

**"Pulp Bleaching:
Principles and Practice"**
Edited by Carlton W. Dence and Douglas W. Reeve

1996, 880 pages, 7" x 10" hard cover page

Order Number: 0102B061

ISBN: 0-89852-063-0

This comprehensive text is a complete revision of *The Bleaching of Pulp*, published by TAPPI PRESS in 1979. The new text covers fundamentals and processes from chemical composition of pulp to technology, production, and the environmental impact of bleaching. Designed as a text book and reference book, *Pulp Bleaching: Principles and Practice* explains what bleaching is, why pulp is bleached, and how bleaching is done. The book is divided into eight major sections which are sub-divided into 36 chapters covering all aspects of pulp bleaching. The book also features discussions on several "hot topics" in pulp bleaching, enzyme assisted bleaching, and bleaching of recycled fiber. In addition, the book is key word indexed and each chapter contains extensive references.

Pulp Bleaching: Principles and Practice will be a valuable textbook for students in pulp and paper programs and a comprehensive reference for everyone involved in pulp bleaching, especially process engineers, project engineers, and technical personnel. Edited by pulp bleaching specialists Carlton W. Dence and Douglas W. Reeve, this book contains the work of 57 co-authors and was sponsored by the Pulp Bleaching Committee of TAPPI's Pulp Manufacture Division.

TABLE OF CONTENTS

Acknowledgements	v
Preface	vii
Section I: Introduction	
I 1: Introduction to the Principles and Practice of Pulp Bleaching	1
Section II: Raw Materials	
II 1: Production of Unbleached Pulp	25
II 2: Bleaching Chemicals: Chlorine Dioxide	59
II 3: Bleaching Chemicals: Chlorine, Sodium Hydroxide, Hydrogen Peroxide, Peroxy Acids, Oxygen, and Ozone	71
Section III: The Chemistry of Bleaching and Brightness Reversion	

Pulp Bleaching: Principles and Practice

Table of Contents

III 1: Chemical Structure Of Pulp Components	91
III 2: Reaction Principles in Pulp Bleaching	113
III 3: Chemistry of Chemical Pulp Bleaching	125
III 4: Chemistry of Mechanical Pulp Bleaching	161
III 5: Chemistry of Brightness Reversion and its Control	183
Section IV: The Technology of Chemical Pulp Bleaching	
IV 1: Oxygen Delignification	213
IV 2: Chlorination	241
IV 3: Chlorine Dioxide in Delignification	261
IV 4: (Oxidative) Alkali Extraction	291
IV 5: Ozone Delignification	321
IV 6: Hydrogen Peroxide as a Delignifying Agent	347
IV 7: Enzyme Treatments of Pulp	363
IV 8: Chlorine Dioxide in Bleaching Stages	379
IV 9: Hypochlorite and Hypochlorous Acid Bleaching	395
IV 10: Hydrogen Peroxide Bleaching	411
IV 11: Bleaching Shives and Dirt	443
Section V: The Technology of Mechanical Pulp Bleaching	
V 1: Peroxide Bleaching of (Chemi)mechanical Pulps	457
V 2: Hydrosulfite (Dithionite) Bleaching	491
Section VI: Bleach Plant Operations, Equipment and Engineering	
VI 1: Pulp Pumping and Hydraulics	513
VI 2: Mixing and Mixers	537
VI 3: Washing and Washers	569
VI 4: Towers and Reactors	597
VI 5: Sensors and Process Control	625
VI 6: Water Reuse and Recycle	647
Section VII: The Properties of Bleached Pulp	
VII 1: Bleached Pulp Composition and Its Determination	675

Pulp Bleaching: Principles and Practice

Table of Contents

VII 2: Brightness: Basic Principles and Measurement	695
VII 3: Strength Properties and Characteristics of Bleached Chemical and (Chemi)mechanical Pulps	717
Section VIII: Pulp Bleaching and The Environment	
VIII 1: Effluent Characteristics and Composition	749
VIII 2: Assessing the Potential Impacts of Pulping and Bleaching Operations on the Aquatic Environment	767
VIII 3: Dioxins and Furans in Effluent, Pulp, and Solid Waste	799
VIII 4: Bleach Plant Air Emissions	821
VIII 5: Environmental Regulations	835
Subject Index	847

Pulp Bleaching: Principles & Practice

Subject Index

A

Absorbable organic halogen (AOX) 217, 256, 282-284, 305, 359, 365, 370, 371-372, 375, 393, 409, 413, 429, 434, 563, 584, 649, 689, 753, 754, 757, 758, 760, 771, 773, 774, 778, 780, 782, 785, 788, 791, 838, 839, 845
Acetaldehyde 208, 823, 830, 843
Acetic acid, chloroacetic acids 41, 147, 257, 325, 330, 366, 713, 824
ACETOCELL Process 41
Acetylation, acylation 197, 198, 202-203, 209, 682, 755
Acidic groups, structures (see also under carboxylic, phenolic hydroxyl, and sulfonic acid groups) 585, 677, 678
 Determination in pulp 684-686
Acid treatment 224, 330, 336, 353, 415, 424, 425, 426, 427, 428, 515, 517, 519, 523
Activated sludge treatment (AST) 488, 651, 779, 799
Activation energy 37-38, 266, 280, 312, 383, 401, 416, 417, 450
Aerated stabilization basin (ASB) 651, 776, 779, 785
Air entrainment 500, 502, 506, 517, 523, 527, 532, 541, 551, 576, 579, 581, 591-592, 610, 658
ALCELL Process 41
Aldonic acids, aldonolactones 38, 40, 149, 152, 176
Alkali (see also sodium hydroxide) 3, 14, 127, 129, 139, 140, 148, 167, 216, 226, 233, 293-295, 314-318, 467, 475, 613
Alkali darkening 140, 398, 403, 405, 421, 429, 469, 475, 477, 497
Alkaline extraction 106, 139, 140, 217, 244, 247, 265, 268, 299, 300, 331-332, 366, 369, 385, 399, 407, 413, 417, 418, 423, 427, 430, 611-612, 744, 759, 824, 829
Alkali-consuming reactions 138-140, 298
Alternative alkali sources 315-318
 Effect on carbohydrates and extractives 297-299
 Factors affecting alkali consumption 297
 Filtrate reuse 317, 666
 Flowsheet for peroxide added in oxygen-reinforced extraction stage 311
 Oxidant-reinforced 297, 305-306, 453, 637, 638
 Oxygen-reinforced 298, 306-310, 385, 386, 392, 399, 428, 453, 542, 544, 670
 Oxygen- and peroxide-reinforced 310-311, 385, 418, 419, 420, 421, 427, 428, 431, 433, 437, 453, 670
 Peroxide-Reinforced 310-311, 314, 392, 413, 414, 417, 418, 419, 420, 422, 431, 434, 453, 660, 666, 813
 Rapid extraction 313-314
 Reaction variables 302-305, 313
 Reaction kinetics, reaction rate 299-302, 304, 305, 309, 312-313
 Role in multi-stage bleaching sequences 293-297
Alkylation, methylation 93, 197-198, 200, 202, 203, 204, 206, 209, 356
Anthraquinone, anthraquinone pulping 34, 39, 40, 45, 78, 375, 670
Anti-chlor 388, 399, 400, 660, 669
Aquatic test organisms 285, 286, 360, 773, 774, 775, 776, 777, 778, 779, 780, 782, 783, 785, 786, 787, 789, 837, 838, 840
Aromatic aldehydes and ketones 96, 99, 107, 122, 124, 135, 136, 142, 144, 145, 146, 148, 169, 171, 172, 175, 178, 193, 195, 196, 199, 200, 201, 761
ASAM Process 41, 44
Ascorbic acid, ascorbates 205-206, 207, 208, 210
Autoxidation 105, 141, 143, 165, 166, 188, 198, 209, 487

B

Beating, beating energy 12, 280, 371, 407, 677, 678, 679, 684, 702, 721, 722, 723, 724, 725, 727, 730, 731, 732, 733, 737, 739, 741, 742, 743, 744
Benthic communities 770, 780, 781, 783, 784, 785, 788, 791
Biological characterization of effluents and receiving environments
 Single-species acute and short-term toxicity tests 772-774
 Extended single-species laboratory exposure 774-778
Mesocosms and experimental streams 778-780
Field studies 780-790
Future trends and research needs 790-792
Biological oxygen demand (BOD) 215, 217, 257, 286, 340, 359, 488, 511, 651, 751-752, 771, 837, 838, 839, 841, 845
Biological treatment of effluents
(see Bleaching effluent)

