

Chemical Publishing Company  
[chemical-publishing.com](http://chemical-publishing.com)

The following pages contain the table of contents,  
index and first few sample pages of this title  
[Click here to purchase this title](#)  
or to visit the product page.

# **Boiler Water Treatment Principles and Practice**

Volume I

*Boiler Basics and Steam-Water Chemistry*

**Colin Frayne**



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

©2002 by Colin Frayne

**Library of Congress Cataloging-in-Publication Data**

Frayne, Colin.

Boiler water treatment : principles and practice / Colin Frayne.  
p. cm.

Includes bibliographical references and index.

ISBN 0-8206-0371-6

1. Feed-water purification. 2. Boilers—Water supply. I. Title.

TJ379.F73 2002

621.1'94—dc21

2002073523

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

---

This is the second book written by Colin Frayne and complements *Cooling Water Treatment: Principles and Practice*, which was published in 2000. Mr. Frayne continues to work as an international water treatment consultant and small business owner. In addition, he is employed in a senior executive capacity by the New York City–based, Metro Group, Inc., a water treatment, mechanical, and environmental services organization.

Colin Frayne has more than 30 years of experience in the practice of industrial chemistry and management of industrial and commercial water systems. Also, he has worked and lectured in over 40 countries and lived on four continents with his family, during which time he has managed various water treatment businesses. Mr. Frayne is British-born but holds dual nationality, having resided in the United States for several years with his wife and two daughters.



---

# PREFACE

---

This is my second book. It follows a similar style and with similar objectives and outlook to *Cooling Water Treatment: Principles and Practice*, which was published in early 2000. In the preface to that book, I stated that “the vital key to successfully providing water treatment programs today is something it has always been—excellent customer service!” In this particular aspect, some things just do not change, and for the vast majority of industrial, institutional, and commercial boiler plant owners around the world, this message is hopefully welcome. I say this because in order to attain and maintain optimum day-to-day boiler waterside operating conditions, owners and operators will continue to need the very best technical advice and other services possible to manage proactively the water treatment programs they employ.

There are some differences, however, between cooling water customers and boiler water customers in their overall requirements for water treatment program management (in **Sandler® Sales Institute** sales training “speak,” the level of customers’ “pain”). And it is these differences that, in part, gave rise to my decision to write this particular book.

It is a certainty (at least in my mind) that there is no *cooling system* anywhere in the world, from the smallest to the very largest, whose owner or operator cannot benefit from working with an appropriately qualified water treatment service company to some degree or other. The complexities of interrelated waterside problems, the variability of today’s water supplies, and the sheer range of modern chemical treatments (now globally available), equipment options, and application techniques are simply overwhelming. This means that owners and operators of cooling water systems cannot remain conversant with all the causes and effects of waterside problems or keep abreast of marketplace technologies and developments in support services.

However, it is not always the case with certain types of modern boiler plant that the respective owners, operators, and technical committees can significantly benefit from working with a water treatment company.

For example, in some very specialized areas of boiler water treatment (such as nuclear power units and especially utility power generation), there is probably little or nothing of any practical value that service companies can teach the current practitioners.

For a second group, however, comprising the owners and operators of just about every other type of commonly available boiler plant, this is not always the case. The engineers responsible for the great majority of “ordinary” boiler plants found in commercial buildings, hospitals, hotels, and general industry around the world typically do not have the same level of resources as the power generation industry. Consequently, they need to be in a position to reliably obtain specialty waterside treatment programs and technical support services.

It is these differences in in-house boiler plant facility resources and the perceived need to obtain technical support from an external source that led me to consider grouping boiler plant systems in a slightly different way than is typically perceived, which in turn provided a focus for this book. Thus, although commercial, industrial, and utility steam generators can be classified in several different ways (such as by pressure, output, fundamental design type, etc.), their owners and operators can be classified as members of one or other of only two groups.

The first group consists almost exclusively of these large utility organizations that operate electrical power generators and employ high-pressure, fossil fuel or nuclear power fired boiler plant for steam generation. This international power generation group understands their own particular waterside problems very well and the chemicals, mechanisms, and protocols needed for proper control. Their field of water treatment is fairly narrow, but they possess an incredibly deep knowledge of high-pressure boiler waterside technology and consequently need no assistance from me. (Nevertheless, for the sake of completeness, and hopefully for the interest of many operators, some information on higher pressure boiler water treatment practice has been included in this book).

The second group consists of every other type of boiler plant owner or operator. This group includes not only all the engineers operating steam generators in countless small factories, commercial premises, and institutional buildings, but also the various larger process industries and some facilities that may, in fact, generate electricity (albeit at only moderately high pressures) such as the cogeneration/combined cycle plants.

Within this second group, the various types and designs of boiler operated are very broad and the classifications and applications of boiler water treatments are equally wide.

At first glance, and despite there having been little in the way of ground-breaking advances in treatment chemicals, equipment, or program applications for many a year, the fundamentals of the science and business of boiler water management appear to be, on the whole, still imperfectly understood by this group.

It also appears that most commonly available technical books and other sources of literature tend to concentrate on the higher pressure “glamour” end of the boiler plant range, and there is little that is sufficiently practical or comprehensive concerning the lower pressure market. And, of course, it is this lower pressure market (when measured by physical number) that globally constitutes the vast majority of boilers and where the user skills and experience in applied water treatment are most often limited.

In mitigation, a deep knowledge of such a specialist area generally is not required for most lower pressure boiler owners and operators, as they need to focus their attention on primary profit-making activities and other core business competencies.

It is, thus, to the second group that this book on boiler water treatment is primarily addressed. My key objective was to provide the reader with useful and practical boiler plant information that will help improve waterside cleanliness and add value to their facilities’ operational efficiencies.

Additionally, a personal objective was to provide the information contained within this book in such a way that it could be used regularly in the field rather than be relegated to a bookshelf with other works of occasional reference. As such, although this book is essentially concerned with applied chemistry, I found it necessary to devote several of the initial chapters to a discussion on some basic but practical engineering aspects. Subjects covered include fluid dynamics, thermodynamics, the various types and designs of boilers to be found, and the function of all the critical system auxiliaries and components. The subject of boiler water chemistry is so inextricably bound up with the mechanical operation of boiler plants and all their various systems and subsystems that it is impossible to discuss one topic without the other.

As with my first book, which covered cooling water treatment, this book also started life after rereading the (still largely relevant) books written by the late James W. McCoy, who was a supervisor of refinery services at Standard Oil Company of California. This time my primary source of inspiration was *The Chemical Treatment of Boiler Water*, which was first published by Chemical Publishing Company of New York in 1981.



In this preface I also wish to highlight the contributions to the subject from some other publications, such as the more modern book *Procedures of Industrial Water Treatment* by J.N. Tanis and the *NALCO Guide to Boiler Water Systems Failure*, as well as the massive, but superb tome, *Steam, Its Generation and Uses* from Babcock & Wilcox, which is now in its 40th edition. These are all excellent works.

Other notaries are the *Consensus on Operating Practices for the Control of Feedwater and Boiler Water Chemistry in Modern Industrial Boilers* (1994 edition), published by the American Society of Mechanical Engineers, and *BS 2486:1997 Recommendations for Treatment of Water for Steam Boilers and Water Heaters* from the British Standards Institution. The 1994 Consensus (with its engineering background) and the 1997 version of BS 2486 (with its strength in operational chemistry) complement each other well. I consider that the tables and propositions contained in these two booklets jointly represent a true standard for boiler water treatment operational control. Consequently, I am pleased to be able to reproduce in this book all the tables from both publications, having received permission from the respective organizations to do so.

An acknowledgment of the more than 160 technical references that supported my efforts is provided in the bibliography at the back of this book.

As before, I give due recognition to my wife, Carol, for her unstinting loyalty and support in this project. Her support was especially important, as during the course of writing this book we relocated from Georgia to New York City and most of the problems associated with moving and then remodeling an old Tudor style house were left to her. During much of this period I was busy working in an office during the day, writing at night, and generally insulated from much of the everyday drama.

I also thank Dr. Bennett P. Boffadi for taking time away from his consulting work to pore through this book and correct my technical mistakes.

Finally, I thank Silvia Soto-Galicia and her staff at Chemical Publishing Co. for their perseverance and confidence in publishing my work for a second time.

Colin Frayne  
New York City, 2002

# CONTENTS

---

Introduction: The Function of Boiler Water Treatment and Its Marketing	xvii
1 Steam Generation	1
1.1 Basics of Steam Generation	4
1.2 Energy, Work, and Power	10
1.3. Boiler Plant Efficiency	14
2 Boiler Types and Applications	23
2.1 Electric Boilers	24
2.2 Fire Tube (Shell) Boilers	29
2.3 Water Tube Boilers	39
2.4 Nuclear Reactor Boilers	61
3 Boiler Plant Subsystems, Appurtenances, and Auxiliaries	67
3.1 Boiler Plant Subsystems	69
3.2 Boiler Appurtenances	72
3.3 Boiler Auxiliaries	82
3.4 Balance of Plant (BOP) Equipment	112
3.5 Boiler Plant Operational and Water Treatment Basics	119
4 Waterside and Steamside Problems: The Basics	131
4.1 Hot Water and Steam System Cycles	132
4.2 The Scope of BW Treatment and Control of Steam/Waterside Chemistry	134
4.3 Fundamental Steam–Waterside Problems and Water Treatment Objectives	140
4.4 Deposition	144
4.5 Corrosion	149
4.6 Fouling	153
4.7 Contamination	154
4.8 Limiting the Potential for Waterside Problems	156

5	Waterside and Steamside Problems: Hot Water Heating and Low-Pressure Steam Boiler Specifics	173
	5.1 Problems with Heating Coils	175
	5.2 Problems Associated with the Use of Glycols	177
	5.3 Problems of Corrosion in Hot Water and Low-Pressure Steam Heating Systems	178
	5.4 Other Waterside Problems in Hot Water Heating and Low-Pressure Steam Systems	180
	5.5 Waterside Problems in Medium-Temperature Hot Water and High-Temperature Hot Water Systems	185
6	Waterside and Steamside Problems: Pre-Boiler Section Specifics	191
	6.1 Overview of Pre-Boiler Section Waterside Problems	192
	6.2 Feedwater Contamination from Makeup Water	193
	6.3 FW Contamination from Returning Condensate	203
	6.4 Problems Associated with the Final Feedwater Blend	206
7	Waterside and Steamside Problems: Boiler Section Specifics	217
	7.1 Boiler Scaling, Fouling, and Deposition	217
	7.2 Passivation and Common Corrosion Problems	237
	7.3 Stress and High Temperature–Related Corrosion	254
	7.4 Other Forms of Corrosion	262
	7.5 Corrosion in Nuclear Powered Steam Generators	265
8	Waterside and Steamside Problems: Post-Boiler Section Specifics	273
	8.1 Steam Purity and Steam Quality	275
	8.2 Corrosive Gases in Steam and Condensate Systems	284
	8.3 Vaporous Silica and Other Steam Volatiles	293
	8.4 Scale and Corrosion Debris Transport	296
	8.5 Oil and Process Contamination	298
9	Pre-Boiler and Post-Boiler Treatment Processes	303
	9.1 Overview of Common External Treatment Process Technologies	306
	9.2 Basic Pretreatment Processes	307
	9.3 Pre-Boiler Purification Technologies	341
	9.4 Post-Boiler Condensate Conditioning	376
	9.5 Novel Pretreatment Oxygen Removal Technologies	382

10	Internal Treatment Programs	385
10.1	Outline of Internal Treatment Control and Programs	386
10.2	Anodic Inhibitor Chemistries	394
10.3	Tannin Programs	403
10.4	Coagulation and Precipitation Program Chemistries	411
10.5	Chelant Program Chemistries	430
10.6	All-Polymer/All-Organic Programs	437
10.7	Chelant-, Phosphate-, or Polymer-Based, Combination Programs	461
10.8	Coordinated Phosphate and Program Derivations	464
10.9	All-Volatile Treatment Program Chemistries	474
10.10	Mixed Treatment and Zero Solids Treatment	476
10.11	An Outline of Water Treatment for Nuclear Powered Steam Generators	477
11	Adjuncts and Conjunctional Treatments	479
11.1	Oxygen Scavenger Chemistries	479
11.2	Oxygenated Treatment (OT)	506
11.3	Ammonia and Amine Adjuncts	510
11.4	Alkalinity Boost Chemistries	545
11.5	Antifoam and Defoamer Chemistries	548
11.6	Multiblend Formulations	555
12	Control of Boiler Water Chemistry	559
12.1	Water Treatment Recommendation Perspectives	560
12.2	Tables and Supporting Notes	566
13	Operational Control of Waterside Surfaces	599
13.1	Sampling and Testing Steam and Condensate	599
13.2	Managing Standby and Idle Boilers	606
13.3	Boiler Inspections	612
13.4	Boiler Cleaning	623
13.5	Some Troubleshooting Notes	657
14	Control of Fireside Conditions and Surfaces	669
14.1	Basic Fireside Problems	670
14.2	Fuel Treatments/Additives	678
14.3	Fuel Treatment Formulations	687
14.4	Combustion Gas Analysis	689

Appendix I Useful Data	695
Appendix II Glossary	711
Bibliography	763
Index	I1

---

# MODERN BOILER WATER TREATMENT PRACTICE

---

Modern boiler water treatment practice is the planned, actioned, and documented management of the waterside of boiler plant systems, to include pre-boiler and post-boiler functions. The objective is to produce and maintain operational and economic benefits for the users.

Achievement is by the integrated provision of innovative chemistry with other appropriate technologies and the application of practical expertise in the field, in order to prevent waterside and related plant operational problems from occurring. Where problems do arise, then detection and identification of the causes, together with suitable remedies that will also prevent reoccurrence, 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 boiler systems and other equipment if success is to be attained and maintained.



---

# INTRODUCTION: THE FUNCTION OF BOILER WATER TREATMENT AND ITS MARKETING

---

Boilers are heat-transfer devices, wherein water, in the form of either *liquid water* or *gaseous steam*, is commonly employed as a medium for the transport of heat to some distant point of use. Although other heat-transfer mediums are sometimes utilized, water is particularly suitable because of its relative abundance, low cost, and high heat capacity. It is generally the medium of choice in most boiler applications, whether for domestic, commercial, institutional, or industrial purposes.

However, a boiler can only carry out its primary functions of transferring heat to water and (in steam generators) separating steam under pressure from water most efficiently if the quality of the various types of water used (such as *makeup water*, *feedwater*, and *boiler water*) are effectively and continuously controlled. The difficulty in this quality control process is that water is a “universal solvent,” and as a result, all sources of water contain various natural concentrations of dissolved minerals and gases in addition to suspended solids and biological matter. The relative amounts of each of these impurities tend to vary considerably with geographic location and season. This phenomenon results in countless permutations of water type and quality around the world, each potentially available as a source of makeup supply to boiler plant systems, evaporators, and other forms of water heating and steam generating devices. In many industrial applications, the negative impact of these natural impurities may be further compounded by the presence of small concentrations of process contaminants.

The effect of these various impurities or contaminants is to hinder the heat-transfer and steam generation processes, to adversely affect the



quality and purity of steam, and to act as primary instigators in the corrosion and wastage of boiler plant system materials of construction. A wide variety of chemical reactions and physical mechanisms can and will take place, including the deposition of various crystalline and noncrystalline scales on the waterside of heat-transfer surfaces, the formation of sludges, metal corrosion, and carryover of contaminants into the steam.

The function of boiler water treatment, therefore, is to control the waterside chemistry of boiler plant systems within certain agreed and relevant parameters and specifications. As these adverse processes are by no means limited to the boiler itself, in practice, *boiler water treatment* also includes *pre-boiler* and *post-boiler* functions and further requires that all the various types of water utilized are controlled through a comprehensive treatment and proactive management program.

Clearly, the lack of or the use of an inappropriate boiler water treatment program creates significant operational difficulties and impacts the economics of the entire process, from start to finish.

With regard to the marketing of boiler water treatment programs and services, in the preface to this book I suggested that, although boiler plant can be classified in several different ways, there are from my perspective, only two groups of boiler plant owner/operator to be addressed.

1. The first group consists almost exclusively of the large utility organizations that operate electrical power generation facilities.
2. The second group consists of all the other types of boiler facilities and is clearly a very large and extremely diverse group, utilizing boiler plant ranging from very small steam producers to very large ones and including many that also produce some electricity together with process steam.

From a water treatment technical and marketing viewpoint, there is, in fact, a fundamental distinction between these two groups, as discussed below.

**Utility power generation group:** This group of boiler operators typically possess boiler plant installations of complex water-tube configuration, often producing steam in excess of 1,500 to 2,000 psig and increasingly, up to double this pressure. They tolerate only very high-purity makeup (MU) water, use very little chemical treatments, and what they do use is generally of a commodity nature.

Internationally, this group has within its ranks an army of experienced chemists and engineers plus a seemingly almost unlimited source of research and development information. Much of this information is

tightly held within the international utility power generation community and if available in book or other hard-copy form is generally prohibitively expensive for outsiders to purchase.

The fundamental reason for the commitment of this group to attaining the highest purity of feedwater (FW) and the most exactly controlled internal boiler waterside conditions is the nature of the primary product made available for sale. This group generates electricity, on which all developed and developing nations critically depend for their economic and social well-being. The production of steam is merely an intermediate, but the quality and quantities of steam produced has a direct bearing on total electricity output, generation efficiency, operational and maintenance costs, and ultimately the price paid by the consumer.

**Heating, process steam, and cogeneration group:** As a contrast to the utility power generation group, operators of all the other types of boiler plant typically have installations producing steam (or hot water) at very much lower pressures. In fact, most facilities operate boilers somewhere within the range of only 5 to 125 psig, although larger process plants and cogenerators may reach pressures of up to 1,500 psig.

Because of the diversity of this group, there is no global standardization with regard to makeup (MU) water, FW quality, or boiler water (BW) chemistry control, irrespective of boiler design, pressure rating, or ultimate steam purpose. True, there are various national standards and boiler manufacturer association recommendations, and while these guides are extremely useful, they seldom universally agree on any given parameter or protocol. In mitigation, they cannot hope to provide answers to the myriad of problems and specific circumstances that develop. Rather, they should be viewed as a starting point for control purposes.

What is clear is that it is seldom that MU water or FW quality (i.e., the lack of contaminants) used by this second group ever reaches the incredible standards demanded and produced by the first group. Indeed, it is not at all uncommon to find lower-pressure boiler installations with MU water and FW both inadequately treated and simply inappropriate to the facilities needs.

Low standards of water treatment and waterside chemistry are generally caused by a combination of bad advice and lack of operator motivation or resources, and provide an initiator for the onset of downstream waterside operational problems. However, despite these apparent water treatment imperfections, most operators somehow still manage to function and produce steam of an acceptable quality and quantity, year after year!

This second group also, in fact, contains many electricity producers, the so-called *cogenerators* or *combined-cycle plant operators*. While there is no apparent clear-cut distinction between these facilities and the large utilities, in practice, the cogenerators tend not to operate at such high pressures (although the generation of power economically usually requires at least 650 psig). Also, although the demands for good quality FW treatment and steam purity in this group is high, it tends not to reach such extremes of sophistication as demanded by the utility group.

It can be seen that the first group demands the highest possible quality of steam purity and steam generation operating control and water-side chemistry is “knife-edge” technology. Consequently, from a water treatment products and services marketing viewpoint, this group offers the minimum of opportunities as a potential source of revenue. Even where an opportunity exists, perhaps for the supply of a special *polymeric dispersant* or an esoteric *oxygen scavenger*, the service company may often discover that because of the bureaucratic and accreditation systems to be worked through, the gain may not be worth the effort.

Looking further at the second group, although many of the larger, non-utility operators around the world retain a resident water services chemist or trained technician, there is a marked tendency for *all* owners or operators, whether large or small, to work in conjunction with a water treatment service company. There is also a common purpose to use branded BW treatment chemical products rather than commodities.

Thus, a good source of potential revenue for products and services exists in the multitude of smaller boiler-houses to be found operating around the globe. It is here that practical advice is most often needed concerning the suitability and correct application of chemical treatments, the regular interpretation of analytical results obtained, and the strategies to be employed to maximize efficiency and reduce costs.

Marketing to this second group is typically based on selling some form of services-based annual contract, using the customers boiler plant operating capacity or potential for steam production as a guide for determining base requirements and for pricing purposes.

*Hot water heating and LP steam systems* are relatively easy to treat, given:

- Customer acceptance of the need for treatment (which is not always forthcoming).
- An appropriate water treatment program (which is not always provided, often due to cost issues).

- Some customer/vendor cooperation (which, thankfully, is usually the case).

In contrast, the treatment of *industrial steam generation plants* is usually more difficult. There is a need to conform to a good working standard and to produce quality waterside conditions for a long period of time without serious upsets, as the systems are always very dynamic and operating conditions can continually vary. This is especially the case with those facilities whose manufacturing operations may employ some form of on-off cycle or up-down batching process, rather than a steady-state, continuous production stream.

With the smallest *heating boilers* or *low volume/low pressure steam producers*, water treatment service companies tend to promote easy-to-understand programs, typically based on only one or two multiple-component, blended chemical products (*multiblends* or *one-drum treatments*), or increasingly, the novel crystalline solid concentrates (*solid water treatment*). These customers often have only very limited, water-related, in-house technical skills, and multiblend product programs will seem attractive because they are relatively easy to apply. However, the blending process makes it notoriously difficult to control individual component reserves in the boiler and generally adds considerably to the overall program costs.

Thus, programs based on multiblends are relatively expensive to use compared with programs based on the use of separate products that are matched to the potential for particular problems identified in a boiler plant. Nevertheless, they remain commonplace for the smallest boiler houses, but as the organizational size of the customer and its volume of daily steam production increases, so the trend for individual chemical treatments on the site tends to predominate. Often, more sophisticated chemical feed and control arrangements are also employed.

Traditionally, customers employ water treatment service companies simply as *external contractors* to assist in the maintenance of clean and efficient waterside surfaces in their various heating, steam generating, cooling, and certain industrial process systems. The customers benefit from genuine improvements in operating efficiency, reductions in maintenance time, and replacement component costs. In addition, where industrial processes are involved they often profit from an “added-value,” due to an improved product quality or reduction in manufacturing cost.

In this external contractor role, water treatment companies providing technical application and problem solving services are required to possess some general design component and process operating knowledge

of all the very many different types of industrial water systems to be found. In addition, they must possess specific and relevant water treatment technical knowledge, together with the practical experience of anticipating and solving water-related problems. Thus, the service companies that can best utilize their “storehouses” of knowledge and provide the necessary customer technical support and practical field skills also tend to gain a good reputation. Ultimately, they generate profit from their solid asset-base of people and knowledge.

It is a fact of life that the cost of providing water treatment services increases with the size and complexity of boiler plant. This cost may be recovered with larger boiler plants by the higher volumes of chemical treatments sold, as often the chemical selling prices will include an allowance for all the anticipated (and expensive) technical service time requirements.

For smaller chemical volume consumers, especially those with little in the way of in-house BW treatment technical skills, the overall program costs can be relatively high. This typically is due to the disproportionately high requirement for on-site technical service time (including the travel time to and from a customer’s site) compared to the volumes of chemical treatment sold. Travel and on-site time is expensive. Typically, the cost of labor and technical service is two to three times the cost of the chemical raw materials used to provide treatments.

