - algae and actinomycetes, 286–288
 - chlorine, 289
 - chlorine dioxide, 734–735, 738–739
 - ozone treatment, 778–779
 - potable water chloramination, 262–263
 - synthetics, 288–289
 - wastewater chlorination, 329–338
 - foul air scrubbing, 333–338
 - prechlorination, 330–333
 - water chlorination and, 285–286
- Off-gases, ozone transfer:
 - reuse, 828–829
 - sidestream injectors, 818–820

- Oil and gas removal, wastewater chlorination, 348–349
- Online chlorine analyzers:
 - compound loop control, 647–653
 - feedback control, 633–637, 644–647
 - process control systems, 607–633
 - Analytical Technology, Inc., 608–611
 - Capital Controls, 614–619, 662–663
 - dechlorination analysis, 657–663
 - field comparisons of, 629–631
 - flow pacing, 641–644
 - GLI International, 619–620
 - Hach CL17 analyzer, 611–614
 - history, 597–598
 - manual systems, 638–639
 - Orion Research, Inc., 620–621
 - process review and configurations, 633–637
 - selection criteria, 631–633
 - Stranco HRR, 657–658
 - Stranco Products, 622–629
 - Wallace & Tiernan, 621–622, 658–662
- Online monitors, ultraviolet light systems, 928
- On-site dilution process, sodium hypochlorite degradation, 467
- On-site generation system:
 - bromide processing, 855–858
 - sodium hypochlorite:
 - brine dilution, 545
 - brine metering, 542
 - brine saturator tank, 537–539
 - current trends, 529–530
 - design criteria, 557–565
 - equipment sizing, 557–558
 - layout, 559–565
 - storage requirements, 559
 - system redundancy, 558–559
 - electrolytic cell, 542–545
 - electrolytic formation, 531–534
 - feed equipment, 556
 - history, 528–529
 - hydrogen dilution blowers, 553–556
 - hydrogen formation, separation, and safety, 546–553
 - air requirement calculations, 551
 - calculation variables, 552
 - outside ventilation air induction rate, 551
 - production calculations, 551
 - room turnover rate calculation, 552
 - room volume calculations, 551
 - manufacturers, 565–571
 - Clortec generators, 565–566
 - Klorigen system, 566–567
 - MIOX, 567, 569
 - OSEC system, 567–568, 570
 - Process Solutions, Inc., 568, 570–571
 - operation and maintenance guidelines, 688–690
 - rectifier, 546
 - salt and brine systems, 530
 - salt quality and bromate formation, 530–531
 - seawater systems, 531
 - soft-water chiller, 540–542
 - soft-water heater, 539–540
 - storage tanks, 556
 - water softener, 534–535
- Open channel reactors, ultraviolet light systems, 921–924
- Operating guidelines:
 - chlorination/dechlorination process controls, 670–673
 - chlorination systems:
 - overview, 678–679
 - planning guidelines, 680
 - standard operating procedures, 679–680
 - dechlorination gas systems, 690–692
 - dechlorination liquid systems, 692–693
 - electrolytic cell design, 5
 - gaseous chlorine systems, 682–687
 - chlorine detection systems and emergency scrubber, 686–687
 - operation guidelines, 682–686
 - operator training and safety, 693
 - regulatory requirements, 697–699
 - risk management plan, 697–698
 - SDWA and state testing and reporting, 698
 - wastewater chlorine use and facilities reporting, 699

- residual analyzers, calibration and, 681–682
- sodium hypochlorite systems, 687–690
- storage systems, 693–697
 - gas cylinders, 693–694
 - liquid chemicals, 696–697
 - rail cars, 695–696
 - ton containers, 694–695
- ultraviolet light systems, 961–965
- Operator training and safety, guidelines for, 693–694
- Organic chloramines:
 - dechlorination, 577
 - germicidal efficiency, 159–161
 - wastewater disinfection, nitrified effluents, 386–390
- Organic compounds:
 - bromo-organic compounds, 871–872
 - ozone treatment, 777–785
 - biological filtration, 780–781
 - biological solids, wastewater, 786
 - chlorination by-products, 779–780
 - color removal, 782
 - cyanotoxins, 785–786
 - EDC/PPCP treatment, 784–785
 - micropollutants/microcontaminants, 783–784
 - particulate removal, 781–782
 - taste- and odor-causing compounds, 777–779
 - total organic carbon oxidation, 780
 - ultraviolet transmittance increase, 782–783
- Organic matter, aqueous chlorine reactions, 141–149
- Organic nitrogen:
 - aqueous chlorine, 116–122
 - breakpoint curve, 120–122
 - reaction mechanisms, 118–120
 - chloramine formation, 182–184
 - dechlorination process, 574–575
 - defined, 117–118
 - germicidal efficiency, 159–161
 - nitrogenous compounds, 93–94
 - wastewater chlorination:
 - chemistry, 328–329
 - nitrified effluents, 384–390
 - wastewater disinfection, chlorine reaction with, 381
- Organic peroxy radicals, ozone reaction, 770–771
- Organo-phosphorus pesticides, oxidation, 987–988
- O-rings, sodium hypochlorite piping:
 - flanged connections, 498–499
 - materials and properties, 506–507
 - valves, 508–510
- Orion Research, Inc. 1770 online analyzer, chlorination/dechlorination process controls, 620–621
- Orthotolidine method:
 - chloramine formation, breakpoint reaction, 103
 - chlorination/dechlorination process controls, 596–598
 - oxidation-reduction, residual chlorine, 137–141
 - residual chlorine analysis:
 - basic procedures, 221–223
 - breakpoint reaction and, 175–179
 - drop dilution, 222–223
 - historical background, 174–175
 - interfering substances, 221–222
 - limitations of, 176–177
- OSec on-site sodium hypochlorite generation systems, 567–568, 570
- Outside ventilation air induction rate, on-site sodium hypochlorite generation, 551
- Oxidant selectivity, chlorine dioxide, 705
- Oxidation:
 - aqueous chlorine, 85–87
 - bromine, 849
 - chlorate, chlorine dioxide disinfection, 731–734
 - iodine, 875
 - pesticides, 985–988
 - potable water chlorination and, iron and manganese, 292–293
 - total organic carbon, ozone reaction, 780
 - volatile organic compounds, 982–985
 - wastewater reuse, 397–400

Oxidation-reduction potential (ORP):
 aqueous chlorine:
 basic principles, 129–135
 measurements, 135–141
 chlorination/dechlorination process
 controls, 602–606
 chemistry of, 668–670
 dechlorination control systems,
 656–657
 documentation and regulatory
 compliance, 675–676
 cyanide wastes, industrial
 wastewater chlorination,
 355–358
 oxidation-reduction, chlorine
 compounds, measurement
 techniques, 135–141
 wastewater chlorination, odor
 control, 332–333

Oxychlorine by-products, chlorine
 dioxide analysis, 740–752
 amperometric titration, 743–747
 colorimetry, 751–752
 diethyl-*p*-phenylenediamine
 titration, 747–748
 flow injection analysis, 750
 IC method, 749
 iodometry, 742
 Lissamine Green B dye, 748
 spectrophotometry, 749–750

Oxygen production reaction (oxygen
 gas formation), sodium
 hypochlorite degradation,
 464, 500

