

Cooling Water Treatment Principles and Practice

**COOLING WATER
TREATMENT
Principles and Practice**

Colin Frayne



CHEMICAL PUBLISHING CO., INC.
New York, N.Y.

©1999

Colin Frayne

ISBN: 0-8206-0370-8

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior permission of the publisher and copyright owner.

Printed in the United States of America

ABOUT THE AUTHOR

Colin Frayne, LRIC, MCIWEM, MICorr. (U.K.) is an international water treatment consultant and small business owner. He has more than 30 years of experience in the practice of industrial chemistry and industrial water systems management, and has worked and lectured in over 40 countries. During those years he has also lived on four continents, with his family, while being variously employed in Q.C. and R & D laboratories, in technical sales, sales management, marketing, training, international business development, import/export, and general management. He graduated in analytical chemistry from North London Polytechnic (now the University of North London), in the United Kingdom, and later obtained various business diplomas from colleges in the U.K. and South Africa, including Wits Business School in Johannesburg. Mr. Frayne is British, but has resided in the United States for several years, with his wife and two daughters. In early 1999 he relocated from Georgia to New York City to join the Metro Group, Inc., an environmental services and water treatment company, in a senior executive capacity.

PREFACE

The water treatment market, like most other services markets, is constantly changing. Today's market is more complex, global, and competitive than ever before. However, the vital key to successfully providing efficient cooling water treatment programs today is something it has always been—excellent customer service!

Gone are the days when the very largest industrial organizations had all the necessary in-house skills to take care of their own water treatment programs, while the small companies either did not know or did not care about water treatment and water management. The tremendous changes in all sectors of the water treatment marketplace in recent years, in line with industry globalization and technology changes in other markets, have forced all players to review and modify how we conduct business. In addition, increased sophistication, production demands, and environmental and financial pressures in all kinds of heat-transfer processes have demanded that buyers, sellers, and users of water treatment products, services, and management systems keep absolutely up to date.

Today, field-based water treatment services need to provide the customer with an increasing depth and rapidity of authoritative information and support. The service demanded is a high-quality mix of applied chemistry, business management, and hands-on technical skills. In addition, practical advice, fully communicated to the customer, both up and down the line is required.

Providing chemical water treatment programs to end-user customers, irrespective of their industrial, commercial, or institutional origins, has always required a blend of tangible and intangible products and services. The particular recipe tends to change back and forth with time, based on a customer's particular application needs and the relevant financial and marketing pressures. Each program reflects a combination of chemical research and applications development, bank-office and home-office support services, plus technical and marketing skills in the field; it is still some art mixed in with science.

The success of all programs, however, depends on both the *chemistry* employed by the water treatment provider and the *chemistry* that jointly develops between the provider's field personnel and the customers. Staying close to the customer, working out problems together, and drawing on a battery of skills, experiences, and technology weapons to provide cost-effective and satisfying solutions is the only way to retain the customer's business. Computer and other technologies available now will probably never replace the need for hands-on, experienced field service personnel. Therefore, water treatment field people must be effective salespeople, communicators, and marketers as well as expert technicians in water systems management if they and their companies are to succeed.

My fascination with the psychology of selling, the international marketing efforts put into cooling water (cooling water treatment products and services are major profit earners for water treatment companies), the variables that collectively contribute to waterside problems, and the management of field skills and resources in resolving problems for the benefit of the customer were, among others, some of the factors that challenged me to write this book.

Personally, I see little point in regurgitating all the finer technical points regarding cooling water chemistry and management, or even remembering everything. The aim of this book is to encompass more than the pure technical matters involved in cooling water treatment. It has been written to be essentially a practical, technical book, international in nature that contains some theory and much practice. It also confronts and discusses the issues of marketing, and buying and selling of water treatment, an integral part of the daily job, yet avoided in almost all other water treatment books. The book was designed to allow both providers and customers to use it regularly, and hopefully it will find its place on desks or will be carried in the field.

Apart from the basics, this book also includes some aspects of cooling water chemical formulations and programming that hitherto have been taboo for open publication (on the possible grounds that if field engineers or their customers got hold of all this information, the secrets of our industry would be out in the open).

Lesson: Customers buy our products and services because of the benefits they can obtain, not because they particularly want to become active water treatment product manufacturers themselves.

Increased knowledge of the raw material components tends to make for more informed consumers. And besides, this type of information is now becoming more readily available from the specialty, raw materials chemical vendors, who provide much of what is blended into modern water treatment chemical formulations.

There are some excellent marketing books available that focus on practical implementation rather than on theory. (My favorite marketing authors include Al Ries, Jack Trout, and Torn Peters.) There are also many superb technical books on water treatment and possibly thousands of papers on water treatment on individual technical subjects. This technical information tends to supplement the classroom training given to field sales and technical services representatives and has mostly been written by experts within the water treatment companies. These books provide authoritative text without any undue self-promotion and, increasingly, they are appearing on the customers' shelves as well, which is a welcome trend and should be encouraged. (Some well-thumbed examples on my own shelves include the volumes from Nalco Chemical Company; Betz Dearborn, a division of Hercules Inc.; and Drew Industrial, a division of Ashland Chemical Co.). By their very nature, these publications cover a wide range of water treatment and tackle each subject in a general and theoretical way.

There is little available that is specifically written about cooling water treatment. James W. McCoy's book is a notable, if slightly dated, exception. The book by J. N. Tanis contains the most practical hands-on sections I have read in a long time, and the recent *NALCO Guide to Cooling Water Systems Failure Analysis* is excellent. These books are concerned with applied water treatment and are suitable for regular use in the field. But there seems to be a need for more of these practical water treatment handbooks to be written and published, and certainly one or two that deal with the sales and marketing issues!

The starting point for *Cooling Water Treatment Practice: Principles and Practice*, was James W. McCoy, whose first edition of *The Chemical Treatment of Cooling Water* was enthusiastically received by the industrial community when it was published by Chemical Publishing Co. of New York in 1974. Mr. McCoy showed his readers how to use water treatment chemicals beneficially and how to evaluate their effectiveness. He also dispelled much of the misinformation prevalent at that time concerning water treatment technology. In this second edition, published in 1983, McCoy acknowledged having some temerity in writing a practical book that might not satisfy the demands of academics, but wrote that most of us can live with their scorn. It is hoped that in today's world there is more tolerance of nonacademic technical authors. The judge concerning the merits or otherwise of this book should be the operations/maintenance/process/production/project engineer who has a water system problem and needs to find an answer—quickly, simply, and economically—either directly from these chapters or via a well-read and experienced water treatment field service

representative. Therefore, McCoy inspired this book, and consequently I am happy to be working with the same publisher.

My personal interest and involvement in all areas of water treatment, but especially in cooling water management, has taken me all over the world and still continues to do so, providing friends and colleagues, a career, and a source of revenue. It has also given me many frustrations and sleepless nights over the years. I have enjoyed researching and writing this book, although at the beginning I did not realize that writing was such antisocial behavior, requiring me, as it did, to work uninterrupted, isolated from all the other activities taking place in the house, and often working through the night. As a consequence, I must give due recognition to my wife, Carol, for enduring the tortuous time I put her through while writing this book. I also thank Silvia Soto-Galicia and her staff at Chemical Publishing Co. for all the support provided in getting this book published. I now have a new and healthy respect for all the other authors of books and technical information who labored under similar circumstances.

Colin Frayne
Macon, Georgia
1998

CONTENTS

Introduction: Marketing Cooling Water Treatment	xvii
1 Cooling System and Heat Exchange Essentials	1
1.1 Evaporative Cooling Systems	3
1.2 Notes on Some Common Types of Cooling Towers	6
1.3 Evaporation and Total Water Usage	10
1.4 Water Usage Calculations	13
1.5 Heat Transfer and Heat Exchangers	15
1.6 Heat Exchanger Waterside Inspection	20
2 Makeup Water Sources and their Impurities	23
2.1 Sources of Water for Cooling System Makeup	24
2.2 Mineral Impurities and Problems Caused	29
2.3 Dissolved Gases and other Impurities	35
2.4 Examples of Variations in Makeup Water Sources	36
3 Makeup Water Pretreatment Processes	43
3.1 Raw Water Flocculation/Clarification Pretreatment Processes	44
3.2 Notes on Chemical Precipitation Softening Processes	51
3.3 Aeration Towers for Makeup Water Pretreatment	54
3.4 Manganese Greensand Oxidation and Filtration	55
3.5 Sand, Anthracite, Multimedia, and Automatic Self-Cleaning Water Filters	56
3.6 Ion-Exchange Softening and Blending	61
3.7 Reverse Osmosis	67
3.8 Acid Dosing	75
3.9 Pretreatment Employing Magnetic and Other Physical Devices	78
4 Corrosion, Fouling, and Deposition	85
4.1 Corrosion Chemistry	87
4.2 Types of Corrosion	94

4.3	Scales, Sludges, Inorganic Deposits, and Foulants	104
4.4	Saturation Indices	112
4.5	Microbiology and Microbiological Fouling	122
4.6	Legionellosis	132
5	Chemical Treatments and Programs for Cooling Water	137
5.1	Some Basics of Chemical Inhibitor Programs	139
5.2	Some Early Inhibitors, Deposit Control Agents, and Cooling Water Programs	140
5.3	Some “Traditional” Cooling Water Inhibitors	148
5.4	Some “Standard” Phosphonates and Organic Polymers	152
5.5	Summary List and Examples of Phosphonates and Organic Polymers	165
5.6	Some Cooling Water Product Formulations	169
6	Microbiological Control Programs	177
6.1	Forms of Biocides	182
6.2	Oxidizing Biocides	183
6.3	Nonoxidizing Biocides	209
6.4	Biodispersants	229
6.5	Other Forms of Microbiological Control	232
7	Buying and Selling Cooling Water Programs	235
7.1	The Basic Starting Position for Selling Cooling Water Programs	237
7.2	The Basic Starting Position for Buying Cooling Water Programs	243
7.3	Selling the Proposal	251
7.4	Notes on Some Cooling Water Program Marketing Strategies	258
8	Surveys, Inspections, and Cooling Water Program Selection	263
8.1	Surveying the Cooling Water System from a Marketing Standpoint	265
8.2	Surveying the Cooling Water System from a Technical Standpoint	267
8.3	Survey Interpretation and Proposal Focus	285
8.4	Cooling Water Program Selection	299
9	Managing Cooling Water Programs	313
9.1	Cooling Water Program Field Services	315
9.2	Cooling Water Management and Good Housekeeping Practice	316

Contents	xv
9.3 The Control of Legionellosis	320
9.4 Precommission Cleaning and Program Start-Up	330
9.5 On-Line (In-Service) and Off-Line Cleaning	341
9.6 Chemical Dosing and Program Control	352
10 Monitoring and Control	367
10.1 Material Balance	369
10.2 Water Sampling, Testing, and Reporting	369
10.3 Inhibitor Monitoring and Control	375
10.4 Corrosion Monitoring and Control	379
10.5 Deposition/Fouling Monitoring and Control	385
10.6 Biomonitoring and Control	389
10.7 Control Using Computer Software Programs	392
10.8 Cooling Water Program Control Parameters and Troubleshooting Guide	396
Appendix 1. Useful Data	417
Appendix 2. Glossary	427
Bibliography	451
Index	457

MODERN COOLING WATER TREATMENT PRACTICE

Modern cooling water treatment practice is the planned, actioned, and documented management of cooling systems to produce and maintain operational and economic benefits for the users.

Achievement is by the provision of innovative chemistry, together with other appropriate technologies, and the application of practical expertise in the field, in order to prevent waterside and operational problems from occurring. When problems do arise, detection and identification of the causes, together with suitable remedies that will prevent recurrence, are required.

Good water treatment practice at site should not be the sole prerogative or responsibility of any one person, rather, it requires the active participation, support, and communication of the service company and the owners and users of cooling water systems and other equipment, if success is to be attained and maintained.

INTRODUCTION MARKETING COOLING WATER TREATMENT

Imagine three drums of different “antiscalent” chemical products in a manufacturer’s warehouse awaiting delivery to, say, a sugar mill customer. The first drum contains a process additive for addition to the feedwater for an RO plant, the second drum contains a performance chemical for the sugar juice multiple effect evaporators, while the third drum holds a water treatment deposit control agent for cooling system hard water makeup. The labels, brand names, and respective selling prices are all different, yet the applications appear to be similar and the formulations for all three products are almost identical! What is the difference?

The selection of the RO process additive formulation and its rate of application was primarily based on the RO feedwater analysis and type of membrane used, and the product is expected to continuously perform its antiscalant duties with a minimum of supplier monitoring. The performance chemical is slightly different; it was recommended to help solve scaling problems in the evaporation process, to permit longer production runs and higher sugar Brix levels, thereby adding value to the customer’s own product. To obtain maximum product performance with this second chemical requires the supplier to advise on monitoring points and periodically review addition rate adjustments.

The third product, however, the water treatment chemical, is merely one component (albeit a very important one) of a comprehensive water treatment program that includes the supply of a variety of on-going customer support and technical services in order that the applications technology provided not only maintains cooling system efficiency but also keeps operating costs within budget and avoids problems from ever-tightening environmental regulations. Thus there are some significant differences in these chemical applications and the customer’s technical service support expectations.

Precisely how and why a chemical product is proposed and then used for any particular process application is at least as important as its formulation components. And it has been shown that the degree of technical support services required to ensure maximum performance can vary considerably!

The fact is that all the aforementioned antiscalent applications add value to the customer's operations, but there is a difference between selling chemicals designed perhaps to maintain consistent operating conditions, or to primarily perform basic value-adding tasks, and the marketing of water treatment chemicals as part of a total products and service package, where intangibles such as customer confidence and freedom from worry are an inherent part of the marketing process. And the difference is the requirement for a high degree of on-going customer site technical services.

Water treatment, based on applied chemicals technology, is a service business. The cooling water sector, because of its inherently large number of variables, is especially so. (In certain countries, the service aspect of the water treatment chemicals market has developed so much, due to market demand or regulations, as to be sometimes completely independent of the chemicals element and now overlaps the maintenance services industry.)

Continual change and development take place in the global water management marketplace. The larger, international "service companies" in the water treatment chemicals market also regularly develop and launch a variety of performance chemicals for value-adding processes, gaining financial benefits from technologies perhaps originally developed for water treatment markets (or vice versa) and thus creating the potential for additional sales. Similarly, many major chemical corporations that manufacture specialty products for different markets continually explore opportunities to develop niches within the water treatment chemicals/service industry market sectors.

Additionally, around the world today there is ever-increasing competition in many market sectors as the traditional boundaries between them fade. There are now many privatized potable water supply companies that were once state-owned, moving into the higher margin and nonregulated specialty sectors. There are also major capital equipment sales corporations, providing alternative technologies (such as wastewater treatment, RO, or ion exchange) that, through acquisitions and mergers, are buying into the water treatment chemicals and services markets.

Many regional markets around the world have grown considerably in recent years, although not always in predicted directions or along traditional lines, and this has encouraged water treatment companies of all

sizes, and from various home market bases, to develop international departments. This explosive market expansion is most noticeable in high-growth economies such as China, India, ASEAN (Association of South East Asian Nations) Pacific Rim states, and certain Latin American countries, where new customers often seek to conduct business and cement relationships with water treatment companies on their own terms, and in ways not always common to those accustomed to operating solely in the United States or Western Europe.

However, with rapid growth and profit opportunity comes financial risk. This was demonstrated by major financial instability problems with Mexico in the mid-1990s, then a little later in the ASEAN countries, especially Thailand, Indonesia, and the Philippines, and, most recently, South Korea, so it is not all "plain sailing." Several major water treatment companies have experienced a loss of sales and profits in the region that may take several years to overcome. In line with the growth in international markets, the rate of change in our industry continues to gather pace. Water treatment service companies have become even more competitive, quality-oriented, aggressive, and technologically astute, while their customers are more knowledgeable about water treatment practice, are more selective concerning potential suppliers, and seek improved value for their continued support. Consequently, the methods and subtleties by which the individual product ranges and technical service skills are presented to the marketplace demonstrate a significant change from only a few years ago.

Many major water treatment companies are now market sophisticates; they have already become world businesses, operating with global strategies, or are on their way to becoming one, and they are not all to be found in the United States any more! Several multibillion Japanese and European companies, starting from different positions, and with considerable strengths in specialty process chemicals, capital water treatment equipment, or potable and wastewater treatment project engineering, have now grown to be major players in the water treatment chemicals and services market and are influencing the marketplace in yet further diverse ways.