As a result of the high costs of technical services, most water treatment vendors employ a variety of methods that allows them to charge an economic rate for the programs they sell. They will negotiate a price with the customer based on providing the most suitable balance of on-site service time and chemical/equipment requirements, that anticipates and resolves problems, meets the customers needs, and relieves his or her “pain.”

Traditionally, a common solution to the problem of matching relatively higher levels of technical support with lower chemical volumes for these smaller customers has been via a one- to three-year, fully inclusive product and services contract. Such a contract will specify the frequency of service visits to be made to the customer’s site and the type of work to be carried out. It will also, perhaps, limit the maximum volumes of chemical treatments to be supplied during the contract lifetime, or perhaps designate the amount of chemicals required based on treating a certain annual volume of boiler FW. Contracts may include for the provision of chemical feed and control equipment and for the supply of labor for boiler cleaning, chemical addition, and drum removal services (drumless delivery). Product and services contract prices may some-

times be specified as a cost-per-unit of steam produced (i.e., so many cents per 1,000 lb. of steam) or a cost-per-unit of production.

Under these conditions, the customer will receive a demonstrable benefit and, provided the on-site time and the volume of chemicals shipped are adequately controlled, the Service Company will derive a satisfactory profit.

Nevertheless, and irrespective of the particular mechanisms of payment for program services rendered, profit and a win-win situation will only arise for both parties if the work performed is managed competently and in a spirit of mutual cooperation.

Thus, if a field representative believes that the task is completed when the testing of water samples is performed and a service report is issued, or if the representative's interpretation of results is poor, problems will undoubtedly develop. Also, if he or she fails to adequately review the "bigger picture" rather than merely individual results, the problems will magnify and the contract will ultimately be lost.

Similarly, if the customer refuses to be involved, at least to some degree, in the ongoing water treatment program or fails to take the advice and undertake necessary actions designed to control the program and the boiler system efficiency, the program will again ultimately fail and the contract will be lost.

Today, the traditional view of boiler water treatment (and water treatment in general) is changing. The marketplace is indicating that water treatment is merely part of a more comprehensive technical support and management services industry for various water, wastewater, and manufacturing process systems. Increasingly, water treatment is widening in scope to support global market demands. It is becoming an outsourcing services business for managing all forms of water, energy, utility, and environmental needs.

Even without the current outsourcing trends, it has always been difficult for service companies to find sufficient numbers of well-trained, experienced, and motivated field representatives. This is because the range of water treatment problems and potential solutions are very wide and the business involves the marketing of many different types of chemicals and equipment, coupled with consulting work and innovative trouble shooting.

In the water treatment industry, the first line of service providers has always been the vendor's technical sales representatives, who, for the most part, are chemists, engineers, microbiologists, or similarly trained people. The field representatives typically rely on a combination of their primary disciplines and a depth of water treatment problem-solving

experience to overcome technical and operational problems and also add value to their customers operations. But in today's global economy, the sheer permutation of available niche services, the growing demands for both outsourcing of non-core utility functions, and economic fine-tuning, requires that water treaters now commonly have to additionally act as managers and administrators of their customers entire water system facilities.

Today, water treatment companies sell environmental reassurance and technology-based utility support services, not chemicals or equipment.

Boiler water treatment is now an energy management function. And while the business and practice of this industry may be well over 100 years old, it remains a vitally important function and is a cornerstone of the global industrial services market.

---

# SYMBOLS AND ABBREVIATIONS

---

Å	angstrom unit
AA/AMPS	acrylic acid/2-acrylamido-2-methyl propane sulfonic acid copolymer
AA/COPS	acrylic acid/sodium 3-allyloxy-2-hydroxy-propane sulfonate (polymer)
AA/NI-AS-LS	acrylic acid/nonionic aromatic and linear sulfonate (polymer)
AA/SA	acrylic acid/sulfonic acid
AA/SA/NI	acrylic acid/sulfonic acid/ nonionic (polymer)
AA/SA/SSS	acrylic acid/sulfonic acid/sodium styrene sulfonate acrylic acid/sulfonic acid/substituted acrylamide (polymer)
ABMA	American Boiler Manufacturers Association
ACH	aluminum chlorhydrate
AGR	advanced gas-cooled reactor
AMP	aminotri-(methylenephosphonic acid)
AMP	2-amino-2-methyl-1-propanol, AKA isobutanolamine
AO	All-Organic
AP	5-aminopentanol
AP/AO	All-Polymer/All-Organic
ASB	Shell Boiler Makers Association (UK)
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
1-AP	1-aminopyrrolidine
ATMP	aminotri-(methylenephosphonic acid)
AVAT	All-Volatile alkaline treatment
AVP	All-Volatile programs



---

# INDEX

---

- Abbott Laboratories, 519
- ABMA Commercial BW Requirements*, 563–565
- Absolute pressure, 7
  - in condenser, 118
- Acacia tannin, 405
- Acetaldehyde, DEHA oxidation product, 495, 496
- Acetaldoxime, 501
- Acetate, DEHA oxidation product, 496
- Accretion, of crystals, 224
- Acid addition, for RO pretreatment, 367
- Acid blend-fill arrangement, in cleaning processes, 639
- Acid breakthrough of ion-exchange plant, 198
- Acid cleaning
  - procedure for larger industrial WT boilers, 655–656
  - procedure for smaller FT boilers, 653–654
  - procedure for smaller WT boilers, 654–655
- Acid cleaning corrosion, 254
- Acid, as corrosion initiator, 238
- Acid dew point, 684
  - temperature, 676
- Acid leaks, 300
- Acid neutralizers, 683–684
- Acid phosphates, 420, 466
- Acid producers, 396
- Acid rain, 43, 675
- Acid/sequestrant resin cleaner program, 349
- Acid smutting, 684
  - wet, 678
- Acid soak, during cleaning, 625
- Acid vapor neutralization, 612
- Acidity dissociation constant, 522, 524
- Acmite, 228, 412
  - in scales, 645
- Acrylamide, 446
- Acrylamide/acrylate copolymers, 317, 445, 455
- Acrylamide/amine copolymer, 317
- Acrylates, 237
- Acrylic acid, 446, 452
  - for RO pretreatment, 369
- Acrylic acid/2-acrylamido-methylpropane sulfonic acid, 447
- Acrylic acid/2-acrylamido-2-methyl propane sulfonic acid, 444
- Acrylic acid/non-ionic aromatic and linear sulfonate, 447, 455
- Acrylic acid/organic phosphate polymer, 451
- Acrylic acid polymers, 316
- Acrylic acid/sodium 3-allyloxy-2-hydropropane, 607
- Acrylic acid/sodium 3-allyloxy-2-hydroxypropane sulfonate, 447
- Acrylic acid/sulfonic acid, 447
- Acrylic acid/sulfonic acid/sodium styrene sulfonate, 447
- Acrylic acid/sulfonic acid/substituted acrylamide, 447
- Acrylic acid terpolymers, 447
- Acrylic acid/vinyl sulfonate copolymer, 455, 447
- Acrylic amide, 446
- Acrysol<sup>®</sup>, 447
- Activated alumina, for lay-up programs, 610
- Activated carbon
  - bituminous coal type, 324
  - coconut shell type, 324
- Activated carbon filters, 323–325
- Acumer<sup>®</sup> 1000-1100, 446
  - 2000-2100-2400-3100, 447
  - 4161, 452
  - 4210, 451
  - 5000, 448
- Adjunct online cleaning formulations, 627–628
- Adjuncts, 385, 389, 479–558
- Adjuncts and conjunctive treatments, 479–558
  - alkalinity boosting chemistries, 545–548
  - ammonia and amine adjuncts, 510–545
  - antifoam and defoamer chemistries, 548–555
  - multiblend formulations, 555–558
  - oxygen scavenger chemistries, 479–506
  - oxygenated treatment (OT), 506–510

- Admiralty brass, protection in cleaning processes, 639
- Advanced Separation Technologies, 353
- Advantage™, 455
- Aeration
  - for iron oxidation and sulfur gas removal, 308
  - to remove iron, 309–310
  - for RO pretreatment, 367
- Aeration and oxidation, 306, 309–310
  - aeration towers, 310
  - pressure aerators, 309–310
- Aeration tower, 214, 309, 310
- After-precipitation, 201–203
  - external treatment carryover and, 201–203
- Aftertreatment deposition, 176
- Agar-agar, historical perspective, 393
- Agefloc™, 318
- Agglomeration, 313
- Air blowing, as passivator, 649
- Air cocks, *see* Boiler vents
- Air, composition of, 689–690
- Air and flue gas management system, 72, 121
- Air heater, 17, 86–87
  - cleaning flue gas side of, 611
  - corrosion from sulfuric acid, 682
- Air heater tube bundle (WT), 45
- Air ingress, prevention of in MPHWH/HPHW systems, 186
- Air in-leakage, 178
- Air management system, 72
- Air ports, inspection of, 620
- Air preheaters, inspection of, 620
- Air temperature, efficiency, 17
- Air vents, 660
- Akzo Nobel Group, 540, 648, 686
- Alamo Water Refiners, 340
- Alarm, high-low water, 82
- ALCO Chemical Company, 455
- Aldehyde, in cleaning processes, 646
- Aliphatic monoalkylamine, 537
- Aliphatic solvents, in fuel additives, 680
- Alkali, demand for, 225
- Alkali/polymer-based multifunctional formulation, 460–464
- Alkaline aluminate and silicate-based boiler compounds, 411–413
- Alkaline boil-outs, 651–653, 625
  - in cleaning processes, 646
- Alkaline citrates, in cleaning processes, 642
- Alkaline copper removal method, in cleaning processes, 645
- Alkaline earth metal salts, deposition by, 220–227
  - deposition of calcium and magnesium salts, control of, 223–227
- Alkaline earth metals, as slag modifier, 682
- Alkaline EDTA cleaning program, in cleaning processes, 638
- Alkaline gluconate programs, in cleaning processes, 646, 651
- Alkaline hardness, condensate corrosion induced by high natural, 288
- Alkaline phosphate solution, as passivator, 172
- Alkaline phosphates, 123, 421
- Alkalinity
  - due to calcium bicarbonate, 314
  - in higher quality water, 304
  - in raw water, 304
  - products for boosting, 548
  - sudden drop in, 196
- Alkalinity, boiler water, 546–547
- Alkalinity boost and adjunct formulation, 548
- Alkalinity boost chemistries, 545–548
  - as adjuncts, 389
  - calculating alkalinity feed-rate requirements, 547–548
  - as conjunctive, 479
  - for lay-up programs, 606
  - notes on boiler water alkalinity, 546–547
  - products for boosting alkalinity, 548
- Alkalinity builders, 545
  - in cleaning formulations, 650
- Alkalinity content tests, 546
- Alkalinity feed-rate requirement (with phosphate), 425
  - calculating, 547–548
- Alkalizing agent, 588
- Alkanolamides, 554
- Alkylamines, 526
  - in cleaning processes, 647
- Alkylene polyamides, 553
- Allied Colloids, 318
- All-membrane processes, for removal of chlorides/fluorides, 477
- All-organic chemistries, functional attributes, 394, 442
- All-organic cooling water programs, 419
- All-organic one-drum program formulation, 558
- All-organic program control chart, 460
- All-organic programs, 388, 437–461
  - designing and operating, 454
  - feed rates, 458
  - formulations, 460–461
- All-organics, to meet boiler plant operating objectives, 455
- All-polymer/all-organic chemistries and products, types of, 226, 394, 437–461, 545
  - as alternatives to PPN programs, 411
  - cooling water programs, 419
  - designing and operating, 454–460
  - functional attributes of AP/AO chemistries, 442–443
  - phosphino polycarboxylic acids, 451–454
  - phosphonates, 448–450

- All-polymer/all-organic chemistries and products, types of (continued)*
- polyacrylate backbone, co- and terpolymers, 447–448
- polyacrylates and related carboxylates, 445–447
- polymaleates, 450–451
- program formulations, 460–461
- tannins and lignin-based sludge dispersants, 444–445
- types of BW AP/AO chemistries and products, 443–454
- All-volatile alkaline treatments, 589
- All-volatile treatment, 478
  - in ammonia anion cycle, 378
  - FW controls, 475
  - producing ammonia in condensate, 381
  - program chemistries, 474–476
  - programs, 54, 252, 256, 389, 464, 526, 546
- Alpha particle, 62
- Alpha quartz, 229
- Alum, 315
- Alum/DADMAC polymers, 318
- Alum/EPIDMA polymers, 318
- Alum/polymer product, 316
- Alum precoat coke filters, 381
- Alumina, sintered, 359
- Aluminum, 210, 412
- Aluminum-bronze, 210
- Aluminum chlorhydrate, 316
- Aluminum hydroxide, 314
  - precoat, 299
- Aluminum oxides, 146
- Aluminium-sodium silicates, 326
- Aluminum sulfate, 314
  - historical perspective, 390
- Alums
  - as clarifying agents, 313
  - partial dealkalizing properties, 313
- Amberpack™ design, of resin bed, 352
- American Boiler Manufacturers Association, 560
- American Industrial Chemical Corporation, Inc., 445
- American Society of Mechanical Engineers, 13, 343, 387, 560
- American Society for Testing and Materials, 599
- Amides, 517
- Amine acetamides, 541
- Amine acetates, 540
- Amine adjuncts, 510–545
- Amine basicity, 526
- Amine carbonates, 522
- Amine corrosion inhibitors, for fuel oils, 686
- Amine cycle, 381
- Amine feeding and sampling, 534
- Amine oxides, 517
- Amine recycling factor, 523
- Amine salts, 517
- Amine treatment, 103
- Amine volatility, DR, 523
- Amines, 170
  - as AVT, 389
  - cavitation effect, 540
  - close-packing arrangement, 542
  - control with AVT programs, 476
  - feeding and sampling, 534
  - filmers, 536–545
  - filming amines, 536–544
  - flash point, 533
  - in fuel additives, 680
  - functional properties of neutralizing amines, 521–530
  - health and safety, 531–534
  - indoor air quality problems, 532
  - monoalkyl, 540
  - monomolecular film, 541
  - neutralization capacity, 521
  - neutralizer/filmer blend, 517
  - neutralizer/VOS blend, 517
  - neutralizing amine summary notes, 534–536
  - neutralizing blend formulations, 529–530
  - non-amine-based condensate treatments, 544–545
  - permissible exposure limits, 532
  - to prevent carbonic acid corrosion, 511
  - primary aliphatic amines, 540
  - producing ammonia in condensate, 381
  - in steam contacting food, 531–532
  - in steam humidifiers, 532–533
  - storage and handling, 531–534
  - straight-chain, 538
  - testing with sulfonphthalein dye, 543
  - thermal stability of, 530–531
  - threshold odor concentration, 532
  - triple blends, 516
  - types of neutralizing amines, 517–521
  - twin-blend neutralizing program, 516
  - vapor/liquid distribution ratio, 527
  - vapor pressure, 533
- Amino methanamide, 505
- 2-Amino, 2-methyl, 1-propanol, 518, 520
- 2-Amino, 3-methyl, 1-propanol, 523
- 4-Aminobutanal, 504
- Aminocarboxylic acids, in cleaning processes, 641
- 2-Aminoethanol, 520
- Aminoguanidines, 505
- Aminohydroxybenzene, 500
- Aminopolycarboxylic acid, 432
- 1-Aminopyrrolidine (1-AP), 504
- 1-Aminopyrrolidine hydrochloride, 504
- Aminothianolamines, 495
- Aminotri(methylenephosphonic acid), 432, 449
- Ammonia, 102, 103, 152, 498, 510, 518, 521, 526

*Ammonia (continued)*

- adjunct, 510–545
- ammonia/amine carryover, 483
- in ammonia anion cycle, 378
- as AVT, 389
- with AVT programs, 475
- carbon dioxide and carbonic acid, 514–517
- in cleaning processes, 637, 644
- in condensate, 381
- control in supercritical boilers, 476
- in OT programs, 508
- in steam and condensate, 492
- in steam-condensate systems, 284–285, 291, 292, 293
- testing in steam/condensate, 602
- Ammonia anion cycle, in condensate polishing, 378
- Ammonia break, 381
- Ammonia control, as functional area requiring chemicals, 387
- Ammonia-copper complex, 285
- Ammonia/hydrazine mix, as passivator, 649
- Ammonia/hydroxide cycle condensate polishers, 380
- Ammonia release, 170, 293
- Ammoniated citric acid/air/nitrite, in cleaning processes, 644
- Ammoniated citric acid, in cleaning processes, 637, 644
- Ammoniated EDTA/hydrazine mix, in cleaning processes, 638
- Ammonium bicarbonate/hydroxide/oxygen, in cleaning processes, 644
- Ammonium bifluoride, 625
  - in cleaning processes, 639, 645, 646
- Ammonium bromate, in cleaning processes, 643
- Ammonium carbamate, 212, 232
- Ammonium carbonate, 381, 646
- Ammonium chloride
  - in clinker treatments, 683
  - in fuel additives, 680
- Ammonium hydroxide, 493, 518
  - GRAS listing, 531
  - in steam-condensate systems, 292
  - for testing sodium, 603
- Ammonium nitrite, in cleaning processes, 643
- Ammonium perborate, in cleaning processes, 643
- Ammonium persulfate, in cleaning processes, 643
- AMO-95<sup>®</sup>, 518
- Amorphous iron oxides, in condensate, 379
- Amorphous, scale, 224
- AMP, *see* 2-Amino, 2-methyl, 1-propanol
- Amphiphilic compounds, 538
- Analcite, 145, 229
  - in boiler deposits, 635
  - historical perspective, 391
  - in scales, 645
- Analysis of glue gas, 691–692
- Angstrom units, 648
- Angus Chemical Company, 518
- Anhydrite, 145, 234
  - in boiler deposits, 635
  - in scales, 645
- Anion exchange dealkalization, as purification technology, 343
- Anion exchange, to limit silica, 294
- Anion permeable membrane, 373
- Anion resin cleaning program, 349
- Anionic or non-ionic surfactant, in cleaning formulations, 651
- Anionic polyelectrolyte sludge conditioners, 316, 406
  - tannins as, 445
- Anions, in ion-exchange, 347
- Annular flow, 6
- Anode, 149
- Anodic and cathodic phosphate inhibitors, 399–400
- Anodic half reactions, 149, 286
- Anodic inhibitor chemistries, 394–403
  - anodic and cathodic phosphate inhibitors, 399–400
  - anodic inhibitor programs, 402–403
  - azoles, 400–402
  - borates, 399
  - nitrites, 395–397
  - molybdates, 397–398
  - silicates, 398–399
- Anodic inhibitor programs, 241, 388, 402–403
- Anodic inhibitors, 171, 438
- Anodic passivating agent, 396
- Anodic polarization, 151
  - by phosphate action, 400
- Anticaking agents, for fireside cleanliness, 611
- Antifoam and defoamer chemistries, 548–555
  - as adjuncts, 389, 479
  - formulations, 554
  - historical perspective, 393
  - mechanisms of foaming and its control, 549–551
  - selection, 551–555
    - block copolymers, 552
    - polyalkylene glycol derivatives, 552–553
    - polyamides, 553–554
    - silicones, 554–555
- Antifoulant, function of all-organics, 442, 443
- Antifreezes, 402
- Antimicrobial 728-8536, as RO membrane cleaner, 371
- Antiscalants, 146
  - function of all-organics, 442
- Antisettling dispersant, 672
- Appurtenances, *see* Boiler appurtenances
- AQ<sup>™</sup> Total, nonchemical technology, 340
- Aqua Magnetics<sup>®</sup>, nonchemical technology, 339

- Aquatreat® AR-232 -602 -900, 446  
AR-540 -550, 447
- Aragonite, 406  
in scales, 645  
sludge, 224
- Argo Scientific, 371
- Argon, in air, 689
- Armohib 28, 31, 648
- Aromatic solvents 110, 150, 686  
in fuel additives, 680
- Arsenic, 210
- ASB Treatment of Water for Shell Boiler, 1997, 1988, 560*
- Ash content, of fuel oils, 683
- Ashland Chemical Corporation, 455, 552
- ASME, 13
- ASME Consensus 1994, 560, 561*
- Aspergillus niger*, 404
- Asphaltenes, 672, 673  
dispersant, 672, 685
- Asphalts, 685
- Asphalts and waxes, cleaning method, 651
- Association of Shell Boilermakers, 560
- ASTM D-1066, 278, 599
- Atomic absorption spectroscopy, 622
- Atomic hydrogen, 256
- Atomizing oil burners, 83
- Attenuating nozzle, 602
- Attenuation water, 90
- Attenuator, 71  
direct type, 91  
heat exchange, 91  
spray (WT), 47  
spray type, 91  
spray water quality, 569  
surface, 91  
WT, 44
- A-type WT boiler design, 50
- Austenitic steels, 169  
stainless steel, 266
- Autoclaves, with amines, 533
- Auto-ignition temperature, 681
- Automatic analyzer, 257
- Automatic nonreturn valves (NRVs), 80
- Autotrol™ controllers, 332
- Auxiliaries, 71  
boiler, 82  
*see also* Boiler auxiliaries
- Auxiliary boiler, *see* Boiler, auxiliary
- Aviation kerosene, infection by *Clostridium*, 686
- Avista, 371
- AVT, *see* All-volatile treatment
- Azeotrope formation, of amines, 511
- Azoles, 400–402
- Bacharach, Inc., 693
- Back-end convection area, 675
- Backflow preventor, 660
- Backpressure, condenser, 118
- Backwash, of ion-exchange resin bed, 329
- Bacteria, separation of by membrane technology, 360
- Bacterial slimes, cleaning in RO plants, 371
- Baffles, 85  
inspection of, 620
- Bag filters  
for condensate conditioning, 376  
related technologies and, 325–326  
for RO pretreatment, 368
- Bag house, 678
- Bagasse, 17, 58, 671, 683  
as fuel, 51
- Baked on sludge, 194, 218, 237, 296, 613
- Balance of plant (BOP) equipment, 71, 86, 112–119  
condensers, 116–117  
electricity generators, 113–115  
steam and water problems affecting turbines, 115–116  
surface condenser operational problems, 117–119
- Balanced draft system, 86
- Balanced polymer, as conjunctural, 479
- Bar gauge, definition of, 3
- Barium, 221
- Bark, 683  
as fuel, 51  
fuel treatment formulation, 687
- Barrier films, 397
- Base load boilers, 465
- Base-exchange softener, 161
- Base-exchange softening, following dealkalization process, 162
- Base-load stage heater units, lay-up, 609
- Basic oxygen furnace boilers, 57  
*see also* Boiler, BOF
- Basic pretreatment processes, 307–341  
aeration and oxidation, 309–310  
pretreatment using natural zeolite, greensand, and synthetic resins, 326–332  
clarification, 313–320  
pre-boiler filtration, 320–326  
precipitation softening, 310–313
- Basic sediment and water, 685
- Basicity, 521, 523–526  
of amines, 511, 523  
degree of, 316
- Basicity dissociation constant, 522, 524, 535
- BASF A.G., 520, 552
- Batch regeneration processes, 351
- Bauxite, for lay-up programs, 610
- Bayer AG, 351, 352, 489
- Bayhibit®AM, 449
- Bead resin deep-bed polishers, 379–382
- Belclene® 161, 370  
161/164, 452