Ozone. *See also* Advanced oxidation
 processes (AOPs)
 analytical methods, 836–842
 concentration in gas, 837–839
 dissolved ozone in residual
 water, 839–842
 applications, 769
 basic properties, 768–771
 decomposition:
 hydrogen peroxide, 979, 990–991
 hydroxide initiation, 978–979
 disinfection applications:
 potable water treatment,
 787–789
 wastewater treatment, 790–792

disinfection by-products, 792–795
 aldehydes, carboxylic acids, and
 ketones, 795
 bromate control, 793–795
 dissolved ozone decay, 772–773
 equipment and generation, 798–832
 air preparation systems, 809–811
 contactors, 821–826
 baffled basins, 822–824
 pipeline designs, 824–826
 cooling water systems, 829–831
 cost studies, 831–832
 cryogenic air separation, 809
 destruction equipment, 826–829
 off-gas reuse, 828–829
 thermal catalytic destruction,
 826–828
 thermal destruction, 828
 gas quality, 801–806
 gas sources, 800–806
 air-based systems, 800–801
 enriched and high-purity oxygen
 systems, 801
 selection criteria, 811–812
 horizontal tube generators, 813–815
 plate type generators, 812–813
 process schematic, 798–799
 PSA technology, 808–809
 supplemental air systems, 829
 theoretical background, 799–800
 transfer methods, 816–821
 aspirating turbine mixers, 821
 fine-bubble diffusers, 816–817
 packed columns, 821
 sidestream injectors, 817–820
 spray chambers, 821
 U-tubes, 821
 VSA technology, 806–808
 health and safety issues, 842–843
 history and application, 767
 inorganic compound treatment,
 773–777
 chlorine, chlorine dioxide,
 monochloramine, 776–777
 iron and manganese, 773–775
 sulfides, 775–776
 organic compound treatment, 777–785
 biologic filtration, 780–781
 biologic solids, wastewater, 786

- chlorination by-products, 779–780
- color removal, 782
- cyanotoxins, 785–786
- EDC/PPCP treatment, 784–785
- micropollutants/microcontaminants, 783–784
- particulate removal, 781–782
- taste- and odor-causing compounds, 777–779
- total organic carbon oxidation, 780
- ultraviolet transmittance increase, 782–783
- physical properties, 768
- potable water treatment:
 - disinfection, 787–789
 - installations, 796
- process calculations, 832–836
 - applied dose, 835
 - gas flow, 832–834
 - production calculations, 834
 - specific energy, 835–836
 - transfer efficiency, 834–835
 - transferred dose, 835
- quench chemicals, 836
- reaction pathways, 769–771
- regulatory issues, 843
- sodium hypochlorite degradation,
 - sodium bromate formation, 474–475
- solubility, 768–769
- ultraviolet photolysis, 979, 991–992
- wastewater treatment:
 - disinfection, 790–792
 - current research on, 378
 - viral inactivation, 370–375
 - installations, 797
- Ozone demand, 771–772
 - ozone transfer, sidestream injectors, 818
- Packed column systems, ozone transfer, 821
- Palin tablet method, residual chlorine measurement, diethyl-*p*-phenylenediamine (DPD) titration, 211
- Particulate accumulation:
 - ozone gas sources, 801
 - ozone removal, 781–782
 - sodium hypochlorite degradation, 473–474
 - ultraviolet light systems, 929–931
- Pentech mixing system, chlorine contact systems design, 406–408
- Peracetic acid, wastewater disinfection, 378
- Perchlorates:
 - sodium hypochlorite degradation, 476
- Perchlaron process, calcium hypochlorite, 518–519
- Percussive devices, well restoration, 306
- Performance testing:
 - advanced oxidation processes, 990–994
 - ultraviolet light systems, 964
- Periodide, chemistry, 879–882
- Peristaltic pumps, sodium hypochlorite metering, 493–499
 - electric drives, 497
 - failure, 496
 - hose and tube life, 498
 - hose pumps, 496–497
 - hose replacement, 497–498
 - tube pumps, 495–496
 - turndown/pressure capabilities, 495–496
- Personal protective equipment (PPE):
 - sodium hypochlorite handling, 462–463
 - ultraviolet light systems, 969–970
- Pesticides, oxidation of, 985–988
- Petroleum products, advanced oxidation, water treatment systems, 984
- Pharmaceutical and personal care products (PPCPs), ozone treatment, 784–785
- Phenolic compounds, industrial wastewater chlorination, 359–360
- Phenylarsine oxide (PAO):
 - amperometric titration, residual chlorine, 176, 194–197, 201
 - back amperometric titration procedure, 202–203

- Phenylarsine oxide (PAO): (*cont'd*)
 chlorine dioxide analysis, oxychlorine by-products, *Standard Methods* 4500-ClO₂-C amperometric methods I and II, 743–744
- pH levels:
 breakpoint curve, chlorine residuals, 107–109
 chlorination/dechlorination process controls, 671–673
 chlorine dioxide:
 sulfite ions, chlorite removal, 730–731
 viral and bacterial inactivation, 706–711
 hypochlorous acid dissociation, 74–77
 oxidation-reduction, chlorine compounds, 140–141
 ozone decomposition, hydroxyl radicals, 979
 ozone disinfection by-products, 793
 potable water chloramination and nitrification, 258
 residual chlorine analysis, free available chlorine test using syringaldazine, 214–215
 sodium hypochlorite:
 basic chemistry, 455
 degradation mechanisms, 468–470
 sodium hypochlorite degradation, 475
 trichoramine formation, 101–103
- Photo-Fenton reaction:
 ozone, 980–981, 992–993
 pesticide oxidation, 987–988
- Photographic processing, cyanide wastes, industrial wastewater chlorination, 358
- Photolysis:
 chlorine dioxide, 728–729
 chlorate generation, 734
 ozone, ultraviolet reaction, 979, 991–992
 sodium hypochlorite degradation, 470–471
- Photometric measurement, ozone concentrations in gas, 837–840
- Photoreactivating enzyme (PRE), UV-inactivated microorganism repair, 900–902
- “Pickle scum” acid neutralization, cyanide wastes, industrial wastewater chlorination, 353–358
- Piping systems:
 chlorine feeders, valve systems and, 445–449
 chlorine leaks:
 buried pipe, 54–55
 container connections, 60
 material failure, 61
 welding cuts, 60–61
 guillotine break, chlorine ton containers, 36–38
 hydrogen peroxide, 996–997
 ozone contactors, 824–826
 sludge conveyance pipelines, septicity control, 346–348
 sodium hypochlorite, 499–507
 fiber-reinforced piping, 504
 gaskets, seals, and o-rings, 506–507
 hastelloy, 506
 high-density polyethylene, 505
 lined steel, 503–504
 polypropylene piping, 506
 polyvinylidene fluoride piping, 505
 thermoplastic piping, 501–503
 titanium, 504–505
 sulfur dioxide dechlorination facilities, 588–589
 ultraviolet light system guidelines, 936
- Planning guidelines, chlorination system operation and maintenance, 680
- Plastic piping, chlorine feeders, valve systems and, 447–449
- Plate generators, ozone generation, 812–813
- Polarography:
 chlorination/dechlorination process controls:
 history, 597
 online analytical measurements, 599–600
 residual chlorine compounds,
 iodometric electrodes,
 membrane sensors, 219
- Polybromide resin system, development of, 853

- Polypropylene (PP), sodium hypochlorite piping, 506
- Polytetrafluoroethylene (PTFE), ozone corrosion, 768
- Polyvinyl chloride (PVC):
 - header failure, chlorine leak, 38–39
 - ozone corrosion, 768
 - sodium hypochlorite storage and handling:
 - basic properties, 501–503
 - storage tank linings, 478
 - valves, 507–508
- Polyvinylidene fluoride (PVDF), sodium hypochlorite piping, 505
- Ponding, wastewater chlorination and biological treatment, trickling filters, 339
- Postdesiccant filter, ozone generation, 811
- Potable water treatment:
 - advanced oxidation processes, 982–990
 - degreasers and solvents, 983
 - disinfection by-product precursor oxidation, 989–990
 - fuel oxygenates, 984–985
 - pesticide oxidation, 985–988
 - petroleum products, 984
 - taste and odor compound oxidation, 988–989
 - volatile organic carbon oxidation, 982–985
- breakpoint curve chemistry and kinetics, 110–115
- bromine chemistry, 851–853
 - bromo-organic compounds, 871–872
- calcium hypochlorite, 518–524
- chlorination:
 - algae/actinomycetes tastes and odors, 286–288
 - aquifer recharge, 299
 - biocidal effects, 232, 234–235
 - coagulation aid, 293
 - color removal, 303
 - consensus indicator organism, 236
 - desalination, 303–304
 - Disinfectants/Disinfection
 - By-products Rule, Stage 1, 239
 - filtration aid, 294–295
 - in Germany, 310
 - groundwater rule, 240
 - hydrogen sulfide control, 299–303
 - impurities in, 21–22
 - Interim Enhanced Surface Water Treatment Rule, 238–239
 - iron and manganese occurrence and oxidation, 290–293
 - leaks, accidents and fatalities, 53–62
 - Long-term 1 Enhanced Surface Water Treatment Rule, 239
 - Long-term 2 Enhanced Surface Water Treatment Rule, 239–240
 - microbes in water supplies, 230–231
 - protozoan inactivation, 235
 - quagga mussels, 299
 - reflecting pools, 304
 - risk management programs, 41–47
 - Safe Drinking Water Act
 - disinfection requirements, 236
 - seawater mollusca fouling, 295–296
 - Surface Water Treatment Rule, 236–238
 - synthetic taste and odor sources, 288–289
 - tastes and odors, 285–289
 - toxic effects and hazards, 30–33
 - in United Kingdom, 306–310
 - virucide applications, 235
 - volume-temperature relationship, 26
 - waterborne diseases, 231–234
 - well restoration, 304–306
 - zebra mussels, 296–298
- chlorination/dechlorination process
 - controls, maintenance issues, 670–673
- chlorine contact systems design, 414–416
- chlorine demand and, 149–151
- chlorine dioxide:
 - chemistry, 704–705
 - disinfection, 727–736
 - overview, 701–703
- dechlorination, process control
 - systems, 653–657
- disinfection process:
 - building disinfection, 283
 - by-products, 261–262