Pulp Bleaching: Principles & Practice

Subject Index

- Biomarkers, endpoints 772, 773, 774, 777, 778, 779, 781, 783, 784, 785, 788, 791, 797
Biphenyl structures 52, 94, 96, 121, 134, 135, 140, 141, 142, 198
Black liquor solids 583-584
Bleachability (see under Unbleached pulp)
Bleached pulp
 Chemical composition 10, 684, 685, 742
 End uses 719
 Light and heat stability 3, 53, 188, 189, 190, 191, 237, 278-279, 298, 316, 349, 358, 406, 429, 430, 487, 506, 585
 Production 6, 7, 8, 215, 287
 Strength properties 49, 150, 216, 237, 280, 328, 331, 358, 371, 431, 437, 584, 727, 739, 740, 741, 742, 743, 744
 Strength testing principles 723
Bleaching
 Chemicals 3-4, 14-16
 Critical parameters 4
 Efficiency 12-13, 16, 247, 264, 305, 356, 389, 419, 479, 544, 602, 650
 Flowsheets 19-20, 2-23
 Gaseous chemicals 17-18
 General description 3-4
 History of 4-6
 Kinetically controlled reactions 326, 327, 544, 602, 610, 611, 612, 614-615
 Objectives 4
 Process conditions 17-18
 Unit operations 20
 Reaction rates, kinetics 544-545, 546, 600
 Selectivity 13, 16, 17, 127, 152-153, 217, 224-225, 243, 247, 349-350, 355, 357, 385, 415, 436, 738
 Sequences 16-17
 Trends 20-24
Bleaching effluent (filtrate) 19
 Biological characterization 770-790
 Biological treatment, treatment costs 19, 53, 257, 359, 434, 653-654, 755, 758, 769, 773, 774-775, 777, 778, 779, 780, 781, 784, 785, 790, 826, 842
 Chemical characterization, characteristics 759-762, 770-771, 775, 790, 838
 Chlorination stage 129, 132, 246, 250, 251, 252, 255, 256, 257, 285-286, 289, 373, 660, 666, 671, 755, 756, 807, 826, 824, 827
 CE 153, 759
 Chlorine/chlorine dioxide stage 278, 585, 660, 752, 753, 754, 755, 758
 Chlorine dioxide stage 251, 252, 282-285, 314, 600, 662, 666, 669, 756
 Color 340, 752-753
 Compounds detected in 760-762
 DE 756, 759
 Discharge volume 19, 649, 651, 710, 773, 781, 784, 786, 837
 Effect on aquatic organisms 770, 775, 776, 780, 781, 779, 780, 781, 782-783, 784, 785, 786, 787, 788, 789
 Elemental chlorine-free (ECF) 340-341, 752, 753, 754, 758, 761, 762, 774, 790, 791
 Extraction stage (E, EO, EOP) 256, 278, 296, 302, 317, 305, 315, 391, 393, 413, 660, 660, 662, 666, 668, 752, 753, 754, 755, 756, 758, 759, 807, 826, 827, 831-832
 Factors affecting reuse (recycling) 658-660
 General characteristics 751-759
 Molecular weight (MW) and MW distribution of dissolved material (see under Molecular weight and molecular weight distribution)
 OCE 756, 759
 Oxygen-stage 234, 235, 671
 Ozone-stage 339, 340, 671
 Peroxide-stage 421, 432, 479, 480, 614, 616
 Reuse (recycling) 226, 250, 251, 255, 258, 278, 384, 434, 478, 479, 666, 670-672
 Screen room 236, 666, 668
 Totally chlorine-free (TCF) 340-341, 666, 752, 753, 774, 777, 790, 791
 Toxicity 23, 129, 135, 153, 176, 256, 285, 340-341, 360-361, 434, 488, 678, 769, 770, 772-778, 781, 782, 784, 785, 790, 791, 837, 838, 839
Bleach plant closure (see Closed cycle bleaching)
Bleaching towers (see Towers)
Breaking length (see Tensile strength)
Brightness (diffuse intrinsic reflectance factor) 3, 12, 107, 174, 186, 269-271, 272, 281, 311, 312, 313, 314, 317, 332, 334, 385, 386, 387, 389, 390, 392, 406, 418, 420, 421, 422, 423, 426, 427, 428, 429, 430, 445, 449, 450, 451, 453, 462, 464, 465, 466, 468, 469, 470, 472, 473, 474, 476, 483, 484, 486, 501, 508, 509, 627, 629, 630, 635, 636, 637, 638, 639, 659, 697-713, 742
Comparison with tristimulus Z factor 706-707
Compensated 404, 634, 635, 640, 641, 642
Definition and interpretation of 697-699
Effect of cleanliness on 445

Pulp Bleaching: Principles & Practice

Subject Index

Effect of light scattering on 701-702
Error sources in measurement 708-709, 711, 712
Fluorescence effect on 703-704
Gloss effect on 709-710
ISO (Integrating sphere) 703, 709-711, 712
Kubelka-Munk relationships 185, 382, 701
Light absorption, light absorption coefficient 12, 48, 167, 185, 193, 194, 195, 196, 382, 384, 632, 701, 702
Light scattering, light scattering coefficient 12, 48, 74, 185, 487, 632, 701-702, 703, 720, 722, 723, 727, 729, 731, 732, 733, 735, 739, 740, 741, 742, 744
Measurement, meters (reflectometers) 705-712
Preparation of sheets for measurement 712-713
Relationship to chromophore concentration 699-701, 704-705
Relationship to whiteness 705
Reversion or heat and light stability (see also Yellowing) 34, 51, 53, 95, 99, 298, 335, 413, 497, 506, 677
Sensors 249, 251
TAPPI (directional illumination) 703, 707-709, 712
Upper limit ("ceiling") 174, 368, 382, 385, 413, 472, 496, 702-703, 745
Wavelength 705-707
Brown stock 228, 373, 813
Burst factor (index) 477, 727, 731

C

Calcium compounds, ions 39, 75, 78, 316, 407, 424, 425, 433, 590, 591, 592, 662, 677, 686
Carbohydrates 105, 106, 107, 117, 122, 148, 150, 151, 153, 167, 176, 247, 256, 257, 263, 381, 493, 585
Content in pulp 685
Conversion to aromatic structures during pulping 107
Degradation depolymerization 37, 40, 117, 145, 151, 152, 176, 224, 233, 234, 298, 325, 329, 330, 353, 366, 726, 727, 739, 742
Determination in pulp 681-683 (see also under Cellulose and Hemicelluloses)
Molecular weight, DP, and molecular weight distribution 280, 370
Peeling reactions 103, 106, 107, 124, 151, 152, 176, 223, 224, 247, 258
Protectors 217, 224, 252, 330
Reactions with bleaching agents 122, 245, 148-152, 232-233
Carbon monoxide 227, 231, 309, 382, 620, 829-830, 842
Carbonyl groups 76, 116, 123, 124, 128, 135, 136, 138, 139, 143, 144, 145, 145, 150, 151, 152, 163, 168, 169, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 206, 221, 222, 223, 224, 247, 298, 324, 325, 351, 381, 404, 430, 435, 436, 437, 461, 487, 493, 494, 679, 683, 734
Carboxyl groups, structures 14, 102, 103, 107, 109, 132, 139, 141, 146, 148, 151, 154, 168, 170, 172, 222, 224, 246, 247, 255, 256, 257, 296, 297, 315, 324, 325, 350, 381, 435-436, 684, 736, 744, 755, 760
Carryover 225, 234, 235, 236, 248, 249, 251, 254, 268, 269, 297, 303, 305, 336, 339-340, 391, 404, 407, 422, 423, 424, 435, 583, 584, 585, 586, 615, 632, 637, 769, 670, 775, 778, 812
Catechol groups, catechols 95, 96, 103, 105, 107, 119, 130, 131, 133, 139, 140, 164, 168, 173, 174, 177, 178, 188, 189, 222, 246, 285, 349, 775, 789
Catechol-metal complexes 96, 105, 165, 166
Cellulases 367, 371, 679
CE K number 249, 250, 254
Cellulose 12, 13, 44, 124, 128, 149, 150, 151, 163, 244, 247, 280, 323, 330, 350, 354, 356, 365, 367, 370, 393, 493, 501, 601, 677, 680, 723
Content in wood and pulp 4, 9, 723, 724, 726, 734, 740
Crystallinity 724, 726, 727
Depolymerization 4, 9, 13, 150, 151, 216, 219, 223-224, 232, 233, 244, 280, 330, 350, 354, 355, 401, 402, 403, 407, 408, 416, 679, 726-727, 734
Determination of content in pulp 681-683
Molecular weight (MW), MW distribution, DP 8, 37, 40, 677, 678, 679, 681, 735
Properties 9
Solvents 679, 680, 681
Structure 9, 117
Cell wall, fiber wall 11, 19, 27-28, 35, 37, 42, 48, 50, 93, 226, 294, 296, 477, 542, 544, 610, 684, 702, 703, 724, 725, 728, 729, 733, 742
Chelating agents, sequestrants 14, 46, 153, 209, 350, 352, 353, 354, 358, 359, 373, 415, 425, 426, 428, 434, 453, 464, 465, 466, 467, 478, 486, 495, 501, 770
Chelation treatments 188, 190, 330, 334, 352, 353, 354, 355, 357, 358, 359, 372, 421, 424, 424, 427, 428, 453, 464-466, 479, 482, 487
Chemical recovery 215, 216-217, 234, 237, 352, 353, 356, 671, 672, 833
(Chemi)mechanical pulp, pulping 34, 43, 163, 167, 174, 177, 188, 206, 425, 463, 493, 572, 684, 719, 728, 744
Composition 728-729