- Belclene*<sup>®</sup> 161 (*continued*)  
 200, 451  
 400, 447  
 511/512, 401
- Belros<sup>®</sup>, 285, 370, 435
- Bel-Trak<sup>®</sup>, 441, 662
- Benzene dicarboxylic polymers, 686
- 1,4-Benzenediol, 499–501
- Benzoate, 395
- Benzotriazole, 395, 401  
 in cleaning processes, 647
- Benzoquinone, 500  
 as catalyst, 495
- Benzyl alcohol, 686
- Benzylamine, 518
- Beta particle, 62
- Betz, 497
- Bicarbonates, 221–223
- Bilges, 74
- Binders, lignins as, 445
- Biocides, fuel oil, 686
- BioLabs, 401, 441, 662
- Birm<sup>®</sup> catalyst, 308, 309
- Black liquor recovery boiler, 57–58, 679; *see also* Boiler, carbon monoxide
- Blast furnace gas, 57  
 as fuel, 51
- Blend-fill station, 655
- Blistering  
 inspection for, 620  
 managing, 625
- Block copolymers, 442, 552  
 as antifoams, 551
- Blocked intake screens, in condensers, 117
- Blowdown  
 calculation of, 78  
 continuous, 74, 76  
 continuous conductivity measurement  
 controlled, 77  
 controlling in LP boilers, 182  
 intermittent, 76  
 intermittent conductivity measurement  
 controlled, 77  
 main arrangement, 75  
 rapid action intermittent arrangement, 77–78  
 regulatory requirement, 75  
 skimmer type, *see* Blowdown surface type  
 surface type, 74, 76  
 timer controlled intermittent, 76
- Blowdown (blow off) valves, 73–79  
 calculating blowdown (BD), 78–79  
 main (primary or bottom) BD arrangement,  
 75–76  
 rapid action intermittent BD arrangement,  
 77–78  
 surface (skimmer) BD arrangement, 76–77
- Blowdown efficiency, 19–20
- Blowdown and heat recovery system,  
 inspection of, 621
- Blowdown valve, *see* Valve, blowdown
- Blowdown water, 75
- Blowdown water and flash steam and heat  
 recovery systems, 94–97
- Boil-out program, 625  
 to remove oil, 299
- Boil-outs, 625  
 of boilers, 123  
 need for, 307  
 using phosphate, 419
- BOF boilers, *see* Basic oxygen furnace boilers
- Boiler  
 appurtenances, 3  
 auxiliaries, 3, 55  
 black liquor recovery, 57  
 BOF, 57  
 carbon monoxide, 57  
 cast iron sectional, 33  
   basic pretreatment needs, 307  
 cleaning, 623–657  
 cleaning LP steam generator, 625  
 coil  
   basic pretreatment needs, 307  
   with external recycle, 593  
   with integral recycle, 593  
 coil type, *see* Boiler, water tube, coil type  
 combined-cycle type, *see* Boiler, water  
 tube, cogeneration  
 compact/special design, water quality  
 needs, 342  
 contamination at startup, 605  
 critical pressure, 42  
 cyclone fired, once-through, subcritical  
 utility, 625  
 direct fired, 23  
 dryback, 32  
 electric, 23, 24  
 electrical resistance, 23, 24–27  
   basic pretreatment needs, 307  
 electrode, 23, 24, 27–29  
   basic pretreatment needs, 307  
   sprayed electrode type, 28  
   steam for turbines, 605  
   submerged electrode, 27  
     variable water level type, 28  
   water-jet type, 28  
 energy and power units, 11  
 enhanced oil recovery, 58  
 field-erected, 9  
 fire tube, 2, 23, 29–39  
   Cornish, 31  
   economic, 30  
   externally fired, 30  
   firebox, 30, 33  
   HRT, 30  
   inspection of, 615–618  
   internally fired, 30  
   Lancashire, 31  
   locomotive, 30

*Boiler (continued)*

- vertical type, 30
  - Scotch marine, 30, 32–33
    - basic pretreatment needs, 307
- firebox, *see* Boiler, fire tube, firebox
- firetube plant steam system cycle, 134
- fluidized bed combustion, 58
- fossil-fueled, 679
- higher-pressure units, water quality needs, 341
- highly rated, water quality needs, 342
- horizontal return tubular, *see* Boiler, fire tube, HRT
- HPHW, 1, 36
  - summary of problems, 187
- hydronic heating, 32
- indirect, 56
- industrial types, *see* Boiler, water tube, industrial
- jet steam, steam for turbines, 605
- larger and more complex plant, water quality needs, 342
- LP energy losses due to deposition, 666
- LP steam, basic pretreatment needs, 307
- LP steam systems, 175, 178–188
- LPHW, 1, 36, 175, 178–188
  - summary of problems, 187
- marine type, *see* Boiler, water tube, marine
- medium-temperature hot water, *see* boiler, MPHWH
- MPHW, 1, 36
  - summary of problems, 187
- MPHW/HPHW, waterside problems, 185–189
- nameplate, 11
- nuclear, 42
- nuclear reactor, 23, 61–66
- packaged, 42
  - horizontal, 34, 35–37
  - vertical, 34, 38–39
- peak-load, 625
- plant, water treatment basics, 119–129
- problems with poor LP system design, 184
- Scotch type, *see* Boiler, fire tube, Scotch marine
- shell, *see* Fire tube
- single phase, 53
- standby, managing, 606–612
- start-up hold times, 504
- steam generation system, 71
- steam–water circulation system, 45
- sugar refinery, 58
- supercritical, 23
- two-phase, 54
- utility, *see* Boiler, water tube, utility power
- vertical, basic pretreatment needs, 307
- vertical type, *see* Boiler, fire tube, vertical
- waste heat, 55
  - steelworks, 57

*Boiler (continued)*

- waste heat type, *see* Boiler, water tube, waste-heat
- waste-to-energy, 59
- water tube, 2, 23, 39–60
  - bent tube design, 41
  - cogeneration, 41, 52–53, 59
  - coil type, 40, 49
  - heat recovery, 53
  - industrial, 40, 49–52
  - inspection of, 618–621
  - marine, 41, 55–56
  - radiant, 42, 53–54
  - special purpose designs, 41, 56–61
  - Stirling<sup>®</sup>, 41
  - utility power, 41, 53–55
  - waste-heat, 41, 56–61
- watertube cogeneration plant steam system cycle, 134
- wetback, 32
- Boiler appurtenances, 71, 72–82
  - blowdown (blow off) valves, 73–79
  - boiler safety and stop valves, 79–80
  - boiler vents, 80
  - feedwater regulators, 80–81
  - pressure gauges, 81
  - soot blowers, 81–82
  - water columns, 82
- Boiler auxiliaries, 71, 72, 82–112
  - baffles, 85
  - blowdown water and flash steam and heat recovery systems, 94–97
  - burners, 82–84
  - condensate pumps and tanks, 98
  - dampers, 85
  - economizers and air heaters, 86–87
  - fans, 85–86
  - feedwater heaters and deaerators, 98–108
  - feedwater pumps, 88
  - feedwater tanks for fire tube boilers, 108–112
  - sampling coils, 93–94
  - spray attenuators, 91
  - steam traps, 91–92
  - stokers, 84
  - superheaters and reheaters, 90–91
- Boiler-bank tube bundle (WT), 46
- Boiler bank tubes (WT), 44
- Boiler-bottom sludge, 296
- Boiler cleaning, 623–657
  - acid cleaning procedure for smaller FT boilers, 653–654
  - acid cleaning procedure for smaller WT boilers, 654–655
  - boiler scales and deposits, 632–635
  - chemical cleaning basics, 625–630
  - cleaning solutions and inhibitors, 635–651
  - determining necessity for, 631–632
  - determining when a boiler needs cleaning, 631–632

*Boiler cleaning (continued)*

- supplementary cleaning notes, 651–657
  - acid cleaning larger industrial WR boilers, 655–656
  - fireside cleaning of small FT boilers, 656–657
  - precommission cleaning and alkaline boil-outs, 651–653
- Boiler compounds, 389
- Boiler cycling, 21, 115
- Boiler draft pressure, 86
- Boiler energy and power units, 11–13
- Boiler heat transfer surface cleanliness, 456
- Boiler indirect fired, 23
- Boiler inspections, 124, 612–623
  - inspecting boiler pretreatment plant, 615
  - inspecting FT boilers, 615–618
  - inspecting WT boilers, 618–621
  - preparation for, 613–614
  - scope of inspection work, 614–615
  - supplementary inspection notes, 621–623
    - deposit analysis, 622
    - nondestructive testing, 622–623
- Boiler Lizard™, for lay-up programs, 610
- Boiler loading efficiency, 10, 19
- Boiler plant
  - appurtenances, 67–129
  - auxiliaries, 67–129
  - operational basics, 119–129
  - operational management processes, 120
  - sub-systems, 67–129
- Boiler plant efficiency, 14–22
  - blowdown efficiency, 19–20
  - boiler loading efficiency, 19
  - combustion efficiency, 15–17
  - feedwater and air temperature efficiency, 17–19
  - steam pressure efficiency, 17
  - steam trap efficiency, 19
  - turbine and condenser operation efficiency, 20–22
- Boiler plant mechanical operational functions, 120–124
  - air and flue gas management system checks, 121
  - boiler inspection work, 124
  - condensate return system checks, 121
  - feedwater supply system checks, 121
  - fuel management system checks, 121
  - instrument and control systems checks, 121–122
  - interlock systems function checks, 121
  - new boiler work, 123
  - off-line, safety, and other appurtenance valve checks, 124
  - periodic chemical cleaning, 122–123
  - water-steam appurtenance checks, 120
- Boiler plant operational and water treatment basics, 119–129

*Boiler plant operational and water treatment basics (continued)*

- boiler plant mechanical operational functions, 120–124
- water treatment program management, 125–129
- Boiler plant sections, 43
  - convection pass section, 43, 44–45
  - exit gas section, 43, 45
  - furnace section, 43–44
- Boiler plant subsystems, 69–72
  - air and flue gas management system, 72
  - balance of plant equipment systems, 71
  - boiler steam generation system, 71
  - condensate return system, 72
  - feedwater supply system, 70–71
  - fuel management, system, 72
  - steam delivery system, 71
  - wastewater treatment system, 72
  - water pretreatment plant system, 69–70
- Boiler plant subsystems, appurtenances, and auxiliaries, 67–129
  - boiler auxiliaries, 82–112
  - boiler appurtenances, 72–82
  - boiler plant systems, 69–72
- Boiler safety and stop valves, 79–80
  - automatic nonreturn valves, 80
  - safety valves, 79
  - stop valves, 79
- Boiler scales and deposits, 632–635
  - carbonates, 633
  - copper salts, 633
  - iron oxides, 633–634
  - magnesium, 634
  - nickel, 634
  - organics, 634–635
  - phosphates, 635
  - silicates, 635
  - sulfates, 635
- Boiler scaling, fouling, and deposition, 217–237
  - deposition by alkaline earth metals salts, 220–227
  - deposition by silicates and other common minerals, 227–237
- Boiler section oxygen corrosion, 243–245
- Boiler section oxygen removal, 480
- Boiler section problems, 217–271
  - boiler scaling, fouling, and deposition, 217–237
  - nuclear powered steam generators, corrosion in, 265–267
  - other forms of corrosion, 262–265
  - passivation and common corrosion problems, 237–254
  - stress and high temperature–related corrosion, 254–262
- Boiler shell, inspection, 617
- Boiler shutdown procedures, 124



- Boiler steam generation system, 71
- Boiler steam-water circulation system, 45–46
- Boiler surfaces deposits, 468
- Boiler surfaces passivation, 241–242
- Boiler surfaces (WT), 44, 53, 71, 86, 144
- Boiler tube failure, understanding the cause and effect of, 157
- Boiler tube, iron oxide deposits, 633
- Boiler types and applications, 23–66
  - electric boilers, 24–29
  - fire tube (shell) boilers, 29–39
  - nuclear reactor boilers, 61–66
  - water tube boilers, 39–61
- Boiler vents, 73, 80
- Boiler wash-down, 122
- Boiler water alkalinity, 546–547
- Boiler water, carryover, 21
- Boiler water chemistry
  - control of, 559–598
    - water treatment recommendation perspectives, 560–566
    - tables and supporting notes, 566–598
  - corrosion caused by unbalanced, 244
- Boiler water, operational stability pH for metals, 524
- Boiler water solids, transport of, 203
- Boiler water treatment programs, 385–478, 479–558
  - meaning of, 139
  - minimum requirements, 134
  - practical objectives, 142
  - servicing functions of, 137
- Boilers
  - as accumulators, 32
  - backup, 607
  - blowdown of, 74
  - cast-iron sectional, 183
  - clean-steam type, 323
  - coil, steam for turbines, 605
  - electrode, water condition guidelines, 564
  - highly rated, 13, 230
  - HW heating, basic pretreatment needs, 307
  - idle, oxygen corrosion in, 243
  - idle, waterside protection for longer-term, 608–611
  - idle, waterside protection for short-term, 606–608
  - integral furnace, 42
  - low-load, oxygen corrosion in, 243
    - low-temperature hot water, *see* Boiler, LPHW
  - natural circulation, 655
  - nuclear powered steam generators, 474
  - once-through, 474
    - steam sampling during commissioning, 605
  - resistance, water condition guidelines, 563–564
- Boilers (continued)*
  - shell, recommended water characteristics, 564–565
  - standby, waterside protection for longer-term, 608–611
  - supercritical, 474
  - watertube, contamination of condensate, 605
    - subcritical, 23
- Boiling
  - convective, 5, 6
  - nucleate, 5
  - surge, 7
  - two-phase, nucleate, 7
- Boiling point, incipient, 6
- Boiling point of water, 4
- Borates, 399
- Borax, 395, 399
- Boric acid, 65, 477
- Boron, rejection rate with RO, 361
- Boroscope™, 124, 619
- Bottom ash, 682
- Bottom drum, *see* Mud drum
- Bourdon tube, 81
- Boyles Law of Gases, 690
- BP Chemicals PLC, 520
- Brackish water, as source for RO, 365
- Breakout of tubes, inspection for, 620
- Brine regenerant, inadequate, 197
- Brine reject, 363
- Briquest® 301 -50A, 449
- Briquest® ADPA 60A, 449
- British Standards Institute, 13, 343, 387, 404, 560, 599
- British Thermal Unit, 11
- Brittle fracturing, 258
- Bromate, in cleaning processes, 644
- Bronze, protection in cleaning processes, 639
- Brown coal, fuel treatment formulation, 687
- Brucite, 224, 423
  - in boiler deposits, 634
  - in scales, 645
- BS 24861978, Treatment of Water for Land Boilers*, 404, 560
- BS 24861997, Treatment of Water for Steam Boilers*, 343, 404, 562–563
- BS 6068 Section 6, 7 1994*, 600
- B-scan ultrasonic testing, 622
- BSI, 13
- BSI® 89, 446
- BS&W, *see* Basic sediment and water
- Btu heat content, of fuels, 670
- Bubble rupture mechanisms, 550
- Bubble thinning mechanisms, 550
- Bubbling fluidized bed, *see* Fluidized bed, bubbling
- Bubbly flow, 6
- Buffering, using phosphate, 419
- Build, own, operate, maintain program, 128

- Bulges, 259
- Bulging, inspection for, 620
- Bunsenite, 233
- Burner cleaning, 649
- Burner registers, 85
- Burners, 82–84
  - atomizing oil burners, 83
  - gas burners, 84
  - inspection of, 620
  - pulverized fuel coal burners, 83
  - vaporizing oil burners, 83
- Butyraldehydeoxime, 501
- BW maximum concentration
  - recommendations for steam boilers, 563
- BW treatment and control of steam/waterside chemistry, 134–140
- BWT–Europe, 340
  
- Calcite, 144, 631
  - in boiler deposits, 633
- Calcite control, with nonchemical technology, 340
- Calcite sludge, 224
- Calcium, 221
  - as slag modifier, 682
- Calcium aluminum silicate, historical perspective, 391
- Calcium-aluminum silicate zeolite, 411
- Calcium bicarbonate, 144, 310
  - alkalinity, 223, 514
  - removal, by degassing, 354
- Calcium carbonate, 144, 176, 221–222
  - in scales, 645, 646
  - limit in RO systems, 369
- Calcium carbonate crystal distortion
  - by phosphate action, 400
  - function of all-organics, 443
- Calcium carbonate crystal, nucleation of, 228
- Calcium carbonate scaling, from hardness
  - breakthrough, 660–661
- Calcium chloride, noncarbonate hardness, 312
- Calcium fluoride, production during cleaning, 639
- Calcium hideout, in reactor water, 382
- Calcium hydroxide
  - as a softening agent, 311
  - in scales, 646
- Calcium-magnesium-aluminum silicate, 411
- Calcium and magnesium salts, control over deposition of, 224–227
- Calcium orthophosphate scale, 235
- Calcium phosphate, 145, 212, 221–222
  - deposits, 234
  - in scales, 645, 646
  - solubility constant, 422
- Calcium salt, in boiler deposits, 633
- Calcium salt crystal structures producing calcite, 406
- Calcium salts, deposition by, 223–224
- Calcium sulfate, 221–222
  - anhydrous, 145
  - deposits, 234
  - in scales, 645, 646
  - limit in RO systems, 369
  - noncarbonate hardness, 312
  - solubility, 234
- Calgon<sup>®</sup>, 422, 497
  - historical perspective, 392
- Calgon<sup>®</sup> RB-304, 494
- Calloway<sup>™</sup>, 318
- Calorific value
  - low in fuels, 683
  - of fuels, 670
- Camellia sinensis*, 408
- Candle filters, for condensate conditioning, 376
- Captive alkalinity program, 464, 469–470
- Carbamates, in fuels, 671
- Carbamide, 684
- Carbazide, 502
- Carbohydrazide (CHZ), 500, 502–504, 510
  - with AVT programs, 474
  - as passivator, 649
- Carbon
  - as combustant, 691
  - reaction producing carbon dioxide, 691
  - reaction producing carbon monoxide, 691
- Carbon content, of fuels, 670
- Carbon dioxide, 102, 152, 217–221, 227, 498, 514–517
  - in air, 689
  - in condensate, 381
  - as corrosion initiator, 238
  - as a dissolving agent for limestone, 311
  - removal by RO, 360
  - removal of in water, 312
  - in steam-condensate systems, 284–285, 510
  - testing in steam/condensate, 602
- Carbon catalyst technologies, 305
- Carbon dioxide absorption value, of amines, 521
- Carbon dioxide, 514–517
  - carryover, 288–291
  - control, as functional area requiring chemicals, 387
  - removal, by ion-exchange, 349
- Carbon filter, 200
- Carbon monoxide, 693
  - as fuel, 51
  - reaction producing carbon dioxide, 691
- Carbon monoxide boilers, 57
- Carbon zeolites, historical perspective, 391
- Carbonate conditioning, 584, 657
  - relationship to form mobile precipitants, 580
- Carbonate control programs, 164
- Carbonate-cycle boiler programs, 413–419

- Carbonate cycle program, 227
- Carbonate hardness, 311
- Carbonate/nitrite mix, as passivator, 649
- Carbonate and phosphate control levels, 580
- Carbonate-polymer programs, 413
- Carbonate removal, using hot-lime precipitation softening, 309
- Carbonate scale, 226
- Carbonate scaling, 238
- Carbonate treatment, 413
- Carbonates, 211–223, 219, 438, 633
  - in boiler deposits, 633
  - cleaning in RO plants, 371
  - as a precipitant, 388
- Carbonic acid, 152, 204, 514–517
  - formation in condensate, 289
  - penetration rates in steam/condensate lines, 514
- Carbonic acid control, as functional area requiring chemicals, 387
- Carbonic acid dihydrazide, 502
- Carbonized or coke deposits, cleaning method, 651
- Carbonized organic components, 237
- Carborundum, in fuel additives, 680
- Carboxy-methylcellulose, 438
- Carboxylate, as combustion catalyst, 681
- Carboxylate groups, 442
- Carboxylic acids
  - contaminants in steam-condensate systems, 291
  - from tannins, 406
- Carboxymethylcellulose, 283
- Carryover, 33, 115, 154, 155, 183, 194, 200, 202, 276, 282, 283, 290, 300
  - boiler sludging and, 194
  - cleaning need, 631
  - control, as functional area requiring chemicals, 387
  - degree of, 604
  - from excess softener chlorides, 661
  - from external treatment, 201–203
  - of external treatment, 229
  - sampling for, 602–604
  - steam–water interface physicochemical factors and, 282–284
- Carryover of external treatment into feedwater, 201–202
- Carryover measurement, 602
- Carryover of water droplets, 8
- Carryunder of steam, 8
- Cartridge filters, for condensate conditioning, 376
- Cartridge filtration, for RO pretreatment, 368
- Cast iron
  - gray, 211, 402
  - nodular, 211
- Cast iron sectional boilers, 33–34
- Castor oil
  - as adjunct, 389
  - historical perspective, 393
- Catalyst, adventitious, 485
- Catalytic devices, 333–341
  - with nonchemical technology, 334
- Catalytic reduction processes, 684
- Catalyzed carbon bed technology, for oxygen removal, 382–383
- Catalyzed hydrazine, 494, 510
- Catalyzed scavengers, 168
- Catalyzed sodium sulfite, 485
  - use of in MPHW/HPHW systems, 186
- Catechol, 506
  - from tannins, 406
- Cathanodic action, of polymer, 448
- Cathode, 149
- Cathodic depolarizing agent, 250
- Cathodic half reactions, 149, 286
- Cathodic inhibitors, 647
- Cathodic polarization, 150
- Cathodic protection, corrosion control through, 167–168
- Cation/anion condensate polishers, 380
- Cation exchange dealkalization, as purification technology, 342
- Cation exchange of hardness, via multifunctional water conditioner, 332
- Cation ion-exchange for hardness removal, 309
- Cation permeable membrane, 373
- Cation resin, cleaning, 349
- Cationic polyelectrolytes, 316
- Cationic polymer coagulants, 313
- Cationic resins, 685
- Cations, in ion-exchange, 347
- Cause and effect problems, 136, 174, 238
  - understanding, 157, 173
- Caustic, 123
  - in cleaning formulations, 649, 651
  - in cleaning processes, 637, 646
  - as corrosion initiator, 238
  - to provide FW alkalinity, 511
  - requirement with phosphate, 423
- Caustic addition, in dealkalization process, 161
- Caustic alkalinity, 546
- Caustic attack, 249–250
- Caustic-based corrosion problems, 464
- Caustic control, as functional area requiring chemicals, 387
- Caustic cracking, 255–256
- Caustic deposits, 227, 232
- Caustic embrittlement, 255–256
  - historical perspective, 393
- Caustic free programs, 54
- Caustic gouging, 249–250
- Caustic precoat coke filters, 381
- Caustic resin cleaning program, 349
- Caustic soda, 30, 411