Potable water treatment: (*cont'd*)

- chloramination, 248–263
 - ammonia-chlorine process, 250–251
 - ammonia N reaction chemistry, 251
 - aquatic life and, 260–261
 - efficiency concerns, 255–256
 - free chlorine residuals, 253–255
 - historical background, 248–250
 - kidney dialysis patients, 260
 - lead concentrations, 261
 - limitations, 253
 - nitrification, 256–260
 - shock-chlorination, 260
- chlorination, 240–248
 - application points, 242–243
 - bromate, 245
 - by-products (DBPs), 243–248
 - chlorination-dechlorination, 247–248
 - chlorine demand, 245–247
 - gas and liquid chlorine, 243
 - haloacetic acids, 244
 - historical background, 241–242
 - total organic halides, 244–245
 - trihalomethanes, 243–244
- chlorine dioxide, 727–728
- coagulated surface water, 310–311
- feed systems, 279–280
- groundwater with iron and manganese, 311
- in-service water storage inspection, 284–285
- new infrastructure, 279–285
- odor formation, 262–263
- softened surface water, 311
- storage tanks, 282
- water mains, 281
- water treatment plants, 282–283
- well disinfection, 284
- distribution system, 263–279
 - flushing, 278
 - monitoring, 273–275
 - operation, 272–273
 - regrowth management, 266–272
 - bacterial growth, 268
 - biofilm formation, 267–268
 - breakthrough, 268
 - coliforms, 269–270
 - corrosion and sediment accumulation, 271–272
 - disinfectant residuals, 271
 - environmental factors, 270
 - nutrient availability, 270–271
 - regulatory compliance, 264–265
 - secondary disinfectant residuals, 275–276
 - treatment plant performance and water quality, 279
 - water age control, 275–276
- iodine applications, 878–879
- lithium hypochlorite, 525–526
- nitrogenous compounds, 92–94
- oxidation-reduction, chlorine compounds, 134–135
- ozone, 787–789
 - applications, 795–796
 - installations, 796
- residual chlorine analysis, 185
 - amperometric determination, 176
 - titration, 187–208
- breakpoint phenomenon, 175–179
- chloramines, 185–186
- chlorination stations, 185
- colorimetric/titrimetric determination, 180
- diethyl-p-phenylenediamine determination, 176–177, 208–214
- colorimetric method, 210–211
- DPD-FAS titrimetric methods, 211–214
- palin tablet method, 211
- spectrophotometric method, 211
- drinking water treatment plants, 185
- FACTS (syringaldazine) method, 214–215
- free chlorine determination, 177–179
- historical background, 174–179
- interferences, 180–182
- iodometric electrode method, 218–219
- iodometric method I, 215–217
- iodometric method II, 217–218
- leuco crystal violet determination, 177, 219–220

- methyl orange method, 177
 - MO method, 220–221
 - nitrified effluents, 187
 - organic nitrogen interference, 182–184
 - orthotolidine method, 221–223
 - drop dilution, 222–223
 - primary effluents, 186
 - recent developments, 179
 - secondary effluents, 186
 - small water supplies, 184–185
 - superchlor-dechlor processing, 572–573
 - ultraviolet light systems (*See also* specific regulatory agency guidelines)
 - in United States, 896–897
 - validation guidelines, 932–954
- Potash (potassium hydroxide), hypochlorite formation and, 452–453
- Potassium iodide (KI) solution:
 - amperometric titration, residual chlorine analysis:
 - back amperometric titration procedure, 202–203
 - phenylarsine oxide reaction, 194–195
- available chlorine, 88–91
- chlorine dioxide analysis, oxychlorine by-products, *Standard Methods* 4500-ClO₂-C amperometric method I, 744
- ozone concentrations in gas, 839
- Potassium persulfate-chlorite solution, chlorine dioxide, 724–725
- Potentiometry, chlorination/dechlorination process controls, online analytical measurements, 600–602
- Pot-type vaporizer chlorine feed systems, 434–435
- Pounds-per-gallon calculations, sodium hypochlorite processing, 456–457
- Powdered activated carbon (PAC):
 - advanced oxidation processes, taste and odor oxidation, 988–989
 - aqueous chlorine and, 145–146
- Power meters, ultraviolet light systems, 964
- Prechlorination:
 - as coagulation aid, 293–295
 - wastewater, odor control, 330–333
- Precision limits, amperometric techniques, residual compound analysis, 200
- Precompressor filters, ozone generation, 810
- Predesiccant filter, ozone generation, 811
- Predisinfection process, wastewater disinfection, 373–375
- Pressure ratings:
 - gaseous chlorine, 1003
 - sodium hypochlorite piping, 499
- Pressure-reducing valve:
 - chlorine feed systems, 436–437
 - ozone generation, 811
- Pressure swing adsorption (PSA), ozone generation, 801, 808–809
- Pressure-type chlorine feeders, 443–445
- Primary wastewater effluents:
 - residual compound analysis, 186
 - reuse practices, 397–400
- Process controls. *See* Control systems
- ultraviolet light systems, 965
- Process flow signal, compound loop control systems, 651–653
- Process Safety Management (PSM) regulations (OSHA), chlorine storage, 45–46
- Process Solutions, Inc. (PSI) on-site sodium hypochlorite generation systems, 568, 570–571
- Programmable logic controllers (PLCs), chlorination/dechlorination process controls, 594–596
 - chemistry and, 663–670
 - compound loop control, 649–653
 - fuzzy logic approach, 637
- Protozoa inactivation, chlorine and, 235
- Pulsar Hypo Pump, sodium hypochlorite transfer systems, 492–493
- Pulsed ultraviolet lamps, ultraviolet light systems, 917–918