Pulp Bleaching: Principles & Practice

Subject Index

- Chemirefiner pulping 43
Chemithermomechanical pulp (CTMP), pulping 6, 34, 42-43, 49, 51, 52, 97, 185, 188, 195, 196, 203, 205, 428, 463, 511, 687, 736, 810
Physical properties 51-52, 486
Chemithermomechanical alkaline pulping 485-487
Chlorate ion 13, 62, 63, 64, 65, 66, 67, 133, 137, 264, 265, 271, 272, 273, 277, 278, 286, 381, 382, 389, 390, 392, 770, 771, 778, 782, 783, 785, 831
Chloride ion 62, 63, 64, 79, 130, 132, 245, 253, 256, 264, 265, 268, 272, 277, 278, 381, 391, 392, 583, 689, 832
Chlorination, chlorination stage 234, 276, 278, 303, 413, 451-452, 542, 544, 563, 604, 606, 610, 635, 769, 775, 777, 778, 807, 814, 829, 831
Chemistry 127-128, 245-246, 295
Chlorine dioxide substitution 251-252, 253, 254, 255
Effect on pulp cleanliness 255
Environmental effects 255-257
Process control 244, 249, 254, 303
Process equipment 252-254
Process variables 248-252
Reaction kinetics 247-248, 600
Schematic representation 244
Chlorine 3, 62, 63, 64, 66, 67, 108, 130, 135, 136, 138, 149, 150, 153, 217, 225, 266, 267, 270, 305, 306, 351, 391, 830, 831, 832, 833
Emissions 823-824, 830, 831, 843, 844
Manufacture 15, 37, 74-76, 827
Properties 18, 73
Reactions with lignin, carbohydrates, and extractives 127-132, 154, 246-247, 591, 610, 759
Radical 128, 149, 151
Safety precautions 73
Storage and handling 76-77, 245
Chlorine dioxide 50, 100, 116, 121, 127, 128, 132, 138, 141, 149, 217, 225, 247, 250, 264, 266, 267, 268, 269, 272, 351, 372, 413, 525, 760, 830, 831, 832, 843, 844
Analysis of solutions 67
Decomposition 61, 67-68
Emissions 381, 392, 823-824, 843, 844
Generation systems 62-67
Health hazards 61
Manufacture (generation) 15, 314, 372, 381, 391, 827
Properties 18, 61
Reactions with lignin and extractives 133-138, 154, 759
Safety and handling precautions 67-68, 393
Sensors 633-634
Chlorine dioxide bleaching 13, 255, 312, 313, 314, 334, 404, 437, 448, 563, 604, 608, 684, 829
Bleaching sequences 384-385
Engineering considerations 292-293
Environmental factors 393
Filtrate reuse (recycle) 250, 384, 666
Process chemistry 381-382
Process flowsheets 383, 384
Process variables 385-392
Pulp quality 393
Reaction kinetics 382-383
Chlorine dioxide delignification 313, 385, 610-611, 829
Alkali requirements 268-269
Brightness development 269-271
Chemical addition mode 266, 270, 271, 272, 274, 285, 754, 813, 825
Economic factors 286-287
Efficiency 266-273, 276, 278, 389
Equipment 273
Filtrate reuse (recycle) 666
Process flowsheets 272, 274
Process variables 252, 273-278
Pulp quality 278-282
Reaction kinetics 265-266, 600, 611
Substitution of chlorine dioxide for chlorine 84, 132, 252, 266-268, 270, 271, 272, 274, 275, 279, 280, 281, 282, 283, 284, 285, 286, 287, 297, 298, 303, 310, 314, 370, 386, 387, 413, 452, 542, 591, 636, 751, 752, 754, 758, 775, 778, 779, 781, 785, 788, 825, 827, 828, 829, 842, 843
Chlorine monoxide radical (hypochlorite radical) 132, 133, 137, 151, 407, 408
Chlorine factor 280, 825
Chlorine multiple 249, 250, 264, 369, 754, 812, 813, 814
Chlorodioxins (see Dioxins)
Chlorodibenzofurans (see Dioxins)
Chloroaromatic structures, compounds 129, 135, 138, 139, 284, 759, 760

Pulp Bleaching: Principles & Practice

Subject Index

Chloroform 256, 257, 285, 397, 407, 409, 410, 761, 823, 824-826, 830, 837, 842, 838, 839, 840, 843, 844
Chloronium ion 116, 128, 130, 131, 152, 814
Chloroorganic structures, compounds 4, 129, 130, 133, 138, 139, 215, 217, 243, 245, 251, 253, 265, 268, 281, 283, 284, 365, 368, 375, 381, 393, 689, 755, 756, 758, 769, 837, 845
Content in fully bleached pulps 282
Determination of chlorine in 689
Chlorophenols 246, 256, 257, 284, 285, 689, 761, 771, 788, 789, 808, 809, 816, 840
Chlorous acid, chlorite ion 62, 67, 133, 134, 263, 264, 272, 277, 298, 381, 388, 389, 631, 638, 660, 662, 831, 832, 666
Chromophores 49, 95, 96, 97, 105, 163-164, 166, 168-170, 171, 174, 175, 178, 192, 194, 197-198, 332, 350, 382-383, 400, 401, 402, 416, 417, 460, 487, 494, 697, 700, 701, 705
Cleanliness 236, 237, 255, 280, 431, 477, 583, 603, 678
Closed cycle bleaching 24, 37, 235, 660, 671-672
Cobalt (see Metals)
¹³C NMR spectroscopy 100, 109, 132, 760, 762
Color 4, 30, 34, 36, 53, 54, 97, 105, 163, 196, 215, 217, 286, 305, 359, 371, 423, 434, 494, 662, 698, 769, 771, 837, 842
Color stripping 54, 494, 510
Condensation reactions, condensed structures 95, 97, 99-102, 106, 134, 140-141, 144, 177, 222, 324, 804, 809
Coniferyl alcohol, coniferyl alcohol groups 93, 98, 129, 137, 178
Coniferaldehyde, coniferaldehyde groups 95-96, 97-98, 129, 137, 164, 165, 168, 169, 177, 178, 192-193, 195, 461, 493, 745
Contactors (see under Mixers and Towers)
Coumaryl (p-hydroxyphenyl) structures 93, 95, 144, 222
Countercurrent washing (see under Washing)

D

Dakin reaction, Dakin-like reaction 168, 171, 173, 174
Dealkylation 52, 103, 118, 119, 130-132, 133, 137, 148, 165, 189, 190, 196, 202, 257, 356, 683, 686
Deckers 236, 357, 373, 478, 482, 590
Defoamers (see also under Washing) 231, 590, 620, 686, 808, 815, 838
Deinked pulp (see Recycled fiber)
Degassing (see under Pumping and Hydraulics)
Dialkyl peroxides (dioxetanes) 142, 143, 144, 145, 152, 170, 171, 172, 222
Dialysis 755, 756
Dichloromonoxide, dichloromonoxide bleaching 128, 407-408
Dienes 208-210
Diffusion and penetration 19, 35, 37, 105, 226, 299, 253, 301, 304, 327, 367, 448, 539, 540, 544, 545, 563, 584, 600, 612, 618, 619
Dimethyldioxirane 324, 423, 438, 670, 741
Dioxins
 Amounts in pulp and paper products 808, 809, 810, 811, 815
 Degradation in environment 817, 818
 Formation reactions 804, 806-807
 Government standards for discharge 816-817
 Physical properties 801
 Reduction strategies 812-816
 Sampling and measurement 817
 Sources of formation in pulp and paper processes 807-812
 Toxicity 801-804
Dioxiranes (see Dimethyldioxirane)
Dirt specks (see Particles)
Disc filter 464, 478, 482
Dispersers (see Kneaders and Mixers)
Displacement bleaching 609
Dissolving pulp 3, 34, 281, 293, 397, 403-404
Dithionite (hydrosulfide) 77, 494
Drainage aids (see also under Washing) 591-592
Drainage, drainage resistance 684, 721, 727, 730, 731, 732, 733, 738, 739, 740
DTPA (diethylenetriaminepentaacetic acid)(see Chelating agents)
Dyes, inks 44, 53-54, 494, 509, 705, 728, 729

E

EDTA (ethylenediaminetetraacetic acid) (see Chelating agents)