- Caustic stress corrosion cracking, 255–256
- Cavitation erosion, 89
- CDI™ system, 375
- Celgard, 383
- Cell-pair, in ED technology, 374
- Cementite, 261
- Cenospheres, 673
- Centrifugal pumps, 88–89
- Ceramic membranes, 359
- Cerium
  - in fuel additives, 680
  - as slag modifier, 682
- Cerium octoate, in fuel additives, 680
- Cerium salts, as fuel additives, 675
- Cerium sulfonate, in fuel additives, 680
- CFR 21 §172.615, 484
- CFR 21 §173.310 (boiler water additives), 60, 444, 452, 460, 484, 489, 553
- CFR 21 §182.304, 497
- CFR 21 §184.1139, 531
- Chain reaction, 61
- Charge neutralization, 313
- Check valves
  - fouling, 201
  - sticking, caused by metal transport, 297
- Checks
  - air and flue-gas management system, 121
  - condensate return system, 121
  - feedwater supply system, 121
  - fuel management system, 121
  - instruments and control system, 121
  - interlock systems function, 121
  - off-line, 124
  - valve, 124
  - water-steam appurtenances, 120
- Chelant attack, 262–265
- Chelant-based combination programs, 460–464
- Chelant-based multifunctional programs, 388
- Chelant corrosion, 262–265, 436
- Chelant demand, 435
- Chelant overlay programs, 458
- Chelant-, phosphate-, or polymer-based
  - combination programs, 461–463
- Chelant/polymer formulation, 460–464
- Chelant program chemistries, 430–437
  - chelant basics, 431–433
  - practical application of chelants, 433–437
- Chelant programs, 226, 388
  - as alternatives to PPN programs, 411
  - for wet lay-up, 609
- Chelant residual, 435
- Chelants, 87, 262, 438
  - as continuous support to existing program, 430
  - as corrosion initiator in cause and effect problems, 238
  - function of all-organics, 442
  - in low-hardness FW, 430
- Chelants (continued)*
  - need for oxygen control, 436
  - used under variable FW conditions, 430
  - with phosphate precipitation programs, 430
  - as solubilizing programs, 430
- Chelating agents, 431
- Chelation stability constants, 433
- Chelating function, of lignins, 445
- Chelation, in cleaning processes, 637
- Chelonate, 435
- Chemical cleaning, 625–630
  - of hot water and LP steam heating boilers, 122
  - of industrial boilers, 122
  - offline cleaning basics, 629–630
  - online cleaning basics, 626–627
  - online cleaning formulations, 627–629
  - of utility boilers, 122
- Chemical dosing, for RO pretreatment, 368
- Chemical incompatibility, 300
- Chemical polishers, 305
- Chemical Publishing Company, 560
- Chemical treatment
  - additions, 125, 126
  - hampered, caused by oily surfaces, 299
  - testing and interpretation, 125–126
- Chemicals, for internal treatment, 385–478
- Chemisorption, of azoles, 400
- Chemisorption bonds, formation of by
  - inhibitors, 647
- Chemisorption process, 151
- Chemitreat PTE (Singapore), 375
- Chemtall, Inc., 318
- Chestnut tannin, 405, 484
  - historical perspective, 392
- Chile niter, historical perspective, 393
- Chipping hammers, 631
- Chloride attack, 588
- Chloride control, as functional area requiring
  - chemicals, 387
- Chloride ions, 169
- Chloride leakage, 197–198
  - into feedwater, 197–198
  - from polishers, 382
- Chloride salinity, control over, 169
- Chlorides, 217
  - as cathodic depolarizing agents, 151
  - effect on nitrite feed rate, 396
  - penetrating deposits, 144
  - in water supplies, 234
- Chlorinated hydrocarbons, in cleaning
  - formulations, 650
- Chlorine addition, for RO pretreatment, 367
- Chlorine, chemisorption by GAC, 323
- Chlorine removal, 323
- Chloroform extraction, 543
- Chlorophenols, 404
- Chordal thermocouple, measurement, 623
- Chromate, 397
  - inhibitors, 580

- Chromic acid
  - in cleaning formulations, 651
  - in cleaning processes, 646
- Chromium<sup>5+</sup>, 268
  - in higher quality water, 305
- Chromium oxides,
  - in corrosion debris, 296
  - transport of, 232
- Chromium transport, 212
- Churn flow, 6
- Ciba Chemical Specialties, 318
- CIP, *see* Clean-in-place
- Circulating fluidized bed, *see* Fluidized bed, circulating
- Circulation rates
  - of boiler water, 14
  - of two-phase mixtures, 14
- Cis-butenedioic anhydride, 443
- Citrate/iron/nitrite mix, as passivator, 649
- Citric acid, 432
  - in cleaning processes, 637, 638
  - as erythorbate stabilizer, 498
  - in RO cleaners, 372
- Citrosolve process, 644, 649
- Clarification, 306, 313–320
  - in anthracite filters, 309
  - definition, 314
  - inorganic coagulants, 314–316
  - organic polymeric coagulants and flocculants, 316–320
  - by sedimentation, 308
- Clarification processes, 313–320
- Clarifloc™, 318
- Clarity, of treated water, 320
- Clean-In-Place, for RO, 366
- Clean-steam generators, 60
- Cleanup rate, during online cleaning, 626
- Cleaner formulations, 650
- Cleaning
  - supplementary notes, 651–656
  - using phosphate, 419
- Cleaning methods, 623
- Cleaning notes, supplementary, 651–657
- Cleaning program, multiple step approach, 655
- Cleaning solutions and inhibitors, 635–656
  - inhibitors for cleaning solvents, 647–648
  - passivators for cleaning solvents, 648–649
  - removal of copper/copper oxides, 641–643
  - solvents for removing copper and copper oxides, 643–645
  - solvents for removing iron oxides, 637–641
  - solvents for removing organics, 649–651
  - solvents for removing scales, 645–647
- Clinker eutectic point, 683
- Clinker treatments, 683
- Closed and dry lay-up programs, 610
- Closed feedwater heaters, 99–100, 305
- Closed loop heating system, 133
- Clostridium*, 686
- Coagulants, 305
  - coagulant aids, 320
  - organic polymeric types, 316–320
- Coagulation, definition of, 313
- Coagulation and precipitation program
  - chemistries, 388, 411–430, 440
  - alkaline aluminate and silicates-based boiler compounds, 411–413
  - carbonate-cycle boiler programs, 413–418
  - phosphate-cycle boiler programs, 419–430
- Coal, 670
  - anthracite, 16
  - bituminous, 17
  - subbituminous, 17
- Coalescence mechanisms, 550
- Coalescing filters, 381
- Coarse black magnetite, 91
- Coarse magnetite corrosion, 242–243
- Coatings, temporary, for lay-up programs, 612
- Cobalt, as catalyst, 505
- Cobalt corrosion products, 267
- Cobalt hydroxide, 289
- Cobalt-induced, outer-core radiation field, 266
- Cobalt oxide, corrosion products in NP
  - primary circuits, 477
- Cobalt salt, 208
- Cobalt<sup>58</sup>, 268
- Cobalt<sup>59</sup>, 267, 477
- Cobalt<sup>60</sup>, 267
- Cobaltic sulfate, 485
- Cobaltous hydroxide, 485
- Cobaltous nitrate, 484
- Cobaltous sulfate, 484
- Coco-alkylamine acetate, 540
- Coconut monoethanolamide, 554
- Co-current resin regeneration, 351
- Code of Federal Regulations 21, 444, 484, *see also* CFR
- Codex® 551, 449
- 8503, 449
- Coefficients of thermal expansion, metals, and deposits, 148
- Co-emulsifiers, oil-in-water, 545
- Cogeneration, 15, 51
- Cogeneration boilers, 52–53
- Coil boilers, 49, *see also* Boiler, water tube, coil type
- Coke, 670
- Coke deposition, caused by oily surfaces, 298
- Coke media, 310
- Coke oven gas, 57
  - as fuel, 51
- Coke, petroleum, 16
- Coking, of oil constituents in heater, 685
- Cold degreasers, 649
- Cold-end acid attack, of economizers, 87
- Cold-end acid corrosion/fouling, 680

- Cold-end sulfuric acid attack, inspection for, 621
- Cold-end zone, fireside, 669
- Cold-end zone problems, 675–677
- Cold-flow improver, 685
- Cold lime process, to limit silica, 294
- Cold plant startup, 120
- Cold precipitator, 678
- Colloidal amorphous silica, 227
- Colloidal clays, 283
- Colloidal material, 306
  - in raw water, 304
- Colloidal metals, function of all-organics, 443
- Colloidal pectins, as process contaminants, 283
- Colloidal starches, historical perspective, 393
- Colloids, 205
- Color problems, due to tannin, 409
- Combination heating and power services, 51
- Combined combustion improver, sludge
  - dispersant, and fuel stabilizer, 688–689
- Combined cycle, *see* Cogeneration
- Combined cycle boiler, *see* Boiler, cogeneration
- Combined cycle boiler systems, 59
- Combined cycle systems, 43
- Combined phosphate/carbonate-cycle programs, 418
- Combining ratio, of oxygen scavengers, 482
- Combustion additives, for fireside cleanliness, 611
- Combustion area, inspection of, 620
- Combustion catalysts, 681–682
  - oil-soluble formulation, 687
- Combustion catalysts and improvers, 681–682
- Combustion efficiency, 15–17
- Combustion and environmental analyzer, 693
- Combustion gas analysis, 689–693
  - analysis of flue gas, 691–692
  - combustion of fuels, 690–691
  - composition of air, 689–690
  - gas measuring equipment, 693
- Combustion improver/stabilizer, formulation, 688
- Combustion improvers, in fuel additives, 680, 681
- Combustion problems, of fuel oils, 672
- Combustion quality characteristics, of solid fuels, 670
- Combustion system (WT), 43
- Combustion temperature, of fuels, 673
- Combustion zone, fireside, 669
- Combustion zone problems, 673–674
- Comet tails, 264, 436
- Compact bed, design of resin bed, 353
- Competing anion effect, 433
- Complex condensed polyphosphates, 420
- Complex silicate scales, 412
- Complexing agent, in cleaning processes, 637
- Composition of air, 689–690
- Compound™ design, of resin bed, 352
- Concentrate recycle RO plants, 366
- Concentrate/reject stream compartment, in ED technology, 374
- Concentrate water, 363
- Concentrated cell corrosion, 246–248
  - crevice corrosion, 247–248
  - pitting corrosion, 248
  - tuberculation, 246–247
  - under-deposit corrosion, 248
- Concentrating effects on corrosion, 468
- Concentrating mechanism, need for in caustic gouging, 249
- Concentration cell corrosion, additional forms of, 248–250
- Condensate, 70, 98
  - low-grade, 282
  - pure, 603
  - sampling temperature, 600
  - variable pH of, 282
- Condensate conditioning, 376–382
- Condensate contamination of feedwater, 202–205
- Condensate line corrosion control, as functional area requiring chemicals, 387
- Condensate line corrosion inhibitors, as adjuncts, 479
- Condensate line, inspection of, 621
- Condensate polishers, 138, 298, 378
- Condensate polishing, 307, 376, 377–382
  - bead resin deep-bed polishers, 379–382
  - to control condensate quality, 591
  - by ion-exchange, 346
  - powdered-resin precoat filters, 379
  - as purification technology, 343
- Condensate polishing capacity, effect due to amine loading, 511
- Condensate pumps and tanks, 98
- Condensate receivers, 109
  - inspection of, 621
  - unvented, 536
- Condensate receiving tank, 72
- Condensate return tank, 109
  - mechanical system, 72, 98, 121
  - vacuum system, 98
- Condensate return pump, inspection of, 621
- Condensate return purification, 307
- Condensate sampling
  - in higher-pressure boilers, 600–601
  - in lower-pressure boilers, 602
- Condensate sampling/testing, 599–605
- Condensate strainer-filter units, 376
  - for condensate conditioning, 376
- Condensate system, iron oxide deposits, 633
- Condensate treatments
  - non-amine-based, 544–545
  - as primary support chemical, 389
  - as program primary support chemicals, 385

- Condensation of steam, partial, 604
- Condensed phosphates, 419, 420
- Condensed tannins, 406, 445
- Condenser in-leakage, 382
- Condenser leaks, 299
- Condensers, 116–117
  - air-cooled steam, 117
  - in boiler deposits, 634
  - chloride in-leakage, 476
  - direct contact, 117
  - main, 56
  - operating efficiency, 20
  - operational problems, 117–119
  - surface, 21, 116
- Conductivity
  - of steam/condensate, 344
  - testing in steam/condensate, 602
  - of treated water, 198
- Conductivity control, with AVT programs, 475
- Confined space entry permits, 599, 614
- Congruent control, 389
- Congruent phosphate program, 464, 470–472, 474, 478, 546
- Conjugate acid, of amine, 524
- Conjunctural treatments, 385, 387, 479–558
- Consensus on Operating Practices for Control of FW and BW, 343
- Constant boiling mixtures in deaerators, of amines, 511
- Contaminant binding, caused by oily surfaces, 298
- Contaminant mass balance summaries, 456
- Contaminants
  - as contributors to boiler scales and deposits, 234
  - in feedwater, 219
- Contaminants control, as functional area requiring chemicals, 387
- Contamination, 140, 154–156
  - as a result of corrosion, 153
  - carryover, 155
  - of condensate, 299
  - foaming, 154
  - from industrial processes, 299–300
  - from oils, fats, and greases, 298–299
  - surging (priming), 155
- Continuous analyzer, 600
- Continuous BD line, sampling from, 605
- Continuous deionization, 372
- Continuous regeneration processes, 351
- Control of boiler water chemistry, 559–598
- Control limits
  - AVT, section 10.9, 475
  - boiler salines, notes to McCoy table, 598
  - carbonate cycle BW, table 10.3, 417
  - carbonate cycle reserves, table 10.2, 415
  - chelant/all-organic, table 10.7, 459
  - coil boilers, notes to BS 24861997 table, 593–594
- Control limits (continued)*
  - coordinated/congruent phosphate, figure 10.5, 471
  - electrode boilers, notes to BS 24861997 table, 594–595
  - electrode, jet type boilers, notes to ASME table, 576–578
  - fired WT boilers, notes to BS 24861997 table, 586–589
  - FW quality guidelines, notes to McCoy table, 597
  - HW systems, notes to BS 24861997 table, 580–582
  - industrial FT boilers, notes to ASME table, 571–573
  - marine propulsion, WT boilers, notes to ASME table, 575–576
  - non-fired WT boilers, notes to BS 24861997 table, 589–591
  - once-through boilers, notes to BS 24861997 table, 592
  - phosphate cycle FT boiler, table 10.4, 428
  - phosphate cycle WT boiler, table 10.5, 429
  - PWR primary coolant, section, 10.11.1, 477
  - tannin residuals, table 10.1, 408
  - very-HP/supercritical boilers, notes to McCoy table, 595–596
  - water for higher pressure boilers, table 9.3, 341
- Control of oxygen, 168–169
- Control parameters, optimizing in HP industrial boilers, 661–662
- Control of water chemistry, 559–598
- Controlled-pH phosphate programs, 464, 467, 469–474
  - congruent phosphate program, 470–472
  - coordinated phosphate program (captive alkalinity program), 469–470
  - equilibrium phosphate program, 472–473
  - formulations, 473–474
  - non-acid phosphate programs, 473
  - precision control phosphate program, 472
- Convection, 47
- Convection area slagging, 674
- Convective boiling mechanisms, 465
- Converters, for LPHW/LP steam, 185
- Coordinated/congruent phosphate, 531
- Coordinated phosphate, 427, 546
- Coordinated phosphate and program deviations, 464–474
  - captive alkalinity program, 469–470
  - HP boiler waterside problems and controlled-pH program considerations, 465–469
  - types of controlled-pH phosphate programs, 469–473

- Coordinated phosphate programs,
  - 389,469–470
  - flaws, 467
  - see also* Phosphate programs, coordinate
- Cooling coils, 600
- Copolymers, 442
  - historical perspective, 393
- Copper, 214, 233
  - as adventitious catalyst, 485
  - as catalyst, 495
  - as combustion catalyst, 681
  - as erythorbate catalyst, 497
  - in fuel additives, 679
  - in higher quality water, 305
  - plating out in the boiler, 141
  - stains of elemental, 232
  - testing in steam/condensate, 602
  - vaporous, 295
- Copper alloy passive films, 406, 445
- Copper-ammonium ion, 293
- Copper carbonate, hydrated, 176
- Copper cathode, with nonchemical technology, 334
- Copper chloride, in clinker treatments, 683
- Copper-complexing agent, 625
- Copper contamination removal, in condensate, 377
- Copper control, as functional area requiring chemicals, 387
- Copper/copper oxides, removal of in cleaning processes, 641
- Copper corrosion, 265
  - due to phosphonate, 448
- Copper cracking, risk during cleaning, 645
- Copper/iron pickup, 162
- Copper and nickel control, with AVT programs, 475
- Copper oxide passivation film, 489
- Copper oxides, 146
  - in boiler deposits, 633
  - in corrosion debris, 296
  - removal, 625
  - steam-distillation, 116
  - steam distilling, 295
- Copper phosphate, trihydrate, 176
- Copper pickup, with hydrazine, 492
- Copper release, 293
- Copper salts, 633
  - in boiler deposits, 633
- Copper in steam, control in super-critical boilers, 476
- Copper-steel couples, 402
- Copper sulfate
  - in boiler deposits, 633
  - as DEHA buffer, 499
- Copper-thiourea monochloride, in cleaning processes, 643
- Copper transport, 212
- Copperas, 315
  - historical perspective, 390–391
- Core reactivity controlling agent, 477
- Cornish boiler, *see* Boiler fire tube, Cornish
- Cornstarch, historical perspective, 393
- Corrosion, 136, 140, 144, 149–153
  - acid, 176, 177, 183, 300, 647
    - due to acid breakthrough, 198
  - acid attack example, 253–254
  - acid cleaning, 254
  - acid phosphate attack, 469
  - acid phosphate corrosion, 468
  - acid pitting, 235
  - acid regenerant infiltration, 252
  - acidic cold-end, inspection for, 620
  - ammoniacal, 265, 285, 293
  - amphoteric, 282
  - anodic area pitting, 265
  - anodic, of economizers, 87
  - anodic half reaction, 286
  - biocorrosion, in condensers, 117
  - boiler section, as functional area requiring chemicals, 387
  - brass, 246, 293
  - carbonic acid, 289–290, 483
  - carbonic acid pitting rates in steam/condensate lines, 514
  - cathodic half reaction, 286
  - caustic cracking, 198
    - risk of, 649
  - caustic embrittlement, 240, 466, 468
  - caustic gouging, 152, 157, 198, 227, 232, 236, 239, 249, 257, 465, 468, 469
    - under deposits, 233
  - caustic-induced, 169
  - caustic-induced, stress corrosion cracking, 227, 236, 466
  - cavitation, 211
  - chelant, 262–265
    - oxygen induced, 207
  - chloride involvement in, 248, 250
  - circumferential fatigue cracking, of condenser tubes, 382
  - cleaning need, 631
  - coarse magnetite, 242–243
  - cold-end, 675
  - cold-end acid, 680
  - concentration cell, 170, 244, 246–250, 466
  - condensate line, 178, 288
  - control of, 167–172
  - copper, 265
    - in condensers, 117
    - of economizers, 87
  - copper oxide, 285
  - copper-induced, 231
  - crevice, 170, 247–248, 476
    - in condensers, 117
  - cupronickel, 246
  - deaerator, 207



*Corrosion (continued)*

dealloying, oxygen induced, 210  
dealuminification, 210  
decarburation, 257  
denickelification, 210  
destannification, 210  
development of fouling, 181  
dezincification, 210  
differential aeration, 178  
differential-aeration cell, 247  
ductile gouging, 231, 236, 249  
during dry layup, 248  
economizer, 87, 207  
embrittlement, 236, 254–256, 387  
enhanced condensate line, 204, 285, 290, 512  
erosion, 176, 204, 211, 300, 508  
  caused by metal transport, 297  
  in condensers, 117  
erosion-corrosion, 520  
exfoliation, 210  
  in FW heaters, 609  
fatigue, 91, 248, 255, 256, 258, 473  
  condenser, 118  
feed-line, 207  
feed tank, 207  
galvanic, 150, 176, 180, 209  
galvanic conditions, 152  
general etch, 153, 245–246, 266  
glycol derived, 177  
gouging, of economizers, 87  
graphitic, 89, 210, 262  
high temperature, 257–260, 261, 466  
high-temperature waterside, 174  
hot-end acid, 680  
in HW systems, 178–180  
hydrogen embrittlement and hydrogen damage, 255, 256–258, 261, 265  
impingement, caused by metal transport, 297  
in LP steam heating systems, 178–180  
in nuclear powered steam generators, 265–267  
in pre-boiler section, 207–211  
in turbine low-pressure stage, 116  
inhibitor, amine-based, 178  
initiator, 246  
inspection of general waterside damage, 616  
inspection of under-deposit, 616  
intercrystalline, 254  
intergranular attack, 254, 266  
intergranular creep cracking, 259  
intergranular oxidation, 261  
  layer dezincification, 210  
liquid metal embrittlement, 265  
localized, 245, 246  
localized conditions, 152  
longitudinal gouging/grooving, 249

*Corrosion (continued)*

low pH, 250, 251–254, 256  
low pH localized, 466  
metal fatigue, 254  
nickel, 285, 293  
nodules, 247  
oxygen, 178, 181, 206, 285–287  
  in boiler section, 243–245  
persistently high temperature, 261  
pinhole, 176  
pitting, 110, 153, 169, 170, 181, 195, 206, 246, 248, 480  
  in condensers, 117  
  under deposits, 233  
plug dezincification, 210  
pre-boiler, as functional area requiring chemicals, 387  
rate-determining steps, 150  
risks to condensate, 194  
saline, 250, 465  
salinity involvement, 248, 250  
salt contamination, 252  
SCC of nickel alloys by lead, in NP secondary circuits, 478  
SCC of SS by chlorides, in NP secondary circuits, 478  
seawater contamination, 252  
selective leaching, 210  
self-limiting effect of magnetite, 512  
shell boiler, 207  
sodium hydroxide involvement in, 248  
spheroidization, 261  
stainless steel, 246  
stress, 245  
stress and high temperature related, 254–262  
stress corrosion cracking, 169, 232, 236, 240, 247, 255–254  
stress cracking, 476  
stress rupture, 260  
sulfate involvement in, 246, 248  
sulfur, in fuel systems, 673  
thermal effect, 254  
thermal fatigue cracking, 255, 258  
thermal oxidation, 261  
thermally induced, 254  
top drum, 207  
transcrystalline, 254  
transgranular, 254  
tube pitting, 207  
tube/tube sheet crevice, in NP secondary circuits, 478  
tuberculation, 110, 153, 170, 178, 180, 246–247  
  of economizers, 87  
tuberculation deposits, 232, 247  
under-deposit, 180, 244, 246  
under-deposit prevention, 652  
zinc, 285, 293