Today it is difficult to determine where many water treatment market sectors begin and end. The market overlaps, the globalization and acquisition strategies of major players, plus the fairly recent phenomenon of alliances between seemingly noncompeting suppliers (seen especially in the United States) have served to further weaken traditional water treatment sector demarcation lines. Now water treatment chemical companies are not manufacturers at all, but are marketers of engineered chemical products and technical support services. They are water systems managers and have a high degree of customer needs awareness, directing their products

and services accordingly. These forward-thinking businesses recognize that a strong market focus, staying close to the customer, and a swift response to changes in the market or to aggressive competitive moves is vital for their survival and future prosperity!

What do all the current global market developments, customer/end-user requirements, and strategic responses have to do with modern cooling water treatment practice? The answer to this lies in water treatment companies grasping the opportunities presented for both the growth in chemicals volumes for cooling water (and other areas) and the higher profit margins to be earned by the tailoring of their products' technical services support to meet the more exacting needs of today's customers. To further explain, it is first worth looking at some specific factors: due to the growth, merging and cross-over of traditional market sectors, it is difficult to pronounce with any real certainty on the true size of the world market for specially water treatment chemicals and services. It is probably now worth approximately \$7 billion per year, with the United States worth over \$3 billion and the Pacific Rim area having grown in excess of \$1 billion, with opportunities continually arising. The old adage of "the harder you look, the more you find" is certainly true here!

Sales of traditional water treatment chemicals and services in the United States (the world's largest water treatment market) have slowed to an annual increase of perhaps only 3 percent in recent years, whereas Pacific Rim and Latin America were averaging 16 percent growth per year until 1997. (Incidentally, sales of performance chemicals is another major opportunity, now typically averaging an annual growth of 13 percent in some parts of the world). Thus to grow, or at least to retain market share in terms of dollar margin income, American water treatment companies must conduct business differently than they have done in the past. Also, to take an appropriate share of the rapidly developing markets in international high-growth economies requires new and revitalized ways of working! This in part explains the buildup of alliances and customer partnerships in the United States as a way of resisting customer base erosion, the need to buy market share in the United States, and the very aggressive acquisition strategies we have seen, that are required to gain entry to those growth markets around the world. (We have also seen in recent times that some large water treatment companies have been much more successful than others in their acquisition and assimilation of smaller competitors.)

The principal subsectors of the water treatment chemicals and services market are for incoming water, boiler water, cooling water, and wastewater. Of these various subsectors, cooling water uses the most innovative chemical raw materials, shows the greatest opportunities for volume growth

(due in no small part to the new industrial and other infrastructural development in high-growth economies), and enjoys the highest percentage gross margin. It also requires the most proficient and far-reaching technical support services.

Typically in the specialty chemicals market, approximately 55 percent of U.S. buyers choose either quality or price as the single most important factor when selecting a supplier, but about 70 percent of those who change their suppliers do so because they did not like the human side of doing business with the product and service provider! This is a people's business and to succeed requires more than just good products. So the global marketing of cooling water treatment in new and innovative ways is vital to the future lifeblood of water treatment companies, and the most important component is the people services element! In view of this statement, it becomes easier to see why today so much emphasis is being placed on gaining business by enhancing customer support services. Some of the strategies employed are:

- The recruitment of considerable numbers of new field personnel, both from within and on either a secondment or permanent basis, to the countries with high-growth economies in order to maximize the penetration of those global growth opportunities presented.
- The redeployment of home office support staff to the field in order to provide additional and closer ties with the customer (and to compensate for experienced field staff sent to obtain a share of the newer, high-growth markets).
- The provision of "customer friendly" laptop computers and design/diagnostic/database software to sales staff and other field personnel in order to provide a competitive edge for gaining and retaining business (but perhaps also to reduce the time requirements for training field staff by traditional means).
- The development and intensive marketing of "real time" chemical product tracing systems and computerized analytical record and data interpretation programs, for customers' water systems, in order to provide a further competitive edge.
- The growth of "customer partnerships," "strategic alliances," and "customer account management technologies," which are terms used in the development of closer working arrangements with customers, and designed to protect service companies' customers from competitive pressure.

The global nature of the water treatment industry, the explosive growth, and the competitive interactions make for interesting times. And, although

this industry, like almost all other industries, is market-driven (i.e., the end-user customer ultimately calls the tune), there are other influences that play a part. It is therefore worth looking briefly at the increasingly influential role of the giant chemical raw material suppliers, who provide much of the specialty additives used in today's water treatment companies formulations, especially those used in cooling water programs.

With limited exceptions, water treatment service companies are not original chemistry researchers; they are applications experts and use a variety of increasingly novel and sophisticated organic chemical raw materials for incorporation in their formulations. The supply of these materials is mainly via a handful of multibillion dollar sales, chemical companies, who are original researchers. They compete aggressively with each other, striving to produce ever more sophisticated, multifunctional, organic performance chemicals, which are designed to tackle higher and higher levels of stressed cooling water treatment applications. These products are then made available to the service companies, often at increasingly elevated prices, and with strong premiums demanded for innovative, value-adding chemistries. Increasingly, the research and manufacturing companies provide awareness campaigns, promoting the features and benefits of their new polymers direct to the end-user customer, thereby stimulating demand yet further. There is no doubt that these companies have had a strong influence in driving up both the attractiveness and the overall value of the cooling water market sector.

The marketing of cooling water treatment today is a both a customer seduction process and a proclamation of the increased strength, adaptability, and value of modern cooling water programs. However, the permutations of chemical product, people skills, field support services, and flexibility in work practices available from individual water treatment companies around the world, whether large or small, and the ways in which these factors can be combined to provide precise solutions to their customers' application problems, go a long way in determining how that company is differentiated and perceived in the marketplace. The customer's perception of each company, the value of its chemical programs, and its hierarchical position in the marketplace is not necessarily directly related to that company's size or revenues, which makes working in this industry both challenging and rewarding, especially to those in the field, who by their combined technical, selling, and problem-solving skills, and by their closeness to the customer, can most directly influence the differentiation of their company and its fortunes.

Apart from the upheaval in the chemical industry as a whole, where new names, such as Novartis, Clariant, Cognis, Avecia, Rhodia, and many others, continue to appear on a regular basis, there are wholesale changes

occurring in the global water utilities and water treatment industry. Mergers and acquisitions are changing the nature and business focus of many of the world's major and minor water treatment players, both the service companies and the specialty chemical producer. Most notable among recent moves are the purchase of both Calgon and Nalco by the French Company Suez Lyonnaise (together for close to \$5 billion) and U.S. Filter by Suez Lyonnaise rival Vivendi, for \$6.2 billion. Also, the merger of Betz with Dearborn, which was then snapped up by Hercules, the decision of Ciba to get back into water treatment (after selling its service company to Drew and its specialty chemical business to FMC some years ago) by acquiring Allied Colloids, and the very recent sale of the Ciba/FMC water additives business to Great Lakes. There seems no immediate cessation in the current penchant for mergers and acquisitions, as companies struggle for strategic advantage. Whether these moves will ultimately provide benefit to water treatment companies and their customers remains, as yet, an open question.

Given the highly competitive and global nature of industry today, the environmental concerns, and the increasingly short-term nature of financial performance assessments, one of the key areas in which water treatment service companies can work closely with their customers, and can provide them with tangible and valuable benefits, is in the field of cooling water management. The modern, high-performance chemicals now available, the speedy computerized information databases and instrumental diagnostic tools increasingly employed, and the various other support services give the customer an unprecedented opportunity to add value to their operations, and for water treatment service companies to continue to make money.

The marketplace is a war zone and the winners are those vendors and customers who work together, for mutual benefit and profitability. The vendors' most important weapons are good people, innovative chemical products, and, increasingly, the ability to provide customers with "real-time," information technology. Computer programs permit on-site predictive analysis, SPC (statistical process control), access to vendor central information databases, benefit/cost comparisons, and financial scenarios.

Above all else, it is the dedication, the good practical knowledge, the experience, the interpretive, communicative, and selling skills of the truly professional water treatment field operator, that makes the difference between success and failure.

BIBLIOGRAPHY

1. Anderson Chemical Company. *ANCOPACK Cooling System Package*. Cooling Water Control Systems Promotional Literature, USA.
2. Ash, Michael and Irene. *Handbook of Water Treatment Chemicals*, 1st edition. Gower Publishers, UK, 1996.
3. ASS/ANZ HB. *Control of Microbial Growth in Air-Handling and Water Systems of Buildings*. Published jointly by Standards Australia/Standards New Zealand, New Zealand, 1995.
4. ASTM. *D2688-90: Standard Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Methods)*. ASTM, USA, 1990.
5. Baltimore Aircoil Company. *Evaporative Condenser Engineering Manual*. Bulletin E115/1-OB, USA.
6. Bardsley, Judy H.; Ellis, Michael J.; Hann, William M. *New Acrylate Polymers for Water Treatment Programs*. Rohm & Haas Company, USA, March 1990.
7. Betz-Dearborn (formerly Grace Dearborn Water Treatment Services, UK). *System Care: Water System Operating and Record Keeping Manual*. Betz-Dearborn, USA, 1991.
8. BF Goodrich Company. *The Role of Polymers in Water Treatment Applications and Criteria for Comparing Alternatives*. Paper presented at 6th Convention, Association of Water Technologies, Inc., November 1993.
9. Boffardi, Bennett P. *Fundamentals of Cooling Water Treatment*. Calgon Corporation, USA, 1987.
10. Bott, T. R. *A Comparison of Chlorine and Ozone for Cooling Water Treatment*. "Waterline," UK, June 1990.
11. Bridger Scientific Inc. *DATS Fouling Monitor System*. Promotional literature, Bridger Scientific, USA.
12. British Association for Chemical Specialities. *The Control of Legionellae by the Safe and Effective Operation of Cooling Systems—A Code of Practice* (see also *Code of Practice Update*, 1995). British Association for Chemical Specialities, 1989.
13. Brunn, Arthur F. *Treatment Service: What Should You Consider When Engaging a Water Treatment Service Company?* Industrial Water Treatment, USA, March/April 1995.
14. Calgon Corporation. *Calgon Software Demonstration Program*. Internet information. <http://www.calgon.com>, Calgon Corporation, USA.
15. Callow, L.M. *Corrosion Monitoring in Inhibited Water*. The Water Management Society, UK, 1995.

16. Carrier Corporation. *Carrier System Design Manual: Part 5, Water Conditioning*, 4th printing. Carrier Corporation, USA, 1972.
17. Chlorine Chemistry Council. *Key Talking Points for Communications Relating to the EPA Recommendations to Phase Out Chlorine and Chlorinated Compounds*. Chlorine Chemistry Council, USA, February 1994.
18. Conley, Jeffery C.; Puzig, Edward H. *Bromine Chemistry: An Alternative to Dechlorination in Cooling Water and Wastewater Disinfection*. "Waterline," UK (reprinted from the proceedings of the 48th International Water Conference, USA), November 2–4, 1987.
19. Darvill, Mike (Hydrotec, Ltd. UK). *Magnetic Water Treatment*. W &WT Journal, UK, July 1993.
20. Degrémont. *Water Treatment Handbook*, 5th and later editions. John Wiley & Sons, USA.
21. Downward, Brian L.; Failon, Brian K. *A New, All Organic High Performance Corrosion Inhibitor for Industrial Cooling Water Systems*. Albright & Wilson, 1996.
22. Drew Industrial Division. *PULSE Analyzer: Advanced Control Systems*. Promotional literature, USA.
23. Eager Jr., Robert G.; Theis, Alan B.; Turakhia, M. H.; Characklis, W. G. *Gluteraldehyde: Impact on Corrosion Causing Biofilms*. Corrosion, USA, 1986.
24. EHS The Health Department, Victoria, Australia. *Guidelines for the Control of Legionnaires Disease*. EHS The Health Department, Victoria, Australia, 1989.
25. Elliot, Thomas C. *Cooling Towers*. "Power" Special Report, USA, March 1973.
26. Ferguson, Robert J. *Computerized Ion Association Model Profiles Complete Range of Cooling System Parameters*. 52nd Annual Meeting, IWC, USA, October 1991.
27. Ferguson, Robert J.; Freedman, A. J.; Fowler, G.; Kulik, A. J.; Robson, J.; Weintritt, D. J. *The Practical Application of Ion Association Model Saturation Level Indices to Commercial Water Treatment Problem Solving*. American Chemical Society, USA, August 1994.
28. FMC Corporation (UK) Ltd. *Process Additives Division. Products for Industrial Water Treatment*. Various technical/commercial literature, UK, 1983–1995.
29. Frayne, C.; Robinson, J. *ANCO Guidelines for the Operation & Maintenance of Cooling Systems to Minimize the Risk of Legionella*. Anderson Chemical Company, Inc., USA, 1995.
30. Frayne, Colin. *Cooling Water Programming: A Basic Guide*. Internal publication for Houseman Ltd., Windsor, Berkshire, UK, 1980.
31. French Creek Software, Inc. *Water Cycle Series Product Information*. Internet information. <http://www.frenchcreeksoftware.com>, USA.
32. Geesey/Lewandowski/Flemming, Editors. *Biofouling and Biocorrosion in Industrial Water Systems*. Lewis Publishers, USA, 1990.
33. Grab, Lawrence A.; Thels, Alan B. *Comparative Biocidal Efficacy vs. Sulfate Reducing Bacteria*. Presented to NACE Annual Conference and Corrosion Show, Paper 184, Corrosion, USA, 1992.

34. Hann, W. M.; Keller, L. H.; Sanders, T. W.; Weinstein, B. *Towards Field-Friendly Traceable Polymeric Dispersants*. 58th IWC Conference, November 1–5, 1997.
35. Harfst, William F. *Chlorine or Bromine: Which Is Right for Your System?* "Power," USA, September 1993.
36. Harris, Arthur; Yeoman, A. M. *Development of an All Organic Ferrous Metal Corrosion Inhibitor*. UK, March 1986.
37. Harris, Norman C. *Modern Air Conditioning Practice*, 3rd edition, McGraw-Hill, Inc., USA, 1983.
38. Hawthorn, Don. *Scaling by Evaporatively Cooled Recirculating Water*. "Waterline," The Water Management Society, UK, 1995.
39. Health and Safety Executive, British Government. *The Control of Legionellosis, Including Legionnaires Disease (HS(G)70)*. Her Majesty's Stationary Office, UK, 1991.
40. Henley, Mike. *Biocontrol: Environmental Rules, Safety Issues Impact Biocide Use*. "Industrial Water Treatment," USA, November/December 1993.
41. Henley, Mike. *Environmental: Future Legislation Appears Likely to Impact Water Treatment Decisions*. "Industrial Water Treatment," USA, November/December 1994.
42. Henley, Mike. *Process Contaminants and their Impact on Biocides*. "Industrial Water Treatment," USA, May/June 1994.
43. Henley, Mike, Editor. *Industrial Water Treatment and Ultrapure Water: Business News & Profiles Sections*, Tall Oaks Publishing, Inc., USA, published periodically.
44. Hensley, John C, Editor. *Cooling Tower Fundamentals*, 2nd edition. The Marley Cooling Tower Company, USA, 1985.
45. Herro, Harvey M.; Port, Robert D. *The NALCO Guide to Cooling Water Systems Failure Analysis*, 1st edition. McGraw-Hill, Inc., USA, 1993.
46. Hollingshad, Charles R.; Peters, William R. *A New Generation of Cooling Water Treatment*. American Power Institute Paper (1984 Annual Meeting, Illinois), USA, April 1984.
47. Houseman Limited. *The Good Water Guide: Chemical Cleaning. Technical and Marketing Notes*. Houseman Limited (Member of Degrémont Group), UK, 1981.
48. Houseman Limited. *Basic Microbiology TMI*. Houseman Limited (Member of Degrémont Group), UK, 1980.
49. IDEX Corporation. *PULSAtrol™ Microprocessor Based Controllers and Monitors Reference Guide*. Promotional literature, Pulsafeeder IDEX Corp., USA.
50. Inversand Company. *Manganese Greensand CR & IR: Technology Notes*. Promotional literature, Inversand Company, USA,
51. Jain, Kiran. *Technical Data on Some Chemicals, HOBr Generation Using Sodium Bromide and Chlorine, Toxicity Assessments, Simazine, Chlorine Dioxide*. Various technical papers, USA, 1993.
52. Johnson, Peter R. *Fundamentals of Fluid Filtration: A Technical Primer*. Tall Oaks Publishing, Inc., USA, 1990.
53. Kataras, William; Brooks, Richard; Malm, Arthur P. *Cooling Towers: Utility Cools with Municipal Effluent*. "Industrial Water Treatment," USA, March/April 1994.