Pulp Bleaching: Principles & Practice

Subject Index

- Effluents (see Bleaching effluents)
Electron spin resonance (ESR) spectroscopy 198, 205, 207
Electrophiles, electrophilic reactions 115, 116, 117, 118-119, 128, 133, 144, 145, 146, 148, 151, 167, 171, 324, 416
Electrophilic displacement 118, 119, 128, 129, 130
Elemental chlorine-free (ECF) bleaching, ECF-bleached pulps 109, 328, 340, 365, 368, 370, 371, 372, 374, 375, 413, 414, 419, 427, 429, 431, 434, 437, 452-453, 586, 684, 685, 740, 742, 743, 751, 752, 753, 754, 757, 758, 760, 761, 762, 790, 792
Emissions 578, 627, 677, 823-833, 842-844
 Control of chlorine and chlorine dioxide 830-833
 Gaseous bleaching chemicals 823-824, 829-830, 842, 844
 Volatile organic compounds 824-830, 838
Environmental regulations 4, 243, 434
 Canada 816-817, 837-839
 Finland and Sweden 844-845
 United States 817, 839-844
Enzone process 370
Enzyme-aided bleaching 330, 354, 365-377, 741
 Economic factors 373-374
 Effect on bleaching chemical requirements 369-371
 Effect on kappa number 368-369
 Effect on pulp properties 330, 371
 Environmental effects 371-372
 Mechanism of enzyme action 366-367
 Process flowsheets 372-373
 Sequences comprised of enzyme treatment 368, 371, 374
Enzymes 14, 15, 48, 365, 372, 373, 374, 375, 435, 686, 741
 Activity 368
 Suppliers 367-368
EROD induction 777, 778, 781, 782, 783, 787, 788, 791
Ethers, ether structures 94, 96, 100, 103, 145, 148
 a- and b- Aryl 94, 96, 98, 99, 100, 103, 104, 106, 131, 144, 146, 147, 148, 197, 200, 201, 202, 203, 204
 Oxiranes (epoxides) 103, 104, 134, 137, 139, 140, 142, 143, 154, 155, 169, 172, 221, 222, 324
 Vinyl aryl 98, 100, 120, 129, 137, 144, 146, 148, 222, 323
Ethylenic (olefinic) groups 102, 109, 116, 120, 129, 130, 133, 134, 138, 145, 146, 148, 154, 163, 178, 195, 323, 436, 437, 461, 487, 591
Extended delignification 37-38, 39, 243, 285, 332, 368-369, 375, 414, 450, 454, 487, 591, 723, 726, 739, 740, 741, 742, 743, 744, 753, 757, 763, 777, 790, 842
Extractable organic halogens (EOX) 108, 282, 283, 284, 754, 771, 773, 789
Extraction (see Alkaline extraction)
Extractives 3, 10, 30, 108, 153-154, 176, 246, 256, 279, 281, 298, 589-591, 677, 686, 769, 771
 Characterization 687
 Content in wood, pulp 29, 108, 279, 281, 477
 Determination in wood, pulp 29, 108, 687-688
Fractionation 687-688
 Removal from pulp 12, 686-687

F

- Fatty acids (see Extractives)
Fiber networks (suspensions) 327, 515, 523, 525, 547, 561, 603, 607, 720, 721, 725, 729, 735, 738
 Characteristics 541
Composition in different bleaching operations 542
Flocs, flocculation 327, 337, 540, 541, 545, 546, 550, 554, 556, 560, 561, 600, 618, 619, 721, 724, 725
Flow velocity 515-517, 525, 528, 529, 530, 533, 549
Rheology 540-542, 545, 546, 603
Strength 46-48, 516-517, 528, 547, 729
Swelling 602, 678, 684, 727, 728, 729, 740, 744
Turbulence in 541-542, 545, 548
Fiber(s)
 Bonding 47, 50, 52, 477, 678, 701, 702, 720, 722, 726, 728, 729, 733, 737, 744
 Characterization, characteristics 462-463, 687, 728-729, 745
 Coarseness 724, 725, 733, 737, 740, 742
 Conformability 50, 477, 724, 727, 732
 Damage 721, 725-726, 734, 738, 740, 741, 742
 Dimensions 632, 701, 724, 725, 729, 733, 737, 745
 Drying 684, 724, 727-728, 729, 734
 Flexibility 45, 47, 50, 51, 723, 737, 477
 Morphology 724, 725, 728, 729, 738

Pulp Bleaching: Principles & Practice

Subject Index

Rigidity (stiffness) 50, 52, 67, 678
Strength 45, 677, 678, 679, 735, 737, 739
Surface 45, 51, 327, 369, 540, 543, 549, 554, 589, 590, 600, 658, 679, 698, 719, 720, 724, 725, 729, 734, 735, 738, 747
Swelling 477, 678, 684, 728, 729
Fiber supply (see Wood supply)
Filler pulp 719, 738, 737, 739, 740, 743
Fillers 48, 254, 488, 666, 697, 720, 723, 728, 738
Filtrate tanks 573, 579, 586, 591, 823
Fines 51, 52, 463, 593, 697, 720, 721, 722, 728, 730, 731, 735, 808
Flow meters (see under Pumping and Hydraulics)
Fluffing, fluffers 228, 230, 327, 336, 337, 554, 555, 562, 609, 600, 604, 613, 616, 617, 618
Fluorescence (see under Brightness)
Formaldehyde 37, 95, 101, 102, 105, 174, 830, 843
Formamidine sulfonic acid 54, 476, 477
Formic acid, formates 62, 66, 152, 169, 208, 210, 257, 330
Freeness 729, 730, 731, 732, 735, 738
Free radicals 116, 121, 122, 124, 128, 132, 134, 136, 143, 149, 165-166, 167, 197, 200, 201, 202, 205, 209, 247, 453, 679, 744
Free radical coupling 121, 128, 134, 135, 144, 198, 222
Free radical scavengers 128, 149, 205-209, 250, 247, 263, 325, 330, 408, 409, 410
Furans (see Dioxins)

G

Gel permeation chromatography (GPC) 105
Gloss (see under Brightness)
Glucomannans (see Hemicelluloses)
Gonad somatic index 786, 797
Groundwood, groundwood pulping 10, 34, 37, 41-42, 47, 49, 50, 105, 176, 177, 187, 189, 190, 196, 462, 463, 493, 511, 690, 736, 810
Guaiacyl units 93, 109, 115, 128, 129, 130, 133, 139, 144, 760

H

Heat reversion (see under Yellowing)
Hemicellulases (see Xylanases)
Hemicelluloses (see also Carbohydrates) 3, 9, 12, 29, 39, 40, 44, 45, 48, 106, 107, 124, 163, 176, 221, 244, 247, 293, 298, 365, 366, 367, 374, 375, 493, 677, 678, 683, 684, 726, 727, 744
Analysis 681-683
Content in wood and pulp 9, 27, 366, 374, 375, 723, 724, 739, 740, 741
Properties 9
Structure 374
¹H NMR spectroscopy 132
Hydrochloric acid 62, 65, 76, 127, 245, 246, 251, 268, 315, 382, 388, 585, 843
Hydrogenation 203-204, 209
Hydrogen ion concentration (pH) 13, 106, 127, 132, 142, 167, 245, 251, 272, 276-277, 297, 328-329, 354, 358, 381, 382, 383, 388-390, 399-400, 404, 405, 408, 421, 450, 497-498, 509, 584, 590, 627, 629, 632-633, 638, 662, 713, 735, 744, 814, 815, 833
Hydrogen peroxide 3, 14, 46, 50, 51, 54, 62, 67, 75, 96, 97, 99, 116, 127, 142, 145, 163, 165, 195, 221, 225, 297, 304, 305, 349, 352, 353, 365, 525, 679, 818
Activation, activators 356, 357, 414, 424, 430, 435, 437
Decomposition, decomposition reactions 77, 142, 167, 176, 219, 224, 319, 349, 350, 353, 355, 415-416, 417, 420, 424, 432, 453, 461, 464, 473, 477
Manufacture 15, 78-79
Properties 77-78, 480
Reactions with lignin 168-174, 415
Reactions with carbohydrates, extractives 174-176, 461
Safety precautions 77-78
Storage and handling 79, 481-482
Hydrogen peroxide bleaching (see Peroxide bleaching)
Hydrogen peroxide bleaching solutions
Composition 166-167
Makeup systems for 478, 480-481
Metal-catalyzed decomposition 167, 414, 666
Recycle 478, 479, 480, 482, 483, 484
Stability, stabilization 414, 481-482
Hydrogen peroxide delignification 413, 744
Environmental factors 359-360
Flowsheets 352, 353, 357, 358
Modified treatments 356-357

Pulp Bleaching: Principles & Practice

Subject Index

- Process control 358
Processes 351-353
Process variables 353-356
Pulp properties 358-359
Sequences 351, 359
- Hydrolysis**
Acid-catalyzed 9, 40, 105, 109, 135, 150, 151, 393, 679, 682, 686
Base-catalyzed 9, 40, 97, 99, 100, 103, 105, 106, 121, 139, 150, 295, 296, 299, 325, 759, 824, 825
- Hydroperoxide (perhydroxyl) anion 96, 116, 141, 144, 152, 154, 166-167, 168, 171, 172, 176, 195, 218, 349, 351, 415, 416, 417, 421, 459, 460, 461, 469, 639, 640
- Hydroperoxyl radicals 116, 142, 144, 145, 146, 151, 197, 200, 205, 209, 210, 218, 219, 324, 329
- Hydroquinone structures, hydroquinones 54, 95, 105, 140, 164, 171, 174, 208, 209, 436, 487
- Hydrosulfite (dithionite), hydrosulfite bleaching solutions 4, 51, 54, 97, 163, 177, 178, 505, 525, 592
- Active bleaching species 176-177, 494-495
Composition 494-495, 502-504
Handling and storage 502-503
Manufacture 15, 503-504
Properties 501-502
Stability 177, 495, 497, 498, 500, 526
- Hydrosulfite bleaching 185, 187, 188, 190, 475, 480, 484, 526, 592, 729, 744, 745
- Brightness response for different pulps 510
Deinked pulps 509-510
Effect on pulp properties 501
Factors influencing brightness response 495-501
Future trends 511-512
Process control 505, 506
Process flowsheets 505, 506, 507, 508
Process variables 495-499
Reactions with chromophores 177-178, 493-494
Safety and environmental factors 510-511
Single-stage systems 504-507
Two-stage systems 507-509
- Hydrotroxy radicals 219
- Hydroxide ion 96, 116, 142, 155, 160, 168, 171, 176, 219, 301-302, 461
- Hydroxonium ion 116
- Hydroxyl radical 46, 116, 141, 142, 144, 145, 146, 151, 153, 167, 168, 171, 173, 176, 219, 223, 225, 324, 329, 349, 350, 415, 416, 424, 459, 460, 461, 487, 689
- p-Hydroxybenzyl alcohol groups 97, 129, 171, 199, 200
- p-Hydroxyphenacyl groups 171, 197, 200
- Hypochlorite (see Sodium hypochlorite)
- Hypochlorite bleaching 151, 255, 257, 313, 317, 397-407, 437, 476, 650, 604, 824, 825, 843
- Environmental effects 407
Economic factors 406-407
Process control 398, 399, 401, 404-406
Process flowsheet 402
Process variables 398-400
Reaction kinetics 400-401
Sequences 17, 50, 397, 403, 406, 407
- Hypochlorite radical 132
- Hypochlorous acid 127, 128, 130, 132, 133, 135, 136, 137, 138, 151, 154, 245, 257, 264, 271, 381, 408, 410, 754
- Bleaching 407-410
Generation 410