- Pumped chlorine solution assembly, chlorine and eductor feed systems, 442–445
- Pumping systems:
 - chlorination/dechlorination process controls, maintenance, 672–673
 - sodium hypochlorite:
 - diaphragm metering pumps, 486–490
 - facilities and base layout, 515–517
 - peristaltic pump, 493–499
 - transfer pumps, 486
 - vapor locking problems, 490–493
- Purity. *See* Impurity detection
- Quagga mussels, control in seawater, 299
- Quench chemicals, ozone processing, 836
- Radioactive decay, sodium hypochlorite degradation, 465
- Radiofrequency-energized electrodeless lamps, ultraviolet light systems, 915–917
- Railroad tank cars:
 - chlorine feed systems, 428–430
 - chlorine leaks, 47–51, 61
 - operation and maintenance, 695–696
- Rainfall, regrowth management, 270
- Raw water chlorination:
 - applications, 242–243
 - septicity control, 346–348
- Raw wool processing, industrial wastewater chlorination, 361
- Reaction mechanisms:
 - oxidation-reduction, chlorine compounds, 135
 - ozone, 769–771
- Reactor classes, ultraviolet light systems, 921–924
- Reagents, residual chlorine titration, amperometric apparatus, 196
- Rechlorination, trichoramine formation, 102–103
- Reclamation systems, wastewater reuse, 398–400
- Record keeping guidelines, chlorination/dechlorination process controls, 673–676
- Rectifier system:
 - on-site sodium hypochlorite generation, 546
 - layout and design, 563–564
 - ozone generation, 814–815
- Redox reactions. *See* Oxidation-reduction potential
- Reduction equivalent dose (RED), ultraviolet light systems, guidelines for, 941–943
- Reduction reaction, chlorite ions, 730
- Redundancy requirements, on-site sodium hypochlorite generation layout, 558–559
- Reflecting pools, chlorination, 304
- Refrigerant dryer, ozone generation, 811
- Regal SmartValve Series 7000 chlorinator, flow pacing, 644
- Regrowth management:
 - dechlorination process, 576
 - potable water distribution system, 266–272
 - bacterial growth, 268
 - biofilm formation, 267–268
 - breakthrough, 268
 - coliforms, 269–270
 - corrosion and sediment accumulation, 271–272
 - disinfectant residuals, 271
 - environmental factors, 270
 - nutrient availability, 270–271
 - wastewater disinfection, 394–395
- Regulatory guidelines:
 - advanced oxidation processes, 994–995
 - bromine compounds, 875
 - chlorination/dechlorination process controls, 673–676
 - chlorine dioxide, 754–755
 - iodine, 887
 - operation and maintenance operations, 697–699
 - ozone treatment, 843
 - sodium hypochlorite processing, 455–457

- ultraviolet light systems:
 - NWRI/AwwaRF Disinfection guidelines, 904, 907–908
 - USEPA *Design Manual for Municipal Wastewater Disinfection*, 908–910
 - USEPA UV Disinfection Guidance Manual, 904–906
 - wastewater treatment, 895–896
 - water distribution systems, 264–265
- Relative humidity, ozone gas sources, 801–802
- Relief/rupture disk installation, on-site sodium hypochlorite generation, hydrogen formation, separation, and safety, 550–553
- Reliquefaction, sulfur dioxide, dechlorination process, 577–579
- Rendering process, wastewater chlorination, 361
- Repair mechanisms, UV-inactivated microorganisms, 899–902
- Reporting requirements:
 - chlorine contact system design, 417
 - operation and maintenance regulations, 698–699
- Residence time distribution (RTD),
 - ultraviolet light systems, microorganism inactivation, 903–904
- Residual disinfectants:
 - analyzer maintenance and calibration, 681–682
 - aqueous chlorine:
 - breakpoint reaction, 104–109
 - germicidal efficiency, 151–161
 - chloramines, 155–161
 - hypochlorite ion, 154–155
 - hypochlorous acid, 153–154
 - inactivation mechanisms, 152–153
 - bromines, 872–875
 - chlorination/dechlorination process controls, 596–598
 - compound loop control, 648–653
 - dechlorination, 653–657
 - history, 597–598
 - chlorine dioxide, 754–755
 - chlorine-organic nitrogen reactions, 119–122
 - dechlorination process, 572–573
 - sulfite compounds, 581–583
 - disinfectant residuals, 275–276
 - dissolved ozone in water, 839–842
 - iodine, 886
 - phenolic wastes, industrial wastewater chlorination, 359–360
 - potable water chloramination, 253–255
 - nitrification, 257–258
 - regrowth management, 271
 - secondary disinfectants, 275–276
 - wastewater chlorination, chemistry, 328–329
 - wastewater disinfection, toxicity levels, 395–396
- water and wastewater treatment:
 - amperometric determination, 176
 - titration, 187–208
 - breakpoint phenomenon, 175–179
 - chloramines, 185–186
 - chlorination stations, 185
 - colorimetric/titrimetric determination, 180
 - diethyl-p-phenylenediamine determination, 176–177, 208–214
 - colorimetric method, 210–211
 - DPD-FAS titrimetric methods, 211–214
 - palin tablet method, 211
 - spectrophotometric method, 211
 - drinking water treatment plants, 185
 - FACTS (syringaldazine) method, 214–215
 - free chlorine determination, 177–179
 - historical background, 174–179
 - interferences, 180–182
 - iodometric electrode method, 218–219
 - iodometric method I, 215–217
 - iodometric method II, 217–218
 - leuco crystal violet determination, 177, 219–220
 - methyl orange method, 177
 - MO method, 220–221
 - nitrified effluents, 187

- Residual disinfectants: (*cont'd*)
 - organic nitrogen interference, 182–184
 - orthotolidine method, 221–223
 - drop dilution, 222–223
 - primary effluents, 186
 - recent developments, 179
 - secondary effluents, 186
 - small water supplies, 184–185
- Return activated sludge (RAS):
 - ozone treatment, 786
 - wastewater chlorination:
 - odor control, 332–333
 - sludge bulking control, 342–345
- Reuse practices:
 - chlorination/dechlorination process controls, 638
 - compound loop control, 649–653
 - chlorine contact systems design, 413
 - ozone off-gas, 828–829
 - ultraviolet light systems, water
 - reuse validation guidelines, 949–953
 - wastewater disinfection, 397–400
- Risk management programs (RMPs):
 - chlorine storage, 41–47
 - OSHA Process Safety Management regulations, 45–46
 - worst-case and alternative release analyses, 46–47
 - operation and maintenance regulations, 697–699
- Room turnover calculation, on-site sodium hypochlorite generation, 552
- Room volume calculation, on-site sodium hypochlorite generation, 551
- Rubber, sodium hypochlorite storage and handling:
 - diaphragm valves, 510–513
 - gaskets, seals, and o-rings, 506–507
 - storage tank liners, 479–480
- Safe Drinking Water Act (SDWA):
 - chlorine disinfectant requirements, 236
 - operation and maintenance regulations, 697–699
- Safety audits, ultraviolet light systems, 968
- Safety requirements:
 - bromine chloride facilities, 865
 - bromine compounds, 874–875
 - chlorine dioxide processing and handling, 752
 - iodine, 886–887
 - ozone treatment, 842–843
 - ultraviolet light systems, 966–970
- Safety units, sodium hypochlorite requirements, 461–462
- Salt process:
 - chlorine manufacturing, 18
 - sodium hypochlorite processing, 475
 - on-site sodium hypochlorite generation, 530
 - salt quality, 530–531
- “Sample-and-hold” control
 - function, chlorination/dechlorination process controls, compound loop control, 649–653
- Sampling techniques:
 - chlorine contact system design, 417
 - ultraviolet light systems, guidelines for, 937–938, 945, 951–952
- Scaling:
 - sodium hypochlorite degradation, 475–476
- “Scalping” water reclamation, wastewater reuse, 400
- Schedule 80 thermoplastic pipe:
 - on-site sodium hypochlorite generation, hydrogen dilution blowers, 554–556
 - sodium hypochlorite, pressure rating, 499–500
- Scrubbers, chlorine feed systems, 450–451
 - emergency scrubbers, 686–687
- Seals and sealants, sodium hypochlorite storage and handling, 506–507