- Corrosion causitive agents, sulfates as, 170
- Corrosion control, as functional area requiring chemicals, 386
- Corrosion, control of, 167–172
  - cathodic protection, 167–168
  - control of oxygen, 168–169
  - control over salinity and adverse chemical reactions, 169–170
  - passivation, 170–172
- Corrosion debris, 218
  - controlling in MPHWH/HPHW systems, 187
  - deposition, 231–237
  - pickup, transport, and redeposition, 204
  - transport problems, with CHZ, 503
- Corrosion-enhancement problems, from oxygen in-leakage, 503
- Corrosion fatigue, 169, 258
- Corrosion in hot water and low-pressure steam heating systems, problems of, 178–180
  - galvanic, acid, and under-deposit corrosion, 180
  - oxygen corrosion, 178–180
- Corrosion inhibition
  - function of all-organics, 443
  - by phosphate action, 400
- Corrosion inhibitor treatments, basic internal types, 307
- Corrosion inhibitors
  - for cleaning solvents, 647–648
  - for fuel oils, 686
  - for fuels, 683–684
  - loss of in LP boilers, 183
  - multi-metal, 178
- Corrosion, intergranular, 466
- Corrosion, localized, 245–246
- Corrosion mechanisms, 149–153
  - influence of dissolved gases, 151–152
  - influence of fouling, 152–153
- Corrosion in nuclear powered steam generators, 265–267
- Corrosion problems
  - affecting pre-boiler section equipment, 209–211
  - oxygen-influenced, 242–248
- Corrosion processes, 141
- Corrosion product, 218
- Corrosion tuberculation, 245
- Corrosive attack, critical areas due to erosion-corrosion, 508
- Corrosive gases and related impurities, 291–293
  - in steam-condensate systems, 284–293
- Corrugation of furnaces, 32
- Cortec Corporation, for lay-up programs, 610
- Costs of amines, 511
- Countercurrent resin regeneration, 351
- Coupling agents, 454, 686
- CPS, Inc., 318
- Cracking, 259, 260
  - inspection for, 619
- Creep, 259
- Creep rupture, 260
- Creep temperature, managing, 625
- Crevice corrosion, 247–248
- Crill™, 545
- Crillet™, 545
- Critical heat flux, 15, 37
- Critical mass, 65
- Critical miscelle concentration, 647
- Critical pressure, 7
- Croda PLC, 545
- Cross-contamination, 299
- Crud, 503
  - levels, 508
  - in NP primary circuits, 478
- Crude oil heater, refinery, 679
- Cryojet™, 624
- Crystal distortion
  - using phosphate, 419
  - of polymers, 413
- Crystal growth retardation, function of all-organics, 443
- Crystal modification, function of all-organics, 443
- Crystal modifiers, 166
- Crystalline iron oxides, in condensate, 379
- Crystalline scale, 136, 201, 224
- Cupric ammonium complex ion, 265, 293
- Cupric copper, as catalyst, 489
- Cupric ion, production during cleaning, 642
- Cupric oxide, 493, 494
  - in boiler deposits, 633
  - cleaning process of, 637
  - deposit on turbine blades, 295
  - production during cleaning, 642
- Cuprite, 233
- Cupro-nickels, 210
  - protection in cleaning processes, 639
- Cuprous chloride, in gas analysis, 693
- Cuprous ion, production during cleaning, 642
- Cuprous oxide, 176, 494
  - in boiler deposits, 633
  - cleaning process of, 637
  - deposit on turbine blades, 295
  - oxidation with air in-leakage, 496
- Cuprous oxide film, need for passive, 241
- Current density of corrosion process, 151
- Cutch, historical perspective, 392
- Cyanamid™, 318
- Cyclic diketones, from tannins, 406
- Cyclohexylamine, 498, 518, 521
  - with AVT programs, 475
  - level in steam contacting food, 531
  - neutralization reactions, 515
- Cyclohexylamine carbonate, 523
- Cyclone furnace, 82
- Cyclone scrubber, 675

- Cyclone separator, 678
- Cyclone tube, cleaning, 625
- Cyclones, 325
  - for condensate conditioning, 376
- Cyclonic flame, 39
- Cytec Industries, 318
  
- Dampers, 85
- Dead plant startup, 120
- Deaerating feedwater heater, 17, 207
- Deerator pegging, 504
- Deerator performance calculation, 107
- Deerator purge gas, 102
- Deerator spray heads and trays, inspection
  - of, 615
- Deerator steam demand, estimation of, 666–667
- Deerator troubleshooting, 104–108
- Deerator vent condenser, 103
- Deerators, 98–108, 161–162, 305
  - acid attack, 209
  - atomizing type, 104
  - chemical, 102
  - exchange packing type, 103
  - see also* Heater, feedwater deaerating
  - lay-up of idle, 611
  - performance calculation, 107
  - pressure, 100
  - reduced venting, caused by metal transport, 297
  - spray type, 103
  - steam demand estimation, 666
  - tray (baffle) type, 103
  - vacuum, 100, 108
- Deerators and other equipment, need for, 161
- Dealkalization
  - by ion-exchange, 346
  - lack of capability in feedwater, 193–196
  - to reduce amine consumption, 532
  - as source of feedwater contamination, 198
- Dealkalization processes, 353–357
- Dealkalizer
  - chloride anion exchange, 195
  - split stream strong acid cation, 195, 198
  - strong acid cation, 195, 198
  - weak acid cation, 195, 198
- Dealloying, 210
- Dearation
  - efficiency, 104
  - problems caused by lack of, 206–209
- Dearborn Chemical Company, 550
- Dearborn Neutox<sup>®</sup> 53, 494
- Decarbonation, 354
- Decarburization, 262, 466
- Dechlorination, 324
- Deconcentration of BW, 74
- Deep-bed sand filtration, 308
- Deflocculation, using phosphate, 419
- Deflocculators, 440
  - function of all-organics, 443
- Defoamer chemistries, 548–558
- Defoamer selection, 551
- Defoamers, as adjuncts, 389
- Degassers, to reduce amine consumption, 533
- Degassing
  - in dealkalization process, 161
  - of carbon dioxide, 354
- Degree of agglomeration, of fuels, 670
- Degrémont/Suez-Lyonnaise, 455
- DEHA, *see* Diethylhydroxylamine
- Dehydroascorbic acid, 498
- Deionization
  - deep-bed, 345
  - for MPHW/HPHW systems, 186
  - packed-bed, 345
  - as purification technology, 342
- Demineralization
  - by ion-exchange, 346
  - as purification technology, 342
  - to reduce amine consumption, 532
  - as source of feedwater contamination, 198
- Demineralization processes, 358–359
- Demulsifier, for fuel oils, 671
- Demulsification effect, of antifoams, 550
- Demulsification, of fuel oils, 671
- Denting, 476
  - in NP secondary circuits, 478
- Deodorants, for fuels, 671
- De-oiling of new boilers, 123
- DEOX<sup>®</sup> process, 383
- Department of Transportation, 484
- Departure from nucleate boiling, 144, 157, 229, 250, 465
- Depassivating agents, 250
  - due to chloride leakage, 197
  - sulfates as, 169
- Depassivation, 169
- Depassivation of metal surfaces, 206
- Depolarization, due to chloride leakage, 197
- Deposit, 140
- Deposit analysis, 622
- Deposit binding, 206
- Deposit control agents, 61, 146, 166, 226, 442
  - as adjuncts, 386
- Deposit formation, signs of, 631
- Deposit modifiers, 682–683
  - as fuel additives, 675
- Deposit morphology, 147
- Deposit problems, in steam turbines, 116
- Deposit thickness, tolerance for, 164, 631
- Deposits on LP boiler tube, 182
- Deposition, 140, 144–148, 201, 218
  - by alkaline earth metal salts, 218–221
  - avoidance of waterside, 164
  - of calcium salts, 223–224
  - cause and effect in higher pressure boilers, 236

*Deposition (continued)*

- cause and effect in lower pressure boilers, 236
- of economizers, 87
- eggshell thickness standard, 164
- of iron oxide and other corrosion debris, 231–237
- limiting, 163–167
- of magnesium salts, 224
- mechanisms of, 146–148
- in pre-boiler section, 211–215
- by silicates, 227–231
- Deposition by alkaline earth metal salts, 220–227
- Deposition control, as functional area requiring chemicals, 387
- Deposition, limiting, 163–167
- Deposition of calcium salts, 223–224
- Deposition of magnesium salts, 224
- Deposition of scale and corrosion debris in pre-boiler sections, 211–215
- Deposits, 136
  - analysis of, 632–635
  - originating from inorganic salts and organics, 233–237
  - in steam systems, 282
  - in superheater, 90
- Deprotonation step, of oxygen scavenger, 482
- Dequest® 2000/2006, 449
  - 2010/2016, 449
  - 2054, 450
  - 2066, 450
- Derusting of new boilers, 123
- Desalination by RO, 360
- Desiccants, 610
- Desilicization processes, 357–358
- Desilicizing, as purification technology, 343
- Desuperheater, *see* Attemperator (WT)
- Desuperheaters, 91
- Desuperheating water, 586, 589
- Desuperheating, water quality limits, 591
- Detergent cleaners, in cleaning processes, 637
- Determining when a boiler needs cleaning, 631–632
- Dew point, 18, 611
- Dew-point condensation, 54
- De-watering agent, 685
- De-wetting functionality, of amines, 539
- D-gluconic acid, sodium salt, 432
- D-glucose, from tannins, 405
- Diamine corrosion inhibitors, for fuel oils, 686
- Diamine salts, in fuel additives, 680
- Diamines, 489–494, 537, 540, 542, 686
  - as biocides for fuel oils, 686
  - in cleaning processes, 647
- 1,2-Diaminoethane, 521
- Diatomaceous earth filters, 381
- 2,2-dibrom-3-nitropropionamide, 371
- Dichlorophen, 404
- Dicyclohexylamine, 519
- Dicyclohexylammonium nitrate, 607
- Diesel tanks, infection by *Clostridium*, 686
- Diethanolamine, 498, 519
- Diethanoglycine, 432
- Diethylamine, DEHA oxidation product, 496
- Diethylaminoethane, level in steam contacting food, 531
- Diethylaminoethanol, 500, 519
  - with AVT programs, 475
- Diethyldihydro, 1, 2, 4, 5-tetrazine, 505
- Diethyleneimidoxine, 520
- Diethyleneoximide, 520
- Diethylenetriaminepenta
  - (methylenephosphonic acid), 450
- Diethylenetriaminepentaacetic acid, 432
  - in cleaning processes, 637
- Diethylethanolamine, 519
- Diethylhydroxylamine (DEHA), 305, 394, 395, 410, 494–497, 500, 510, 512, 519
  - as AVT, 389
  - with AVT programs, 474
  - use of in MPHW/HPHW systems, 186
  - as passivator, 649
- Diffuse layer thickness, reduction of, 313
- Diffusion barrier, 647
- Dihydro-tetrazine, 505
- Dihydroxyacetone (DHA), 505
- Dihydroxy flavonoids, 406
- Dihydroxyacetone, 505
  - 1,3-Dihydroxyacetone, 505
  - 2,3-Diketo-l-gluconic acid, 498
- Diisobutylammonium sulfate, 607
- 3,6-Dimethyl, 1-2-dihydro, 1, 2, 4, 5-tetrazine, 505
- Dimethylamine, for testing sodium, 603
- Dimethylamino-2-propanol, 519
- 2-Dimethylaminoethanol, 519
- Dimethylaminoethylpropanol, 520
- Dimethylisopropanolamine, 519
- Dimethylpolysiloxanes, 554
- Diminished phosphate salt solubility, 471
- Dioctylsulfosuccinate, in cleaning formulations, 651
- Diphenylamine, in cleaning processes, 647
- Diphenyldihydro, 1, 2, 4, 5-tetrazine, 505
- Dipotassium phosphate, 402
- Direct fired steam generator, *see* Boiler, waste heat
- Dirt Loading, 631–632
  - conditions for lack of tolerance, 473
  - levels, 456
  - standards and example, 632
- Dirt pockets, 176
- Disc steam traps, 92
- Disodium hydrogen phosphate, 421
  - in cleaning solutions, 652

- Disodium phosphate, historical perspective, 392
- Dispersants, 166, 283, 305
  - flocculating effect of, 219
  - function of all-organics, 442, 443
  - lignins as, 445
  - silica specific, 294
  - use of in MPHW/HPHW systems, 187
  - water-in-oil type, 684
- Dispersion effect, 424
- Dissociation constants
  - amine basicity, 525
  - for amines, 524
  - for water, 525
- Dissociation reaction
  - for primary amine, 524
  - of amines, 527
- Dissolution of organics, in cleaning processes, 637
- Dissolved/entrained hydrogen in FW and steam as indicator of corrosion rates, 663–665
- Dissolved gases, influence of in corrosion mechanisms, 151–152
- Dissolved oxygen, 151
  - reduction needs in FW, 578
- Dissolved oxygen removal, high demand for, 285
- Dissolved oxygen testing
  - Chemets® ampoules, 105
  - Rhodazine D method, 105
  - Winkler method, 105
- Distearoylethylenediamide, 554
- Distribution pipework, 71
- Distribution Ratio, 521
  - of amines, 511, 526–530
- Disulfides, in scales, 646
- Ditetraammonium-EDTA, in cleaning processes, 638
- Divinylbenzene, 347
- DMA-2-P@-77, 519
- Dodecylamine, 540
- Domestic heating coil
  - internal corrosion, 176
  - internal deposition of, 176
- Double pass RO plants, 366
- Dow Chemical Co., 352, 361, 371, 432
- Downcomer tubes (WT), 45
- Downcomers, inspection of, 619
- Downflow precipitation softening, 311
- Draft, 85
- Draft gauge, 693
- Drain pan, 660
- Draw-and-fill cooling, 607
- Drawing compounds, cleaning, 651
- Drew Industrial Division, 455, 501, 552
- Drop runoff rate, 536
- Droplet flow, 6
- Dropletwise condensation process, 536
- Drum plates, inspection of, 620
- Drumless delivery, 132
- Drumless delivery service, 127
- Dry ice blasting, 624
- Dry lay-up
  - corrosion problems, 248
  - programs, 606, 610
  - protection of waterside by, 610–611
- Dry powder polyelectrolytes, 316
- Dryback boiler, *see* Boiler, dryback
- Dryout, 14, 55, 229
- D-type WT boiler design, 50
- Dual-amine technology program, 537
- Dual-chelant programs, 460
- Dual-temperature systems, 133, 394
  - inhibitor requirements, 396
- Ductile fracture, 258
- Ductile gouging and caustic attack, 249–250
- Duke Power Company (Charlotte NC), 489
- Duomeen OL, 686
- DuPont Company, 361
- Dust binder, for solid fuels, 671
- Dust collector (WT), 45
- Dust content, of solid fuels, 671
- Dutch oven furnace, 59
- DVGW Guidelines, 340
- Dyes, causing discoloration of condensate, 206
- Ebullient cooling, 53
- E-cell™, 375
- Ecologychem, Inc., 305, 383
- Economic boiler, 30, *see also* Boiler, fire tube, economic
- Economizer problems, 87
- Economizers, 14, 44, 17, 71, 86–87, 98, 153, 305
  - and air heaters, 86–87
  - cleaning flue gas side of, 611
  - inspection of, 618, 620
  - iron oxide deposits, 633
  - non-steaming, 86
  - outlet header (WT), 45
  - oxygen scavenger feed point note, 583
  - steaming, 86
- EDI stack, in ED technology, 374
- EDTA (neutralized tetrasodium)
  - in cleaning processes, 646
  - as erythorbate stabilizer, 498
  - see also* Ethylenediaminetetraacetic acid
  - in RO cleaners, 372
- EDTA/organic acid mix, in cleaning processes, 638, 646
- Effective water treatment practice, 156–158
  - control of water chemistry, 157–158
  - training and experience, 156
  - understanding cause and effect, 157
- Egg-shell scale, inspection of, 616
- Eggshell thickness of scale, historical perspective, 392

- Elagitannins, 405
- Electric boilers, 24–29
  - electrical resistance boilers, 25–27
  - electrode boilers, 27
- Electric heaters, 305
- Electric Power Research Institute, 464
- Electric powered steam generators, to reduce amine exposure, 533
- Electrical generators, 20, 113
- Electrical resistance boilers, 25–27
- Electrical resistivity of steam/condensate, 344
- Electricity generators, 113–115
  - impulse stage turbines, 114
  - large steam turbine generators, 113–114
  - reaction stage turbines, 114
  - smaller steam turbine generators, 114–115
- Electrochemical corrosion process, 149, 647
- Electrochemical series, 150
- Electrode boilers, 27–29
  - sprayed electrode boilers (water-jet electrode boilers), 28–29
  - submerged electrode boilers, 27–28
- Electrodeionization, 374–376
- Electrodemineralization, 372–376
  - purification by, 372–376
- Electrodialysis, 307, 366, 372, 373
  - as purification technology, 342
- Electrodialysis reversal, 372, 373–374
  - to limit silica, 294
- Electroionization, to limit silica, 294
- Electrolyte, 149
- Electrolytic devices, 334
- Electromagnetic filtration (EMF) and electromagnetic separation (EMS), 377
- Electromagnetic radiation particles, 62
- Electromagnetic separators, 298
  - for condensate conditioning, 376
- Electromotive force, 167
- Electronic nonchemical devices, 334
- Electropure, 375
- Electrostatic devices, 333–341
- Electrostatic nonchemical devices, 334
- Electrostatic precipitators, 45, 54, 675, 678
- ElectroStatic Technologies, nonchemical technology, 339
- Electrostatic units, in nonchemical technology, 337
- Elf Atochem, 489, 494, 519
- Elimin-Ox<sup>®</sup>, 502
- Ellagic acid, 408, 505
  - sodium salts, 405
- Ellagotannin, 406
- Emergency standby, 607
- Emission control systems (WT), 43, 45
- Emission levels, of nitrogen oxides, 16
- Emissions zone, fireside, 669
- Emissions zone problems, 677–678
- Emulsification, 550
  - by non-ionic detergents, 637
  - Emulsified fatty acid soap, in fuel additives, 680
- Emulsifiers
  - in cleaning formulations, 650
  - lignins as, 445
  - water-in-oil type, 545, 671
- Emulsifying degreasers, 649
- Emulsion additives, 684
- Emulsion breaker, 685
  - for fuel oils, 671
- Emulsion polymers, 316
- Energy balance summaries, 456
- Energy loss estimation, in scaled LP boilers, 666
- Energy losses in low-pressure boilers caused by deposition, 666
- Energy, work, and power, 10–14
  - boiler energy and power units, 11–13
  - heat release coefficients, 13–14
- Ener-tec<sup>®</sup>, nonchemical technology, 339
- Enhanced oil recovery boilers, 58, *see also* Boiler, enhanced oil recovery
- Enriched fuels, 63
- Entrained boiler water, in steam, 604
- Entrainment, 155, 281
- Enthalpy, of evaporation, 4
- Enthalpy loss, 16
- Entropy, 431
- Environmental issues, of amines, 511
- Environmental Protection Agency, 484
- Environmental protection programs, 43
- Enzyme-based reodorants, 671
- Eosin, 543
- Epichlorohydrin-dimethylamine polymers, 317
- Epitaxial nucleation, with nonchemical technology, 340
- Equilibrium phosphate concentration theory, 472
- Equilibrium phosphate program, 389, 464, 472–473
- Equipment failure, 136
- Equivalent square feet of steam radiation surface, 12
- Erosion
  - critical areas due to erosion-corrosion, 508
  - of economizers, 87
  - gas-side dust erosion, 87
  - of preboiler system, 201
  - solid particle, 116
  - at steam-water interface, 282
- Erosive microjets, 211
- Erythorbate, as passivator, 208, 649
- Erythorbic acid and sodium erythorbate, 394, 497–499
- Etch oxygen corrosion, 245
- Ethanedioic acid, in cleaning processes, 638
- Ethanol, 2-(diethylamino), 519
- Ethanolamine, 500, 520

- Ethanoldiglycine, 432
- Ethoxylated aryl/organosiloxane polymer, 555
- Ethoxylated diamines, 540
- Ethoxylated soya amine, 537
- Ethoxylation of amines, 538
- Ethylene bisricinoleamide, 554
- Ethylene bistearamide, 554
- Ethylene glycol, 402
- Ethylenecarboxylic acid, 446
- Ethylenediaminetallowdiamide, 554
- Ethylenediaminetetraacetic acid, 262, 431, 448
  - in cleaning processes, 637
- Ethyoxyated (3) N-tallow-1, 3-diaminepropane, 540
- Eutectic temperature, 681
- Eutectics of metal oxides, 675
- Evaporation, application to reduce TDS, 162
- Evaporator, 61
  - see also* Seawater evaporator
  - thermo-compression, 61
  - vapor compression, 61
- Excess air
  - problems caused by inadequate, 673
  - problems caused by too much, 673
- Excess air requirements, 691
- Exchange of ionizable materials, in condensate, 378
- Exfoliation of high temperature oxide scales, 115, 259
- Exit gas, as combustant, 691
- Exit-gas volume, 677
- Expansion joint cracking, inspection for, 621
- Expansion tank, 660
- External conditioning, need for, 158
- External conditioning processes, as compliment to chemicals, 385
- External and internal treatments, historical perspective of, 389–393
- External treatment carryover and after-precipitation, 201–203
- External treatment equipment, 305
- External treatment process technologies, 306–307
- External treatments, 304, 389–394
  - historical perspective, 389–394
  - meaning of, 139
- External water treatment processes, development of, 3
- Fabric filters, 54
- Fan coil units, 132, 660
- Fans, 85–86
  - forced draft fans, 85
  - induced draft fans, 85–86
  - inspection of, 620
- Fast rinse, of ion-exchange resin bed, 329
- Fatigue cracking of turbine blade, 116
- Fatigue failure, 144
- Fats
  - contamination from, 298–299
  - separation of by membrane technology, 360
- Fatty amines, 517, 540
- FBC boilers, *see* Fluidized bed combustion boilers
- Feeding hydrazine, 491–492
- Feeding sodium sulfite, 487
- Feedline blockages, 204
- Feedwater and air temperature efficiency, 17–19
- Feedwater contamination from makeup water, 193–203
  - acid breakthrough of ion-exchange plant, 198
  - chloride leakage, 197–198
  - external treatment carryover and after-precipitation, 201–203
  - hardness breakthrough, 196–197
  - lack of softening or dealkalization capability, 193–196
  - organic fouling, 200
  - sodium and silica leakage, 198–199
- Feedwater control levels for solids, alkalinity, silica, 578
- Feedwater contamination from makeup water, 193–202
- Feedwater delivery, 88
- Feedwater heaters, 71, 98–108
  - closed, 71, 99–100
  - closed high pressure, 86
  - closed low pressure, 86
  - deaerating type, 20, 71
  - direct type, 71
  - efficiency, 17
  - electrical resistance type, 71
  - high pressure, 100
  - indirect type, 71
  - lay-up of idle, 611
  - low pressure, 71, 100
  - open deaerating, 86
  - open type, 71, 100
  - regenerative, 98
  - steam sparge pipe type, 71
  - supply system, 45
  - volume demands, 219
- Feedwater heaters and deaerators, 98–108
  - closed feedwater heaters, 99–100
  - high-pressure FW heaters, 100
  - low-pressure FW heaters, 100
  - open feedwater heaters, 100–108
- Feedwater problems in final blend, 205–213
- Feedwater pumps, 88–89
  - centrifugal pumps, 88–89
  - reciprocating FW pumps, 89
  - steam turbine-driven FW pumps, 89
  - turbine pumps, 89
- Feedwater regulators 73, 80–81