54. Kelly, Dennis, et al. *Triogen Ozone Cooling Tower Planning Manual*. Barr & Wray Ltd., UK, 1993.
55. Kemmer, Frank N., Editor. *The NALCO Water Handbook*, 2nd edition. McGraw-Hill, Inc., USA, 1988.
56. Kuechler, Thomas C.; Rakestraw, Lawrence F.; Graham, David F.; Matson, Jack V. *Development of Monsanto's Towerbrom[®] Microbiocide, A New Bromine Microbiocide for Recirculating Water Systems*. American Water Technologies Conference, December 1991.
57. Kurtz, John B.; Bartlett, Christopher; Tillet, Hilary; Newton, Ursula. *Field Trial of Biocides in Control of Legionella Pneumophila in Cooling Water Systems*. "Ecology and Environmental Control," UK, 1983.
58. Laronge, Thomas. *The Waterside: A Return to Tradition*. "Industrial Water Treatment," USA, July/August 1994.
59. Laronge, Thomas. *The Waterside: Beyond Tradition*. "Industrial Water Treatment," USA, November/December 1994.
60. Laronge, Thomas; Freedman, Arthur J. *The Importance of Control in Operating Modern Cooling-Water Systems*. "Industrial Water Treatment," USA, July/August 1995.
61. LXF Incorporated. *Track 2 & Water Treatment Handbook on-Disk*. Internet information. <http://www.lxf.com>, USA.
62. LXF Incorporated. *Track 2 Process Management Software*, USA.
63. Macleod Smith, R. I.; Mager, George. *Cooling Tower and System Design Improvements*. The Water Management Society, UK, 1994.
64. Magnatech Corporation. *Non-Chemical Water Treatment Systems*. Literature from Magnatech Corporation (Superior Manufacturing Division), USA.
65. Masler III, William F.; Amjad, Zahid. *Advances in the Control of Calcium Phosphonate with a Novel Polymeric Inhibitor*. NACE/"Corrosion" Paper No. 11, USA, March 1988.
66. McCoy, James W. *The Chemical Treatment of Cooling Water*, 2nd edition. Chemical Publishing Co., N.Y., USA, 1983.
67. McGrane, William K.; Ditzler, Lee. *Ozone: A Study of the Effects of Biocides on Legionella Pneumophila*. "Industrial Water Treatment," USA, November/December 1995.
68. Metal Samples. *Corrosion Monitoring Products for Industrial Processing and Water Treatment*. Promotional literature, Metal Samples, USA.
69. Nalco Chemical Company. *Azole Fluorescence Study: A Cooling Water Diagnostic Program*. Promotional literature, Nalco Chemical Company, USA.
70. Nalco Chemical Company. *Smart System (Advanced Control Systems)*. Promotional literature, Nalco Chemical Company, USA.
71. Nalco Chemical Company. *Trasar[®] Technology and Services for Cooling Water Treatment: Q & A*. Promotional literature, Nalco Chemical Company, USA.
72. Nipa Laboratories Ltd. *The Problem of Microbial Growth in Water Systems*. Internal Technical Department Report, Nipa Laboratories Ltd., UK.
73. Owens, Dean L. *Practical Principles of Ion Exchange Water Treatment*. Tall Oaks Publishing, Inc., USA, 1985–1995.

74. Paul, David H. *Back to Basics: Understanding a Water Analysis Report*. Parts I & II. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, January/March 1998.
75. Pipe, Sue, General Editor. Various "Waterline" and "Waterscan," The Water Management Society, UK.
76. *Positioning: The Battle for Your Mind*, 1st edition—revised. McGraw-Hill, Inc., USA, 1986.
77. Powell, Sheppard T. *Water Conditioning for Industry*, 1st edition. McGraw-Hill, Inc., USA, 1954.
78. Preston Jarvis. American Industrial Chemical Corporation. *Chelates and Their Uses*. An ENCEE Product Review, USA.
79. Puri, Vijay K. *Pretreatment of Water for Cooling Water and Steam Generating Systems*. Calgon Corporation, USA, 1983.
80. Relenyl, Atilla G. *DTEA 15%, Presentation Notes*. USA, 1997.
81. Ries, Al; Trout, Jack. *Marketing Warfare*. McGraw-Hill, Inc., USA, 1986.
82. Rohm & Haas Company. *Optidose Traceable Polymer System*. Video and launch notes. Rohm & Haas Company, USA, 1998.
83. Rohm & Haas Company. *Engineering Manual for the Amberlite® Ion Exchange Resins*. Rohm & Haas Company, USA.
84. Rohrback Cosasco Systems, Inc. *Corrosion Monitoring Equipment, Systems and Service*. Promotional literature, Rohrback Cosasco Systems, Inc., USA.
85. Salaices, Maria; Waterhouse, Bert; Waddams, A. L.; Kamatari, O. *Chelating Agents: A CEH Product Review Document*. Promotional literature, Preston Jarvis/American Industrial Chemical Corporation, USA.
86. Sandler, David H. *You Can't Teach a Kid to Ride a Bike at a Seminar*. Dutton, USA, 1995.
87. Schultz, R. A. *Microbiocides—A Necessary Supplement to Chlorination*. Presented to National Association of Corrosion Engineers, Houston, Texas, 1980.
88. Schwieger Robert G. *Heat Exchangers*. "Power" Special Report, USA, June 1970.
89. Silbert, Marvin D. *Computers: What Is Your System Doing?* Tall Oaks Publishing, Inc., USA, November/December 1996.
90. Simpson, Greg D.; Kuykendall, Clay, Miller, Jay; Averett, Bill. *The Safe and Effective Use of Chlorine Dioxide*. "Industrial Water Treatment," USA, September/October 1995.
91. Simpson, Greg D.; Laxton, Garry D.; Miller, R. F.; William, R. *A Focus on Chlorine Dioxide for "Stressed" Cooling-Water Systems*. "Industrial Water Treatment," USA, September/October 1994.
92. Skidmore, Teresa. *Tolcide PS Biocides: Technical and Marketing Information*. Albright & Wilson, Water Management Chemicals, UK, 1997.
93. Smith, Craig B.; Owens, Randy. *Microbiological Screen Test Data: A Technical Report on MBT/Thione/Isothiazolinone*. Vinings Industries Inc., USA, 1994.
94. Steelhammer, Joe C.; Watson, Carl F.; Youmans, Richard O. *Trends in Industrial Water Treatment: Methods for Microbiological Control*. "Industrial Water Treatment," USA, July/August 1995.

95. Strauss, Sheldon D., Senior Editor. *Instrumentation Advances Improve Fouling*. Corrosion Monitoring, "Power," USA, 1992.
96. Strauss, Sheldon D.; Puckorius, Paul R. *Cooling-Water Treatment, A Special Report*. "Power," USA, June 1994.
97. Strauss, Sheldon D.; Puckorius, Paul R. *Cooling-Water Treatment, A Special Report Update*. "Power," USA, May 1995.
98. Stuart, Christine M; Eastin, Phillip M. *Chemical Treatment: Alkaline Phosphate—A New Direction for Phosphate Cooling Water Regimens*. As reproduced in "Industrial Water Treatment," Vol. 25, No. 1, January/February 1993.
99. Sullivan, Patrick J. O'Brian, Frank. *Biocontrol: Performance of HPA With Oxidizing Biocides*. As reproduced in "Industrial Water Treatment," Vol. 28, No. 1, January/February 1996.
100. Tanis, J. N. *Procedures of Industrial Water Treatment*, 1st edition. Ltan Inc., USA, 1987.
101. The Purolite Company, *Purolite® Product Data Manual: The Purolite Company*, USA.
102. The Water Management Society (formerly Working Party of the Industrial Water Society). *Cooling Water Treatment: A Code of Practice*. The Water Management Society, UK, 1982.
103. The Water Management Society. *Site Logbook for Water Services*. The Water Management Society, UK, 1990.
104. Thompson, John. *Electronic Water Descaling: The Alternative to Chemicals?* "Waterline," The Water Management Society, UK, Winter 1997.
105. U.S. Filter Corporation. *Permutit® Water and Waste Treatment Data Book*, 18th printing. U.S. Filter Corporation, USA.
106. van Brederode, H.; Bessems, E. *Antimicrobial Fatty Amine Derivatives*. A paper presented in London, June 1992.
107. Various Authors and Editors. *BETZ Handbook of Industrial Water Conditioning*, 8th edition. Betz-Dearborn, USA, 1980.
108. Various Authors and Editors. *Principles of Industrial Water Treatment*, 9th edition. Drew Chemical Corporation, USA, 1987.
109. Willa, James. *Evolution of the Water Cooling Tower*. "CTI Journal," 1992, Vol. 13, No. 1, Cooling Tower Institute, USA.
110. Young, Thomas J. *The Proper Use of Modern Polymer Technology in Cooling Water Programs*. Association of Water Technologies Inc. Paper (3rd convention), USA, December 1990.
111. Zuhl, Robert W.; Amjad, Zahid; Masler III, William F. *A Novel Polymeric Material for Use in Minimizing Calcium Phosphate Fouling in Industrial Cooling Water Systems*. Cooling Tower Institute Paper No. TP87-7, USA, February 1987.
112. Zuñiga, Patricia O.; Miller, Kenneth; Winters, Michael. *A Cooling Water Fouling Monitor Senses Upsets, Evaluates Changes*. Reprinted from "Chemical Processing," April 1990.

INDEX

A

- AA/COPS, 165, 166
- AA/HPA, 148, 161, 165, 166
- AA/MA, 163, 166
- AA/MAA/E/AM, 153
- AA/SA, 156
- AA/SA/SSS, 156, 167
- ABDAC, 183, 220
- Absorbent, 21
- Absorber, 22
- Absorption refrigeration plants, 19
- Account vulnerability factors, 243
- Accretion, 107
- Acid addition, pretreatment for RO, 72–73
- Acid cleaners, mild, 407
- Acid contaminants, 410
- Acid copper chromate, 10
- Acid corrosion, 97
 - in heat exchangers, 272
- Acid dosing, 75–78
 - acid as part of treatment program, 76–77
 - excessive, 404
 - sulfuric acid requirement calculation, 78
- Acid leaks, 396
- Acid producer, *thiobacillus thiooxidans* as, 103
- Acid rain, 36
- Acrolein, 214
- Acrylamide/acrylate copolymers, 48
- Acrylamide/amine copolymers, 48
- Acrylic acid, 47, 148
 - copolymers, 153, 156
 - terpolymers, 156
- Acrylic acid hydroxypropyl acrylate copolymer, 148, 165
- Acrylic acid methacrylic acid, ester, acrylamide tetrapolymer, 153
- Acrylic acid sodium 3-allyloxy-2-hydroxypropane sulfonate copolymer, 165, 166
- Acrylic acid/sulfonic acid/sodium styrene sulfonate, 156
- Acrylimido-2-methyl-propane sulfonic acid, 164, 166
- Acrysol® QR-1086, 166
- Activated sludge processes, 28
- Activation, of polymers, 50
 - of sodium bromide, 196
- Active biocorrosion, 103–104
- Active corrosion mechanisms, 94
- Active deposition sites, 401
- Actives, 306, 307
 - requirement of, 307
- Actual saturation pH (pH Actual), 117
- Acumer® 1000, -1100, -2000, -4210, 166
 - 3100, -4161, 167
 - 5000, 154, 167
 - 2000, -3100 with Optidose, 379
- Added value services, 365
- Adenosine triphosphate, 389
 - testing, 391
- Adjustable flow-rate chemical dosing pump, 356
- AEC, 162
- Aeration pretreatment, RO and, 72
- Aeration towers, makeup water pretreatment and, 27–28, 54–55
- Aerobacter* sp., 130
- Aerobes, 124
- Aerobic biofilm, 127–128
- Aerosol formation, Legionellosis and, 133
- After-the fact inhibitor monitoring, 376–377
- After-the fact monitoring, 375, 376–377
- Aging time of polymers, 50
- Air purge vents, 332

- Air scouring of sand filters, 59
- Air scrubbing effects, 105–106
- Air washer cleaning, 397–398
- Air washers, 396–397
 - cleaning, 397–398
- Air washers, cleaning of, 397
- Air-blown foulants, 105, 330
- Air-bumping, 408
- Akzo Nobel B.V., 220
- Alabama Specialty Products Inc., 382
- Albright & Wilson, 168, 223
- Alcaligenes*, 130
- ALCO Chemical Co., 168, 215
- Alcohol contaminants, 410
- Aldehyde group, 214, 223
- Algae, 6, 102, 122, 123, 126
 - cyanophyta* (blue-green), 127
 - chlorophyta* (green), 127
 - rhodophyta* (red), 127
 - phaeophyta* (brown), 127
 - chrysophyta* (yellow), 127
- Algaecides, 139, 225
- Algal biomass, 212
- Algal blooms, 26, 29
- Algal growth, 123
- Algal slimes, 184
- Aliphatic guanides, 217–218
- Alkaline hardness salts, 32
- Alkaline phosphate cleaners, 407
- Alkaline phosphate program, 172
 - selection notes, 310
- Alkaline zinc programs, 161, 172
 - formulations, 172–173
- Alkaline zinc/organic programs, 171–173
- Alkaline zinc/organic programs,
 - product formulations for, 171–173
- Alkalinity, 30, 54
 - limits, 398
 - P and M titration, 375
 - reduction of, 45, 46
- Alkyl epoxy carboxylate, 162–163
- Alkyl isothiazolin-3-ones, 218–219
- Alkyl phosphonium group, 222, 223–224
- Alkyl sulfonate, 214
- Alkylbenzylmethylammonium chloride, 220
- Alkyldimethylbenzylammonium chloride, 220
- Alkylthioamine group, 217
- All Organic closed loop program, 161
- All Organic products, 377
- All Organic programs, 38, 101, 148, 149, 308
 - product formulations for, 174–175
 - selection notes, 310
- Allodos, 356
- Alpha iron oxide, 112
- Alum + DADMAC, 49
- Alum/polymer product, 46
- Aluminum 93
 - limits, 399
 - presence in deposits, 411
- Aluminum chlorhydrate, 47
- Aluminum sulfate as coagulant, 45
- AMA[®]-220, 222
 - 230, 215
 - 410W, 219
- Ameoba proteus*, 131
- American Legion, 1976 convention in Philadelphia, 132
- Amine/TBTO combination, 404
- Amines, as cooling water inhibitor, 148–149
- Aminotri(methylenephosphonic acid), 157, 185
- Ammonia, 28, 36, 415
- Ammonia contaminants, 410, 415
- Ammonia to nitrate, 104
- Ammoniacal chlorine demand, 191
- Ammoniacal corrosion in heat exchangers, 272
- Ammoniated citric acid, 342
- Ammonium bifluoride, 342
- Ammonium hydrogen difluoride, 342
- Ammonium radical in polyacrylates, 155
- AMP, 157
- Amperage draw of pump, surveying, 273
- AMPS, 164, 166
- Anaerobes, 124
 - sessile microorganisms, 123
- Anaerobic biofilm, 128
- Analytical reports, 373–375
- Analytical testing, 372–373
- Analytical tracing, 356
- Angus Chemical Co., 215, 223
- Anhydrite, 110, 112
- Anion, 374
- Anionic dispersants, 230–231
- Anionic polymers, 47
- Anode, 88
- Anodic inhibitor, polyphosphonate as, 141
- Anodic polarization, 91

- Anodic reactions, 89
 Anthracite filters, 56
 Antifoam, 345
 Antifoulants, 139, 140
 Antimicrobial 7287, 217
 Antiscalents, 139
 Approach temperature, 279
 Aquacar® 515, 542, 545, 218
 Aquatic organisms, 29
 Aquatreat® AR-232, -540, -602, -900, 166
 Aragonite, 112
 Aromatic polyamide (aramid) RO membrane, 69
 Arquad®, 220
Ascomycetes, 131
 Asexual reproduction, 123
 Association of Water Technologies, 395
 ASTM D1125-77, ?????
 ASTM D2688, coupon testing and, 380
 Atmospheric conditions, surveying, 273
 Atmospheric spray towers, 5
 ATMP, 147, 156, 157
 reduced effectiveness due to chlorine, 185
 ATP meter, 389, 391
 Austenitic stainless steels, 91
 Automated chemical dosing, 8
 Automatic self-cleaning water filters, 27, 60–61
 Azoles, 148, 165, 168
 as cooling water inhibitor, 149
- B**
- β -Bromo- β -nitrostyrene, 214
Bacillus sp., 124, 130
 cereus, 130
 mycoides, 130
 subtilis, 130
 Backflow preventer, 364–365
 Backwash water, filters and, 56
 Bacteria, 123–125
 types of, 130
 see also specific bacteria
 Bacteria levels, 399
 Bacteria monitoring, 356
 Bacteriacides, 139, 225
 Bacterial cell, structure of, 124
 Bacterial slimes, matrices of, 129
 Bacterial-induced fouling, 122
 Bag filters, for RO, 73
 Baltimore Aircoil Co. (BAC), 206
 Barium, presence in deposits, 411
 Barnacles, 131
 Barquat®, 220
 BARTS™, 391
 Basamid™, 222
 Base-exchange softening, 61
 BASF AG, 168, 231
 Basic zinc carbonate, 191
 Basicity, 46
Basidiomycetes, 131
 Basin condition, 282
 Bayer Corporation, 168
 Bayhibit® AM, 167
 BBAB, 214
 BCAs, 382
 BCDMH, 182, 184, 194, 199, 233
 comparison, 204
 BCP products, 231
 Beckman, 356
 Bed depth, of filter media, 56, 58
 Beer brewing microorganisms, 122
Beggiatoa sp., 103, 130
 Bel-Trak® inhibitor monitoring, 378–379
 Belclene® 494, 161
 -283, -494, -500, 167
 -161, -164, 159, 167
 -200, -400, 166
 -511, -512, 168
 -575, 161, 167
 -350, 224
 Bellacide® 375, 209
 Benzalkonium chloride, 220
 1,2-Benzisothiazolin-2-one, 219
 Benzoate, 150
 Benzotriazole, 149
 Betz® 2020, 166
 Betz-Dearborn, 137, 148, 162, 168
 monitors, 385
 software, 394
 BF Goodrich Co., 168
 BHAP, 214
 Bicarbonate, 31
 Biguanides, 217
 Binary fission, 123, 129
 Biochemical oxygen demand, 10
 Biocidal Products Directive, 179
 Biocide selection, 213–224
 acrolein, 214
 alkyl sulfonate, 214
 BHAP, 214
 Bronopol, 214–215
 carbamates, 215
 chlorophenols, 216