- Seawater:
 - bromine in, 849
 - chlorination effects, 874
 - chlorine chemistry and, 122–129
 - broamine formation and decay, 127–129
 - bromide effect, 123–126
 - ionic strength effects, 126–127
 - chlorine chemistry, 122–129
 - broamine formation and decay, 127–129
 - bromide effect, 123–126
 - ionic strength effects, 126–127
 - desalination, 303–304
 - mollusca control in, 295–299
 - on-site sodium hypochlorite
 - generation systems, 531
- Secondary disinfection, chlorine dioxide, 734
- Secondary wastewater effluents:
 - coliform standard, wastewater treatment, 366–368
 - residual compound analysis, 186
 - reuse practices, 397–400
 - wastewater chlorination:
 - foul air scrubbing systems, 333–338
 - viral inactivation, 370–375
- Second-order reaction law, sodium
 - hypochlorite degradation, 467
- Sediment accumulation, potable water
 - chlorination, 271–272
- Selleck-Collins wastewater disinfection
 - model. *See also* CT criteria
 - chlorine dose and effluent quality, 382–384
- Sensor instrumentation:
 - sodium hypochlorite storage tanks, 483–484
 - ultraviolet light systems, 926–927
 - temperature sensors, 928–929
- Septicity control, wastewater
 - chlorination, 345–348
- Settled particulates, sodium hypochlorite
 - degradation, 473–474
- Sewage treatment:
 - chlorination:
 - history, 326–327
 - odor control, 329–338
 - chlorine dioxide, 735–736
 - disinfection process, 375–378
 - wastewater disinfection process, viral inactivation, 368–375
- Shock-chlorination, potable water
 - chloramination, 260
- Short term exposure limit (STEL),
 - chlorine dioxide, 703–704
- Sidestream injectors, ozone transfer, 817–820
 - baffled basin contactors, 822–824
- Signal simulators, gaseous chlorine
 - system operations, 682–684
- Silica, chlorine contamination, 24
- Silicon-controlled rectifiers, ozone
 - generation, 814
- Silver, chlorine chemical reactions, 30
 - cyanide wastes, industrial wastewater chlorination, 353–358
- Silver chloride, formation of, 30
- Single-indicator-electrode titrator,
 - amperometric titration, residual compound analysis, 188–190
- Size parameters:
 - chlorine contact systems design, 411, 413
 - chlorine feed systems, 418–420
 - ultraviolet light systems, 932–954
- Sludge bulking control:
 - phenolic wastes, industrial wastewater chlorination, 359–360
 - wastewater chlorination and biological treatment, 340–345
- Sludge conveyance pipelines, wastewater
 - chlorination, septicity control, 346–348
- Sludge volume index (SVI), wastewater
 - chlorination, 342–345
- Small water supplies, residual chlorine
 - analysis in, 184–185
- Snift gas, chlor-alkali plant, chlorine
 - electrolysis, 17
- Socket welding, titanium piping, sodium
 - hypochlorite storage and handling, 505
- Sodium bromate, sodium hypochlorite
 - degradation, 475
- Sodium carbonate, sodium hypochlorite
 - degradation, 474

- Sodium chlorate, sodium hypochlorite and, 463
- Sodium chlorite:
 - health and safety requirements, 752–753
 - impurities, chlorate generation, 733
- Sodium cycle ion exchanger, on-site sodium hypochlorite generation, water softening systems, 535–537
- Sodium hydroxide:
 - chlor-alkali plant, chlorine electrolysis, 17
 - on-site sodium hypochlorite generation, process overview, 531–534
 - wastewater chlorination, ammonia removal, 351–352
- Sodium hypochlorite:
 - aqueous chlorine solutions, 82–85
 - chlorine alkalinity, 144
 - chlorine gas dissolution and hydrolysis, 68–74
 - concentration, 455–457, 466–468
 - degradation, 463–477
 - Arrhenius equation, 465
 - concentration effects, 466–468
 - impurities, 471–475
 - pH effects, 469–470
 - rate estimation, 464–466
 - recommendations and guidelines, 476–477
 - settled particulates, 473–474
 - sodium bromate, 474–475
 - sodium carbonate, 474
 - suspended solids, 473
 - temperature effects, 468–469
 - ultraviolet light effects, 470–471
- facility layouts, 513–518
 - access and clearances, 517
 - control panels, 518
 - elevation differences, 513–514
 - tank and pump bases, 515–517
- fire codes requirements, 461–462
- freezing point, 458
- hazards of, 462–463
- health and safety requirements, 753
- history of, 453
- manufacturing requirements, 454–456
- on-site generation system:
 - brine dilution, 545
 - brine metering, 542
 - brine saturator tank, 537–539
 - current trends, 529–530
 - design criteria, 557–565
 - equipment sizing, 557–558
 - layout, 559–565
 - storage requirements, 559
 - system redundancy, 558–559
 - electrolytic cell, 542–545
 - electrolytic formation, 531–534
 - feed equipment, 556
 - history, 528–529
 - hydrogen dilution blowers, 553–556
 - hydrogen formation, separation, and safety, 546–553
 - air requirement calculations, 551
 - calculation variables, 552
 - outside ventilation air induction rate, 551
 - production calculations, 551
 - room turnover rate calculation, 552
 - room volume calculations, 551
 - manufacturers, 565–571
 - Clortec generators, 565–566
 - Klorigen system, 566–567
 - MIOX, 567, 569
 - OSEC system, 567–568, 570
 - Process Solutions, Inc., 568, 570–571
 - rectifier, 546
 - salt and brine systems, 530
 - salt quality and bromate formation, 530–531
 - seawater systems, 531
 - soft-water chiller, 540–542
 - soft-water heater, 539–540
 - storage tanks, 556
 - water softener, 534–535
- piping systems, 499–507
 - fiber-reinforced piping, 504
 - gaskets, seals, and o-rings, 506–507
 - hastelloy, 506
 - high-density polyethylene, 505
 - lined steel, 503–504

- polypropylene piping, 506
- polyvinylidene fluoride piping, 505
- thermoplastic piping, 501–503
- titanium, 504–505
- storage tank criteria, 477–485
 - fiberglass-reinforced plastic tanks, 478, 480
 - high-density polyethylene, 480–483
 - level instrumentation
 - requirements, 483–484
 - lined steel tanks, 479–480
 - titanium, 483
 - top access, 485
 - underground storage tanks, 485
- structure and properties, 454–455, 460–461
- system design calculation, 458
- system operation and maintenance, 687–690
- transfer and feed equipment, 486–499
 - contour plates, 491
 - diaphragm metering pumps, 486–490
 - electric drives, 497
 - hose and tube life, 498
 - hose pumps, 496–497
 - hose replacement, 497–498
 - liquid dosing systems, 498–499
 - peristaltic pumps, 493–499
 - specialty pumps, 492–493
 - stroke length limits, 491
 - transfer pumps, 486
 - tube failure, 496
 - tube pumps, 495
 - tubular diaphragms, 491–492
 - turndown/pressure capabilities, 495–496
 - vapor locking problems, 490–493
- truck unloading procedures, 484
- valve systems, 507–511
 - ball valves, 508–510
 - diaphragm valves, 510–513
- vapor pressure, 458–460
- wastewater disinfection, 376
- Sodium hypochlorite-hydrochloric acid-chlorite solution, chlorine dioxide, 725–726
- Sodium/mercury amalgam, mercury cells, chlorine electrolysis, 11–15
- Sodium thiosulfate, chlorine dioxide analysis, oxychlorine by-products, *Standard Methods* 4500-ClO₂-C amperometric method II, 744
- Softened surface water, disinfection, 311
- Soft-water chiller:
 - on-site sodium hypochlorite generation, 540–542
 - layout and design, 561–565
 - sodium hypochlorite operation and maintenance guidelines, 689
- Soft-water heater, on-site sodium hypochlorite generation, 539–540
 - layout and design, 561–565
- Solid chlorite, solid chlorite, 720, 726
- Solubility:
 - aqueous chlorine, 68–74, 1007
 - calcium hypochlorite, 522–523
 - chlorine, 27–29
 - corrosive properties, 30
 - chlorine gas dissolution and hydrolysis, 68–74
 - ozone, 768–768
 - sulfur dioxide, dechlorination process, 578–580
- Solution lines and diffusers, bromine chloride facilities, 864
- Solution strength, sodium hypochlorite processing, 456–457
- Solvay sodium ammonia process, early chlorine manufacturing, 3
- Solvents, advanced oxidation, water treatment systems, 983
- Solvent-welded joints:
 - sodium hypochlorite piping, 499
 - thermoplastic piping, sodium hypochlorite, 502–503
- Sonic chlorine feeders, 443–445
- Sparklers, ultraviolet light systems, 918
- Specific energy, ozone calculations, 835–836
- Specific heat, chlorine, 27