- Feedwater regulators (continued)*  
float FW regulator, 81  
thermo-expansion FW regulator, 80  
thermo-hydraulic FW regulator, 80–81
- Feedwater supply system, 70–71  
checks, 121
- Feedwater tanks for fire tube boilers, 108–112
- Ferric ammonium carbonate, hydrated basic, 212, 232
- Ferric carbide, 262
- Ferric chelonate, production during cleaning, 645
- Ferric chloride, 314
- Ferric hydroxide, 309, 315, 433  
in boiler deposits, 634  
corrosion in steam/condensate lines, 513  
formation in corrosion reaction, 286
- Ferric hydroxide precoat, 299
- Ferric ion chelation, 433
- Ferric ions, production during cleaning, 640
- Ferric iron, 497, 663
- Ferric oxide, 145, 243, 493  
as slag component, 682  
black corrosion in steam/condensate lines, 514  
in boiler deposits, 634  
corrosion in steam/condensate lines, 513  
production during cleaning, 640  
red, corrosion in steam/condensate lines, 514
- Ferric phosphate, 235
- Ferric sulfate, 315
- Ferrite, 261
- Ferrite ions, 465
- Ferromagnetic iron oxide, separation, 377
- Ferroso-ferric oxide, 243  
corrosion products in NP primary circuits, 477
- Ferrous bicarbonate, 180, 181, 214, 512  
resulting from condensate corrosion, 289
- Ferrous carbonate, 512
- Ferrous chelonate, production during cleaning, 645
- Ferrous hydroxide, 433  
corrosion in steam/condensate lines, 513  
formation in corrosion cell, 286  
presence in strong alkaline conditions, 265  
in secondary galvanic corrosion process, 293
- Ferrous ions, production during cleaning, 640
- Ferrous metasilicate, 181, 212, 230
- Ferrous oxide, in boiler deposits, 634
- Ferrous sulfate, 315  
historical perspective, 390
- Ferrous sulfide, contaminant in steam-  
condensate systems, 291
- Ferrous transition process, 397
- Ferrous-ferric oxide, in boiler deposits, 634
- Ferrous-ferrite, 243
- Ferrous/ferric/Mo oxides complex, 397
- Fiberscope, 623, 631  
use in inspections, 619
- Film boiling, caused by oily surfaces, 298
- Film formers, for lay-up programs, 612
- Film forming corrosion inhibitors, for fuel  
oils, 686
- Film-forming emulsifiers, 545
- Filmers, application of, 540–543
- Filming amine and filming-neutralizing amine  
blend formulations, 543–544
- Filming amines, 510, 536–544  
application of filmers, 540–543  
in cleaning processes, 647  
functional properties and mode of action  
of, 537–539  
mode of action, 537–539  
as primary support chemical, 389  
to reduce amine consumption, 533  
tendency to strip iron oxide deposits, 543  
types of, 539–540
- Filmwise condensation process, 536
- Filter alum, historical perspective, 390
- Filter media, 321, 322
- Filters  
activated carbon, 323–325  
air scouring, 323  
anthracite, 320  
backwashing using air scour, 321  
bag, 325–326  
bed depth, 321  
candle, 325  
cartridge, 325  
ceramic membrane, 325  
dual media, 322  
effective grain size, 321  
gravity, 320  
greensand, sizing and operation,  
327–328  
horizontal tank type, 321  
roughing, 322, 342  
triple media, 322  
inspection of, 615  
multimedia, 322–323  
naked, 325  
precoat, 325  
pressure media bed, 320  
sand, 320, 321–322  
vertical tank type, 321
- Filter-aids, 305, 325  
for cartridge filters, for condensate  
conditioning, 376
- Filtration  
deep-bed sand, 308  
historical perspective, 390  
of suspended solids, in condensate, 378
- Fin-tube convectors, 132
- Final feedwater blend, problems associated  
with, 206–215



- Final feedwater blend, problems associated with (continued)*
- corrosion problems affecting pre-boiler section equipment, 209–211
  - deposition of scale and corrosion debris in pre-boiler sections, 211–215
  - inadequate feedwater deaeration, 206–209
- Fines, of polymers, 320
- Fire tube (shell) boilers, 29–39
- development of FT boiler designs, 30–34
  - modern, packaged horizontal and vertical boilers, 34–39
- Firebox boilers, 33, *see also* Boiler, firetube, firebox
- basic pretreatment needs, 307
- Fireside, basic problems, 670–678
- Fireside cleaning, 649
- of small FT boilers, 656–657
- Fireside cold lay-up, 612
- Fireside conditions and surfaces, control of, 669–693
- basic fireside problems, 670–678
  - combustion gas analysis, 689–693
  - fuel treatment formulations, 687–689
  - fuel treatments/additives, 678–686
- Fireside control, 669–693
- Fireside hot lay-up, 611
- Fireside problems, 670–678
- cold-end zone problems, 675–677
  - combustion zone problems, 673–674
  - emission zone problems, 677–678
  - high-temperature zone problems, 674–675
  - pre-flame zone problems, 670–673
- Fireside protection of idle boilers, 611–612
- Firing rates, effect on turbines, 115
- Fish mouth rupture, 260
- Fissures, 259
- Fixed water level, submerged electrode boilers, 28
- Flaking, in FW heaters, 609
- Flame impingement, cause and effect problem, 174
- Flame misalignment, 617
- Flame photometer, 9
- for testing sodium, 603
- Flameout, 81
- Flash steam and heat recovery systems, 18, 20, 71, 94–97
- Flash rusting, 649
- Flashpoint, of amines, 511
- Flavon-3,4-diols, from condensed tannins, 406
- Flavotannins, 406
- Flaxseed oil, historical perspective, 393
- Fleck™ controllers, 332
- Float FW regulator, 81
- Float thermostatic steam traps, 92
- Floc, 314
- Floc size, of treated water, 320
- Flocculants, 305
- organic polymeric types, 316–320
- Flocculation, 313
- in boilers, 237
  - processes, 313–320
- Flocculation improvers, 440
- Flocon® 100, 370
- 260, 371
- Floerger, 318
- Flow improvers, for fuels, 671
- Flue gas damper (WT), 45
- Flue gas exit stack, inspection for, 621
- Flue gas management system, 72
- Flue gases
- analysis, 691–692
  - as combustant, 691
  - high dust-burden, 675
- Fluid Systems, Inc., 361
- Fluidized bed combustion boilers, 58, *see also* Boiler, fluidized bed combustion
- Fluidized bed reactor, 679
- Fluidlite™ design, of resin bed, 352
- Fluidtron Electronic fluid treatment systems, 339
- Fluorescent tracer dye, 660
- Fluorescent tracing systems, online, 662
- Fluorometers, 662
- Flushing stage, during cleaning, 625
- Flux rate, of hollow fiber RO modules, 363
- Fly ash, 85, 682
- sulfated, 673
- Foam breakers, 549
- Foam control, as functional area requiring chemicals, 387
- Foam stabilizers, 549
- Foams, stable, 205, 300
- Foaming, 115, 154, 155, 183, 200, 283–284, 548
- mechanisms of control, 549–551
- Fogging, 280, 284
- Food Chemical Codex, 497
- Food and Drug Administration, 484
- Food, as process contaminants, 283
- Force, 10
- Forced draft fans, 85
- Forced outages, 612
- Formaldehyde, 371
- as RO membrane cleaner, 371
- Formates, 498
- Formic acid, in cleaning processes, 637, 638
- Formulations, on-line cleaning, 627–629
- Foulants, 140
- cleaning in RO plants, 371
  - control, as functional area requiring chemicals, 387
  - controlling in MPHW/HPHW systems, 187
- Fouling, 137, 140, 153–154, 203, 218
- due to boiler sludging, 194
  - of conductivity electrodes, caused by oily surfaces, 299

- Fouling and deposition, influence of in
  - corrosion mechanisms, 152–153
- Fouling inspection for, 621
- Four pipe heating, system, 133
- Fractures, 259
- Fre-flo™ Water Systems, 340
- Free-amine, 527
- Free carbon dioxide, 102
- Free caustic, 464
  - need for in caustic gouging, 249
  - presence of in corrosion processes, 468
- Free caustic alkalinity, 226, 546
- Free caustic programs, 389
- Free-caustic regimen, 239
- Free convection, 6
- Free hydroxyl alkalinity, 464
- Free potassium hydroxide alkalinity, 568
- Free sodium hydroxide alkalinity, 568
- Freeboard, of ion-exchange resin bed, 329
- Freeze-point depressants, for fuels, 671
- Freeze protection, 177
- Frequency modulation devices, in
  - nonchemical technology, 334
- Frothing, 548
- FSHR, *see* Flash steam and heat recovery systems
- FT boiler designs, development of, 30–34
  - cast iron sectional boilers, 33–34
  - firebox boilers, 33
  - horizontal return tubular boilers, 30
  - internally fired FT boilers, 30–32
  - Scotch marine boilers, 32–33
- FT boilers, inspection of, 615–618
  - fireside inspections, 617–618
  - waterside inspections, 615–617
- Fuel-to-air ratio, 15
- Fuel corrosion inhibitors, 683–684
- Fuel filter plugging, 672
- Fuel line plugging, 672
- Fuel management system, 72
- Fuel management system checks, 121
- Fuel oil conditioners, 685–686
  - formulation, 688
- Fuel oil storage additives, 685
- Fuel oils, 17
  - problems with, 671–673
- Fuel preparation equipment, 72
- Fuel treatment for lower grade solid fuels, 687
- Fuel treatment formulations, 687–689
  - combined combustion improver, sludge dispersant, and fuel stabilizer, 688–689
  - fuel oil emulsion breaker, 689
  - fuel treatment for lower grade solid fuels, 687
  - liquid fuel oil conditioner/stabilizer, 688
  - liquid, oil-soluble combustion catalyst and slag modifier, 687–688
- Fuel treatment program, 669
- Fuel treatments/additives, 678–686
  - acid neutralizers (fuel corrosion inhibitors), 683–684
  - clinker treatments, 683
  - combustion catalysts and improvers, 681–682
  - emulsion additives, 684
  - fuel oil conditioners and storage additives, 685–686
  - NO<sub>x</sub> emission control additives, 684–685
  - slag modifiers and deposit modifiers, 682–683
- Fuels, combustion of, 690–691
- Fugitive dust, in solid fuels, 671
- Full-flow condensate polishing program, 476
- Full-service and outsourcing programs, 127–129
- Fulvic acids, 319, 568
  - contaminant in steam-condensate systems, 291
- Functional attributes of all-polymer/all-organic chemistries, 442–443
- Functional neutralizing amines, 521
- Furfuraldehyde, in cleaning processes, 647
- Furnace area catalyst, 681
- Furnace heat flux, measurement, 623
- Furnace heat release coefficients, 13
- Furnace heat release rates, 12
- Furnace, membrane (WT), 46
- Furnace puff, 81
- Furnace structural system (WT), 43
- Furnace-wall generating tubes, inspection of, 619
- Fusible plugs, 73
- Fusion point, of slag, 682
- FW contamination from returning condensate, 203–206
  - corrosion debris pickup, transport, and redeposition, 204
  - oil and process contamination, 204–206
  - oxygen loading, 203–204
  - transport of boiler water solids, 203
- FW deaeration, 306
  - to reduce amine consumption, 533
- FW pump turbines, 89
- Gallic acid, 506
  - from tannins, 405
  - sodium salts, 405
- Gallotannin, 208, 405
- Galvanic, acid, and under-deposit corrosion, 180
- Galvanic series, 150
- Gamlen®, 679
- Gamma-ferric oxide, 406
- Gamma-hydrated ferric oxide, 648
- Gamma iron oxide, 407
- Gamma iron oxide/tannin complex, 406
- Gamma rays, 62

- Gas burner combustion tester, 693
- Gas burners, 84
- Gas governor, 84
- Gas measuring equipment, 693
- Gas oil, 685
- Gas scrubbers, 45, 54
- Gas transfer membrane technology, for oxygen removal, 383
- Gas turbines, 53, 679
- Gas velocity, high, 617
- Gaseous fuels, 673
- Gases, influence of in corrosion mechanisms, 151
- Gasification, 83
- Gauge cocks, 73, 82
- Gauge glass blowdown lines, 82
- Gauge glasses
  - blowdown of, 75
  - flat, 230
  - see also* Water column gauge glass
- Gauge pressure, definition of, 2
- G.E. Betz, 350, 371
- General waterside corrosion, avoidance via coordinated phosphate, 464
- Generally Recognized As Safe, 484
- Generating tube bank, inspection of, 620
- Generating tubes
  - inspection of, 619
  - see also* Membrane wall tubes
- Giant silica, 228
- Glassy polysilicates, 398
- Glassy scales, 228
- Glauconite greensands, 326
- Global warming, 43
- Gluconate-ferrous ion complex, in cleaning processes, 640
- Gluconates, 123, 444
  - as iron chelants, 406
  - as passivator, 649
- Gluconic acid, 432
- Glucose, 544
- Glucose derivatives, historical perspective, 393
- Glycerol, in RO cleaners, 372
- Glycol, ethylene, 177
- Glycol inhibitors, 402
- Glycollic acid/formic acid mix, in cleaning processes, 640
- Glycols
  - problems with use of, 177
  - propylene, 177
  - winterization with, 177
- Goethite, 233
- Good-Rite® K-752, 370, 446
  - K732, 446
  - K781, K797, K798, 447
- Goof balls, 537, 541
- Granular activated carbon, 324
- Graphite, 65
- Graphite moderated fuels, 63
- Graphitization, 259, 262
- GRAS, *see* Generally Recognized As Safe
- Grease, 381
  - in boiler deposits, 634
  - cleaning, 651
  - contamination from, 298–299
  - removers, 649
- Great Lakes Chemical Corp. 370, 401, 441, 662
- Green liquor, 58
- Green vitriol, historical perspective, 390
- Greenhouse gases, emissions of, 676
- Greensands, 326
- Grooving of horizontal tubes, condensate corrosion producing, 289
- Gross heating values of fuels, 16
- Ground fault arcing, 577
- Guanidine, nonvolatile derivatives, 505
- Gulping, 281, 284
- Gunk balls, 537, 541
  - caused by oily surfaces, 298
- Gunking, 236
- Gunmetal, 210
- Hagan® phosphate, historical perspective, 392
- Hampene® 150, 432
- Hampshire Chemical, 432
- Hard water, definition, 217
- Hardness, in raw water, 304
- Hardness breakthrough, 196–197, 328
  - breakthrough into feedwater, 196–197
  - in lower pressure boilers, 660–661
- Hardness conditioning, 306
- Hardness destabilization, 398
- Hardness precipitation and deposit control, 400
- Hardness removal, by nonchemical treatments, 306
- Hardness roughing treatment, 161
- Hardness salt sources, 220–223
- Hardness salts, 160
- Hardness stabilization
  - by phosphate action, 400
  - function of all-organics, 443
  - using phosphate, 419
- Header
  - connecting (WT), 45
  - inspection of, 619
- Header bottom, inspection of, 620
- Headers (WT), 43
- Health issues, of amines, 511
- Hearth furnace, 324
- Heat of dilution, in cleaning processes, 641
- Heat energy, 1, 20
- Heat exchangers, for LPHW/LP steam, 185
- Heat flux, 6, 69, 665
- Heat flux density, 219
- Heat recovery boiler, *see* Boiler, water tube, heat recovery

- Heat recovery calculation, 96–97
- Heat release coefficients, 13–14
- Heat-recovery boiler, *see* Boiler, waste heat
- Heat recovery system, 75
- Heat saturation temperature, 4
- Heat sink, 4
- Heat transfer coefficients, 13, 218
- Heat transfer rate, per unit area, 6
- Heaters, feedwater deaerating, 98–108
- Heating coils
  - finned copper, 175
  - problems with, 175–177
- Heavy aromatic naphtha, for fuel oils, 686
- Heavy-duty industrial cleaners, 649
- Heavy fuel oils, 673
- Heavy water, 65
- HEDTA/citric mix, in cleaning processes, 638
- Helium, in air, 689
- Helmholtz double layer, 394
- Hematite, 145, 146, 154, 168, 170, 233, 296, 663
  - in boiler deposits, 633, 634
  - hydrated passive film, 241
  - as particulate oxide, 232
  - transport, 297
- Henry's Law, 102
- Heterogeneous reactions, of hydrazine, 492
- Hexadecylamine, 540
- Hexafluoroferric ion, production during cleaning, 639
- Hexahydric alcohol, 544
- Hexamethylenediaminetetra (methylenephosphonic acid), 449
- Hexaphos<sup>®</sup>, 422
- Hexylamine, 518
- Hideout, 235, 473, 588, 589
- High-alkalinity feedwaters, effect on amine feed, 521
- High alumina porcelain insulators, 576
- High ash fuels, 673
- High concentrations of caustic/salines, effect of, 468
- High-firing cycle operations, 250
- High iron levels, significance of in chelant program, 658–659
- High-opacity stack gases, 677
- High oxygen residuals, corrosion caused by, 243
- High-pressure FW heaters, 100
- High-pressure industrial boilers, treatment programs and control in, 661–665
  - monitoring dissolved or entrained hydrogen in FW and steam as indicator of corrosion rates, 663–665
  - monitoring iron oxide transport, 662–663
  - monitoring via tracer and tagged polymer systems, 662
- High-pressure steam systems, 37
- High purity/quality FW process configurations, 343
- High-purity steam generation, 60–61
  - clean-steam generators, 60–61
  - kitchen steam generators, 60
- High quality/purity steam applications, water quality needs, 342
- High silica levels in raw water makeup, 658
- High sludge problems in lower pressure boilers, 657–658
- High temperature corrosion, 259–262, 681
- High-temperature zone, fireside, 669
- High-temperature zone problems, 674–675
- High water losses in HW heating and other closed-loop systems, 658–660
- Higher pressure boiler waterside programs and controlled-pH program considerations, 465–469
- Higher quality condensate, 304
- Higher quality makeup water, 304
- Higher quality, pre-boiler water treatment, definition, 147
- HLB value
  - in cleaning formulations, 651
  - see also* Hydrophile-lipophile balance of water-in-oil dispersants, 684
- Hoechst Celanese, 383
- Hold-down design, of resin beds, 351
- Hollow fiber permeator, 363
- Hollow fiber RO modules, 363
- Homogeneous oxygen scavenging reaction, of hydrazine, 492
- Homopolymeric carboxylates, 446
- Homopolymers, 442
- Horizontal return tubular boilers, 30
- Hot alkaline wash, 625
- Hot and cold lime-soda processes, 311
- Hot-end acid corrosion/fouling, 680
- Hot lime process, to limit silica, 294
- Hot-lime/softening processes, 327
- Hot precipitator, 678
- Hot-spot scaling, 141
- Hot standby, of LP boilers, 607
- Hot water generators, 49–50, 67
- Hot water and steam system cycles, 132–134
- Hot water heating and low-pressure steam boiler specifics, 173–189
  - problems of corrosion in hot water and low-pressure steam heating systems, 178–180
  - problems associated with use of glycols, 177
  - other waterside problems, 180–185
  - problems with heating coils, 175–177
  - waterside problems in medium-temperature hot water and high-temperature hot water systems, 185–189
- Hot water heating system cycle, 132–133

- Hot water return tank, 109
- HTHW/HPHW systems, 395
- Humic acids, 319, 568
  - contaminant in steam-condensate systems, 291
- Humidifiers, with amines, 533
- Hydranautics, Inc., 361
- Hydrazine, 123, 168, 170, 305, 382, 395, 489–494, 521, 578
  - with AVT programs, 474
  - breakdown in steam-condensate systems, in cleaning processes, 638
  - control with AVT programs, 476
  - feed points, 491
  - feeding hydrazine, 491–492
  - HQ as catalyst for, 500
  - hydrazine reactions, 492–494
  - level in steam contacting food, 531
  - non-volatile derivatives, 505
  - in OT programs, 508
  - as oxygen scavengers, 483
  - as primary support chemical, 389
  - producing ammonia in condensate, 381
  - in steam-condensate systems, 292
  - using with condensate pre-coat filters, 379
- Hydrazine hydrate, 489
- Hydrazine replacements, 168
- Hydrazine reactions, 492–494
- Hydrazine sulfate, 489
- Hydrocarbon contaminants, 237
- Hydrocarbon removal, using multifunctional water conditioners, 332
- Hydrocarbons, cleaning method, 651
- Hydrochloric acid, 625
  - in cleaning processes, 638, 646
  - forming under pits, 250
- Hydrochloric acid/bifluoride mix, in cleaning processes, 639
- Hydrochloric acid regenerant, 349
- Hydrochloric acid/stannous chloride, 640
- Hydrochloric acid/thiourea mix, in cleaning processes, 643
- Hydrofluoric acid, in cleaning processes, 639, 646
- Hydroquinone, 499–501
- Hydrogen
  - as combustant, 691
  - reaction producing water, 691
  - in steam-condensate systems, 291
  - testing in steam/condensate, 602
- Hydrogen analyzers, 663
- Hydrogen blanket, 152
- Hydrogen bonding, 445
  - in water, 2
- Hydrogen carryover, limit in steam, 291
- Hydrogen cation ion-exchange softening, with ED, 374
- Hydrogen damage, 256–258, 466, 665
- Hydrogen embrittlement, 256–258, 466, 588
- Hydrogen in FW and steam, as indicator of corrosion, 663
- Hydrogen in steam, limits, 665
- Hydrogen peroxide, as RO membrane cleaner, 371
- Hydrogen phosphate ion, 466
- Hydrogen production
  - with boiler loading, 665
  - with general corrosion, 665
  - with localized corrosion, 665
- Hydrogen sulfide
  - contaminant in steam-condensate systems, 291
  - control via multifunctional water conditioner, 332
  - evolution during cleaning, 646
  - removal, by zeolites, 327
  - in steam-condensate systems, 284–285
  - from sulfite, 486
- Hydrogen/hydroxide cycle condensate polishers, 380
- Hydrogenated tallowalkylamine acetate, 540
- Hydrolysis, of phosphates, 400
- Hydrolyzable tannins, 405, 444, 505
  - hydrolysis products of, 408
- Hydrolyzed polyacrylamide polymers, 317
- Hydromag®, nonchemical technology, 338
- Hydronic heating plants, 67
- Hydronic systems, 132
- Hydrophile-lipophile balance, 539
- Hydrophilic nature, of filming amines, 538, 539
- Hydrophobic nature, of filming amines, 538
- Hydroquinone, 489, 499–501, 506
  - as catalyst, 495
  - from tannins, 406
- 3-Hydroquinuclidine, 520
- Hydrotrope, 686
- Hydroxborates, 477
- Hydroxide alkalinity, 546
  - requirements with phosphate, 420
- Hydroxide ion, presence in corrosion cell, 286
- Hydroxyacetic acid, in cleaning processes, 640
- Hydroxyacetic acid/formic acid mixture, 625
- Hydroxyapatite, 145, 224, 235, 422, 423
  - in boiler deposits, 635
  - historical perspective, 392
  - in scales, 645
- Hydroxycarboxylic acids, 432
- 2-Hydroxyethylamine, 520
- Hydroxyethylenediaminetriacetic acid, in cleaning processes, 637
- 1-Hydroxyethylidene-1,1-diphosphonic acid, 432, 449
  - in cleaning processes, 640
- Hydroxyethyliminodiacetic acid, 434