- Biocide selection (*continued*)
 - chlorothioether, 216
 - DBNPA, 216–217
 - DTEA, 217
 - guanides, 217–218
 - gluteraldehyde, 218
 - isothiazolines, 218–219
 - MBT, 219
 - polyquat, 219
 - quats, 220
 - sulfone, 220–221
 - TBTO, 10, 221
 - TCCBN, 221–222
 - TCMTB, 222
 - thione, 222
 - THPS (TKHPS), 222–223
 - Trisnitro, 223
 - TTPC, 223–224
- Biocide use, related legal problems, 179
- Biocides, 9
 - forms of, 182–183
 - liquid biocides, 183
 - solid or powdered biocides or biostats, 182–183
- Biocides, health and safety with, 179
- Biocides, nonoxidizing, 209–229
 - combinations, 224–226
 - primary microbiological problem areas, 211–213
 - selection of, 211, 213–224
- Biocides, oxidizing, 183–209
 - bromine, 194–204
 - calcium hypochlorite, 189
 - chlorine, 184–187
 - chlorine dioxide, 191–194
 - gaseous chlorine, 187–188
 - isocyanurates, 189–191
 - sodium hypochlorite, 188–189
- Biocides, risk assessment and registration of, 180–182
- Biocorrosion, 102–104
 - active, 103–104
 - passive, 102–103
- Biodeposits, 102
- Biodispersant consumption, surveying, 278
- Biodispersants, 139, 153, 177, 185, 212, 229–232, 392, 345
 - anionic, 230–231
 - cationic, 231–232
 - nonionic, 231
- Biofilm, 6, 102, 123, 127–130
- Biofilm control agents, 392
- Biofilm monitors, 389–390
- Biofilm slime penetrants, 225
- Biofouling, 122, 179
- Biologically induced corrosion, 97
- Biomass, 102, 127, 330
- Biomonitoring and control, 389–392
 - ATP meter, 391
 - biofilm monitors, 389–390
 - dip-slides, 390–391
 - laboratory-derived tests, 391
 - mesh screen coupons, 392
 - microbiological inspections, 391–392
- Biosan, 390
- Biostatic effect, 128, 182, 212
- Biostatic slow-release bromination, 180
- Biostats, 177, 391
- BIRM[®], 54–55
- bis*(tributyl-tin) oxide, 221
- bis*(trichloromethyl) sulfone, 220
- bis*-bromoacetyl butene, 214
- Bispora* sp., 131
- BIT, 219
- Blank coupons, 382, 388–389
- Bleach, 184, 188
- Bleed (*B*), 12, 13
 - control systems, 8, 355
- Blended water, 63
 - softened water and, 61
 - supplies for, 32
- Blending, ion-exchange softening and, 32, 61–67
- Block copolymers, 153, 231
- Blowdown control systems, 355
- Blue-White Company, 356
- BNS, 214
- BOD, 10
- Boots Company, 215
- Borax, 150
- Boroscope[®], 21
- Brackish water, RO systems, and, 70
- Bran and Luebbe, 356
- Brand differentiation, 299
- Brass, 93, 98
- Breakpoint, 187
- Breakthrough of hardness, 64
- Bricorr[®] 288, 162, 167
- Bridger Scientific, 386
- Brine reject, 68
- Briquest[®] ADPA 60A, 167
 - 301-50A, 167
- BRM, 10, 214
- Bromicide[®], 199
- Bromide ion, 197

- Brominator, 182
 - bromine feeding and control, 201
 - Bromine, 194–204
 - products, 194
 - release agents, 194
 - Bromine/chlorine solid biocides, marketing, 204–205
 - Bromoamines, 195
 - 1-Bromo-3-chloro-5,5-dimethylhydantoin, 182, 194, 199
 - 2-Bromo-4-hydroxyacetophenone, 214
 - 2-Bromo-2-nitropropane-1,3-diol, 214–215
 - Bronopol, 214–215, 224
 - Brown rot producers, 131
 - Brucite, 112
 - BTA, *see* Benzotriazole
 - Buckman Laboratories, 168, 214, 219
 - software, 395
 - Buffering capacity, demineralized water and, 62
 - Building block corrosion inhibitor, 160
 - Built environment, 331
 - Bulk handling, 365
 - Bulk water precipitation, 105, 107, 108
 - Burroughs NTU Model, 117
 - Buying cooling water programs, 243–262
 - chemical product pricing, 248–249
 - field service representative, 249–251
 - latest chemical technology, 247–248
 - service time allocation, 249
 - size of water treatment company, 244–246
 - suitability of chemical products, 246–247
 - By-George, 356
 - By-pass feeder, 363
- C**
- Calcite, 112
 - Calcium bicarbonate, 30, 51, 52, 106
 - Calcium bicarbonate, 44
 - Calcium carbonate, 30, 106, 112
 - crystal distortion, polyphosphates as, 142
 - crystalline scale deposition, 106–108
 - removal, 344
 - scaling in RO, 74
 - solubility, equilibrium point, 140
 - Calcium chloride, 53
 - Calcium concentration factor, 409
 - Calcium deposits, cleaning off-line, 342
 - removal by OLC, 408
 - Calcium hardness limits, 399
 - Calcium hypochlorite, 182, 189
 - Calcium orthophosphate, 109
 - Calcium orthophosphate, amorphous, 109
 - Calcium palmitate, 30
 - Calcium phosphate, 107, 109, 112
 - cleaning, 345
 - scale deposition, 38, 108–109
 - Calcium stearate, 30
 - Calcium sulfate, 33, 53, 107, 112
 - cleaning, 345
 - limit for RO, product concentration rule, 110
 - scale deposition, 109–110
 - Calgon Corp., 168, 393
 - Calguard Cooling® software, 393
 - Calloway Chemical Co., 168
 - Calorifiers, role of in *Legionella pneumophila*, 132
 - Cambridge Scientific Co., 356
 - CaO/CO₂ equilibrium, 89
 - Caplain BAISPEC Program, 117
 - Carbamates, 215
 - MBT combination, 224
 - Carbon dioxide, 28, 35, 36, 51, 106
 - Carbon dioxide, free, 51
 - Carbon dioxide, subsurface water and, 35
 - Carbon steel, 87
 - cleaning by acid, 342
 - in corrosion processes, 93
 - Carbonate alkalinity, 31
 - Carbonate fouling, 53
 - Carbonate hardness, 31, 51
 - Carbonate presence in deposits, 411
 - Carbonic acid, 36
 - Carboxylate/sulfonate/nonionic functional terpolymer for iron control, 75
 - Carboxylates, 159
 - Cartridge filtration, RO and, 73
 - Catalytic/magnetic water treatment devices, 78–79
 - Catch-all polymer products, 153
 - Cathodic corrosion inhibitors, 158
 - Cathode, 88
 - Cathodic depolarization, 103
 - Cathodic polarization, 91
 - polyphosphonates as polarizers, 141
 - Cathodic protection, 88
 - Cathodic reactions, 89
 - Cation, 374

- Cationic biodispersants, 231–232
- Cationic polymers, 47
- Causative agents, 92
- Caustic contaminants, 410
- Caustic soda, 45
 - formation of with hypochlorous acid when using bleach, 189
- Cellulose acetate membranes, RO and, 68
- Centrales, 132
- Changing chemical treatment programs, 399–400
- Charge neutralization, 44
- Chelants, 145–146
 - cleaning and, 343
- Chemical biocides, 177–233
- Chemical cleaners for open cooling systems, 337
- Chemical cleaning, 340
 - of closed loop systems, 331, 333
- Chemical consumption, surveying, 272
 - of competitors, 276
 - variability with COC, 277
- Chemical delivery system strategy, 261
- Chemical dosing
 - monitoring and control systems, 283
 - pretreatment for RO, 73
 - program control and, 352–365
 - advanced dosing and control systems, 360–363
 - background, 354–356
 - bulk handling, 365
 - dosing chemicals, 358–360
 - dosing to closed-loop systems, 363–365
 - equipment for open systems, 358–358
- Chemical dosing pumps, 355
 - adjustable flow-rate, 356
- Chemical-induced wastage problems, 272
- Chemical inhibitor, development of in case history, 298
- Chemical inhibitor programs, basics of, 139–140
- Chemical inhibitors, 88
 - component of program, 303
- Chemical inhibitors, selection of, 04
- Chemical oxygen demand, 10
- Chemical precipitation softening processes, 51–54
- Chemical product pricing, 248
- Chemical savings potential, surveying, 277
- Chemical treatments and programs, 137–176
 - chemical inhibitor program basics, 139–140
 - cooling water product formulations, 169–176
 - alkaline zinc/organic programs, 171–173
 - All Organic programs, 174–175
 - chromate programs, 169–170
 - closed-loop programs, 176
 - environmentally acceptable programs, 175–176
 - molybdate programs, 173–174
 - soft and lean water programs, 175–176
 - stabilized phosphate programs, 170–171
 - early inhibitors, deposit control agents, and cooling water programs, 140–148
 - chelants, 145–146
 - chromate treatment programs, 143–145
 - combined threshold effect and corrosion inhibition/phosphate treatment program, 141–143
 - controlled calcium carbonate deposition program, 140–141
 - deposit control agents (DCAs), 146–148
 - “standard” phosphonates and organic polymers, 152
 - phosphonates, 156–159
 - phosphinocarboxylic and phosphonocarboxylic acids (PCAs), and carboxylates, 159–163
 - polyacrylates, 154–156
 - polymaleic acid and derivatives, 163–165
 - “traditional” cooling water inhibitors, 148–152
 - amines, 148–149
 - azoles, 149
 - molybdate, 149–150
 - nitrite, 150–151
 - silicates, 151
 - zinc, 151–152
- Chemicals risk assessment program, 180
- Chiller heat exchangers, 21–22
- Chlamydomonas* sp., 132

- Chloramines, 188
- Chlorides, 32–33
 - in corrosion processes, 91–92
 - seasonal variations of, 26
- Chlorinated isocyanurates, 182
- Chlorinated thioether, 216
- Chlorinator, 187
- Chlorine, 137, 139, 184
 - activity, 184
 - addition pretreatment, RO and, 72
 - application rates, 185
 - availability with pH, 186
 - breakdown of ATMP, 157
 - demand, 187
 - gaseous, 187
- Chlorine, combined, 187, 188
- Chlorine dioxide, 184, 189, 190, 191–194
- Chlorine dosing procedure during cleaning, 346
- Chlorine, free, for HOBR generation, 203
- Chlorine, free residual of, 187
- Chlorine helpers, 185
- Chlorine injection, 180
- Chlorine–nitrogen bonds, 184
- Chlorine stabilizer, 190
- Chlorococcales, 132
- Chlorococcus humicola*, 132
- Chlorophen, 216
- Chlorophenols, 216
- Chlorophyll, 125, 184
- Chlorothioether, 216
- Chromate, 414
 - passivator, 338
- Chromate treatment programs, 77, 137, 138, 143–145, 232
 - application notes, 144–145
 - high pH, 144
 - low pH, 144
 - product formulations for, 169–170
 - selection notes, 309
- Chromated copper arsenate, 10
- Chromite ion, 414
- Chromium, presence in deposits, 412
- Chroococcales, 131
- Circulating water chemistry, 88
- Circulation rate (CR), 13
- Cirripedia, 131
- Citric acid, 145, 342
 - microorganisms in production process, 122
- City waters, 25
- Clarification, 45
- Clarification pretreatment process, 44–45
- Clean metal surfaces, corrosion prevention and, 32
- Clean Water Act, 187
- Clean-in-place units, RO and, 71
- Cleaner formulation for open cooling systems, 337
- Cleaner, multifunctional, 336
- Cleaning formulation for de-oiling, 343
- Cleaning in-service, 344
- Cleaning rig, 333
- Clearon Corporation, 199, 205
- Closed loop system, 16
 - cleaning, 30
 - cleaning comparison, 336
 - cleaning formulation, 334
 - dosing to, 363
 - formulations, 176
 - program formulations, 176
 - sampling, 370
- Clostridium nigrificans, 130
- Coagulant aids, 56
- Coagulant/flocculant polymers
 - application of, 49–50
 - selection of, 48–49
- Coagulants for de-oiling, 349
- Coagulation, 44
- Cobratec TT-100, 168
- COC, *see* Cycles of concentration
- Coccus, 124
- Coco diamine, 220
- Cocurrent flow, 16
- COD, 10
- Codex® 551, -8503, 167
- Coelastrum* sp., 132
- Coke catalyst for aeration tower, 27
- Colloidal silica, 110–111
 - from bulk water, 111
- Colorimeter, 308
- Colorimetric tests, 372, 389
- Combined threshold effect and corrosion inhibition/phosphate treatment program, 141–143
- Comma bacteria (*Vibrio*), 124
- Communications and data management, 361
- Communications software, 393
- Competitor biocide consumption, surveying, 278
- Competitor chemical consumption, surveying, 276
- Compression refrigeration plants, 19

- Computer software programs, system management and, 392–395
- Computerized results tracking, 40
- Concentrate recycle RO, 71
- Concentrate water, 68
- Concentration cell corrosion, 32, 97–99
 - crevice corrosion, 98
 - tuberculation, 98–99
 - under-deposit corrosion, 98
- Concrete industrial cooling towers, 9–10
- Condenser, 16
- Condenser and chiller heat exchangers, 19
- Conduction, 16
- Conductive heat flow (Q), 16
- Conductivity monitoring, 352
- Conductivity, TDS, 415
- Coniothyrium* sp., 131
- Conjugales, 132
- Consumption of water, surveying, 272–276
 - cooling tower incoming/outgoing temperatures, 274
 - cooling water recirculation rate, 273
 - cycles of concentration, 275
 - drift (windage), bleed, leaks, and other losses, 274
 - evaporation rate, 274
 - current atmospheric conditions, seasonal weather, operational differences, 273–274
 - hours/days of operation per year, 273
- Continuous dosing of inhibitor, 361
- Continuum® AEC, 162, 167
- Controlled calcium carbonate deposition program, 140–141, 143
- Convection, 16
- Cooling range, 12
- Cooling system and heat exchange essentials, 1–22
 - evaporation and total water usage, 10–13
 - evaporation/water usage formulas and relationships, 13–14
 - example of using water usage calculations, 15
 - evaporative cooling systems, 3–5
 - common types of cooling towers, 6–10
 - evaporative condensers, 8–9
 - wood-frame.concrete industrial cooling towers, 9–10
 - galvanized steel blow-through (forced draft) cooling towers, 8
 - hyperbolic, natural draft cooling towers, 6
 - packaged, fiberglass-reinforced plastic cooling towers, 6–8
 - heat exchanger waterside inspection, 20–22
 - chiller heat exchangers requiring inspection, 21–22
 - heat transfer and heat exchangers, 15–20
 - types of common heat exchanger, 18–20
 - plate and frame heat exchangers, 18–19
 - shell and tube heat exchangers, 19–20
 - water usage calculations, 13–15
 - example, 15
- Cooling systems, basic design, 268
- Cooling system survey case history, Middle East, 286–299
- Cooling Tower Carbonate Equilibrium (CTCE) Model, 117
- Cooling Tower Institute, 395
- Cooling towers
 - common types, 6–10
 - evaporative condensers, 8–9
 - galvanized steel-blow-through (forced draft), 8
 - hyperbolic, natural draft, 6
 - packaged, fiberglass-reinforced plastic, 6–8
 - wood-frame and concrete industrial towers, 9–10
 - design, 400–401
 - fill-pack, 404–405
 - surveying, 280
 - types employed by industry, 269
- Cooling water program selection, influencing factors, 299–311
 - categories of inhibitor treatment program, 303–311
 - full chemistry-spectrum inhibitor treatments, 304–305
 - inhibitor categories, 305
 - inhibitor formulations, 308–309
 - inhibitor performance, 305–307
 - notes on inhibitor formulations, 309–311
 - external factors, 300–302