- Spectrophotometric methods:
 chlorine dioxide analysis, oxychlorine
 by-products, 749–750
 residual chlorine measurement,
 diethyl-*p*-phenylenediamine
 (DPD) titration, 211
- Spray chambers, ozone transfer, 821
- Springs, microbes in, 230
- Stability properties, calcium
 hypochlorite, 523
- Stabilized neutral orthotolidine
 (SNORT), residual chlorine
 analysis, 177, 179
- Stable intermediates, oxidation-
 reduction, 134
- Stack gas scrubbing, cyanide wastes,
 industrial wastewater
 chlorination, 353–358
- Stagnant area surveillance program,
 potable water treatment and
 distribution, 275
- Standard Methods* 4500-ClO₂-C, chlorine
 dioxide analysis, oxychlorine
 by-products:
 amperometric method I, 743–744
 amperometric method II, 744
- Standard operating procedures
 (SOPs), chlorination system
 operation and maintenance,
 679–680
- Standard potentials, half-reactions,
 oxidation-reduction, chlorine
 compounds, 129–135
- Standards and certifications, calcium
 hypochlorite, 524–525
- Starch-iodide forward titration, residual
 compound analysis:
 iodometric method I, 215–217
 nitrite interference, 205–208
- State testing and reporting requirements,
 operation and maintenance
 regulations, 698–699
- Static mixers, chlorine contact systems
 design, 406
- Steadifac method, residual chlorine
 analysis, diethyl-*p*-
 phenylenediamine-ferrous
 ammonium sulfate
 procedure, 213
- Steel case hardening, cyanide wastes,
 industrial wastewater
 chlorination, 353–358
- Steel tanks, sodium hypochlorite
 storage, 479–480
- Stoichiometry:
 breakpoint curve, 106–109
 decomposition products,
 115–116
 oxidation-reduction, 133–135
- Storage tanks. *See also* Tanker trucks/
 tanker cars
 bromine chloride facilities, 864
 chlorine feed systems, 418–419,
 430–431
 disinfection process, 282
 in-service inspection and,
 284–285
 on-site sodium hypochlorite
 generation, 556
 layout and capacity, 559, 563–565
 operation and maintenance,
 693–697
 sodium hypochlorite:
 degradation mechanisms, 469
 facilities and base layout, 515–517
 fiberglass-reinforced plastic tanks,
 478, 480
 high-density polyethylene, 480–483
 level instrumentation
 requirements, 483–484
 lined steel tanks, 479–480
 on-site sodium hypochlorite
 generation, 556
 selection criteria, 477–485
 titanium, 483
 top access, 485
 underground storage tanks, 485
- Stranco control system:
 dechlorination process, 657–658
 oxidation-reduction, chlorine
 compounds, 140–141
 wastewater chlorination, odor control,
 332–333
- Stranco Products, chlorination/
 dechlorination process controls
 HRR system electrodes, 623, 626,
 628–629
- Strantrol analyzer, 622–626

- Stroke length limits, sodium hypochlorite transfer systems, 491
- Sulfate conversion, wastewater chlorination and hydrogen sulfide, 335–338
- Sulfate-reducing bacteria, hydrogen sulfide control, 300–303
- Sulfide-oxidizing bacteria, hydrogen sulfide control, 300–303
- Sulfides, ozone treatment, 775–776
 - destruction catalyst, 826–828
- Sulfite compounds:
 - chlorite removal, 730–731
 - dechlorination process, 581–583
 - chemical properties, 581–582
 - contactor design, 582–583
 - dose calculations, 583
 - facility design, 592–593
 - history, 572–574
- Sulfonator operation and maintenance, gaseous chlorine, 690–692
- Sulfur dioxide:
 - dechlorination process:
 - chemical properties, 577–581
 - contactor design, 580–581
 - dose calculations, 581
 - facility design, 586–591
 - history, 572–574
 - sulfonator operation and maintenance, 691–692
 - vapor pressure vs. temperature, 1006
- Sulfur generation, wastewater chlorination and hydrogen sulfide, 335–338
- Sulfuric acid-chlorite solution, chlorine dioxide, 725
- Sulfurous acid formation, sulfur dioxide dechlorination process, 579–580
- Sunlight. *See* Ultraviolet (UV) light
- Superchlorination. *See also* Dechlorination
 - disinfection by-products, 247–248
 - history, 572–573
 - trichoramine formation, 102–103
- Superoxide ions, ozone reaction, 770–771
- Surface discharge lamps, ultraviolet light systems, 918
- Surface water:
 - disinfection, 310–311
 - microbes in, 230
- Surface Water Treatment Rule (SWTR):
 - chlorine dioxide, 754
 - chlorine disinfectants, 235–238
 - microbe removal guidelines, 231
 - ozone transfer, baffled basin contactors, 823–824
 - potable water disinfection, chlorine dioxide, 725–728
- Suspended solids:
 - sodium hypochlorite degradation, 473
 - ultraviolet light systems, 929–931
- Swimming pool systems:
 - bromine in, 854
 - oxidation-reduction, 140–141
- Synthetic organic compounds (SOCs):
 - ozone treatment, 767, 781–782, 784–785
 - taste and odor from, 288–289
- System redundancy, on-site sodium hypochlorite generation layout, 558–559
- T_{10} detention time, ozone disinfection process, 787–788
- Tablet system, calcium hypochlorite, 518–523
- Tanker trucks/tanker cars. *See also* Storage tanks
 - chlorine feed systems, 427–430
 - chlorine leaks:
 - packager tank car leak, 57–58
 - unloading process, 36
 - on-site sodium hypochlorite generation, brine saturator tanks, 537–539
 - sodium hypochlorite, unloading systems, 484
 - sulfur dioxide dechlorination facilities, 587–589
- Tank surging, well restoration, 306
- Taste control:
 - advanced oxidation processes, 988–989
 - algae and actinomycetes, 286–288
 - chlorine, 289
 - chlorine dioxide, 734–735, 738–739

- Taste control: (*cont'd*)
 - ozone treatment, 778–779
 - of synthetics, 288–289
 - water chlorination and, 285–286
- Teflon, sodium hypochlorite storage and handling, 507
- diaphragm valves, 510–513
- valves, 509–510
- Temperature:
 - bromine chloride, 858–859
 - chlorine feed systems, 418–420
 - chlorine gas dissolution and hydrolysis, 69–74
 - hypochlorous acid dissociation, 74–77
 - ozone gas sources, 802
 - sodium hypochlorite degradation, 464–466, 468–469
 - ultraviolet light systems:
 - measurements, 964
 - sensors, 928–929
- Temperature-density relation, liquid chlorine, 1005
- Tennant's bleaching power, hypochlorite discovery and, 453
- Terrorist activity, intentional chlorine release, 32–33
- Tertiary treatment systems:
 - wastewater chlorination, viral inactivation, 371–175
 - wastewater reuse, 397–400
- Testing requirements, operation and maintenance regulations, 698–699
- Tetraethyl lead, bromine production, 850
- Textile wastes, industrial wastewater chlorination, 360–361
- Thermal catalytic destruction, ozone discharge, 826–828
- Thermal destruction, ozone discharge, 828
- Thermodynamics, oxidation-reduction, 133–135
- Thermofusion welding, sodium hypochlorite piping, 499
- Thermoplastic piping, sodium hypochlorite, 501–503
 - pipe supports, 503
 - solvent cement, 502–503
- Thiosulfate titration, residual chlorine analysis, iodometric method I, 215–217
- Threaded connections, sodium hypochlorite piping, 501
- Three-body collision reaction, ozone generation, 799–800
- Three-chemical systems, chlorine dioxide chemistry, 718–719
- Titanium, sodium hypochlorite storage and handling:
 - piping, 499, 504–505
 - storage tanks, 483
- Titanium dioxide, ozone reactions:
 - hydrogen peroxide-ultraviolet reactions, 981–982
 - ultraviolet light, 981 993–994
- "Title 22 reuse water," chlorine contact systems design, 413
- Titrimetric methods, residual chlorine measurement, 180
 - amperometric apparatus, 195–196
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate (DPD-FAS), 211–214
- Ton containers:
 - chlorine feed systems, 424–427
 - chlorine leaks:
 - brush fires, 59
 - consumer accidents and fatalities, 53–54
 - flexible connection failure, 39
 - nitrogen trichloride explosions, 60
 - pipeline guillotine break, 36–38
 - operation and maintenance, 694–695
- Top-access construction, sodium hypochlorite storage tanks, 485
- Total dissolved solids (TDS)
 - concentration, hypochlorous acid dissociation, 78–80
- Total fan efficiency, on-site sodium hypochlorite generation, hydrogen dilution blowers, 554–556
- Total Kjeldahl nitrogen (TKN), 117–118