- Hydroxyl ions  
 from free caustic program, 241  
 localized over-concentration, 144
- Hydroxylamine, 495
- Hydroxylamine sulfate, 495
- Hydroxylation, of fuels, 673
- Hydroxymethyl benzene, 686
- 2-Hydroxytriethylamine, 519
- Hyfor Process, in cleaning processes, 640
- Hygrosopic nature of dry polymer, 319
- Hyperfiltration, 360
- Hypoferrite ions, 465
- ICI PLC, 545, 552
- ID fans, cleaning flue gas side of, 611
- Ideal gas, 690
- Ideal gas law, 7, 677
- Idle boilers, fireside protection of, 611–612
- Idle boilers (longer-term offline), protection of, 608–612
- Ignition temperature, of fuels, 673
- Ignitor, 82
- Imidazoline carboxylate, 686
- Imidazoline surfactant, in cleaning processes, 647
- Iminodiacetic acid, 434
- Impingement, 204, 300
- Impingement problems, fireside, 617
- Impulse stage turbines, 114
- Impulse steam traps, 92
- Impurity concentration in reactor water, maximum, 382
- Inadequate feedwater deaeration, 206–209
- Inconel alloys, 266  
 600, 266  
 800, 266, 477
- Incongruent phosphate, effects on corrosion, 468
- Indian mangrove, historical perspective, 392
- Indirect steam generator, *see* Boiler, indirect
- Induced draft fans, 85–86
- Industrial processes, contamination from, 299–300
- Industrial WT boilers, 49–52  
 hot water generators, 49–50  
 water tube steam generators, 50–52
- Infrared thermometry, 623
- Inhibitor levels, maintaining in LP boilers, 182
- Inhibitors  
 acid cleaning, 254, 647  
 Armohib® types, 648  
 general adsorption types, 647  
 nitrogen types, 647  
 Rodine® types, 648  
 sulfur types, 647  
 anodic types, 647  
 for cleaning solvents, 647–648  
 for HF/mineral acid mixes, 648
- Inhibitors (continued)*  
 for hydrochloric acid, 648  
 for organic or powdered acids, 648  
 for SCC, 256
- Initial-fill dose of chemical inhibitor, 123
- Inorganic coagulants, 314–316  
 historical perspective, 390
- Inorganic oxidizing cleaners, 643  
 in cleaning processes, 642
- Inorganic process contaminants, 283
- Inorganic salts and organics, deposits from, 233–237
- Inspecting boiler pretreatment plants, 615
- Inspecting steam and condensate equipment, 621
- Inspection  
 additional notes, 621  
 of boilers, 612–623  
 FT boiler fireside, 617–618  
 FT boiler waterside, 615–617  
 pretreatment equipment, 615  
 scope of work, 614–615  
 WT boiler waterside, 618–621  
 WT fireside, 620–621
- Inspection attendant, 614
- Inspection process, informal, 613
- Inspection notes, 621–623
- Inspection safety, 614
- Inspection work, scope of, 614–615
- Instruments and control systems checks, 121–122
- Inspector  
 authorized or regulatory, 612  
 informal, 612  
 plant, 612
- Interfacial tension, 539
- Intergranular creep cracking, 260
- Interlock systems function checks, 121
- Intermediate flow, 6
- Internal energy, 2
- Internal softening, 657
- Internal softening reaction, 289
- Internal treatment chemicals, as polishers, 385
- Internal treatment control and programs,  
 outline of, 386–393  
 historical perspective of external and  
 internal treatments, 389–393  
 types of internal treatment program,  
 387–389
- Internal treatment programs, 305, 385–478  
 all-polymer/all-organic programs, 437–461  
 all-volatile treatment program chemistries,  
 474–476  
 anodic inhibitor chemistries, 394–403  
 chelant-, phosphate-, or polymer-based  
 combination programs, 461–463  
 chelant program chemistries, 430–437  
 coagulation and precipitation program  
 chemistries, 411–430

*Internal treatment programs (continued)*

- coordinated phosphate and program
  - derivations, 464–474
- development of, 3
- mixed treatment and zero solids treatment, 476
- nuclear powered steam generators, water treatment for, 477–478
- outline of internal treatment control and programs, 386–393
- tannin programs, 403–410
- types of, 387–389

## Internal treatments

- caustic soda, 31
- historical perspective, 389–394
- lignin, 31
- meaning of, 139
- phosphate, 31
- soda ash, 31
- starch, 31
- wattle tannin, 31

## Internally fired FT boilers, 30–32

## Interplast S.A., 679

Inverse-temperature solubility, 145

- problems, 234

## Inverted-bucket steam traps, 92

## Iodine number, 324

## Ion exchange, 306, 307, 345–359

- mixed bed demineralization, 51
- twin bed demineralization, 51

## Ion-exchange basics, 347–351

## Ion-exchange, demineralization, continuously regenerating type, 353

## Ion exchange plant, inspection of, 615

## Ion-exchange resin bead polymer composition, 347

## Ion-exchange resin bead structures, 347

## Ion-exchange resin bed

- anion, 347
- cation, 347
- double compartment design, 352
- layered design, 352
- mixed design, 352
- multiple bed design, 352
- sandwich design, 352
- single compartment design, 352
- stratified, 331
- stratified design, 352

## Ion-exchange resin cleaning, 349

## Ion-exchange resins, 326–331

- absorption, 330
- acrylic, 347
- anion, 347
- anion ion-exchange, 327
- bed expansion, 329
- carboxylic acid, 327
- cation, 327, 347
- checking, 615
- cross-linking, 327, 347

*Ion-exchange resins (continued)*

- exhaustion of, 328
- freeboard, 351
- gel type, 327, 347
- generic categories, 347
- hydrogen form, 327
- inert, 353
- inspection for cracked and broken beads, 615
- iron fouling, 615
- iron fouling problems, 328
- isoporous, 330
- loss of capacity, 615
- macroporous, 327, 330
- macroporous type, 347
- macroreticular, 327, 330
- quaternary ammonium, 327
- sodium form, 327
- strong acid cation, 327, 347, 348
- strong base anion, 330, 347, 349
- strong/weak acid, 327
- strong/weak base, 327
- sulfonated polystyrene, 327
- type 1, 349
- type 2, 349
- weak acid cation, 347, 348
- weak base anion, 331, 347, 349
- special grades, 344

## Ion-exchange softeners, for MPHW/HPHW systems, 186

## Ion-exchange softening, 308

- for RO pretreatment, 367

## Ion-exchange, softening by, 328–330

## Ion-exchange system design basics, 351–359

## Ion-exchange systems, practical functions, 353–359

## Ion-selective electrodes for sodium analysis, 198

## Ionics, 375

## Iron, 221, 306, 412

- as adventitious catalyst, 485
- carryover, 276
- as combustion catalyst, 681
- contaminant in steam purity, 603
- control via multifunctional water conditioner, 332
- as erythorbate catalyst, 497
- in fuel additives, 679
- in higher quality water, 305
- in raw water, 304
- soluble, 212
- testing in steam/condensate, 602
- understanding significance with chelant program, 658–659

## Iron and manganese removal using greensands, 327–328

## Iron and silica transport polymers, 468

## Iron carbide, 257, 262

## Iron chelants, 406, 445

- Iron contamination removal, in condensate, 377
- Iron control terpolymer, for RO pretreatment, 371
- Iron control
  - as functional area requiring chemicals, 387
  - with AVT programs, 475
- Iron deposits, feedline, 213
- Iron dispersants, use of in MPHW/HPHW systems, 187
- Iron dispersion, as adjunct requirement, 389
- Iron fouling of softener, 197
- Iron metaphosphate, 400
- Iron oxide and other corrosion debris deposition, 231–233
- Iron oxide transport, monitoring of, 662–663
- Iron oxides, 633–634
  - black, 287
  - in boiler deposits, 634
  - in condensate, 231, 232
  - corrosion debris, 297
  - in corrosion debris, 296
  - corrosion products in NP primary circuits, 477
  - gamma, 172
  - hydrated passive film, 241
  - magnetic, passive film, 241
  - particulate, 171
  - transport, 297
  - removal with cleaning solution, 625
- Iron particulates, contamination in WT boilers, 605
- Iron pick up, with hydrazine, 492
- Iron removal
  - by zeolites, 327–328
  - via aeration, 309
  - via polymer-assisted flocculation, 308
- Iron salts, in water supplies, 231
- Iron silicate scales, 230
- Iron silicates, 298
- Iron in steam boilers, recommendations for maximum total, 563
- Iron tallate, in fuel additives, 680
- Iron tannate complex, 445
- Iron tannate film, 407
- Iron tannate-magentite film, 208
- Iron tannates, 171, 406
- Iron transport, 168, 212, 388, 440
  - as adjuncts requirement, 389
- Iron<sup>59</sup>, 268
- Isep<sup>®</sup>, resin bed design, 353
- Isoascorbic acid, 394, 497–499
  - thermal decomposition limits, 591
- Isobutanolamine, 518, 523
- Isobutanolamine carbonate, 523
- Isobutylenes, 446
- Isokinetic multiport nozzle, 601
- Isopropyl alcohol, 686
- Isothiazolinones, 404
  - as biocides for fuel oils, 686
  - as RO membrane cleaner, 372
- IX resins, basics of, 347–351
- IX system designs, basics of, 351–353
- IX systems, practical functions of, 353–359
  - dealkalinization processes, 353–357
  - demineralization processes, 358–359
  - desilicization processes, 357–358
- Jar testing, 319
- Jet-type electrode boilers, 546
- Jetting boilers, 624
- Johnson March Systems, Inc., 661
- Kathon<sup>®</sup>, 404
- Kelig<sup>®</sup> 100, 445
- Kerosine, in cleaning processes, 637
- Ketones, 500
- Kinetic energy, 10
- King Lee, 371
- Kitchen steam generators, 60
- Kraft lignins, 445
- Kraft pulping process, 57, 445
- Krypton, in air, 689
- Kurita Water Industries Ltd., 504
- Lack of softening or dealkalization capability, 193–196
- Lancashire boiler, *see* Boiler, fire tube, Lancashire
- Lancashire boiler compound, 393
- Large steam turbine generators, 113–114
- Larson-Lane steam analyzer, 278, 603
- L*-ascorbic acid, 497–499
- Latent heat, 97
- Latent heat of vaporization, 4, 7
- Law, Henry's, 515
- Lay-up
  - boiler, 120
  - of boilers, 606
  - dry, 91, 246
  - fireside, 611
  - using phosphate, 419
- Lead and lag boiler operation, 184–185
- Lewis base, 524
- Ligand, 431
- Light water, 283, 551
- Lignin sulfonates, 433
- Lignin/tannic acid polymer test, 409
- Lignins, 30, 403, 438, 443, 445
  - as adjuncts, 386
  - as decharacterizer, 485
  - historical perspective, 392
- Lignites, 17, 670
  - fuel treatment formulation, 687
- Lignosulfonates, 237, 283, 404, 433, 438
- Lime, as a softening agent, 311



- Lime/cement kiln, 679
- Lime-soda softening process, 161, 311
- Limestone, dissolution of, 310
- Limiting deposition, 456
- Linear kinetic cell, nonchemical technology, 339
- Linear polyols, 552
- Linseed oil, as adjunct, 389
- Liqui-Cel<sup>®</sup>, 383
- Liquid face velocity rates, in organic traps, 324
- Liquid fuel oil conditioner/stabilizer, 688
- Liquid, oil-soluble combustion catalyst and slag modifier, 687–688
- Lithium hydroxide, 65
- Live plant startup, 120
- Localized acidic concentration
  - DNB effect, 253
  - process contaminant effect, 253
  - shielding deposits effect, 253
  - waterline evaporation effect, 253
- Localized corrosion, 245–246
  - historical perspective, 393
- Lockout/tagout procedures, 614, 657
- Long-chain cationic surfactants, filmers as, 536
- Long-term overheating, 157, 259–260, 466
- Lonza S.A., 540
- Loss on ignition, in boiler deposits, 635
- Low-alloy steel boiler tubes, corrosion of, 141
- Low ash fuels, 673
- Low heat-transfer rates, 147
- Low-to-high fire rates, 16
- Low-level alarm point, sampling from, 605
- Low-load conditions, 21
- Low NO<sub>x</sub> burners, 684
- Low pH corrosion, 251–254
  - acid cleaning corrosion, 254
  - general corrosion, 251–252
  - localized corrosion, 252–254
- Low-pressure FW heaters, 100
- Low-pressure steam systems, 36
- Low-temperature corrosion, 681
- Lower water-wall headers, 74
- LP steam systems, 394
- LPHW heating systems, inhibitor requirements, 396
- l*-Threonic acid, 498
- LTHW/LPHW systems, 394
- Lumenside, of membrane contactors, 383
- Lysing, of water molecules, in ED technology, 374
- Macroporous resins, in bead resin deep-bed polishers, 380
- Magnafloc<sup>™</sup>, 318
- Magnesium, 221, 634
  - in boiler deposits, 634
  - in fuel additives, 679
- Magnesium (continued)*
  - as a softening agent, 312
  - as slag modifier, 682
- Magnesium aluminate, 411
  - historical perspective, 391
- Magnesium anodes, 167
- Magnesium-based additives
  - as slag modifier, 682
  - as fuel additives, 675
- Magnesium-based treatments, to neutralize acid vapor, 612
- Magnesium and calcium salts, control over deposition of, 224–227
- Magnesium carbonate, in scales, 646
- Magnesium chloride, in boiler water, 234
- Magnesium fluoride, production during cleaning, 639
- Magnesium hydroxide, 145, 224, 228, 423, 472, 658
  - in fuel additives, 680
  - in scales, 645, 646
- Magnesium hydroxyphosphate, in boiler deposits, 634
- Magnesium orthodisilicate, 224
  - hydrated, 214
- Magnesium oxide, in fuel additives, 680
- Magnesium phosphate, 154, 212, 423, 472
  - basic, 235
- Magnesium silicate, 214, 224, 228
  - in scales, 646
  - sludge, 412
- Magnesium tallate, in fuel additives, 680
- Magnetic devices, 167, 333–341
- Magnetic particle separators, 138
- Magnetite, 146, 153, 170, 227, 233, 406, 407, 631, 663
  - blisters, 259
  - in boiler deposits, 633, 634
  - coarse, 243, 257
  - coarse black, 91
  - crystalline, 298
  - formation in corrosion reaction, 286
  - needles, 251
  - as particulate oxide, 232
  - removal during cleaning, 640
- Magnetite film, need for passive, 241
- Magnetite-passivation effect, of sulfite, 486
- Main (primary or bottom) blowdown arrangement, 75–76
- Main blowdown valve, *see* Valve, blowdown
- Main condenser, *see* Condenser, main
- Maintaining inhibitor levels and controlling blowdown and surging, 182–184
- Makeup water, 70
  - pretreatment system, 45
- Malachite, 212, 232
- Maleates, 438, 442, 443, 450
- Maleic anhydride, 443, 450
- Malodors, in fuels, 671

- Managing standby and idle boilers, 606–612
  - freside protection of idle boilers, 611–612
  - protection of idle boilers (longer-term offline), 608–612
  - protection of standby boilers (short-term offline), 606–608
- Manganese, 54, 214, 221, 268, 306
  - as combustion catalyst, 681
  - control via multifunctional water conditioner, 332
  - in fuel additives, 679, 680
- Manganese chloride, in clinker treatments, 683
- Manganese fouling of softener, 197
- Manganese greensand, 326
- Manganese removal, via aeration, 309
- Manganese salts, in water supplies, 231
- Manganous chloride, in fuel additives, 680
- Mannich polymers, 317
- Manoxol OT, 543
- Maracel<sup>®</sup> XE, 445
- Maraspense<sup>®</sup>, 445
- Maricite, 469
- Marine boilers, 55–56
- Mass balance profiles, for amines, 535
- Mass burning fuel, 59
- Materials balance, assessment, 181
- Maximum allowable working pressure, 191
- Maximum continuous rating, 12, 95, 165
- Maximum permissible temperature of tube alloys, measurement, 623
- Mayonnaise emulsions, as process contaminants, 283
- Mayoquest<sup>®</sup> 1230 -1500 -2100, 449
  - 1635 -1860, 450
  - 3000, 451
- McCoy Chemical Treatment of Boiler Water* 1984, 560
- McDermott-Canning, Inc., 679
- MCR, 12
- Mechanical cleaning, 623
- Mechanical deaeration, 98
- Mechanical work, 20
- Media filtration, 306, 307
- Medium hardness water, definition, 217
- Mekor<sup>®</sup>, 501
- Membrane capacity rating, 365
- Membrane contactors, 383
- Membrane distillation, 360
- Membrane purification technologies, 305, 307, 359–376
- Membrane softeners, 360
- Membrane wall tubes (WT), 42, 43, 45, 46
- Metal acrylate deposition, 446
- Metal aluminates, spinels as, 642
- Metal burning, 261
- Metal damage, of pre-boiler system, 203
- Metal failure, thermally induced, 254
- Metal ferrates, spinels as, 642
- Metal oxide powder, in fuel additives, 680
- Metal passivation benefit of tannins, 404, 408
- Metal scaling, 261
- Metal-scan techniques, 622
- Metal surface cleaner, function of all-organics, 443
- Metal surface cleaning, by phosphate action, 400
- Metal transport polymers, 485
- Metal wastage, 55, 136, 149
- Metals in FW, weighted mean content limits, 586, 592
- Metasilicates, 398
- Methacrylamide, 446
- Methacrylic acid, 446
- Methane, reaction producing carbon dioxide and water, 691
- Methanoic acid, in cleaning processes, 638
- 3-Methoxy, N-propylamine, 520
- 3-Methoxypropylamine, 521
- Methoxypropylamine, 500
- Methyl orange alkalinity, 546
- Methylethylketoxime (MEKO), 501–502
  - with AVT programs, 475
- 2-Methylpropenoic acid, 446
- Microanodes, 149
- Microbiocide, for fuel oils, 671
- Microbiological biofilms, in fuel oils, 672
- Microbiologically induced corrosion, in fuel systems, 686
- Microcathodes, 149
- Microdroplets of boiler water, 284
- Microfiltration, 359
- Microorganisms, in fuels, 671
- Microporous polypropylene hollow fiber gas transfer membranes, 383
- Mill scale
  - in boiler deposits, 634
  - cleaning, 651
  - contamination in WT boilers, 605
  - redeposition, 232
  - removal, from boiler, 625
  - transport, 605
- Milliequivalents per liter, 347
- Millipore membrane filter, 663
- Mineral acidity, removal, 356
- Minimal reserve alkalinity, 472
- Mist flow, 6
- Misting, 155, 280, 284
- Misting control, as functional area requiring chemicals, 387
- Mixed bed, design of resin bed, 353
- Mixed treatment and zero solids treatment, 476, 478
- Mixing, of dry polymer, 320
- Moderator, 477
  - water as, 62
- Modulation mechanisms, for FW supply, 280
- Modulation, of output, 35

- Moisture absorbents, 610
- Molecular hydrogen, 257
- Molecular orientation, of amines, 538
- Molecular sieves, 326
- Molybdate/nitrite formulation, 403
  - programs, 398
- Molybdate/silicate programs, 398
- Molybdates, 183, 394, 397–398
  - as anodic inhibitors, 388
- Monel 400, 266
  - protection in cleaning processes, 639
- Monitoring via tracer and tagged polymer systems, 662
- Monoalkyl tertiary amines, 540
- Monoamines, 537, 542
- Monoaminoguanidines, 505
- Monoammonium citrate, in cleaning processes, 637, 644
- Monoatomic adsorbed hydrogen, 150
- Monobed design, of resin bed, 352
- Monoethanolamine, 500, 520
- Monomers, 442
- Monosodium phosphate, historical perspective, 392
- Monsanto Chemical Company, 519
- Morlex® DEEA, 519
- Morpholine, 381, 498, 518, 520, 521
  - in ammonia anion cycle, 378
  - with AVT programs, 475
  - level in steam contacting food, 531
  - neutralization reactions, 515
  - as primary support chemical, 389
- MTHW/MPHW systems, 395
- MU water pretreatment, 306
- Mud drum, 41
  - inspection of, 619
- Mudcovers, 124
- Multiblend formulations, 555–558
- Multifunctional water conditioners, 331–332
- Multimedia filters, 322–323
  - for RO pretreatment, 368
- Multiport valve, 601
- Municipal solid waste, as fuel, 51
- Municipal waste incinerator, 679
- Muriatic acid, 629
  - in cleaning processes, 638
- Myrobalan tannins, 405
  
- Naked MB condensate polishers, 380
- Nanocrystal formation, with nonchemical technology, 334, 340
- Nanofiltration, 360
- Naphtha
  - in cleaning formulations, 651
  - in cleaning processes, 637, 649
- Naphthenic-based fuels, 672
- National Sanitary Foundation, *see* NSF International
- National Starch, 455
  
- Natrolite, 229
- Natural circulation, 6
- Natural tannins, 388
- Natural uranium fuels, 63
- Natural zeolite treatments, 306
  - historical perspective, 390
- Navy boiler compound, 393
- Necking down of vertical tubes, condensate corrosion producing, 289
- Negative ion exchange, 326
- Negative ions, 347
- Neon, in air, 689
- Nepheline, 229
- Nephelometric turbidity units, 322
- Net positive suction head, 88
- Net thermal efficiency, 54
- Neutral phosphates, 421
- Neutralization capacity, 521–523, 535
  - of amines, 511
- Neutralization pH, of amines, 522
- Neutralization/passivation, during cleaning, 625
- Neutralizer/filmer amine blend formulations, 543–544
- Neutralizing acid washes, 653
- Neutralizing amine summary notes, 534–536
- Neutralizing amines, functional properties of, 521–530
  - basicity, 523–526
  - neutralization capacity, 521–523
  - types of, 517–521
  - volatility, relative volatility, and distribution ratio or partition coefficient, 526–530
- Neutralizing capacity, 521
- Neutron particle bombardment, 61
- New boiler work, 123
- NexGuard®, 662
- N*-hydroxyethylenediaminetriacetic acid, 432
- Nickel, 210, 634
  - in fuels, 673
  - in higher quality water, 305
- Nickel compounds in fuel, 674
- Nickel oxides, 146
  - in boiler deposits, 634
  - in corrosion debris, 296
  - corrosion products in NP primary circuits, 477
  - transport of in condensate, 231, 232
- Nickel sesquioxide, in boiler deposits, 634
- Nickel transport, 212
- Nickelic oxide, in boiler deposits, 634
- Nickelous oxide, in boiler deposits, 634
- NIPA Laboratories, 404
- Nipacide®, 404
- Nitrates, 217
  - in steam-condensate systems, 292
- Nitric acid, 171
  - in cleaning processes, 641