I

- Impellers (see Pumps and Mixing)
Infrared (IR) spectroscopy 132, 687, 690, 745
Inks (see under dyes)

K

- Kappa factor 250, 264, 268, 270, 276, 283, 285, 369, 826
Kappa number 10, 48, 50, 232, 233, 243, 264, 267, 269, 274, 279, 280, 283, 307, 308, 311, 329, 333, 353, 354, 355, 359, 368, 386, 392, 398-399, 422-423, 629, 635
C-stage 299
CE 248, 269, 294, 299, 300, 302, 303, 304, 306, 307, 310, 311, 315, 316, 317, 369, 400, 407, 815
C(EO) 307, 308
C(EOP) 311
(DC)E, (D+C)E, (CD)E 265, 267, 269, 564

Pulp Bleaching: Principles & Practice

Subject Index

DE 265, 266, 276, 277, 387
E(O) 276, 307, 398-399, 642, 645
EP 276
Kappa number analyzer 632, 636, 637, 642
Ketyl free radical 197, 198, 200, 201, 209, 487
Kneaders 476, 550, 556
Knots (see Particles)
Kraft process, kraft pulp 6, 10, 34, 35-38, 97, 102-103, 109, 131-132, 282, 305, 307, 349, 351, 366, 369, 370, 371, 387, 719, 726, 736, 740, 743
Pulp composition 44, 47
Kubelka-Munk relationships (see under Brightness)

L

Laccases (see Enzymes)
Leucochromophores 146, 166, 168, 174, 177, 487, 493
Light absorption, light absorption coefficient (see under Brightness)
Light interactions with paper 11, 697, 698
Light scattering, light scattering coefficient (see under Brightness)
Lignin 3, 9, 12, 16-17, 33, 34, 50, 100, 115, 119, 122, 127, 135, 138, 153, 163, 177, 188, 197, 198, 216, 218, 220, 244, 246, 248, 257, 294, 306, 323, 349, 350, 351, 365, 416, 436, 446, 461, 493, 585, 601, 678, 683, 697, 699, 727, 729, 759, 760
Chemical modification of during bleaching 97, 108-109, 684
Chemical modification of during pulping 97, 99-106, 106, 184, 684
Content in wood and pulps 9-10, 12, 34, 36, 37, 49, 269, 307, 422, 450, 627, 632, 677, 724, 741
Determination in wood and pulp 50
Determination in bleached pulp 683-684
Effect of sulfidity on degradation 99
Hardwood 93, 128
Interunit linkages 94, 106
Kraft 99, 100, 102, 103, 105, 144, 148, 349, 758
Linkage with carbohydrates 37, 93, 103-105, 108, 223, 294, 759
Milled wood lignin (MWL) 97, 107, 109, 165, 196, 198, 203
Model compounds 122, 129, 130, 133, 135, 137, 138, 139, 145, 153, 166, 168, 193, 198, 199, 350, 414
Modification of functional groups 93, 97, 102, 103, 106, 124, 165, 197-198, 200, 201, 202-204
Softwood 93, 128, 129, 165, 246
Structure, functional groups 9, 93-95, 96, 422, 684-685
Ligninases (see Enzymes)
Lignosulfonates, lignosulfonic acids 97, 106, 132, 193, 684
Lignox process 352, 741
Liver somatic index (LSI) 783, 786, 797

M

Magnesium compounds, ions 39, 75, 78, 153, 216, 224, 225, 330, 353, 354, 356, 424, 425, 427, 428, 431, 432, 592
Magnesium sulfate heptahydrate (Epsom salt) 224, 354, 415, 427, 460, 480
Manganese (see under Metals)
Mannanes 367
Mass transfer of bleaching chemicals 19, 216, 218, 225-226, 227, 326, 544-546, 599-601, 603, 609, 612, 615, 618, 619, 625
Materials of construction 16, 373, 410, 525, 527, 530, 586-589, 669
Alkaline extraction stage 73-74
Chlorination stage 73, 245
Chlorination-chlorine dioxide stage 587, 588
Oxygen stage 81-82, 229, 530
Ozone stage 339
Peroxide stage 78, 357, 433, 467
Mesocosms 778-781, 791
Metals, metal ions 45, 46, 105, 166, 173, 190, 198, 223, 243, 330, 352, 421, 424, 425, 426, 427, 463-464, 466, 475, 482, 484, 500, 677, 678, 684, 690
Content in wood and pulp 47, 454, 484
Determination in pulp 689-690
Effect in bleaching 427, 428, 465-466, 501, 689
Sources in bleaching systems 46
Transition 41, 45, 96, 142, 145, 146, 163, 166, 171, 197, 219, 224, 329, 350, 353, 354, 355, 415, 417, 419, 424, 425, 427, 428, 453, 460, 464, 472, 473, 500-501, 770, 771
Methanol 44, 62, 63, 64, 66, 130, 131, 132, 133, 136, 137, 140, 142, 143, 147, 148, 168, 197, 227, 247, 256, 325, 330, 620, 684, 823, 826-829, 843

Pulp Bleaching: Principles & Practice

Subject Index

Methoxyl (alkyl-aryl ether), alkoxy groups 102, 103, 105, 109, 129, 130, 138, 148, 165, 167, 190, 196, 222, 247, 759, 760
Methyl ethyl ketone 823, 830, 843
Milox process 41, 437
Minox process 351-352
Mixed function oxidases 777
Mixers 216, 468, 556, 603-604
 Continuous stirred tank 546-548, 556, 563
 Dynamic 548, 554, 556
 Fluffers, fluffing (see also under fluffers, fluffing) 543, 554, 556
 High-consistency 479, 554-555, 557
 High-shear 87, 216, 226, 228, 253, 254, 272, 304, 305, 309, 337, 338, 358, 482, 548, 549, 554, 556, 557, 558, 559, 561, 562, 563, 603, 608, 609, 611, 614, 615, 616, 617, 671, 677, 725
 Peg (paddle) 453, 478, 482, 549-550, 554, 556, 558, 561
 Shredders 554, 556
 Static 253, 254, 272, 481, 504, 516, 548-549, 554, 556, 558, 561
 Steam (see also Peg mixers) 46, 216, 226, 228, 384, 390, 391, 402, 403, 477, 521, 528, 550, 604, 605, 611, 612
 Tower 547, 559
Mixing 251, 253, 304, 336, 454, 525, 544-554, 600
 Assessment 557-561
 Efficiency 392, 454, 482, 499-500, 559
 Energy (Power) consumption 543, 544, 547, 550, 557, 561-562
 Fluidization (see also Fluidization under Pumping) 327, 338, 542, 548, 550, 563
 Fluid shear in 541, 546, 547, 548, 549, 551, 554
 Gas contacting 542-544, 549, 551, 557, 601
 General principles 539-544
 Index 558, 564
 Laboratory-scale 563
 Power dissipation in 541-542, 543, 544, 545, 547, 548, 550, 561-562
 Quality 544, 557, 561-562, 563, 564
 Rate 544-545, 562-563
 Scales of 539-540, 546, 547, 558-561
 Turbulence 541-542, 543, 545, 546, 547, 548, 554, 556, 561, 604
Molecular weight, molecular weight distribution 105, 148, 256, 301, 591, 679-681, 754-758
Monox-L (see Free radical scavengers)
MOXY process 39
Muconic acids, muconic acid lactones 121, 131, 132, 133, 134, 135, 136, 137, 143, 146, 148, 221, 222, 246, 324, 436, 756, 759, 760
Multivariate data analysis 677, 690-691
Mutagens, mutagenicity 129, 135, 285, 286, 769

N

Nitrilamine (cyanamide) 357, 435
Nitrogen dioxide 225, 306, 357, 842
Nonwood fiber 30-31, 39, 50
Nucleophiles, nucleophilic reactions 116, 117, 118, 120, 123, 124, 130, 138, 142, 144, 151, 165, 167, 168, 171, 176, 221, 295, 296, 415, 435, 461
Nucleophilic displacement 139-140, 142, 296