- Total organic carbon (TOC):
 - dissolved ozone decay, 772–773
 - ozone chemistry, 767
 - disinfection by-products control, 779–780
 - oxidation reactions, 780
 - taste and odor compounds, 778–779
 - ozone demand, 771–772
- Total organic halides (TOX), as
 - disinfection by-product, 244–245
- Total residual chlorine:
 - amperometric titration, 198
 - diethyl-*p*-phenylenediamine-ferrous ammonium sulfate procedure, 212–213
- Total suspended solids (TSS):
 - wastewater chlorination, sludge bulking control, 343–345
 - wastewater disinfection, ultraviolet (UV) light treatment, 378
- Total trihalomethanes (TTHMs):
 - bromine chemistry, 871–872
 - chlorine disinfectants
 - requirements, 239
 - as disinfection by-product, 243–244
 - ozone control, 779–780
 - potable water chloramination, free chlorine residuals, 254–255
 - water age control, 275–276
- Toxicity:
 - bromine residuals, 874
 - chlorine, 30–33
 - chlorine dioxide, 753
 - dechlorination process, 574–575
 - iodine residuals, 886
 - sulfur dioxide, dechlorination process, 579–580
 - wastewater chlorine residuals, 395–396
- Toxic substance theory, chlorine
 - disinfectants, inactivation mechanisms, 152–153
- Trade percent, sodium hypochlorite processing, 456–459
- Transfer equipment:
 - ozone generation, 816–821
 - aspirating turbine mixers, 821
 - dose calculations, 835
 - efficiency calculations, 834–835
 - fine-bubble diffusers, 816–817
 - packed columns, 821
 - sidestream injectors, 817–820
 - spray chambers, 819
 - U-tubes, 821
- sodium hypochlorite, 486–499
 - contour plates, 491
 - diaphragm metering pumps, 486–490
 - electric drives, 497
 - hose and tube life, 498
 - hose pumps, 496–497
 - hose replacement, 497–498
 - liquid dosing systems, 498–499
 - peristaltic pumps, 493–499
 - specialty pumps, 492–493
 - stroke length limits, 491
 - transfer pumps, 486
 - tube failure, 496
 - tube pumps, 495
 - tubular diaphragms, 491–492
 - turndown/pressure capabilities, 495–496
 - vapor locking problems, 490–493
- Transport accidents, chlorine, 47–52
 - highway transportation, 51–52
 - railroad transportation, 47–51
- Treatment plant performance
 - evaluation, water distribution systems, 279
- Triadimenol, oxidation of, 988
- Trichloramine. *See* Nitrogen trichloride
 - wastewater disinfection, nitrified effluents, 386–390
- Trichloride ion, chlorine gas dissolution and hydrolysis, 72–74
- Trickling filters, wastewater chlorination and biological treatment, 338–339
- Trihalomethanes (THMs). *See also* Total trihalomethanes (TTHMs)
 - bromine chemistry, 871–872
 - chlorination/dechlorination process controls, 596–598
 - chlorine dioxide, 701–702
 - chlorine dioxide control, 740
 - wastewater disinfection by-product, 390–393
- Tri-iodide, chemistry, 879–882

- Troubleshooting strategies, ultraviolet light systems, 965–966
- True block valves, sodium hypochlorite storage and handling, 509–510
- Trunnion structures, chlorine feed systems, ton containers, 425–427
- Tube-type vaporizer, vaporizer chlorine feed systems, 433–434
- Tubular diaphragm pump, sodium hypochlorite transfer systems, 491–492
- Tyndall effect, hydrogen sulfide removal, 147
- Typhoid fever:
 - potable water chlorination, 231–232
 - wastewater disaffection process, viral inactivation, 368–375
- Ultraviolet (UV) light systems:
 - ballasts, 924–925
 - basic principles, 893
 - chemical and biological properties, 897–898
 - chlorination/dechlorination process controls, 665–670
 - chlorine dioxide exposure, 728–729
 - cleaning systems, 927–928
 - dose calculations, 902–904
 - equipment overview, 910
 - functional testing, 964
 - health and safety issues, 966–970
 - hydrogen peroxide, 979–980, 991–992
 - lamps, 910–921
 - electrodeless mercury vapor lamps, 914–917
 - excimer lamps, 918–920
 - mercury vapor lamps, 910–914
 - metal halide lamps, 917
 - pulsed lamps, 917–918
 - lamp sleeves, 925–926
 - maintenance activities, 961–963
 - microbial inactivation, 898–901
 - microbial repair, 899–902
 - microbial sensitivity, 899–900
 - online monitors, 928
 - operating activities, 963–965
 - ozone demand, 771–772
 - photo-Fenton reaction, 980–981, 992–993
 - photolysis, 979, 991–992
 - potable water treatment, 898–899
 - reactors, 921–924
 - sensors, 926–927
 - sodium hypochlorite degradation, 470–471
 - system guidelines, 904–910
 - temperature sensors/water level probes, 928–929
 - thermoplastic piping, sodium hypochlorite, 502–503
 - titanium dioxide, 981, 993–994
 - titanium dioxide-hydrogen peroxide, 980–981
 - transmittance, 782–783, 929
 - troubleshooting strategies, 965–966
 - validation guidelines, 933–954
 - (*See also* specific agencies)
 - biodosimetry data analysis, 940–941, 946–948, 950, 952
 - challenge microorganisms and dose requirements, 935, 943–944, 949, 951
 - collimated beam analysis, 938–940, 945–946, 952
 - computational fluid dynamics, 959–960
 - dose-monitoring and test conditions, 936–937, 944–945, 951
 - dosimetry data analysis, 940–942
 - dyed microspheres, 960–961
 - location and test stand considerations, 935–936, 949–951
 - nonbiological, mathematical-based modeling, 955–958
 - potable water, 934–935
 - sampling and data recording, 937–938, 945, 951–952
 - wastewater and water reuse, 949

- wastewater disinfection, 378
 - European systems, 893–894
 - North America, 894–896
- water quality issues, 929–931
 - fouling, 931–932
 - particle/suspended solids, 929–931
 - transmittance, 929
- Uncertainty of validation, ultraviolet light systems, 940–943
- Underground storage tanks (UST), sodium hypochlorite, 484
- United Kingdom, potable water chlorination in, 306–310
- United States Environmental Protection Agency (USEPA):
 - Design Manual for Municipal Wastewater Disinfection*, 908–910
 - Environmental Technology Verification (ETV) program, ultraviolet light system guidelines, 948–949, 953
 - risk management programs, chlorine storage, 41–47
 - ultraviolet wastewater treatment systems, historical background, 895–896
- Urea, ammonia hydrolysis, organic nitrogen, 119–120
- U-tubes, ozone transfer, 821
- UV Disinfection Guidance Manual (UVDGM)*, ultraviolet light systems:
 - biodosimetry data analysis, 940–943
 - challenge microorganisms and dose requirements, 935
 - collimated beam analysis, 938–940
 - dose-monitoring approaches and validation test conditions, 936–937
 - guidelines in, 904–906
 - potable water treatment, 896–897, 934–935
 - sampling and data recording, 937–938
 - validation location and test stand considerations, 935–936
- UVDIS software program, ultraviolet light systems guidelines, nonbiological, mathematical-based modeling, 955–958
- Vacuum density, gaseous chlorine, 1004
- Vacuum regulator:
 - compound loop control systems, 651–653
 - gas chlorine feed system, 438–442
 - sulfur dioxide dechlorination facilities, 588–589
- Vacuum swing adsorption (VSA), ozone generation, 801, 806–808
- Validation guidelines. *See also* specific regulatory agencies
 - ultraviolet light systems, 933–954
 - biodosimetry data analysis, 940–941, 946–948, 950, 952
 - challenge microorganisms and dose requirements, 935, 943–944, 949, 951
 - collimated beam analysis, 938–940, 945–946, 952
 - computational fluid dynamics, 959–960
 - dose-monitoring and test conditions, 936–937, 944–945, 951
 - dosimetry data analysis, 940–942
 - dyed microspheres, 960–961
 - location and test stand considerations, 935–936, 949–951
 - nonbiological, mathematical-based modeling, 955–958
 - potable water, 934–935
 - sampling and data recording, 937–938, 945, 951–952
 - uniform validation protocols, 954
 - wastewater and water reuse, 949
- Valve systems:
 - chlorine feed systems:
 - cylinders, 421–424
 - pipe and valve systems, 445–449
 - pressure-reducing valve, 436–437
 - tank cars and trucks, 428–430
 - ton containers, 424–427
 - chlorine leaks, packing failure, 61