- application, monitoring, and control factors, 302
 - basic program design and operation factors, 302
 - customer-influence factors, 301–302
 - primary environmental and water pretreatment factors, 301
 - system process and design factors, 301
 - internal factors, 302–303
- Cooling water programs, buying and selling of, 235–262
 - marketing strategies, 258–262
 - business alliances, 259
 - contract “technical” specification services, 261
 - customer partnership, 259–260
 - free-on-loan/patented chemical delivery systems, 261
 - image building, 260–261
 - ISO 9000 quality programs, 260
 - national accounts, 260
 - promotion of visible differentiating/niche market features, 262
 - selling the proposal, 251
 - aspects to consider, 252–255
 - modern nontraditional sales development systems, 257–258
 - sales sequence, 255–257
 - starting position for selling, 237–243
 - competition and product performance-to-cost balance, 242–243
 - salesperson’s job, 239–240
 - selling products and services, 240–242
- starting position for buying, 243–250
 - chemical product pricing, 248–249
 - field service representative, 249–250
 - latest chemical technology, 247–248
 - service time allocation, 249
 - suitability of water treatment chemical products, 240–247
 - water treatment company size, 244–246
- Copolymers, 147, 152, 153
- Copper, 401
- Copper inhibitors, 137
- Copper oxide, 112
- Copper redeposition in heat exchangers, 272
- Copper salts, presence in deposits, 412
- Copper sulfate, 26, 412
- Copper sulfide, 414
- Copperas, 45
- Corrator[®] probe, 21, 355
- Corrosion chemistry, 87–93
 - chlorides in cooling water, 91–92
 - cooling water metals corrosion vulnerability, 93
 - corrosion mechanism considerations, 91
 - corrosion process in water, 88–90
 - galvanic series, 90
 - sulfates in cooling water, 92–93
- Corrosion coupon, 368, 380
- Corrosion, fouling, and deposition, 85–135
 - corrosion chemistry, 87–93
 - chlorides in cooling water, 91–92
 - cooling water metals corrosion vulnerability, 93
 - corrosion mechanism considerations, 91
 - corrosion process in water, 88–90
 - galvanic series, 90
 - sulfates in cooling water, 92–93
 - legionellosis, 132–135
 - OSHA guidelines on, 135
 - microbiology and microbiological fouling, 122–132
 - bacteria, 123–125
 - types of, 130
 - biofilm, 127–130
 - fungi, 125–126
 - types of, 131
 - microorganisms, 123
 - phytoplankton, 126–127
 - types of, 131–132
 - zooplankton, 126–127
 - types of, 131
- saturation indices, 112–121
 - calculation of LSI and SI, 110–121
 - Langelier Saturation Index, 112–115
 - limitations of, 116–117
 - Puckorius (Practical) Scale Index, 116

- Corrosion, fouling, and deposition
(*continued*)
- Ryznar Stability Index, 116
 - saturation models, modern
 - software programs and, 117–121
 - Stiff and Davies Saturation Index, 115–116
 - value of, 118–119
 - scales, sludges, inorganic deposits, and foulants, 104–112
 - calcium carbonate crystalline scale deposition, 106–108
 - calcium phosphate scale deposition, 108–109
 - calcium sulfate scale deposition, 109–110
 - inorganic deposits and foulants, 111–112
 - scaling, 105
 - silica and silicate scale deposition, 110–111
 - sludge, 105–106
 - types of corrosion, 94–104
 - biocorrosion, 102–104
 - concentration cell corrosion, 97–99
 - galvanic corrosion, 99–100
 - guide to corrosion rates, 95–96
 - oxygen corrosion, 96–97
 - white rust, 100–102
- Corrosion monitoring and control, 379–385
- ERM corrosion measurement, 384
 - LPRM corrosion measurement, 384–385
 - weight loss coupons, 380–383
- Corrosion probes, 385
- Corrosion racks, 355
- Corrosion rate, 95–96
- calculations, 383
 - measurement of, 383
 - rate-measuring equipment, 368
- Corrosion, types of, 94–104
- biocorrosion, 102–104
 - concentration cell corrosion, 97–99
 - corrosion rates, 95–96
 - galvanic corrosion, 99–100
 - oxygen corrosion, 96–97
 - white rust, 100–102
- Countercurrent flow, 16
- Counterflow, 4
- Counterflow towers, characteristics of, 5
- Coupons, 380–383
- Crabs, 131
- Crag Fungicide®, 222
- Crenothrix polyspora*, 130
- Crevice corrosion, 18–19, 98
- Cross-flow, 4
- Cross-linking, 63
- Crossflow towers, 5
- Crystal distortion properties, of PMA, 163
- of polyphosphonates, 141
- Crystal growth retardation, polyphosphonates as, 142
- Crystalline hydroxyapatite, 109
- Crystalline scale, 107
- Crystoballite, 112
- Cupric oxide, 312
- Cuprite, 112
- Cupronickel, 98
- Cuprous oxide, 412
- CYA, 190
- Cyanides, presence in deposits, 412
- Cyanuric acid, 190
- Cycles of concentration (COC), 8, 12, 13, 275, 399, 401–402
- limits, 401
 - relationship to total alkalinity, 115
- Cyclotella* sp., 132

D

- DADMAC, 49
- Dantobrom® RW, 199
- Data management and communications, 355, 361, 394
- Database information, 355
- DATS™, 386
- Daughter cells, 124
- DAZ, 222
- DAZOMET, 222
- DBNPA, 182, 194, 216–217, 224
- cost-per-application problem, 225
- DCAs, 146, 401
- in calcium deposit removal, 408
 - halogens and, 201
- DCCA, 204
- DCEMH, 204
- DCEMH, 204
- DCT(MPA), 159
- De-oiling open cooling systems, 338
- formulation for, 343
 - in-service, 349
 - off-line, 343

- Dead Sea Bromine Group, 199, 205
Deaeration, 88
Dealkalization, 32
2-(Decylthio)ethanamine, 217
Decontamination and cleaning,
 methods for, 321
Decontamination, cleaning and, 321
Deep cleaning, 398
Deflocculating effect of polymers, 146
Defoaming, 230
DegrTmont, 168, 204
DEHA, 62
Dehumidification, in air washers, 396
Delignification, 185
Demineralization, 52
Deposit Accumulation Testing System
 (DATS), 386
Deposit control, 402–403
Deposit control agents (DCAs), 12,
 104–105, 139, 146–148
 halogens and, 201
Deposit control monitor, 366, 368, 386
 examples of observations, 387
Deposit, on-line removal of from heat
 exchangers, 408
Deposit sample analysis and report
 interpretation, 403–404
Deposition, 1, 104
 cause and effect, 402
 definition, 86
 factor in program selection, 303
 on heat exchanger tubes, 271
 rates, 401
Deposition of foulants, 21
Deposition/fouling monitoring and
 control, 385–389
 blank coupons, 388–389
 microprocessor-controlled deposit
 monitors, 386–387
 portable deposit/corrosion monitors,
 388
 test heat exchangers, 387–388
Dequest® 2000, -2010, 167
Design factors in program selection,
 301
Desulfovibrio desulfuricans, 103, 130
Detergency, 230
DETP (MPA), 159
Developed potential measurement,
 corrosion monitoring, 379
Dew point, 11
Dezincification, in heat exchangers,
 272
DFA assay, 328
Diamine treatments, 353
Diamines, 148, 218, 220
1,2-Diaminocyclohexanetetakis(methy-
 lene phosphonic acid), 159
Dianodic™, 137
 I, 148
 III, 148
Diatoma vulgare, 132
Diatoms, 132
DIBAM, 215
2,2-Dibromo-3-nitrilopropionamide,
 182, 216–217
Dichlor, 190
Dichloroisocyanurate, 190
 comparison, 204
Dichlorophen, 216
Diethylenetriaminepenta(methylene
 phosphonic acid), 159
Diethylhydroxylamine (DEHA), 62
Differential aeration cell, 97, 146
Differential oxygen concentration cells,
 97, 102, 105
Differential temperature, of two,
 conducting surfaces (*T*), 16
Differentiation strategies, 258
 market features strategy, 262
Diffuse layer thickness, reducing, 44
2,2-Dihydroxy-5,5-dichlorodiphenyl-
 monosulfide, 216
Dimethylhydantoin, 201
Dip-slides, 368, 390–391
Dipolar nature of water, 23
Direct fluorescent antibody method,
 328
Direct fluorochromatic staining, 389
Direct weight loss method of corrosion
 monitoring, 379
Dirt pockets, 332
Discharge water standard, 28
Disinfection stage, for cleaning cooling
 systems, 326
Dispersant, polymers, 35, 139
Dispersant with zinc, 152
Dispersing polymers, anionic charge
 of, 153
Dissolved gases, water impurity and,
 35–36
Distribution deck levels, 273
Distribution system, surveying of
 tower, 281
Divided flow heat exchanger, 20

- Divided shell heat exchanger, 20
- Divinylbenzene copolymer with styrene, 63
- DMH, 201
- DNA, of bacterial cell, 124
- DNM 30, 215
- Dodecylguanidine hydrochloride, 217
- Dolomite, 29
- Dosing and control, 352–365
 - advanced systems, 360–363
 - background, 344–356
 - bulk handling and the “drumless society,” 365
 - dosing to closed-loop systems, 363–365
 - equipment for open cooling systems, 36–358
 - limitations, 361
 - notes on dosing chemicals, 358–360
- Dosing chemicals, notes on, 358
- Dosing, defined, 354
- Dosing microbiocides, 362
- Dosing pot, 363
- Dosing pumps, 355
- Double pass heat exchanger, 20
- Double pass RO, 71
- Double savings via increase in COC, 277
- Dow Chemical Co., 159, 217
- Draining/cleaning stage, cleaning cooling system and, 326–XXX
- Dressenia polymorpha*, 131
- Drew Industrial Software, 394
- Drift (*D*), 12, 13
- Drift eliminators, 7
- Drift losses, surveying, 274
- Drip-feed arrangements, 354
- Drip-irrigation marketing, 241
- Drop count, 308
- Drumless delivery, 365
- “Drumless society,” 365
- Dry cooling systems, 1–2
- Dry cooling tower, 1
- DTEA, 179, 217, 392
- Dual biocide programs, 225
- Dual media filters, 58
- Dual temperature systems, 333
- Duomeen[®], 220
- Dust and dirt, in-service removal of, 350
- Duty (*Q*), 16
- ## E
- Early inhibitors, deposits control agents, and water cooling programs, 140–148
 - chelants, 145–146
 - chromate treatment programs, 143–145
 - combined threshold effect and corrosion inhibition/phosphate treatment program, 141–143
 - controlled calcium carbonate deposition program, 140–141
 - deposit control agents (DCAs), 146–148
- Easi-cult, 390
- Ecology, of cooling systems, 129
- Ecosystems, 129
- EDTA, 145, 158, 407
 - for cleaning, 343
- Effective grain size, of filter media, 56
- Electrical conductivity, 415
- Electrical resistance measurement, 384
 - of corrosion, 380
- Electrochemical series, 900
- Electrochemical corrosion, 21
- Electrodes for pH/ORP, 358
- Electrolytic water treatment devices, 79
- Electronic pumps, 357
- Electronic water treatment devices, 79
- Electrostatic water treatment devices, 79
- Emulsion polymers, 47
- End-covers, 19
- Energy recovery turbine systems, RO and, 71
- English China Clay Co., 168
- Enterobacter*, 130
- Enthalpy, 11
- Environment, legal problems with biocides and, 179
- Environmental Protection Agency (U.S.), 186
- Environmental services, 321
 - workshops for, 321
- Enzyme test meters, 389
- EP:PO copolymers, 231
- EPA, *see* Environmental Protection Agency
- Epichlorohydrin-dimethylamine, 48

- EPIDMA, 49
 PAC and, 49
 EPRI software, 393
 Equivalent weight, 375
 ERM, *see* Electrical resistance
 measurement
 Erosion corrosion, 272
Escherichia coli, 130
 Estuary water, 26
 Ethylene oxide: propylene oxide, 231
 Ethylenediaminetetraacetic acid, 145
Euglena sp., 132
 Euglenales, 132
 Evaporation (*E*), 13
 Evaporation rate losses, surveying, 274
 Evaporation, total water usage and,
 10–13
 Evaporative condensers, 8–9
 Evaporative cooling systems, 3–5
 Evaporator, 16, 22
 Excel Industries, 168
- F**
- Facultative anaerobes, 124
 Fan area of tower, surveying, 281
 Fast-track mechanical services, 331
 Fatty amines, 148
 Feed and bleed, 355
 Fentichlor, 216
 Ferric chloride, 45, 46
 Ferric hydroxide, 27
 Ferric iron, 34
 Ferric oxide, presence in deposits, 413
 Ferric sulfate, 45, 46
Ferrobacillus sp., 130
 Ferromagnetic iron oxide, 112
 Ferrous iron, 34
 Ferrous oxide, presence in deposits,
 413
 Ferrous sulfate, 45
 Ferrous/ferric/Mo/oxides complex, 149
 Field service representative, 249
 Field services, 315–316
 Filamentous green algae, 127
 Fill, 4
 in cooling towers, 404
 Fill (cooling tower fill-pack), 404–405
 Filter media, 56
 Fish-eyes, 50
Flavobacterium sp., 130
 Flavoprotein tests, 389
 Floating baskets, 354
 Flocculation pretreatment process,
 44–45
 Fluorides, presence in deposits, 412
 Fluorspar, 412
 Flux rate conversion factors, 69
 FMC, 168
 Food and beverage contaminants, 410
 Fool's gold, 414
 Forced draft towers, characteristics
 of, 4
 Foreign matter, adherent, 333
 Foulants, indirect, 105
 Fouling, 86–87, 104,
 Fouling effect testing, 387
 Fouling factor, 17
 in program selection, 303
 surveying, 270
 Fouling monitor, 18, 368
 Fouling organisms, 103
Fragilaria sp., 132
 Free cooling, 273, 397
 Free mineral acidity, 89, 396
 French Creek software, 393
 French Creek Water Cycle, 117
 Frequency modulation devices, 79
 Fruit acids, 410
 Fruiting bodies, 125
 Fulvic acids, 36, 49, 184
 Fungi, 102, 122, 125–126
 types of, 131
 Funnel type dosing pot, 364
- G**
- Gallionella ferrugine*, 130
 Galvanic corrosion, 99–100
 in heat exchangers, 271
 Galvanic series, 90
 Galvanized steel, 343
 Galvanized steel blow-through (forced
 draft) cooling towers, 8
 Galvanized towers, 407
 Galvanizing, corrosion and, 87
 Gamma iron oxide, 32, 76, 112
 Gaseous chlorine, 181, 184, 187
 General corrosion, chlorides and, 32
 General etch corrosion, 89