O

Octanol-water partition coefficient 284, 754
Opacity 42, 48, 51, 477, 697, 699, 719, 720, 727, 738, 743, 744
Organophosphonates (see Chelating agents)
Organosolv pulping 40-41
Oxidation, oxidizing agents 3, 14, 100, 105, 116, 119, 122, 124, 127, 131, 133, 134, 137, 141, 145, 146, 150, 165, 217, 219, 223, 245, 246, 303, 305, 350, 358, 382, 408, 413, 414, 416, 417, 423, 429, 436, 438, 493, 509, 612, 679, 684, 760, 818
Oxidation-reduction potential (ORP) 53, 254, 436, 630, 833
Oxidized white liquor 217, 226, 227, 228, 230, 237, 250, 617, 636, 638
Oxidizing equivalents of bleaching agents 15, 16, 132
Oxygen 3, 45, 62, 96, 100, 116, 121, 133, 145, 149, 167, 171, 196, 197, 202, 205, 220, 226, 249, 297, 304, 305, 351, 365, 420, 432, 679
 Activation 414
 Chemistry 218-219
 Manufacture 15, 82-84
 Properties 18-19, 81, 226, 308
 Reactions with lignin and carbohydrates 141-144, 151, 220-224
 Safety precautions 81-82
 Singlet 145, 219

Pulp Bleaching: Principles & Practice

Subject Index

- Stepwise reduction of 142, 218
Transportation and handling 81, 84-85
- Oxygen delignification 50, 105, 109, 142, 151, 153, 155, 227, 266, 269, 270, 285, 306, 309, 332, 333, 352, 355, 359, 370, 375, 414, 437, 448, 450-451, 527, 530, 542, 563, 584, 589, 601, 608, 612-613, 614-615, 616, 620, 636, 670-671, 679, 723, 734, 740, 741, 743, 752, 753, 756, 758, 773, 777, 778, 781 842, 827
Effect on pulp quality 237
Filtrate reuse in 226, 228, 230, 234, 235, 250
Heat effects 218, 226
High-consistency 229-231
Medium-consistency 227-229
Oxygen and alkali consumption 226-227
Processes and equipment 227-232
Process flowsheets 216, 228, 230
Process variables 232-234, 417-428
Reaction kinetics 226, 232, 600, 612, 619
Reactors 227, 228, 229, 230, 231, 237, 612-613, 614-615
Relationship to other mill operations 234
Selectivity 219, 224-225, 227, 232, 233, 234, 235, 236, 615
Typical operating data 227
- Ozone 3, 46, 54, 96, 116, 121, 141, 149, 150, 152, 153, 215, 217, 249, 303, 365, 414, 429, 431, 679, 818
Decomposition 145, 329, 617
Destruction 87-88, 336
Emissions 824, 842
Manufacture (generation) 85-87, 323, 336, 338, 339
Properties 18-19, 85, 323, 326
Reactions with lignin model compounds 145-149
Reactions with lignin and carbohydrates 148, 149, 150, 151, 323-325
- Ozone bleaching (delignification) 151, 153, 303, 370, 385, 414, 427, 437, 453, 542, 557, 563, 670, 671, 679, 684, 734, 741, 742, 790
Additives 329-331
Alkali extraction in following stage 331-332
Environmental factors 340-341, 752
Filtrate reuse 339, 340
Location in multi-stage sequences 333-336
Materials of construction 339
Process conditions 325-332
Process equipment 336-339
Process flowsheets 334, 337, 338
Reaction kinetics 327
Reactors 613-614, 616-617
Selectivity and effectiveness 323, 324, 325-326, 327, 329, 333, 336, 340
Sequences 330, 331, 332, 334, 335, 336

P

- P4501 induction 777, 779, 781, 784, 786, 787, 791
Papricycle process 315-318, 670
Particles 42, 48, 52, 244, 253, 275, 359, 401, 445, 521, 563, 643, 645-646, 668, 728, 729, 738, 745, 815
Content reduction 454-455
Measurement of 446, 689
Types 445
- Particle bleaching 3, 12, 16, 48, 255, 281, 445-455, 501, 544
Approaches for improving cleanliness 454-455
Chlorination stage 244, 451-452
Chlorine dioxide stage 280-281, 381, 389-390, 392, 393, 448, 449, 450, 454
Degradation patterns during 448-450
ECF sequences 452-453
Effect of particle size and origin on bleachability 445-448
Hypochlorite stage 403
Oxygen delignification stage 450-451
Peroxide stage 487
TCF sequences 453-454
- Peracetic acid (see Peroxy acids)
Perhydroxyl ions (see Hydroperoxide ion)
Perhydroxyl, peroxy radicals (see Hydroperoxyl radicals)
Permanganate number 10, 48, 50, 265, 266, 269, 392
Peroxidases 366, 375
Peroxide bleaching of mechanical pulps 153, 334, 604, 612, 614, 684, 741
Chemistry 414
Economic factors 434

Pulp Bleaching: Principles & Practice

Subject Index

- Effect on pulp quality 430-431
- Environmental factors 434
- Factors affecting brightness 417-428
 - Filtrate reuse in 666
 - Kinetics and stoichiometry 416-427
 - Process flowsheets 432-434
 - Typical bleaching sequences 428-430
- Peroxide bleaching (brightening) of (chemi)mechanical pulp 97, 153, 185, 187, 414, 453-454, 507-508, 592, 614, 639, 683, 684, 687, 688, 690, 744
 - Bleach plant configurations 484
 - Chemical consumption in 465
 - Effect on pulp properties 477
 - Environmental factors 488
 - Factors affecting brightness response 461-477
 - General description 460
 - Hyperalkali 477
 - Kinetic models 472
 - Monitoring and control 483
 - Oxygen-pressurized 414, 420, 422, 430, 433, 608
 - Process flowsheets 474, 477, 478, 479, 485, 486
 - Process variables 478-480
 - Recycled fiber 54, 474-477
 - Refiner bleaching 485
 - Selection guide for proper conditions 484-485
 - Single- and two-stage 478-480
 - Typical bleaching responses 472
- Peroxy acids, peracids 41, 197, 200, 205, 209, 230, 414, 435, 436, 437, 741
 - Chemical pulp bleaching with 437-438
 - Effect on materials of construction 80
 - Manufacture 80
 - Properties 79-80
 - Safety hazards 79-80
 - Storage and handling 80-81
- Peroxymonosulfuric acid (Caro's acid) 54, 80, 430, 435, 436, 438
- pH (see Hydrogen ion concentration)
- Phenolic hydroxyl groups 14, 95, 97, 99-100, 131, 140, 141, 142, 166, 168, 196, 197, 198, 201, 202, 209, 220, 222, 268, 356, 357, 425, 678, 684, 777
 - Determination of in pulp 684
- Phenolic, non-phenolic nuclei 103, 120, 133, 134, 135, 137, 141, 142, 143, 144, 146, 148, 200, 307, 324, 416, 436, 437, 670, 760, 762
- Phenolate ions 105, 139, 140, 142, 144, 219, 220, 296, 350, 461
- Phenoxy radicals 121, 133, 135, 142, 144, 166, 171, 196, 197, 198, 199, 201, 202, 203, 204, 205, 209, 219, 350, 487
- ³¹P NMR spectroscopy 194, 222
- Polysulfide pulping 34, 38-39, 45, 670
- Physical properties of pulp (see Strength properties)
- Pitch (see Extractives)
- Polyethylene glycol (PEG) 205, 818
- Polyoxometalates 435, 741
- Polymers, polymerization 93, 100, 118, 165, 206, 256, 257, 293, 324, 592, 679, 681, 755, 757
- Polysaccharides (see Carbohydrates)
- Polyvinylpyrrolidone 205
- Post-color (PC) number (see under Yellowing)
- Prenox process 225
- Presses 11, 30, 614
 - Screw 478, 482, 572, 593-594
 - Twin-role 230, 464, 478, 482, 579-580, 613
 - Twin-wire 464, 478, 482, 572, 594
- Process control 4, 399, 400, 404-406, 669, 677, 833
 - Control loop tuning 586, 629, 636
 - Chlorination stage 635-636
 - Chlorine dioxide, chlorine dioxide-chlorine delignification stages 636-637
 - Chlorine dioxide bleaching stage 638-639
 - Fuzzy logic 642, 644-645
 - In-line process and quality measurements 628-634
 - Open loop bump test 640, 641
 - Optimization of control loop performance 640-644
 - Oxygen stage 637-638
 - Peroxide stage 639-640
- Pulp flow, pulp suspension viscosity (see Pumping)
- Pulping 33-44
 - Miscellaneous chemical processes 40-41
 - Process classification 33-34