- Valve systems: (*cont'd*)
 - gaseous chlorine system operations, 683–684
 - ozone generation, 811
 - sodium hypochlorite, 507–513
 - ball valves, 508–510
 - diaphragm valves, 510–513
 - storage tank operation and maintenance, 696–697
- Van't Hoff relationship, chlorine gas dissolution and hydrolysis, 69–74
- Vapor density:
 - chlorine, 27
 - sulfur dioxide, dechlorination process, 578–580
- Vaporizers, liquid chlorine feed systems, 431–436
- Vapor locking, sodium hypochlorite transfer, 486–493
- Vapor pressure:
 - bromine chloride, 858–859
 - chlorine, 27
 - sodium hypochlorite, 458–460
 - sulfur dioxide, dechlorination process, 577–579
- Velocity profile, ultraviolet light system guidelines, 936, 946–947
- “Vented” ball valves, sodium hypochlorite storage and handling, 510
- Ventilation systems, on-site sodium hypochlorite generation, 551–553
- Viruses:
 - chlorine dioxide disinfection, 737–738
 - chlorine inactivation, 235
 - wastewater disaffection process and, 368–375
- Viscosity, gas and liquid chlorine, 1004
- Viton (FKM), sodium hypochlorite storage and handling, 510
 - ball valves, 508–510
 - diaphragm valves, 510–513
- Volatile fatty acids (VFA), wastewater chlorination:
 - odor control, 332–333
 - septicity control, 346–348
- Volatile organic compounds (VOCs), advanced oxidation processes, 982–985
- Volatile suspended solids (VSS), wastewater chlorination, sludge bulking control, 343–345
- Voltametry:
 - chlorination/dechlorination process controls, online analytical measurements, 599
 - dechlorination process, sulfur dioxide leak detection, 589–591
- Volume-temperature relationship:
 - chlorine, 26
 - liquid chlorine, 1007
- Volumetric flow calculations, on-site sodium hypochlorite generation, hydrogen dilution blowers, 553–556
- Wallace & Tiernan online analyzers:
 - chlorination/dechlorination process controls, 621–622
 - compound loop control systems, 651–653
 - dechlorination process control, 658–662
- Wastewater treatment:
 - advanced oxidation processes, 982–990
 - degreasers and solvents, 983
 - disinfection by-product precursor oxidation, 989–990
 - fuel oxygenates, 984–985
 - pesticide oxidation, 985–988
 - petroleum products, 984
 - taste and odor compound oxidation, 988–989
 - volatile organic carbon oxidation, 982–985
- breakpoint curve chemistry and kinetics, 110–115
- bromine chemistry, 851, 853
- chlorination:
 - ammonia removal, 349–352
 - biological treatment, 338–345
 - BOD reduction, 339–340
 - sludge bulking control, 340–345
 - trickling filters, 338–339
 - chemistry, 327–329

- history, 326–327
- industrial applications, 352–361
 - free and combined cyanides, 352–358
 - phenols, 359–360
 - textile wastes, 360–361
- odor control, 329–338
 - foul air scrubbing, 333–338
 - prechlorination, 330–333
- oil and grease removal, 348–349
- reporting requirements, facilities maintenance and operations, 699
- septicity control, 345–348
- chlorination/dechlorination process controls:
 - maintenance issues, 670–673
 - overview, 594–596
- chlorine contact systems design, 413
- chlorine demand and, 149–151
- chlorine dioxide:
 - disinfection, 735–736
 - regulatory issues, 755
- chlorine leaks, 55–57
- chlorine storage, USEPA risk management programs, 41–47
- dechlorination process, 574–575
 - speciation, 576–577
 - sulfur dioxide, 588–589
- disinfection process:
 - by-product formation, 390–394
 - chlorine chemistry, 379–390
 - constituent reactions, 379–382
 - dose and effluent quality, 382–384
 - nitrified effluent chlorination, 384–390
 - chlorine dioxide, 735–736
 - coliform standard, 364–368
 - dechlorination, 576–577
 - dechlorination indications, 396–397
 - history, 363–364
 - methods and techniques, 357–378
 - organism regrowth, 394–395
 - residual chlorine toxicity, 395–396
 - viruses, 368–375
 - wet weather disinfection, 416–417
- lithium hypochlorite, 525–526
- nitrogenous compounds, 92–94
- organic nitrogen formation, 117–118
- ozone:
 - applications, 795–796
 - biologic solids treatment, 786
 - disinfection process, 790–792
 - installations, 795
- residual chlorine:
 - amperometric determination, 176
 - back titration procedure, 202–203
 - iodine solution monitoring, 203–204
 - nitrogen trichloride, 204–205
 - titration, 187–208
- breakpoint phenomenon, 175–179
- chloramines, 185–186
- chlorination stations, 185
- colorimetric/titrimetric determination, 180
- diethyl-p-phenylenediamine determination, 176–177, 208–214
 - colorimetric method, 210–211
 - DPD-FAS titrimetric methods, 211–214
 - palin tablet method, 211
 - spectrophotometric method, 211
- drinking water treatment plants, 185
- FACTS (syringaldazine) method, 214–215
- free chlorine determination, 177–179
- historical background, 174–179
- interferences, 180–182
- iodometric electrode method, 218–219
- iodometric method I, 215–217
- iodometric method II, 217–218
- leuco crystal violet determination, 177, 219–220
- methyl orange method, 177
- MO method, 220–221
- nitrified effluents, 187
- organic nitrogen interference, 182–184
- orthotolidine method, 221–223
 - drop dilution, 222–223
- primary effluents, 186
- recent developments, 179
- secondary effluents, 186
- small water supplies, 184–185

- Wastewater treatment: (*cotn'd*)
 - reuse practices, 397–400
 - ultraviolet light systems:
 - in Europe, 893–894
 - in North America, 894–896
 - regulatory guidelines for, 949
 - uniform validation protocols, 954
- Water age control, potable water
 - treatment and distribution, 275–276
- Waterborne disease:
 - potable water chlorination, 231–234
 - wastewater disaffection process, viral inactivation, 368–375
- Water Champ induction unit, chlorine
 - contact systems design, 409–412
- Water hardness properties, wastewater
 - chlorination, foul air scrubbing systems, 334–338
- Water immersion, vaporizer chlorine
 - feed systems, 435–436
- Water level probes, ultraviolet light
 - systems, 928–929
- Water mains, disinfection, 281
- Water quality standards:
 - chlorine by-products and, 340–341
 - ultraviolet transmittance, 929
- Water softening systems:
 - on-site sodium hypochlorite generation, 534–535
 - sodium hypochlorite operation and maintenance guidelines, 689
- Water temperature, regrowth
 - management, 270
- Water treatment. *See* Potable water treatment; Wastewater treatment
- Water treatment plants, disinfection
 - process, 282–283
- Weighing devices, chlorine feed systems, 423–424
- Weldon process, early chlorine
 - manufacturing, 3
- Wells:
 - disinfection process, 284
 - restoration of, 304–306
- Wet-chemistry measurements, ozone
 - concentrations in gas, 839
- Wet sensors, ultraviolet light systems, 926–927
- Wet weather disinfection, wastewater
 - treatment, 416–417
- Withdrawal rate, sulfur dioxide,
 - dechlorination process, 577–579
- Wood storage tanks, sodium
 - hypochlorite, 483
- Workplace design:
 - chlorine dioxide monitoring, 753–754
 - sodium hypochlorite storage and handling, 513–518
- Worst-case analyses, risk management
 - programs, 46–47
- Wunsche electrochemical process,
 - bromine production, 849
- Zebra mussels:
 - chlorine dioxide control of, 740
 - control in seawater, 297–298
- Zero chlorine residual:
 - dechlorination control systems, 655–657
 - dechlorination process, 572–573