- Glass-reinforced plastics, filter tanks and, 57
- Glaucinite greensand, 55
- Glucosheptonates, 158, 175
- Gluconic acid, 145, 158
cleaning and, 343
- Gluteraldehyde, 183, 218
BCP combination, 225
cost-per-application problem, 225
limits, 405
polyquat combination, 225
- Glycocalyx, 124
- Glycol mixtures, 176
- Good housekeeping, 88, 316, 318, 405
- Good-Rite® K372, -K752, 166
-K781, -K797, -K798, 167
- Grain, 374
per gallon, 65
size of filter media, 56
- Gram equivalent, 375
- Gram stain, 124
- Gram-negative bacteria, 124
bacilli, 130
organisms, 212
slime formers, 124
- Gram-positive bacteria, 124
- Graphitic corrosion, 272
- Gravity filters, 56
- Grease, 330, 335
- Great Lakes Chemical Corp., 160, 168, 199, 205, 209, 361
- Guanidine/guanides, 217
coco diamine combination, 225
MBT combination, 224
quat combination, 224
- Gypsum, 29, 33, 110, 112
- H**
- Hach Co., 356, 390, 391
- Half-life (HL), 13, 35
- Halofoms, 184
- Halogene®, 199
- Halogen-enhancing biocides, 210
- Halogen-resistant inhibitors, 210
- Halogens
adding value through, 195
comparison of, 205
- HAN (heavy aromatic naphtha), 220
- Hard water, 29–32
- Hardness salts, 30–32
destabilization, 151
stabilization by polyphosphonates, 142
stabilization effect, 141
- Head-loss monitor, 389
- Heat exchanger waterside inspection, 20–22
chiller heat exchangers requiring inspection, 21–22
- Heat exchangers, design of for applications, 270–272
mechanical and chemical-induced wastage problems, 272
potential problem areas, 270–272
- Heat exchangers, inspection of, 368
- Heat flux, 16
- Heat transfer and heat exchangers, 15–20
types of heat exchangers, 18–20
plate and frame, 18–19
shell and tube, 19–20
- Heat-transfer coefficient (U), 16
reduction in rate, 105
- Heating, ventilation, and air conditioning (HVAC), 1
cooling system layout (typical), 2
services, 331
- Heavy aromatic naphtha (HAN), 220
- Heavy fouling cleanups, 346
- HEDP, 147, 156
reduced effectiveness due to chlorine, 185
- Hematite, presence in deposits, 413
- Hemihydrate, 110, 112
- Heptonates, 158, 175
- Hercules, 168
- Hexamethylenediaminetetra (methylene phosphonic acid), 159
- Hexavalent chromate, 144
- High permeate TDS water reject system for RO, 71
- High resistivity water, 62
- High stress tolerant All Organic program, 41
- Higher pH chromate programs, 144
- HMDT(MPA), 159
- HOB_r, 194–204
calculation exercise, 198
generation of, 196–204
- HOCl availability, 205
- Holding capacity, surveying, 278
- Holding time index, 35
- Hollow fiber modules, 69
- Hollow fiber permeator, 68
- Homopolymer, 152

- Horizontal tank filter, 57
Hormogonales, 131
Hot water heat exchanger, 22
Hot water storage tanks (calorifiers),
 role of in Legionellosis, 132
Hours of operation, surveying, 273
HPA, 150, 160
HPAA, 161
HPCA, 150, 160
HPCA inhibitor, 160–161
Humic acids, 36, 49, 184
HVAC, 1
 cooling system layout (typical), 2
 services, 331
Hydantoin, 182, 194
 derivatives, 199
Hydrocarbon contaminants, 410
Hydrocarbon leakage, 403
Hydrochloric acid, 187, 342
Hydrofluoric acid, 412
Hydrogen bonding, 23
Hydrogen peroxide, 209
Hydrogen sulfide, subsurface water
 and, 28, 35
Hydrolytic stability, 143
Hydrolyzed starches, 146
Hydromag[®] water treatment device, 82
Hydrophile-lipophile balance, 146
Hydroxyapatite, 109, 112
1-Hydroxyethylidene-1,1-diphosphonic
 acid, 158
Hydroxylaminephosphate esters, 147
2-Hydroxymethyl-2-nitro-1,3-propa-
 nediol, 223
2-Hydroxypropyl methanethiosulfonate,
 214
Hydroxyphosphinocarboxylic acid,
 150, 185
Hydroxyphosphonoacetic acid, 160
Hydroxyphosphonocarboxylic acid, 160
Hydroxypropylacrylate copolymer, 148
Hygroscopic action, 22, 49
Hygroscopic polymers, 49
Hyperbolic, natural draft cooling
 towers, 6
Hyphae, 125
Hypobromous acid, 189, 194, 195
Hypochlorite ion, 185
Hypochlorous acid, 185, 189
Hypohalogens, availability of
 undissociated, 186
Hypoidous acid, 206
ICI Plc., 168, 231
Imidazolines, 148
Impedance measurement, corrosion
 monitoring, 380
In-service cleaning, 341–352
 example, 346
 removal of dust and dirt, 350
 removal of oil, 349
Incoming water temperatures,
 surveying, 274
Indirect dry cooling systems, 1
Induced draft towers, characteristics
 of, 4
Industrial cooling system layout, 2
Industry application of cooling
 systems, 268
Information database software, 394
Inhibited acid, for closed loop systems,
 334
Inhibitor monitoring and control,
 375–379
 after-the fact inhibitor monitoring,
 376–377
 Bel-Trak[®], 378–379
 Optidose[™], 378–379
 semicontinuous, 377–378
 tracer inhibitor monitoring, 377
 TRASAR[®], 378
Inhibitor treatment programs,
 categories of, 303
Inhibitors
 categories, 305
 formulations, 308
 measurement, 368
 performance of, 305
 reserve, 375
Inspections, 263
 for microorganisms, 391
Inverse solubility, 107
ioBio[™], 206
Iodine, 206
Iodofors, 206
Ion predictive modeling, 119
Ion-exchange softening and blending,
 26, 61–67
 ion-exchange resins for softener,
 63–64
 softener-sizing exercise, 65–67
 water softener selection and
 operation considerations, 65
Ion-generators, 232

- Ionically banded resin bed, 64
 - Iron, 405–406
 - in corrosion processes, 93
 - as water impurity, 34
 - Iron bacteria, 104, 130
 - Iron bisulfide, 414
 - Iron carbonate, 112
 - Iron deposits, cleaning off-line, 342
 - Iron dispersant polymers, 247
 - Iron dust fallout, 39
 - Iron fouling, 64
 - Iron oxide, 112
 - presence in deposits, 412
 - removal by OLC, 407
 - Iron removal, in cooling systems, 338
 - Iron salts, 34
 - as coagulant, 45–46
 - Iron sulfide, 112, 414
 - Iron-depositing bacteria, 404
 - ISO 14000 strategy, 260
 - ISO 9000 series, 316
 - quality strategy, 260
 - Isocyanurates, 182, 184, 189–191
 - sodium bromide blend, 190, 194
 - sodium bromide solids, 203
 - Isothiazolines (isothiazolones), 218–219, 224
 - cost-per-application problem, 225
 - limits, 405
 - polyquat combination, 225
- J**
- Jackets, as heat exchanger 18
 - Jar testing, 50
- K**
- K'Netix®, 396
 - Kaolin, polymers for, 138
 - KATHON™, 219
 - Klebsiella*, 130
 - Kunz Model, 117
- L**
- L:G ratio, 279, 280
 - Laminar flow, 17
 - Langelier saturation Index, 62 112–115
 - inherent limitations of, 114
 - Larson and Buswell Index, 115
 - Larson-Skold Corrosivity Index, 115
 - Latent heat, 10
 - of vaporization, 23
 - Lay-up, of cooling system, 415
 - Lean water, 31
 - Lean water program formulations, 175
 - using silicates, 151
 - Legionella* sp., 126, 130
 - cleaning and disinfecting cooling system and, 326
 - limitations of testing, 406
 - pneumophila, 197
 - serotype 1, 132
 - rapid assay method, 328
 - testing, 327, 406
 - Legionella* assay, standard culture method for, 328
 - Legionella*
 - cleaning and disinfecting programs to control, 321
 - disinfection against, 326
 - testing, 406
 - Legionella pneumophila*, serotypes/varieties of, 132
 - Legionellosis, 5, 25, 62, 132–135
 - control of, 320–329
 - cooling water environmental services, 321–322
 - legionella testing, 327–329
 - log books, 329
 - protocols or cleaning cooling systems and, 326–327
 - risk assessment, 322–324
 - risk management, 320–321
 - use of chemical treatments and services, 324–326
 - exposure risk from, 133
 - fatality rate of, 133
 - immunosuppressed individuals and, 133
 - Legionnaires' disease, 5, 25, 62, 132–135, 197
 - symptoms of, 132–133
 - susceptibility to, 133
 - Lepidocrocite, 112
 - Leptothrix ochracea*, 130
 - Lignin sulfonates, 145
 - Lignins, 137, 146, 184
 - Lime and lime-soda softening, 25
 - Lime softening processes, hot and cold, 51
 - Lime-softened water, 121
 - Limestone, 29, 51

- Line, 51
 - Linear polarization resistance
 - measurement, 384–385
 - of corrosion, 380
 - Liquid Metronics, 356
 - Liquid to gas ratio, 4, 279, 280
 - Lithium hypochlorite, 182
 - LMI, 356
 - LMTD, *see* Logarithmic mean temperature difference
 - Local film damage corrosion, 91
 - Log books, 329
 - Logarithmic mean temperature difference (LMTD), 16
 - Lonza Group, 168, 199, 205
 - Loss on ignition, 404
 - Louvers, surveying, 281
 - Low chromate programs, 144
 - Low Mo tracer program selection notes, 311
 - Low oxygen tolerant aerobic bacteria, 123
 - Low pH chromate programs, 144
 - Low phosphorus product, 162
 - Low pressure condenser, 22
 - Low pressure steam, 21
 - LPRM, *see* Linear polarization resistance measurement
 - LSI (Langelier Saturation Index), 12, 384
 - calculations, 119
 - SI and, as prediction tools, 118
 - LXF software, 394
 - Lyonnais Des Eaux/DegrTmont, 168, 204
- M**
- M and P alkalinity, 375
 - MA/EA/VA, 163, 164
 - Macroporous resins, 63
 - Magnesite, 29
 - Magnesium bicarbonate, 30
 - Magnesium carbonate, 52
 - Magnesium hydroxide, 34, 111, 112
 - Magnesium hydroxyphosphate, 112
 - Magnesium phosphate, 112
 - Magnesium, presence in deposits, 413
 - Magnesium salts, 108
 - Magnesium silicate, 111, 112
 - Magnetic devices, 78–84, 23
 - arguments for and against, 79–81
 - compared with chemical inhibitors, 84
 - examples of, 81–84
 - Magnetite, 112, 404
 - presence in deposits, 413
 - Maintenance chemical treatment startups, 335
 - Makeup water (MU), 12, 13
 - pretreatment processes and, 43–84
 - Makeup water sources and their impurities, 23–41
 - dissolved gases and other impurities, 35–36
 - sources of water for cooling system makeup, 24–25
 - city waters, 25–26
 - secondary use waters, 28–29
 - subsurface waters, 27–28
 - surface waters, 26–27
 - mineral impurities, problems caused by, 29–35
 - chlorides, 32–33
 - hardness salts, 30–32
 - iron, 34
 - reporting terminology and formats, 30
 - silica, 33–34
 - sulfates, 33
 - turbidity, 34–35
 - variations in makeup water sources, examples of, 36–41
 - Maleic acid chemistry, 147
 - Maleic anhydride, 164, 164
 - Maleic anhydride, ethyl acrylate, vinyl acrylate terpolymer, 164
 - Managing cooling water programs, 313–365
 - chemical dosing and program control, 352–365
 - control of legionellosis, 320–329
 - field services, 315–316
 - good housekeeping practice, 316–319
 - on-line (in-service) and off-line cleaning, 341–352
 - precommission cleaning and program start-up, 330–341
 - Manganese, 104
 - limits, 406
 - presence in deposits, 413
 - Manganese dioxide, 27
 - Manganese greensand oxidation and filtration, 55–56

- Manganese polymer phosphonate program selection notes, 310
- Manganese salts, 34
- Manganese zeolite filters, 28
- Manganese/aminophosphorus acid, 159
- Mannich polymers, 48
- MAPA, 159
- Marine acorn (rock barnacle), 131
- Marine crustacea, 131
- Marine organism control, 353
- Material balance, 369
- Maximum inhibitor concentration, 305
- Maximum performance limitation, 306
- Mayoquest® 1230, -1500, -2100, 167-3000, 166
- MBT, 149, 218, 219
 - TCBMT combination, 224
- MCDMH, 201
- MDD, 383
- MEA, 161
 - prevention of chlorine degradation and, 185
- Mechanical draft towers, 3
 - forced draft, characteristics of, 4
 - induced draft, characteristics of, 4
- Mechanical timer, 357
- MECT™, 224
- Media catalyst for aeration tower, 27
- Medium hardness water, 31
- Melamine process, 39
- Membranes, 67
 - capacity, 71
 - filtration, 391
- Mesh screen coupons, 393
- Metal Samples®, 382, 385
- Metal surface cleaners, 140
 - polyphosphates as, 142
- Metal wastage, 88
- Methane, subsurface water and, 35
- Methylene bis(thiocyanate), 219
- 2-Methylpentane, diamine, tetrakis (methylene phosphonic acid), 159
- MIC, 212
- Micractinium* sp., 132
- Microanodes, 88
- Microbiocide dosing, 362
- Microbiocides, 139, 177
- Microbiological control programs, 88, 177–233
 - biodispersants, 229–232
 - forms of biocides, 182–183
 - liquid, 183
 - solid or powdered, 182–183
 - health, safety, responsible care, and environmental legal problems, 179–180
 - nonoxidizing biocides, 209–229
 - basic question for selection, 211
 - combinations, 224–226
 - operating requirements, 226–227
 - primary microbiological problem areas, 211–213
 - program guide, 229
 - starting point for biocide selection, 213–224
 - structures, 227–228
 - oxidizing biocides, 183–209
 - bromine, 194–204
 - calcium hypochlorite, 189
 - chlorine, 184–187
 - chlorine dioxide, 191–194
 - gaseous chlorine, 187–188
 - iodine, 206
 - isocyanurates, 189–191
 - ozone, 206–209
 - peracetic acid, 209
 - sodium hypochlorite, 188–189
 - risk assessment and registration of biocides, 180–182
 - ultraviolet light disinfection, 232–233
- Microbiological factor, program selection and, 303
- Microbiological inspections, 391–392
- Microbiological organisms in water, 36, 122
- Microbiological problem areas, 211
- Microbiology and microbiological fouling, 122–132
 - bacteria, 123–125
 - types of, 130–132
 - biofilm, 127–130
 - fungi, 125–126
 - types of, 131
 - in-service cleaning and removal of, 345–349
 - microorganisms, 123
 - phytoplankton, 126–127
 - types of, 131–132
 - zooplankton, 126
 - types of, 131
- Microcathodes, 88
- Microcolonies, 129
- Microcrystals, 107
- Microcystic* sp., 131
- Microorganisms, 123
 - inspection for, 391

- Microprocessor-based control technology, 352, 355
- Microprocessor-controlled deposit monitors, 386–387
- Mild steel/carbon steel, 87
- Mill scale, 39, 330, 335
 - presence in deposits, 412
- Milton Roy, 356
- Mineral impurities, problems caused by, 29–35
 - chlorides, 32–33
 - hardness salts, 30–31
 - iron, 34
 - reporting terminology and formats, 30
 - silica, 33–34
 - sulfates, 33
 - turbidity, 34–35
- Minimum inhibitory concentration, 212–213, 305
 - monitors, 389
- Minimum kill concentration, 212–213
- MKC, *see* Minimum kill concentration
- MM pressure filtration pretreatment for RO, 73
- Mn polymer phosphonate program
 - selection notes, 310
- Mo, 149, 150, 360, 368
- Mold testing, 390
- Molluscs, 131
- Molybdate, as cooling water inhibitor, 149–150
- Molybdate programs, formulations, 173–174
- Molybdenum/molybdates, 149, 150, 360, 368
 - high Mo/polymer/phosphonate program, 40
 - low Mo/multiorganic program, 40
 - program formulations, 173
 - selection notes, 311
- Monitoring and control, 367–415
 - biomonitoring and control, 389–392
 - ATP meter, 391
 - biofilm monitors, 389–390
 - dip-slides (paddle testers), 390–391
 - laboratory-derived tests, 391
 - mesh screen coupons, 392
 - microbiological inspections, 391–392
 - control parameters and troubleshooting guide, 396–415
 - acid leaks, 396
 - air washers, 396–397
 - air washer cleaning, 397–398
 - alkalinity, 398
 - aluminum, 399
 - bacteria levels, 399
 - calcium hardness, 399
 - changing chemical treatment programs, 399–400
 - cooling tower design, 400–401
 - copper, 401
 - critical factors for scale deposition, 401
 - cycles of concentration, 401–402
 - deposit control, 402–403
 - deposit sample analysis and report interpretation, 403–404
 - fill (cooling tower fill-pack), 404–405
 - gluteraldehyde, 405
 - good housekeeping, 405
 - isothiazoline, 405
 - iron, 405–406
 - legionella* testing, 406
 - manganese, 406
 - oil leaks, 406
 - on-line biofilm removal, 406–407
 - on-line process contaminant deposit cleaning, 407
 - on-line deposit removal from heat exchangers, 408
 - pH operating range, 408–409
 - phosphate, 409
 - process contamination, 409–411
 - scales and deposits, 411–414
 - temporary shut-down, 415
 - total dissolved solids, 415
 - zinc, 415
- control using computer software programs, 392–395
- corrosion monitoring and control, 379–385
 - blank coupons, 388–389
 - ERM corrosion measurement, 384
 - LPRM corrosion measurement, 384–385
 - weight-loss coupons, 380–383
- deposition/fouling monitoring and control, 385–389
 - microprocessor-controlled deposit monitors, 386–387
 - portable deposit/corrosion monitors, 388
 - test heat exchangers, 387–388