Pulp Bleaching: Principles & Practice

Subject Index

- Selectivity in 37, 450, 723, 738, 744
Pulp suspensions (see also Fiber networks) 515-517, 540-544, 547, 548, 549, 551, 554, 558, 560
Pulpwoods of North America 28
Pulp-water relationships 11
Pumping and Hydraulics 38
 Basic concepts 518-521
 Cavitation 518, 519, 521, 522, 531
 Degassing, deaeration 517, 522, 523, 525, 526, 527, 528, 529, 551, 585, 617, 658
 Flow metering, flow meters 403, 533-534, 583, 634
 Flow velocity 515, 516, 517, 521, 525, 528, 529
 Fluidization of pulp suspensions 517, 522, 523
 Frictional losses 516, 517, 526, 527, 528, 529
 General design considerations 529-534
 Low-consistency pulp 517, 521-522, 544
 Medium-consistency systems 274, 515, 517, 520, 554
 Mixing during 525, 554
 Net positive inlet pressure (NPIP) 518, 521
 Net positive inlet pressure requirement (NPIPR) 519
 Net positive suction head (NPSH) 518, 521, 522
 Net pressure suction head requirement (NPSHR) 519, 521, 522
 Partial flow 531
 Pressure measurement 530
 Pulp suspension behavior 515-518
Pumps 80, 468
 Centrifugal medium consistency 11, 357, 384, 403, 433, 506, 515, 516, 517, 518-519, 521, 522-526, 529, 531, 544, 593, 603, 609, 611
 Drive chains 531-532
 Efficiency 521, 525
 Fittings and supports 516, 531
 Gear 520, 527-528
 Impellers 517, 518, 519, 522, 523, 525, 546-547, 548
 Maintenance 521, 532-533
 Performance curves 519
 Open feed 521
 Positive displacement 383, 515, 520-521, 526-528, 529, 533
 Seals 532
 Single-screw 527
 Size selection 530
 Suction 528
 Thick-stock 230, 311, 384, 398, 399, 400, 402, 482, 515, 526, 611, 613, 614
 Twin-screw 520, 526-527, 529, 530

Q

- Quinone methides 98, 100, 101, 103, 105, 116, 117, 123, 143, 164, 165, 171, 172, 204, 220, 221, 493
o- and p-quinonoid units, quinones 54, 96, 97, 99, 105, 116, 118, 119, 120-121, 130, 131, 132, 133, 134, 135, 137, 139, 140, 141, 142, 146, 147, 164, 165, 168, 170, 171, 172, 173, 176, 177, 178, 188, 189, 193, 194, 197, 202, 206, 208, 209, 221, 222, 246, 351, 436, 493, 494, 684, 756, 759

R

- Reactors (see Towers and Reactors)
Recycled (secondary) fiber, recycling 6, 31, 32, 43-44, 512, 703, 704, 727-728, 811
 Bleachability, brightness response 52-53, 474, 475, 476
 Color stripping 54
 Composition 52
 Deinking 44
 Dyes 53-54, 704
 Hydrosulfite bleaching of deinked fiber 476, 509-510
 Peroxide bleaching of deinked fiber 474
 Physical properties of 52
 Pulping 43-44
Reduction, reducing agents 54, 62, 63, 64, 67, 75, 97, 102, 116, 119, 134, 141, 142, 177, 189, 195, 202, 203-204, 206, 209, 298, 484, 493, 494, 502, 504, 509
Refiner bleaching 497, 504-506, 507
Refiner mechanical pulp (RMP), pulping 14, 34, 42, 49, 177, 187, 194, 463, 497, 736
Refining, refiners 97, 166, 237, 407, 485, 497, 505, 507, 516, 721, 722, 726, 728, 742
Reflectance (see Brightness)
Reinforcement pulp 719, 720, 735, 736, 737, 738
Repulping (see Pulping under Recycled fibers)
Resin acids (see Extractives)

Pulp Bleaching: Principles & Practice

Subject Index

Runnability and factors affecting 176, 720-721, 738

S

- Scale, scaling 407, 428, 466, 481, 485, 590, 649, 668
Scanning electron microscopy (SEM) 50-51, 446, 447, 448
Scrubbing, scrubbers 76, 384, 617, 810, 823, 825, 830-833, 843
Seal tanks, seal tank design 650, 657, 658-659, 660, 662, 668, 671, 824
Semichemical pulping, semichemical pulps 34, 43, 735, 736
Sensors 4, 251, 254, 358, 402, 403, 404-406, 619, 586, 628, 643
 Chlorine 633-634
 Chlorine dioxide solution 633-634
 Consistency 586, 629, 634
 Dual 358, 634, 635, 636, 637, 639
 Optical (for brightness and kappa number) 251, 254, 272, 274, 358, 398, 403, 404, 405, 628-629, 630, 632, 637, 642
 pH 358, 403, 404, 405-406, 629, 632-633
 Polarographic (for residual chemical) 254, 403, 404, 630, 638
 Redox (for chemical residual) 254, 630
 Stock flow 586, 634
Shives (see Particles)
Shive analysis, shive analyzer 643, 645-646
Short-term tensile test 745
Showers, shower water (see also under Washing) 576, 577, 579, 586, 591, 650, 653, 655, 657, 660, 662, 666, 669, 670, 671, 827
Shredding, shredders 327, 404, 554, 555, 556, 604
Sivola process 34, 40
Size exclusion chromatography (SEC) 680-681, 687-688, 754, 755, 757, 758
Sodium borate 495, 504
Sodium borohydride 151, 201, 202, 204, 298, 325, 331, 484, 495, 496, 504, 511, 679, 682, 734
Sodium carbonate 296, 297, 298, 299, 302, 303, 309, 314, 315, 316
Sodium chlorate (see Chlorate)
Sodium formate (see Formic acid and Formates)
Sodium hydrosulfite, sodium dithionite (see Hydrosulfite, Dithionite)
Sodium hydroxide 14, 35, 38, 39, 138, 226, 227, 228, 237, 268, 269, 293, 296, 297, 302, 303, 305, 306, 309, 312, 314, 315, 316, 352, 355, 356, 357, 383, 384, 385, 388, 389, 423, 426, 460, 469, 476, 503, 504, 511, 525, 585, 606, 612, 831
 Manufacture 15, 74-76, 314
 Properties 73-74
 Storage and handling 77
Sodium hypochlorite 16, 64, 65, 75, 127, 141, 151, 152, 154, 245, 305, 313, 314, 315, 413, 423, 429, 433, 525, 824-825, 831
Sodium molybdate 356, 435
Sodium pyrophosphate, sodium tripolyphosphate 153, 501
Sodium silicate 315, 353, 354, 415, 424, 427, 428, 460, 464, 466-467, 480, 481, 483, 485, 612, 639, 640
Sodium sulfate, sulfate ion 36, 62, 66, 67, 75, 583, 589, 832
Sodium sulfide 35, 36, 38, 39, 99, 103, 104, 315, 832-833
Sodium sulfite, sodium bisulfite 42, 43, 97, 116, 176, 177, 178, 188, 189, 193, 205, 208, 253, 426, 494, 495, 503, 504, 509, 745, 773
Sodium tungstate 435
Steryl esters (see Extractives)
Stilbene quinones 52, 117, 164, 166, 171, 172, 175, 207
Stilbenes 93-94, 97, 100, 103, 117, 120, 129, 137, 144, 146, 148, 149, 166, 174, 175, 176, 198, 222, 323
Stock chest bleaching 506-507
Stone cell aggregates 446-447
Stora process 34, 40
Strength (mechanical) properties of bleached pulps (see also Strength properties under Bleached pulps) 16, 730-735
 Chemical pulps 659, 679, 730-735
 (Chemi)mechanical pulps 477, 735-736
 Effect of (Chemi)mechanical pulp bleaching 744-745
 Effect of kraft pulp bleaching 738-743
 Effect of sulfite pulp bleaching 743-744
 Factors affecting 186, 723-728
 Relationship to viscosity 734-735, 739, 740, 742
 Relevance of standard tests in commercial papermaking 736-738
 Strength property pairs 732-735, 736
Strength property measurements
 Future trends 75

Pulp Bleaching: Principles & Practice

Subject Index

Interpretation of test results 732-735, 736
Standard testing procedures, tests 729, 730-732
Underlying principles 722-723
Sugars, sugar analysis 45, 105, 107, 368, 682
Sulfamic acid 128, 149, 247, 682
Sulfite pulp, sulfite pulping 6, 10, 34, 35, 39-41, 49, 50, 97, 132, 154, 187, 188, 189, 190, 279, 293, 305, 307, 351, 353, 357, 422, 428, 430, 719, 726, 736, 740, 743-744, 812
Sulfonic acid groups, sulfonation 43, 51, 97, 106, 177, 178, 494, 684, 723, 729, 745, 813
 Determination of in pulp 684
Sulfoxylate ion 177, 494
Sulfur 34, 832, 833
Sulfur dioxide, sulfur dioxide-water 39, 62, 63, 65, 116, 176, 177, 353, 373, 388, 400, 426, 460, 477, 478, 479, 484, 494, 503, 506, 509, 606, 637, 638, 639, 660, 669, 832, 842
Sulfur dioxide anion radical 116, 176, 178, 494
Sulfuric acid (see also Sulfate ion) 63, 64, 65, 67, 80, 330, 353, 358, 373, 435, 477, 484, 504, 511, 525, 682
Superoxide anion radical 116, 141, 142, 145, 167, 171, 176, 205, 218, 219, 220, 349, 415, 416, 424, 459, 460
Surfactants 474, 475
Suspended solids (see Total suspended solids, TSS) 651
Syringyl units 93, 128, 129, 130, 144, 166, 760