Monitoring and control (*continued*)

- inhibitor monitoring and control, 375–379
 - after-the-fact, 376–377
 - Optidose™ and Bel-Trak®, 378–379
 - semicontinuous, 377–378
 - tracer, 377
 - TRASAR®, 378
- material balance, 369
- water sampling, testing, and reporting, 369–375
 - analytical reports and reporting conventions, 373–375
 - analytical testing, 372–373
 - water sampling, 370–372
- Monochlorodimethylhydantoin, 201
- Monoethanolamine, 161, 185
- Monovalent cation, in polyacrylates, 155
- Monsanto Company, 203, 205
- Most probable number, 391
- Mougeotia* sp., 132
- MPDT(MPA), 159
- MPN, *see* Most probable number
- MPY, 383
- Mud treatments, 139
- Multifunctional cleaner, 336
- Multimedia filters, 58–59
- Multimedia filtration, 26
- Multimedia filtrations, 56
- Muriatic acid, 342
- Mussels, 131
- Myacide® AS, 215
- Mycelium, 125
- Mylone™, 222
- Mytiltidae, 131

N

- N-1386 HG, 220–221
- NABAM, 215
- Nalco, 360
 - software, 394
 - TRASAR®, 378
- National Starch & Chemical Co., 21, 168
- Natural draft towers, 3
- Navigator/Marksman software, 394
- Negative surface charge, of foulants, 153
- Neptune Co., 356
- Niche market strategy, 262

- Nikkiso Co., 356
- Nipa Hardwicke, Inc., 216
- Nipacide®, 216
- Nitric acid corrosion, 104
- Nitrifying bacteria, 103
- Nitrotriacetic acid, 145
- Nitrite, 364
 - as cooling water inhibitor, 150–151
 - borate/TTA formulations, 151
 - passivator, 338
- Nitrite-based treatment alternatives, 161
- Nitrococcus* sp., 130
- Nitrogen compounds, 29, 188
- Nitrogen converters, 130
- Nitrosomonas* sp., 103, 104
- Noncarbonate hardness, 31, 51
- Nonchemical biocidal processes, 181–XXX
- Nonionic biodispersants, 231
- Nonionic polymers, 47
- Nonoxidizing biocides, 180–183, 209–229, 345
 - basic question for selection, 211
 - combinations, 224–226
 - operating requirements, 226–227
 - primary microbiological problem areas, 211–213
 - program guide, 229
 - starting point for biocide selection, 213–224
 - structures, 227–228
- NTA, 145, 158
 - for cleaning, 343
- Nucleation, 107
 - of calcium carbonate crystal, 111

O

- O-P ratios, 404
- Oddo-Thomson Index, 115
- Off-line cleaning, 341–352
- Off-line de-oiling, 343
- Oil, 36, 330, 335
 - managing leaks, 406
- On-line and off-line cleaning, 341–352
 - in-service removal of calcium carbonate, 344–345
 - in-service removal of calcium phosphate, calcium sulfate, and silica, 345
 - in-service removal of dust, dirt, and air-blown contaminants, 350

- in-service removal of
 - microbiological fouling, 345–349
 - in-service removal of iron oxides, 343–344
 - in-service removal of oil, 349–350
 - off-line de-oiling, 343
 - on-line cleaning of
 - calcium/iron/silica deposits, 342–343
 - program start-up, 350–352
 - On-line biofilm removal, 406–407
 - On-line heat exchanger, 40
 - On-line monitoring of inhibitor reserves, automatic, 360
 - On-line process contaminant/deposit cleaning, 407
 - OnGard[®] software, 394
 - Open cooling system, 3–6
 - cleaning, 330
 - sampling, 370
 - Open cooling system/passivation, formulation for, 337
 - Operating exchange capacity of resins, 64
 - Operational checks, 368
 - Optidose[®] inhibitor monitoring, 361, 378–379
 - Organic actives, 307, 308
 - Organic inhibitors, 138
 - Organic phosphate, 137
 - Organic phosphonates, 147
 - Organic polymeric coagulants and flocculants, 47–48
 - Organic polymers, 138
 - Organic program selection notes, 310
 - Organic + Tracer program selection notes, 311
 - Organics, presence in deposits, 413
 - Organo-bromine group, 214, 216
 - Organo-sulfur group, 214, 215
 - Orifice plate, 273
 - Orthobenzylparachlorophenol, 216
 - Orthophosphate, 108
 - Orthophosphate passivator, 338
 - Orthosilicate, 151
 - Oscillatoria* sp., 131
 - OSHA, 134
 - guidelines on Legionnaires' disease, 135
 - Osmonics-Lakewood Co., 356
 - Osmotic pressure, 68
 - Osmotic shock of resin, 63
 - Out-of-service cleaning, 330, 341
 - Out-of specification conditions, procedures for overcoming, 317
 - Outgoing water temperatures, surveying, 274
 - Oxidation potential 88
 - Oxidizing biocides, 181, 183–209
 - Oxygen corrosion, 96–97
 - Oxygen, makeup water and, 35–36
 - Ozone, 206–209
 - Ozone generators, 206
- P**
- P and M alkalinity, 375
 - Pacesetter Plus[®] software, 394
 - Pacific Standard Specialties, 168
 - Packaged, fiberglass-reinforced plastic cooling towers, 6–8
 - Paddle testers, 390–391
 - Pain funnel, 258
 - Paints and coatings, use of, 88
 - Pandorina* sp., 132
 - Paramagnetic iron oxide, 112
 - Paramecium* sp., 131
 - Parker-AMCHEM/Henkel, 342
 - Partial softening, 32
 - Passivated barrier film, 76
 - Passivated metal surfaces, 330
 - Passivating open cooling systems, 338
 - Passivation, 87, 330
 - of coupons, 382
 - of open cooling systems, 334
 - polyphosphates as, 142
 - Passivators, 338
 - Passive biocorrosion, 102–103
 - Passive corrosion mechanisms, 94
 - Passive iron oxide, 32
 - Pathogenic organisms, 130
 - PBS/AM, 148
 - PBTC, 156, 158
 - PCA 288 inhibitor, 162
 - PCA inhibitors, 159–160
 - PCAs, 159–163
 - type 4, 160–161
 - type 16, 159, 160
 - type 288, 162
 - PCBs, 186
 - Pediastrum* sp., 132
 - PEG, 148, 344
 - Penales, 132
 - Peniophora mollis*, 131
 - Pentane-1,5-dial, 218
 - Peracetic acid, 209

- Periodic dosing, of biocide, 361
- Periodic membrane flush, automatic, 71
- Permanent hardness, 31, 32, 51, 52
- Permeate water, 67
- Permeators, 69
- Peroxyacetic acid, 209
- Petro[®] ULF, 231
- pH, control unit, 355, 356
 - excessive, 404
 - operating range, 408
- pH/ORP electrodes, 358
- pH_{actual} (actual saturation pH), 117
- Phos[®] 2, -6, -9, 167
- Phosphate contaminants, 40
 - limits, 408
- Phosphate ester bond, 156
- Phosphate program, 141
 - selection notes, 309
- Phosphate stabilizers, 247
- Phosphate-specific dispersant, 404
- Phosphate/Organic program selection notes, 311
- Phosphates, 29
- Phosphates, 29, 108, 157, 368
 - concentration factor, 408
 - presence in deposits, 413
- Phosphates hydroxyamines, 147
- Phosphinocarboxylates, 148
- Phosphinocarboxylic and phosphonocarboxylic acids (PCAs) and carboxylates, 159–163
 - alkyl epoxy carboxylate (AEC), 162–163
 - PCA inhibitors, 159–160
 - HPCA inhibitor, 160–161
 - PCA 288 inhibitor, 162
 - POCA inhibitor, 161–162
- Phosphonates, 138, 145, 148, 152, 156–159, 344, 368
 - halogens and, 201
- Phosphonates and organic polymers, examples of, 165–167
- 2-Phosphonobutane, 1,2,3,4-tetra-carboxylic acid, 148
- Phosphono-butanetricarboxylic acid, 156, 158
- Phosphonocarboxylic acids, 159, 162
- Phosphoric acid, 342
- Photochemical decomposition, 192
- Photosynthesis, 106
- pH_s, 118
- Physical inspection, of tower, 280–282
 - fan area, 281
 - overall tower condition, 282
 - plenum area, 281
 - sump (basin) and structural components, 282
 - top distribution system, 281
 - tower fill and louvers, 281
- Phytoplankton, 123, 126–127
 - types of, 131–132
- Pickled steel, 332
- Pitot tubes, 273
- Pitting corrosion, 91, 97
 - from chlorides, 32
- Pitting rate, 383
- Pitting, tuberculation and, 89
- Planktonic bacteria, 102
- Planktonic organisms, 123
- Plastic coupon, 389
- Plate and frame heat exchangers, 18–19
- Plenum area of tower, surveying, 281
- Plenum chamber, 10
- Plume, 6
- Pluronic L62LF, 231
- PMA, 147, 163
- PMC Specialties Group, Inc., 219
- POC cleaner formulation, 337
- POCA, 161
- POCA inhibitor, 161–162
- Poly[oxyethylene(dimethylimino)ethylene, dichloride], 219
- Polyacrylamide, 48, 49
- Polyacrylate treatment for RO, 74
- Polyacrylates, 137, 154–156
 - as dispersants, 109
- Polyacrylic acids, 147, 154
- Polyaluminum chloride (PAC), 46–47
- Polyamine/DADMAC, 48
- Polyamine/EPIDMA, 48–49
- Polyamines, 47
- Polyamino acid, 154
- Polyaspartates, 154
- Polychlorinated biphenyls (PCBs), 186
- Polycol[®] 43, -90, -100, 166
- Polydiallyl-dimethylammonium chloride, 48
- Polyelectrolytes, 35, 47
- Polyethylene glycols, 148
- Polyhexamethylenebiguanide hydrochloride, 217
- Polyhydroxymonocarboxylic acid, 146
- Polymaleic acid and Polymaleic acid (PMA), 137, 147, 163–165

- and derivatives, 163–165
- treatment for RO, 75
- Polymer phosphate passivator, 339
- Polymers, 6, 148
- Polymers, activation of, 50
- Polymethacrylic acid, 147, 154
- Polyphosphinocarboxylic acid
 - treatment for RO, 74
- Polyphosphonates, 108, 137, 141, 145
 - bond, 156
 - passivator, 339
 - treatment for RO, 74
- Polyquat, 219
- Polysaccharide coating, 125
 - slimes, 129
- Polysilicates, 151
 - program selection notes, 311
- Polysilicates, glassy, 151
- Polysperse[®], 167
- Pontiac fever, 132, 133
- Poria monticola*, 131
- Poria nigrescans*, 131
- Poria oleraceae*, 131
- Portability, testing equipment and, 372
- Portable deposit-corrosion monitors, 388
- Post flushing, 331, 340
 - of closed loops, 334–335
- Potassium chloride, 415
- Potassium N hydroxymethyl-n-methyl-dithiocarbamate, 215
- Potassium permanganate, 28, 55
- Potential chemical savings, surveying, 277
- Potential water savings, surveying, 276
- Potentiostatic polarization curves, 380
- Pour plates, 391
- Practical heat transfer coefficient, 17
- Practical maximum COC, 401
- Practical Saturation Index, 115
- Prechlorination stage, for cleaning cooling systems, 326
- Precipitation, secondary, 53
- Precommission cleaning and program start-up, 330–341
 - of closed-loop systems, 331–335
 - of open recirculating systems, 335–341
- Predictive software, 393
- Prefilming, 330
- Preflushing, 331
 - cleaning closed loops and, 333
- Preoperational cleaning, 330, 407
- Preoperational cleaning, 339
- Pressure filters, 56
- Pressure vessel aerators, 28
- Pretreatment process, makeup water and, 43–84
 - acid dosing, 75–78
 - acid as part of treatment program, 76–77
 - sulfuric acid requirement calculation, 78
 - aeration towers, 54–55
 - chemical precipitation softening processes, 51–54
 - ion-exchange softening and blending, 61–67
 - ion-exchange resins for softener, 63–64
 - softener-sizing exercise, 65–67
 - water softener selection and operation considerations, 65
 - magnetic and physical devices, 78–84
 - arguments for and against, 79–81
 - compared with chemical inhibitors, 84
 - examples of, 81–84
 - manganese greensand oxidation and filtration, 55–56
 - raw water flocculation/clarification, 44–50
 - aluminum chlorhydrate, 47
 - aluminum sulfate, 45
 - coagulant/flocculant polymers application of, 49–50
 - selection of, 48–49
 - iron salts, 45–46
 - organic polymeric coagulants and flocculants, 47–48
 - polyaluminum chloride, 46–47
 - reverse osmosis, 67–75
 - chemical treatment for antiscaling/antifouling duty, 74–75
 - pretreatment requirements, 72–73
 - RO design considerations for cooling/industrial applications, 69–72
 - selecting RO membranes, 68–69
- sand, anthracite, multimedia, and automatic self-cleaning filters, 56–61 air scouring, 59
- automatic self-cleaning water filters, 60–61
- multimedia filters, 58–59
- sand filters, 57

- Pretreatment process, makeup water and (*continued*)
 sand filter-sizing exercise, 59–60
- Primary foulants, 105
- Primary microbiological problem areas, 211
- Probes, corrosion measurement, and, 385
- Process contaminant/deposit cleaning on-line, 407
- Process contamination/leaks, 184, 330, 409
- Product application problems, 404
- Product formulations, cooling water, 169–176
 alkaline zinc/organic programs, 171–173
 All Organic programs, 174–175
 chromate programs, 169–170
 closed-loop programs, 176
 environmentally acceptable programs, 175–176
 molybdate programs, 173–174
 soft and lean water programs, 175–176
 stabilized phosphate programs, 170–171
- Program control requirements, 353, 396
- Program performance software, 393
- Program selection, factors in, 299–311
 categories of inhibitor treatment program, 303–311
 full chemistry-spectrum inhibitor treatments, 304–305
 inhibitor categories, 305
 inhibitor formulations, 308–309
 inhibitor performance, 305–307
 notes on inhibitor formulations, 309–311
 external factors, 300–302
 application, monitoring, and control factors, 302
 basic program design and operation factors, 302
 customer-influence factors, 301–302
 primary environmental and water pretreatment factors, 301
 system process and design factors, 301
 internal factors, 302–303
- Programmable logic control (PLC) systems, RO and, 71
- Promotion of visible differences strategy, 262
- Propenaldehyde, 214
- Proprietary acrylate terpolymer, 167
- Protective films, 87
- Proteus vulgaris*, 130
- Pseudomonas aeruginosa*, 130
- Pseudomonas* sp., 102, 130
- Psychometric range, 3
- Puckorius (Practical) Saturation Index, 116
- Pulp and paper, copolymers for, 138
- Pulsafeeder, 356
- Pulse timer, 357
- Purolite® C-100, 66
- PWT grades of polymers, 48
- ## Q
- Quantifiable servicing standard, 316
- Quaternary ammonium compound (quat), 183, 220,
 TBTO combination, 224, 225
- ## R
- Radiation, 16
- Raw water flocculation/clarification pretreatment processes, 44–50
 aluminum chlorhydrate, 47
 aluminum sulfate, 45
 coagulant/flocculant polymers, application of, 49–50
 coagulant/flocculant polymers, selection of, 48–49
 iron salts, 45–46
 organic polymeric coagulants and flocculants, 47–48
 polyaluminum chloride, 46–47
- Real-time monitoring, 352
- Real-time data, 355
- Recarbonation reactions, 53
- Record keeping
 risk management and, 320
 systems, 317
- Red-water, 151
- Redicote®, 220
- Reduction, 88
- Refrigerant, 21
- Refrigeration, evaporation and, 14
- Relative humidity (RH), 11, 446
- Removable test surface monitor, 390

- Repelling (dispersing) effect of polymers, 153
- Reporting analysis and conventions, 373–375
- Residence time, 401
- Resins, exhaustion of, 64
- Resistant strains, 225
- Respiratory tract infection, 397
- Responsible Care, 227
- biocides and, 179
- Reverse osmosis (RO), 27, 32, 67–75
- chemical treatment for antiscal-
 ing/antifouling duty, 74–75
- pretreatment requirements, 72–73
- RO design considerations for
 cooling/industrial applications,
 69–72
- selecting RO membranes, 68–69
- Rhodia Co., 168
- Rio Linda®, 194
- Risk management, 320
- RO membranes, 68–69
- membrane capacity, 71
- RO, *see* Reverse osmosis
- Rock barnacle, 131
- Rod-shaped bacteria (bacillus), 124
- Rodine®, 342
- Rohm & Haas, 154, 168, 219, 361
- Rohrback Cosaco, 385
- Rosemount, 356
- Roughing filter, 58
- Round bacteria (coccus), 124
- Rubber contaminants, 410
- Rust, 335
- presence in deposits, 412
- Ryznar Stability Index/Ryznar
 Index/SI, 115
- S**
- Salting rate, 64
- Sampling water, 370
- Sand, anthracite, multimedia, and
 automatic self-cleaning filters,
 56–61
- Sand filters, 57–58
- sand filter-sizing exercise, 59–60
- Sand filtration, 26
- Sandler selling system, 258
- Saprophytic fungi, 125
- Saturation indices, 112–121
- calculation of LSI and SI, 110–121
- Langelier Saturation Index, 112–115
- limitations of, 116–117
- Puckorius (Practical) Scale Index,
 116
- Ryznar Stability Index, 116
- saturation models, modern software
 programs and, 117–121
- Stiff and Davies Saturation Index,
 115–116
- value of, 118–119
- Saturation pH (pHs), 112
- Scale, amorphous, 107
- Scale deposition, critical factors for,
 399, 401
- Scale/scaling, 105, 107
- deposits and, 411
- monitors, 368
- rates, 401
- tendency overpredictions, 402
- Scales, sludges, inorganic deposits, and
 foulants, 104–112
- calcium carbonate crystalline scale
 deposition, 106–108
- calcium phosphate scale deposition,
 108–109
- calcium sulfate scale deposition,
 109–110
- inorganic deposits and foulants,
 111–112
- scaling, 105
- sludge, 105–106
- Scaling tendency, overprediction of,
 402
- Scenedesmus* sp., 132
- Seawater, RO systems and, 70
- Secondary inhibitors, 140
- Secondary precipitation, 53
- Secondary use waters, 28–29
- Sedimentation, 45
- Seeding points for silicate
 precipitation, 111
- Self-cleaning filters, 27
- Selling cooling water programs,
 237–243
- competition and product perfor-
 mance-to-cost balance, 242–243
- salesperson's job, 239–240
- selling products and services,
 240–241
- Semicontinuous monitoring and
 control, 376, 377–378
- Semipermeable membranes, 68
- Sensible heat transfer, 10
- Sequacel HD, 167
- Sequestrants, 145
- Serpentine, 111, 112

- Serratia* sp., 130
- Service time allocation, 249
- Servicing standard, 316
- Sessile bacteria, 102
- Sessile bacteria, 102
 - fouling, 122
- Sessile organisms, 123
- Settling period, of polymers, 50
- Shell and tube heat exchangers, 19–20
- Shercide® 97, 222
- Shielding effects, 105
- SI (Stability Index), 115
- Sick building syndrome, 397
- Siderite, 112
- Siderocapsa* sp., 130
- Sidestream sand filters, 27
- Silica, 33–34, 51, 112, 404
 - amorphous, 110
 - cleaning, 342, 345
 - colloidal and amorphous, 110
 - control using PMA, 163
 - deposit cleaning off-line, 342
 - polymer for RO, 75
 - specific deposit control polymers, 34
- Silica polymer for RO, 75
- Silica-specific deposit control polymers, 34
- Silicate anions, 111
- Silicates, 137, 150
 - as cooling water inhibitor, deposition control rule, 111
 - in heat exchangers, 272
 - presence in deposits, 414
 - salts, 110
 - scale deposition, 110
- Silicone defoamer, 231
- Silt density index (SDI), 73
- Silt/dust/dirt, 6, 404
- Single pass heat exchanger, 20
- Slime, 6
- Slime formers, 130
- Slimeformers, 139
- Sling psychrometer, 11
- Sludge, 29, 105–106
- Slug dosing, 354
- Smart System® software, 394
- Soda ash, 45, 51
- Sodium bromide, 183, 189, 194
 - activation of, 196
- Sodium carbonate, 52
- Sodium chloride, 24
- Sodium chlorite, 189, 193
- Sodium cyanide, 146
- Sodium cycle softening, 61
- Sodium dichloro-*s*-triazinetriene, 190
- Sodium dichromate, 143
- Sodium dimethyl dithiocarbamate, 215
- Sodium glucoheptonate, 145, 158
- Sodium hexametaphosphate (SHMP), 106, 141
- Sodium hypochlorite, 183, 184, 188–189
- Sodium, in polyacrylates, 155
- Sodium lignosulphonate, 146
- Sodium mercaptobenzothiazole, 137, 149
- Sodium molybdate, 149
- Sodium nitrite, 150
- Sodium polyacrylate, 158
- Sodium polymethacrylates, 155
- Sodium salts of polyacrylic acid, 147
- Sodium styrene sulfonate, 164
- Sodium tripolyphosphate, 158
- Soft rot producers, 131
- Soft water, 30, 31
- Software programs, 393–395
- Sokalan® CP2, -CP5, -PA20, PA25, 166
- Solubility limits, 105
- Solution heat exchanger, 22
- SPC software, 367, 373–374
- SPC software, 367, 373–374,
- Specialty services, component in managing programs, 313
- Spectrophotometric testing, 373
- Spectrum™, 210
- Spiral bacteria (spirillum), 124
- Spiral wound cartridge, 68
- Spiral wound elements, 69
- Spirillum, 124
- Spirogyra* sp., 132
- Split-stream softening, 63
- Spore, 125
- Spore-formers, 130
- Square wave generators, 79
- SRBs, 6, 94, 103, 130, 185, 212
 - testing, 390
- SS/MA, 165
- SSS, 164
- Stability Index, 115
- Stabilized liquid bromine, 198, 204
- Stabilized phosphate programs, 38, 138, 148
 - formulations, 170
 - selection notes, 309
- Stabilizers, 140
- Stabilizing polymeric dispersants, 109
- Stable water, 53

- Stabrex™, 204
- Stainless steel (SS), cleaning by acid, 342
 - in corrosion processes, 93
- Standard hydrogen electrode, 90
- “Standard” phosphonates and organic polymers, 152–165
 - phosphonates, 156–159
 - phosphinocarboxylic and phosphonocarboxylic acids (PCAs), and carboxylates, 159–163
 - polyacrylates, 154–156
 - polymaleic acid and derivatives, 163–165
- Starches, 137
 - in weaving plants, 397
- Statistical process control programs, 355, 367
- Steel, 87
 - cleaning by acid, 342
 - in corrosion processes, 93
- Steel, grit blasted, 332
- Stemphylium* sp., 131
- Stiff and Davis Saturation Index, 115–116
- Strandco®, 50
- Stress corrosion cracking, 19, 91
 - in heat exchangers, 272
- Stress, in heat exchangers, 31
- Stress factors, 33
- Stress tolerant, All Organic program, 41
- Stress tolerant, problems-specific polymer program, 38
- Stroke pumps, adjustable, 357
- Strong base cation resin, 63
- Strong base resin, 63
- Subsurface waters, 27
- Suez-Lyonnaise Des Eaux/DegrTmont, 168, 204
- Sugar contaminants, 410
- Sulfate-reducing bacteria (SRB), 6, 38, 94
- Sulfates, 33
 - in corrosion processes, 92–93
- Sulfonated styrene copolymers, 153
- Sulfone, 220–221
- Sulfone/quat combination, 224
- Sulfonic acid copolymers, 153
- Sulfur bacteria, 103, 130
- Sulfur dioxide, 36
- Sulfur trioxide, 36
- Sulfuric acid/zinc/polymer/phosphonate program, 41
- Sulfuric acid/zinc polyphosphate/polyacrylate program, 49
- Sulfurous acid, 36
- Sump condition, surveying, 282
- Super-Ox-II™, 190
- Superior® water conditioner products, 82
- Supersaturation, 105, 401
- Supplemental alkali, 45
- Surface acting agents, 229
- Surface shielding, 97
- Surface tension, 24
- Surface waters, 26
- Surfactant properties of amines, 149
- Surfactant type biocides, 185
- Surfactants, 229
- Surveying and inspecting water system, 263–299
 - marketing standpoint, 265–267
 - technical standpoint, 267–285
 - calculating cooling tower airflow
 - L:G ratio and approach temperature, 279–280
 - chemical dosing, monitoring, control systems, 282–283
 - competitor biocide/biodispersant chemical product consumption, 276–279
 - competitor scale/corrosion/dispersant chemical consumption, 276–277
 - cooling system volume (holding capacity), 277–278
 - daily annual water consumption, 272–276
 - design of heat exchangers, chillers, related equipment, 270–272
 - industry application and basic design, 268–269
 - physical inspection of the cooling tower, 280–282
 - types of cooling tower employed, 269
 - water analysis and water records, 284
 - interpretation and proposal focus, 285–299

Suspended solids (SS), 26
 turbidity and, 34–36
 Synergizers, 144
 Synperonic® L62LF, 231
 Synprolam™, 220
 Synthetic water treatment polymers,
 147
 System UVEX™, 232
 Systems process control software, 394

T

TAB, 327
 TAB testing, 390
 Tablet dispensers, 354
 Tagging, 3376
 Tallow diamine, 220
 Tamol® 850, -960, 166
 Tannic acids, 184
 Tannins, 146
 Tap water, RO systems and, 70
 Taprogge®, 353
 TBC testing, 390
 TBTO, 10, 221
 TBZ, 221
 TCCA, 204
 TCCBN, 221–222
 TCMTB, 222
 alkyl-sulfonate combination, 224
 TDC/conductivity, 415
 limits, 416
 monitoring, 352
 TDS monitoring and bleed control,
 automatic, 352
 Temperature differential (ΔT), 12
 surveying, 274
 Temporary hardness, 31, 51
 Temporary shut-down, 415
 Terpolymers, 147, 152, 153
 2-(Tert-butylamino-4-chloro-6-
 (ethylamino)-s-triazine, 221
 Test heat exchangers, 387–388
 Testing water, 372
 Tetrachloro-2,4,6-cyano-3-benzonitrile,
 221
 Tetrahydro-3,5-dimethyl-2H-1,3,5-
 thiadiazine,-2-thione, 222
 Tetrakish, hydroxymethylphosphonium
 sulfate, 222
 Tetrapolymers, 153
 Textile material contaminants, 410
 TFC membranes, 69, 70
 Thermal backwash, 353
 Thermal shock, of resin, 63
 Thin film composite (TFC) RO
 membrane, 69
 of polyamide on sulfone, 70
Thiobacillus ferrooxidans, 130
Thiobacillus thiooxidans, 103, 130
 2-(Thiocyanomethyl(thio)benzothia-
 zole, 222
 Thiomethyldialkylamino-s-triazine, 221
 Thione, 222
Thiothrix sp., 103, 130
 Thiourea, 342
 THMs, 186
 THPS (TKHPS), 222–223, 340, 346,
 406
 Threshold effect, 141, 142
 by phosphate program, 141
 ThruGuard® software, 393
 Timer control dosing, automatic, 355
 Timer-actuated biocide dosing,
 automatic, 362
 Timer-controlled dosing, 355
 Timer-operated chemical dosing for
 closed loops, 364
 Tin, 404
 Titanium alloy cleaning by acid, 342
 Titration, 308
 TKHPS (THPS), 222–223, 340, 346,
 406
 Tobacco dust, 397
 Toll-blender, 247
 Tollicide®, 223
 Tolyltriazole, 149
 Total aerobic bacteria, 327
 testing, 390
 Total alkalinity, 30, 113, 115, 119, 120,
 121
 Total bacteria counting, 390
 Total dissolved solids (TDS), 24
 limits, 415
 Total hardness, 30
 Total phosphate reserve, 404
 Total product reserve, 362
 Total residual oxidant, 198
 Tower condition, surveying, 282
 Tower fill, surveying, 281
 Tower Pro™ tablets, 190
 Towerbrom®, 203
 Toxicants, 180
 Traced polymer, 378
 Tracer inhibitor monitoring, 376, 377

Tracer, Mo as, 150
 surveying, 278
 Track 2™ (for Windows), 394
 “Traditional” cooling water inhibitors,
 148–152
 amines, 148–149
 azoles, 149
 molybdate, 149–150
 nitrite, 150–151
 silicates, 151
 zinc, 151–152
 TRASAR® inhibitor monitoring and
 control, 360, 378
 Smart System® software, 394
 TRC®-233, 166
 Tri-calcium phosphate, 109, 112
 Triazine, 221
 Tributyltetradecylphosphonium
 chloride, 223–224
 Tributyl tin oxide, 10
 Trichlor™, 190
 Trichloroisocyanurate, 190, 191
 comparison, 204
 Trichlorotriazinetrione, 190
 Triethanolamine phosphate ester, 147
 Trihalomethanes, 184, 186
 Triple media filters, 58–59
tris(hydromethyl)nitromethane, 223
 Trisnitro, 223
 Triton® DF-20, 230
 Trivalent chromate, 144
 TRO, 198
 Troilite, 112
 Troubleshooting, 316
 exercise, 268
 guide, 396–415
 TTA, 149, 150, 407
 with HPCA, 161
 TTPC, 223–224, 340, 346, 392, 406
 Tube bundles, 10
 Tuberculation, 97, 98–99
 in heat exchangers, 271
 Turbidity, 34–35
 RO feed-water and, 73
 Turbulent flow, 17
 Two pack programs, 304

U

Ultralow chromate programs, 144
 Ultraviolet light disinfection, 232–233

Under-deposit corrosion, 9, 91, 97, 98
 in heat exchangers, 272
 Unicellular organisms, 125
 Unihib® 106, 167
 305, 167
 Union Carbide, 230
 Universal solvent, water as, 23, 29
 UV lamp, phosphonate testing and, 308
 UV systems, 232–233

V

V-notch weirs, 373
 Vantage Company, 394
 Vantocil® IB, 218
 Verichem Inc., 221
 Versa® TL-4, 166
 TL-7, 166
 Versatemp® systems, 333
 Versenex®, 159
 Vertical tank filter, 57
 Vibrio, 124
 Vinings Industries, 215, 219
 Viscosity of water, 24
 Volume (V), 13
 Volvocales, 132
 Vulcan Chemical Technologies, 194
 Vulnerability of account, factors in, 243

W

Water analysis and water records, 284
 Water analysis examples, 36–41
 Khuzistan, Iran, 41
 Lima, Peru, 40
 Northern Iran, 38–39
 southern South Korea, 40
 Sumatra, Indonesia, 39–40
 Tamil Nadu, India, 38
 Tel Aviv, Israel, 38
 western South Korea, 39
 Water chemistry, fundamentals of,
 23–24
 Water Cycle® software, 393
 Water sampling, testing, and reporting,
 369–375
 analytical reports and reporting
 conventions, 373–375
 analytical testing, 372–373
 sampling, 370–372
 Water softener selection/operation
 considerations, 65

- Water sources, cooling system makeup and, 24–29
- city waters, 25–26
 - secondary use waters, 28–29
 - subsurface waters, 27–28
 - surface waters, 26–27
- Water treatment history, 264
- Water treatment program charts, 300
- Water treatment reinstatement stage for cooling systems, 326
- Water usage calculations, 13–15
- evaporation/water usage formulas and relationships, 13–14
 - example, of using water usage calculations
- Water usage, evaporation and, 10–13
- Water/chemical double savings, surveying, 276
- Waterman[®] software, 393
- Weak acid cation resin, 63
- Weak base resin, 63
- Weight loss coupons, 380–383
- Wet cooling systems, 1–2
- Wet-analysis tests, 354
- Wet/dry combined towers, 6
- Wetting, 230
- What-if projections, 116, 120
- software, 393
- Whatman[™] 41, 340
- White rot producers, 131
- White rust, 8, 39, 100–102, 112
- control of, 101
- Whole chemical product, 374
- Wide-mouthed closure dosing pot, 364
- Windage losses, surveying, 274
- Witco, 231
- Wood product contaminants, 410
- Wood rot, 125
- Wood-frame and concrete industrial cooling towers, 9–10
- WSCP[™], 219
- X**
- XBINX[®], 219
- Y**
- Yeasts, 123, 125
- mold testing and, 390
- Yellow algae, 127
- Z**
- Zero discharge, 25, 68
- Zinc, 137, 147, 157, 368
- as cooling water inhibitor, 151–152
 - as cathodic inhibitor, 151
 - corrosion processes and, 93
 - limits, 415
 - presence in deposits, 404, 414
 - reserve, 152
 - stabilizers, 152
- Zinc carbonate, 101, 112
- Zinc chromate program selection notes, 309
- Zinc phosphonate, 152
- Zinc polyphosphate passivator, 338
- Zinc salts, 151
- Zinc/organic programs, 138
- formulations, 172
 - HPCA and, 161
 - orthophosphate/organic program, 39
 - phosphate/organic programs formulations, 172
 - polymer/phosphonate programs, 39, 161
 - polymer phosphonate program selection notes, 310
- Zinc hydroxide, 92, 151
- Zooplankton, 123, 126
- types of, 131
- Zygnema sp., 132