T

Tear strength (tear index, tear factor) 47, 48, 49, 52, 237, 280, 328, 371, 431, 477, 486, 487, 551, 679, 720, 727, 731, 732, 739, 740, 741, 743
Tear-tensile relationship 49, 328, 431, 679, 732, 733, 736, 743
Tensile strength (tensile index, breaking length) 47, 49, 52, 205, 206, 208, 237, 280, 327, 371, 431, 477, 486, 487, 551, 679, 720, 727, 731, 732, 733, 739, 740, 741, 743
Thermomechanical pulp (TMP) 34, 42, 49, 51, 97, 185, 187, 188, 189, 190, 195, 462, 463, 511, 736, 744, 810
Thickening, thickeners (see also Presses) 593, 594
Thioethers 207-208
Thiols 206-207, 210
Thiourea dioxide (see Formamidine sulfinic acid)
Total organic carbon (TOC) 278, 359, 752, 753, 756, 757
Total organic chlorine (TOCl) 282, 753, 756, 757
Total suspended solids (TSS) 651, 769, 770, 771, 837, 838, 839
Totally chlorine-free (TCF) bleaching TCF-bleached pulp 328, 334, 336, 340, 365, 370, 372, 373, 419, 422, 424, 429-430, 431, 432, 437, 510-511, 584, 585, 684, 685, 739, 740-743, 751, 752, 753, 754, 758, 760, 790, 792
Towers and Reactors 216, 217, 230, 231, 244, 303, 305, 307, 311, 313, 337, 338, 357, 375, 385, 403, 419, 432, 433, 453-454, 475, 477, 483, 497, 506, 507, 509, 581
 Alkaline extraction 611-612
 Chlorination 610
 Chlorine dioxide 610-611
 Contacting reactors 558, 559, 608-609, 616-617
 Contactors (see also Mixers) 603-604
 Design criteria 327, 600, 604-609, 656-657
 Displacement bleaching 546, 609
 Downflow towers 217, 304, 305, 398, 402, 604, 605, 607, 608, 611, 612-614
 General design principles and considerations 599-603
 Inlet and discharge requirements for towers 606-608
 Mixer/reactors (see also Mixers) 608, 614-616
 Oxygen-reinforced alkaline extraction towers 611, 670
 Peroxide towers 612, 614
 Safety considerations 619-620
 Tray reactors 231, 609
 Troubleshooting 619-620
 Upflow towers 216, 308, 309, 381, 384, 505, 506, 507, 604-608, 610-612, 617
 Upflow-downflow towers 381, 384, 600, 606, 610-611
Toxicity (see Bleaching effluents)
Tristimulus values 510, 704, 706, 707

U

Ultim-O process 649
Ultrafiltration 755, 757, 758
Unbleached chemical pulps 7
 Bleachability 49-50
 Chemical composition 10, 36, 38, 39, 40, 44-46, 50, 244, 255

Pulp Bleaching: Principles & Practice

Subject Index

- Heterogeneity 48-49
- Lignin accessibility in 48
- Optical properties of 36, 37, 41, 48
- Strength (mechanical) properties 45, 46-49
- Unbleached mechanical and chemimechanical pulps
 - Bleachability 97, 463
 - Chemical composition 29
 - Optical properties of 37, 51-52
 - Strength (mechanical) properties 49, 50-51, 726, 728-729, 733, 744
- Uronic acid, uronic acid anhydrides 29, 45, 684, 685, 686
 - Determination of 685-686

V

- Vapor pressure osmometry 755, 757, 758
- Vent gases 823, 824, 826, 827, 829, 830
- Viscosity 13, 36-37, 45, 46-47, 223, 224-225, 233, 234, 235, 236, 237, 250, 251, 252, 253, 278, 279, 298, 314, 325, 327-328, 329, 330, 331, 333, 349, 352, 354, 393, 398, 399, 400, 403, 404, 408, 409, 410, 427, 428, 435, 437, 612, 613, 626, 660, 680, 734, 739, 740
 - Relationship to paper strength 9, 325, 679, 680, 734-735, 742
 - Relationship to polymer weight and DP 37, 46, 298, 679, 726, 734
- Solvents used in determination 679, 681, 720, 827

W

- Washers 216, 229, 244, 477, 659, 668, 823
 - Alkaline extraction (including oxidant-reinforced) 402, 404, 407, 585, 587, 588, 590, 662, 666
 - Atmospheric diffusers 21, 575, 580-581, 584, 609, 650, 671
 - Brown stock 228, 359, 586, 627, 632, 637, 671
 - Chlorination-stage 254, 311, 660
 - Chlorine/chlorine dioxide-stage 587, 660, 662, 666
 - Chlorine dioxide-stage 660, 666
 - Discharge consistency 399, 593, 657, 668
 - Drum displacement 11, 20, 21, 575, 576, 579
 - Elimination of unneeded 659, 669-670
 - Factors affecting selection of 575
 - Hypochlorite-stage 398, 402, 588
 - Loading factors 576, 678
 - Manufacturing and design considerations 588-589
 - Material selections for different bleaching stages 586-587
 - Oxygen-stage 587, 590
 - Peroxide-stage 588
 - Pressure 23, 229, 572, 575, 578-579, 584, 658, 670
 - Pressure diffusion 433, 572, 581-582, 585, 650, 671, 828
 - Three-washer bleach plant 666-667
 - Vacuum drum filter 216, 572, 575-578, 579, 583, 585, 586, 593, 658, 668, 827, 828
 - Wash presses 22, 572, 575, 576, 579-580, 582, 584, 658, 671, 828
- Washing 36, 310, 392
 - Bleached high-yield pulp 592-594
 - Brown stock 234, 244, 252, 253, 275, 352, 353, 375, 573, 574, 575, 586, 589, 650, 666, 668, 669, 671
 - Control 585-586
 - Countercurrent flow component 657-658
 - Defoamers and drainage aids 590, 591-592
 - Dilution/extraction 571-572, 650
 - Direct countercurrent 660-662
 - Displacement 571-572, 573, 579, 580, 581, 593, 650
 - Efficiency (performance parameters): dilution factor, displacement ratio, equivalent displacement factor, Norden efficiency factor, wash liquor ratio, wash yield 105, 234, 572-575, 577, 579, 582-583, 632, 653, 657, 659, 668, 669
 - Equipment and equipment selection 575-583
 - First and second bleaching stages 585, 671
 - Improvement procedures 668-670
 - Jump-stage countercurrent 662, 664, 665
 - Jump-stage split-flow 665, 668
 - Mechanical pulp 592-594
 - Ozone and peroxide stages 585
 - Pitch and extractives removal 587
 - Post-oxygen delignification 228, 234, 235, 236, 511, 573, 574, 580, 583, 584, 579, 586, 587, 588, 589, 671
 - Second chlorine dioxide stage 587
 - Split flow countercurrent 662, 663, 665
 - Wash ratio (see also Efficiency under Washing) 657, 662, 668
- Water
 - Balance in bleach plant 652

Pulp Bleaching: Principles & Practice

Subject Index

- Conservation measures in bleaching 668-670
- Consumption by United States pulp and paper industry 649
- Mass balance in bleach plant, mass balance calculation 654-656
- Restricted use advantages in bleaching 651-654
- Use in different washing sequences 650
- Water (filtrate) reuse (see also under Bleaching effluent) 649-672
 - Closed cycle operation 671-672
 - Factors affecting 658-660
 - Improved systems for 668-671
 - Non-chlorine bleaching sequences 671-672
- Whiteness 12, 698, 703, 704
- White liquor 237, 315, 590, 636, 638, 831, 832
- White water 250, 251, 252, 466, 474, 506, 660, 661, 662, 663, 664, 665, 666, 668, 669, 677, 688
- Wood
 - Anatomy and morphology 27-31, 635, 724
 - Ash, ash content 29, 96
 - Chemical composition 29, 244
 - Chipping, chips 27, 31, 35, 255, 434, 454, 455, 463, 677, 734, 744, 809, 838
 - Combustion 810-811
 - Compression 446, 447, 448, 725, 809
 - Consumption 31
 - Residues 27, 31, 33
 - Species used for pulping in North America 28, 31
 - Supply 32, 33

X

- Xylan (see Hemicelluloses)
- Xylanases 48, 365, 366, 367, 368, 369, 370, 371, 372, 373, 375

Y

- Yellowing (reversion) 406, 417, 469, 500, 506, 509, 575
 - Aging tests 186, 430
 - Effect of bleaching on 188-189
 - Effect of metal ions 190
 - Effect of pulping 188
 - Effect of oxygen 196-197
 - Effect of wood species 187
 - Inhibition of 202-209
 - Light-induced 186, 190-209, 475, 487, 683
 - Mechanism of 197-202
 - Optical measurement of 185-186, 190-191
 - Post-color (PC) number 185, 186, 188, 189, 190, 191
 - Relative reflectivity 191-192
 - Thermal (heat-induced) 153, 185, 186-190, 209, 298, 475, 683

Z

- Zero-span tensile test 371, 679, 680, 733, 745