- Nitric acid regenerant, 349
- Nitrilotriacetic acid, 262, 432, 448
- Nitrite-based inhibitors, 151  
to stifle anodic reaction, 241
- Nitrite/borate/TTA formulation, 396
- Nitrite chemistries, as anodic inhibitors, 388
- Nitrite/molybdate programs, 396
- Nitrite/silicate formulation, 403
- Nitrites, 209, 394, 395–397  
as anodic inhibitor, 395  
as passivator, 395  
in steam-condensate systems, 292
- Nitrobacter agilis*, 395
- Nitrogen  
in air, 689  
in steam-condensate systems, 284
- Nitrogen blanket, for out-of-service deaerator, 107
- Nitrogen blanketing, 608
- Nitrogen dioxide, evolution of, 641
- Nitrogen oxides, 16
- Nitrogen pressurization, 608
- N,N*-diaminourea, 502
- N,N*-diethylethanolamine, 519
- N,N*-diethylhydroxylamine, 494–497, 519
- N,N*-dimethylethanolamine, 519
- Non-acid phosphate programs, 473, 464, 473
- Non-amine-based condensate treatments, 544–545
- Noncarbonate hardness, 311
- Noncatalytic reduction processes, 684
- Nonchemical treatments (magnetic, electrostatic, and similar devices), 333–341  
examples of nonchemical technologies for scale and hardness control, 338–341  
review of nonchemical treatment technology, 334–338
- Noncombustible deposits, in furnaces, 683
- Noncombustible residuals, of fuels, 670
- Noncondensable gases, 92, 151  
in higher quality water, 304
- Nondestructive testing (NDT), 622–623
- Non-fired steam generator, *see* Boiler, indirect
- Nonfoaming surfactants, 123
- Nonhydrolyzable tannin polymer functional groups, 407
- Nonhydrolyzable tannins, 406, 445
- Nonionic block copolymers, 552
- Nonionic functional groups, of all-organics, 442
- Nonionic polyelectrolytes, 316
- Nonionic surfactants, 545
- Nonvolatile alkalis, 589
- Nonwetable boiler surfaces, 206
- Normal operating water level, 80
- Noselite, 229
- Novel pretreatment oxygen removal technologies, 382–383
- Novel pretreatment oxygen removal technologies (continued)*  
oxygen removal using catalyzed carbon bed technology, 382–383  
oxygen removal using gas transfer membrane (GTM) technology, 383
- Noveon, Inc., 370
- NO<sub>x</sub> emission control additives, 684–685
- NO<sub>x</sub> gases, emissions of, 676
- NSF International, 60, 318, 484
- NTA, *see* Nitrilotriacetic acid
- N*-tallow-1,3-diaminepropane, 540
- Nuclear fission process, 61
- Nuclear fuel control rod system, 65
- Nuclear grade anion exchange, 477
- Nuclear plant, materials selection, 266
- Nuclear plant steam generator materials selection, 266
- Nuclear power reactors, 62–63  
containment system, 65  
coolant primary circulation system, 62, 63, 65  
heat-sink, 65  
integrated control system, 65  
pressurizer, 65  
primary-coolant pumps, 66  
steam generator, 65, 66  
vertical recirculating, inverted U-tube, 66  
vessel, 63
- Nuclear powered steam generators  
corrosion in, 265–267  
water treatment for, 477–478  
treatment of primary circuit coolant water, 477–478  
treatment of secondary circuit working fluid, 478
- Nuclear reactor boilers, 61–66  
*see also* Boiler, nuclear reactor  
nuclear steam supply system, 63–65  
principles of nuclear reactor boiler plant operation, 65–66  
straight tube NO steam generator, 66  
vertical recirculating inverted U-tube NP steam generator, 66
- Nucleate boiling region, 6
- Nucleation of microcrystals, 224
- Nuclides  
artificial, 62  
naturally occurring, 62
- o*-Diaminohydroxybenzene, 500
- O-type WT boiler design, 50
- Oak tannin, 405
- Occupational Safety and Health Administration, 484
- Octadecylamine, 536, 537, 540  
as primary support chemical, 389  
for wet lay-up, 609  
level in steam contacting food, 531

- Octadecylamine acetate, 540
- Octadecylamine carbonate, 540
- ODA, 540, *see also* Octadecylamine
- Odor removal, using multifunctional water conditioners, 332
- Odorless kerosene, in cleaning processes, 649
- Odors, objectionable, 300
- Offline cleaning basics, 629–630
- Off-line, safety, and other appurtenance valve checks, 124
- Oil balls, caused by oily surfaces, 298
- Oil/hydrocarbon contamination, 204
- Oil preheaters, inspection of, 620
- Oil and process contamination, 204–206, 298–301
  - from industrial processes, 299–300
  - from oils, fats, and greases, 298–299
- Oil removers, 649
- Oil-soluble emulsifier, PEG as, 553
- Oil-soluble surfactant, in cleaning formulations, 651
- Oils, 237, 381
  - in boiler deposits, 634
  - as contaminant, 154
  - cleaning, 651
  - contamination in WT boilers, 605
  - contamination from, 298–299
  - as deposit binder, 154
  - separation of by membrane technology, 360
- Oily/rusty surfaces, cleaning method, 651
- Oily sludges, 672
- Oily surfaces, 298
  - cleaning method, 651
- Oleophilic resins, 381
- Olin Mathieson Corporation, 489
- On-line cleaning, 625
  - basics of, 626–627
  - need for, 617
- On-line cleaning formulations, 627–629
- Once-through boiler, 53
- ONDEO Degrémont, 352
- ONDEO Nalco, 455, 497, 502, 544, 662
- One-drum product programs, 555
- One-stop shop services, 128
- Opacity, 681
  - of stack gases, 677
- Open and dry lay-up programs, 610
- Open feedwater heaters, 100–108
  - atomizing deaerators, 104
  - exchange packing deaerators, 103
  - pressure deaerator troubleshooting, 104–108
  - spray deaerators, 103
  - tray (baffle) deaerators, 103
  - vacuum deaerators, 108
- Open FW heaters, 100
- Operational control of waterside surfaces, 599–667
  - boiler cleaning, 623–657
  - boiler inspections, 612–623
  - managing standby and idle boilers, 606–612
  - sampling and testing steam and condensate, 599–605
  - troubleshooting notes, 657–667
- Optical fiber camera, 623
- Optidose®, 441, 662
- Order of chelation, 433
- Organic acids, in cleaning processes, 637
- Organic chemical treatment, overdosing, 219
- Organic flocculants, historical perspective, 390
- Organic fouling of feedwater, 200–201
- Organic matter, 200
- Organic phosphates, 448
- Organic polymeric coagulants and flocculants, 316–320
- Organic process contaminants, 283
- Organic scavengers, 330–331
- Organic soils, causing foaming, 549
- Organic-solute process contaminants, 550
- Organic surfactants, in cleaning formulations, 649
- Organic traps, 200, 324, 330–331
  - by ion-exchange, 346
- Organics, 306, 634–635
  - in boiler deposits, 634
  - cleaning process, 637
  - cleaning in RO plants, 371
  - in raw water, 304
- Organopolysiloxane, 552
- Orifice plate, inspection of, 621
- Orsat apparatus, 691
- Orsat gas analysis, 406
- Orthophosphates, 400, 419, 420, 424, 466
- Orthophosphoric acid, 420
- Orthosilicates, 398
- Osmonics, Inc., 361, 375
- Osmotic pressure, 363
- Osmotic shock, to ion-exchange resin, 327
- OT, *see* Oxygenated treatment
- Outages, planned for cleaning, 625
- Outer-core radiation field, 267
- Outsourced water services, 305
- Outsourcing
  - labor, 128
  - makeup water, 70
  - programs, 127–129
  - services, 115, 132
  - utilities, 128
- Overfeed stokers, 84
- Overheating effects and high-temperature corrosion, 240, 259–262
  - decarburization, 262
  - graphitization, 262
  - high-temperature corrosion, 261
  - long-term, 238, 258, 259–260
  - managing, 625
  - metal burning and metal scaling, 261

- Overheating effects and high temperature corrosion (continued)*
- short-term, 238, 259, 260–261
  - signs of, 618
  - spheroidization, 261–262
  - thermal oxidation, 261
- Overlay product, chelants as, 434
- Overlays, polymers as, 454
- OVGW Guidelines, 340
- Oxalates, 498
- Oxalic acid, 498
  - in cleaning processes, 638
- Oxidation, 149
  - to remove iron, 309–310
- Oxidation potential, 149
- Oxides
  - as combustion catalyst, 681
  - as slag modifier, 682
- Oximes, 501
- Oxyammonium, 495
- Oxygen, 102
  - in air, 689
  - as a cathodic depolarizer, 152
  - in condensate with hydrazine, 492
  - control of, 168–169
  - as corrosion initiator, 238
  - from makeup water, 178
  - as a pre-boiler corrodant, 151
  - in steam-condensate systems, 284, 285–297
- Oxygen control, 586, 590
  - as functional area requiring chemicals, 387
- Oxygen corrosion, 178–180
  - cause and effect problem, 174
  - of economizers, 87
- Oxygen damage, inspection of, 616
- Oxygen infiltration, 285–288
  - from operating practices, 287
- Oxygen-influenced boiler corrosion problems, 242–248
  - boiler section oxygen corrosion, 243–245
  - coarse magnetite corrosion, 242–243
  - concentrated cell corrosion, 246–248
  - general etch oxygen corrosion, 245
  - general wastage corrosion, 245
  - localized corrosion, 245–246
  - uniform rate corrosion, 245
- Oxygen in-leakage, 178, 503
- Oxygen loading, 203–204
- Oxygen pitting corrosion, in fuel systems, 686
- Oxygen removal
  - using catalyzed carbon bed technology, 382–383
  - using gas transfer membrane (GTM) technology, 383
- Oxygen removal, DA claims and performance, 481
- Oxygen removal technologies, novel types, 382–383
- Oxygen scavenger chemistries, 479–506
  - aminoguanidines, 505
  - 1-aminopyrrolidine, 504
  - carbohydrazide, 502–504
  - diethylhydroxylamine, 494–497
  - dihydroxyacetone, 505
  - erythorbic acid and sodium erythorbate, 497–499
  - hydroquinone, 499–501
  - hydrazine, 489–494
  - methylethylketoxime, 501–502
  - sodium bisulfite, 487–488
  - sodium metabisulfite, 488–489
  - sodium sulfite, 483–487
  - tannins, 505–506
  - tetrazines, 505
- Oxygen scavengers, 102, 178
  - as adjuncts, 479
  - for lay-up programs, 607
  - as primary support chemical, 389
  - as program primary support chemicals, 385
  - as reducing agents and passivators, 482
  - tannin as, 404
  - from tannins, 406
  - use of novel chemistry organics, 168
- Oxygen scavenging
  - as functional area requiring chemicals, 387
  - via tannins, 388
- Oxygen scavenging capability, 179
- Oxygen solubility, 481
- Oxygenated treatment (OT), 168, 480, 506–510, 586, 590
- Oyster shell, as fuel additive, 678
- PAC/DADMAC polymers, 318
- PAC/EPIDMA polymers, 318
- Packaged, horizontal FT boilers, 35–37
- Packaged vertical boilers, 38–39
- Packed-bed design, of resin bed, 352
- Paraffin crystal modifier, 685
- Paraffin crystalline waxes, 672
- Paraffin waxes, in fuel oils, 672
- Paraffinic-based fuels, 672
- Parker Amchem/Henkel Group, 648
- Partial pressure of atmospheric gases, 102
- Partial pressure, of carbon dioxide in steam, 515
- Particle fluidization, 424
- Particle size, of solid fuels, 670
- Particulate adsorption, function of all-organics, 442
- Particulate sludge dispersants, for fuel oils, 686
- Partition coefficient, of amines, 511, 526–530
- Passivated film, thickness of, 648
- Passivated layer, corrosion problems when imperfect, 244
- Passivated surface, inability to form, 240
- Passivating control, via tannins, 388

- Passivation, 169, 170–172
  - of boiler surfaces, 241–242
  - function of all-organics, 443
  - with hydrazine, 493
  - by phosphate action, 400
  - using phosphate, 419
- Passivation enhancement process, of HQ, 500
- Passivation and common corrosion problems, 237–254
  - boiler surface passivation, 241–242
  - low pH corrosion, 251–254
  - other forms of concentration cell corrosion, 248–250
  - oxygen-influenced boiler corrosion problems, 242–248
- Passivation of new boilers, 123
- Passivators for cleaning solvents, 648–649
- Passive film, of iron oxide, 227
- Passive oxide film, 170
- Passivity, 241
- p*-Benzoquinone, 499
- PCA 16, 452
- p*-Dihydroxy benzene, 499–501
- Peaking steam generators, 465
- Pearl River Products, 318
- Pearlite, 261
- Peat, 17
- Peat moss, fuel treatment formulation, 687
- PEG-6 distearate, 454
- PEG-8 oleate, 454
- Penicillium glaucum*, 404
- Penetrants, in cleaning formulations, 650
- Pennad 150<sup>®</sup>, 519
- Pennstop<sup>®</sup>, 494
- Pennstop<sup>®</sup> 85%, 519
- Peracetic acid, as RO membrane cleaner, 371
- Perborate, in cleaning processes, 644
- Percol<sup>™</sup>, 318
- Periodic chemical cleaning, 122–123
- Permanent hardness, 223, 311
- Permanent noncarbonate hardness, 312
- Permanganate reduction test, 409
- Permeable membrane, in electrodialysis, 373
- Permeators, 363
- Permutit, 353
- Pesticides, removal by carbon filters, 323
- Petroleum coke, 237
  - as fuel, 51
- Petroleum products, removal by carbon filters, 323
- Petroleum spirit, in cleaning processes, 637, 649
- PF, 42
- Pfizer, sodium erythorbate FCC, 497
- pH
  - fluctuating, 300
  - testing in steam-condensate, 602
- pH/alkalinity control, as functional area requiring chemicals, 387
- pH buffering-type programs, 464
- pH control, with AVT programs, 475
- pH of feedwater, out of balance, 203
- pH of treated water, 198
- Phenolic formaldehyde demulsifiers, 381
- Phenolic molecules, as tannins, 404
- Phenothiazine, in cleaning processes, 647
- Phenylethylene, 443
- Phosphate anodic/cathodic inhibitors, 399–400
- Phosphate-based combination programs, 460–464
- Phosphate-based multifunctional programs, 388
- Phosphate-chelant program, 419, 424
- Phosphate conditioning, 584
- Phosphate-cycle, 413
- Phosphate-cycle benefits and formulations, 427–430
- Phosphate-cycle boiler programs, 419–430
  - phosphate-cycle benefits and formulations, 427–430
  - phosphate-cycle reactions, 422–425
  - phosphate-cycle requirement calculations, 425–427
  - phosphate product selection, 419–422
- Phosphate deposits, 202
  - cleaning in RO plants, 371
- Phosphate ester bond, 448
- Phosphate feed point, 424
- Phosphate feed-rate requirement, 426
- Phosphate feedline deposits, 212
- Phosphate hideout, 468, 471
- Phosphate hideout point, 427
- Phosphate/nitrite mix, as passivator, 649
- Phosphate overlay programs, 458
- Phosphate/polymer-based multifunctional formulation, 460–464
- Phosphate-polymer programs, 419, 430
- Phosphate precipitant, requirement to remove calcium, 412
- Phosphate precipitation programs, 154, 400
- Phosphate product selection, 419–422
- Phosphate programs
  - congruent, to prevent free hydroxyl ion, 240
  - coordinated, 250, 256
  - to prevent free hydroxyl ion, 240
  - equilibrium, to prevent free hydroxyl ion, 240
  - simple, 430
  - for wet lay-up, 609
- Phosphate reversion, 400
- Phosphate scaling, 238
- Phosphate sludge, 226
- Phosphate-sludge conditioner, 424
- Phosphate treatment programs, 54
- Phosphate wastage, 468
- Phosphates, 30, 123, 217 219, 395, 411, 438, 635

- Phosphates (continued)*  
 in boiler deposits, 635  
 in cleaning formulations, 649  
 control parameters, 420  
 corrosion inhibitor, 183, 419  
 demand for, 225  
 loss of reserve, 196  
 as a precipitant, 388  
 properties and uses, 419–422  
 threshold and crystal distortion effects, 424  
 in water supplies, 235
- Phosphates as precipitation agents, 419
- Phosphino/acrylic acid, 407
- Phosphino polycarboxylic acids, 451–454
- Phosphinocarboxylic acid dispersant, 226, 283
- Phosphinocarboxylic acids, 407, 413, 444, 607  
 as adjuncts, 386
- Phosphonate, use of to control iron fouling, 197
- Phosphonate/citric resin cleaner, 349
- Phosphonates, 388, 432, 438, 444, 448–450  
 in cleaning processes, 640
- Phosphono/phosphino polycarboxylates, 444
- 2-Phosphonobutane-1,2,4-tricarboxylic acid, 449
- Phosnopolycarboxylic acids, 451
- Phosphoric acid, 420, 421  
 in cleaning processes, 641  
 in RO cleaners, 372
- Phosphoric/citric/sodium gluconate resin cleaner, 349
- Phos<sup>®</sup> 2 -6 -9, 449
- Physicochemical operating conditions, 143
- Pickup of scale and corrosion debris, 296–298
- Pipe-threading compounds, cleaning, 651
- Pitot tube, inspection of, 621
- Pitting  
 of economizers, 87  
 indications of active corrosion in steam/condensate lines, 514  
 indications of inactive corrosion in steam/condensate lines, 514
- Pitting corrosion, 248
- Planning, to avoid waterside problems, 173
- Plastic deformation, 256
- Plated copper metal, cleaning process, 637
- Plated metallic copper, removal by cleaning, 645
- Plenum unit, 50
- Pluronic<sup>®</sup> L61, L62D, L62LF and L101, 552
- PMA, *see* Polymaleic acid
- PMC Specialties, 401
- POE 4 sorbitan monolaurate, 544
- POE-POP ether, 686
- Polar character, of organic contaminant, 331
- Polacryl<sup>®</sup> A30-43 -A40-43 -A50-43 -F70-40S, 446
- Polarization, 150
- Polaroid<sup>™</sup>, 124
- Polisher effluent quality, minimum, 382
- Polishers, three-bed, 345
- Polishing chemical treatments, 125
- Polishing process, 305
- Polyacrylamide polymers, 318, 438, 445, 446
- Polyacrylamides, 438, 445, 446
- Polyacrylate backbone, co- and terpolymers, 447–448
- Polyacrylates, 438, 442, 443, 444, 455–447  
 for RO pretreatment, 369
- Polyacrylic hydrazide, 502
- Polyacrylic sulfonate, 662
- Polyalkylene glycol (PAG) derivatives, 552–553  
 as antifoams, 551
- Polyalkylene glycol monobutylether, 553
- Polyalkylene polyamides, 284, 550
- Polyaluminum chloride, 315
- Polyamide RO membranes, 360
- Polyamides, 550, 553–554  
 as antifoams, 551
- Polyamine/DADMAC polymers, 317
- Polyamine/EPIDMA polymers, 317
- Polyamines, 316
- Polycarboxylic component, of polymers, 454
- Polycol<sup>®</sup> 100, 451  
 43, 447
- Polydiallyl-dimethylammonium chloride polymers, 317
- Polyelectrolytes, 316–320
- Polyether glycols, 552
- Polyethersulfone RO membranes, 360
- Polyethoxylates, as adjuncts, 389
- Polyethylene glycol, 444, 454, 553
- Polyethylene glycol 600 monolaurate, in cleaning formulations, 651
- Polyethylene glycol-8 dioleate, 553
- Polyfunctional amines, 535
- Polyhydroxy aldehydes/ketones, 405
- Polyhydroxyphenols, 405
- Polymaleates, 445, 450–451
- Polymaleic acid, 56, 444, 450, 455  
 for RO pretreatment, 370
- Polymer-based combination programs, 460–464
- Polymer-based multifunctional programs, 388
- Polymer/phosphate/chelant formulation, 460–464
- Polymer tagging, 441
- Polymeric coagulant/flocculant blends, 318
- Polymeric dispersants, in fuel additives, 680
- Polymeric sludges and tars, cleaning method, 651
- Polymerization, of oil constituents in heater, 685
- Polymerized silica, separation of by membrane technology, 360



- Polymers
  - for coagulation/flocculation, 316–320
  - demand for, 225
  - dry types, 319
- Polymethacrylates, 438, 444
- Polymethacrylic acids, 445
- Polymethylimine, in cleaning processes, 647
- Polyoxyalkalene glycols, 551, 552
- Polyoxyethylene sorbitan fatty acid esters, 544
- Polyoxyethylene-polyoxypropylene ether, 686
- Polyoxypropylene/polyoxyethylene condensates, 552
- Polyphos<sup>®</sup>, 422
- Polyphosphate bond, 448
- Polyphosphates, 398, 433
  - as anodic inhibitors, 400
  - as cathodic polarizers, 400
  - for RO pretreatment, 369
  - thermal degradation, 424
- Polyphosphinocarboxylic acid, 370
- Polypropylene glycol-polyethylene glycol ether, 686
- Polypure, Inc., 318
- Polyquats, as biocides for fuel oils, 686
- Polysaccharides, 405
- Polysaccharoses, 405
- Polysilicates, 398
  - as a precipitant, 388
- Polysilicones, as adjuncts, 389
- Polysperse<sup>®</sup>, 452
- Polysulfone RO membranes, 360
- Polysulfone support layer, 363
- Polyvinyl alcohol, 610
- Polyvinylidene fluoride RO membranes, 360
- Poor air removal, in condensers, 117
- Porcelain insulators, M Alk. limits with, 594
- Porous waterside deposits, 464
- Positive ion exchange, 326
- Positive ions, 347
- Post-boiler conditioning, 138
- Post-boiler condensate conditioning, 376–382
  - condensate strainer-filter units, 376
  - electromagnetic filtration and electromagnetic separation, 377
- Post-boiler external treatment, 307
- Post-boiler section, 71
  - corrosion summary, 512–514
  - oxygen removal, 480
- Post-boiler section problems, 273–301
  - carryover, 550
  - corrosive gases in steam and condensate systems, 284–293
  - oil and process contamination, 298–300
  - scale and corrosion debris transport, 296–298
  - steam purity and steam quality, 275–284
  - vaporious silica and other steam volatiles, 293–295
- Post-boiler water subsystems, 45
- Post-combustion additive, 675
- Potassium hydroxide, 545
  - as adjunct, 389
  - in gas analysis, 693
- Potassium mercaptobenzothiazole, 401
- Potassium permanganate, 327
  - in cleaning formulations, 651
- Potassium polysilicates, 398, 412
- Potato peelings, historical perspective, 393
- Potential energy, 10
- Pour-point depressants, 672, 685
- Pour-points, of paraffinic waxes, 672
- Powdered resin filtration, 379
- Powdered-resin precoat filters, 379
- Power, 11
- Praestol<sup>™</sup>, 318
- Pre-boiler and post-boiler treatment, processes, 303–383
  - basic pretreatment processes, 307–341
  - common external treatment process technologies, 306–307
  - novel pretreatment oxygen removal technologies, 382–383
  - post-boiler condensate conditioning, 376–382
  - pre-boiler purification technologies, 341–376
- Pre-boiler conditioning, 138, 304
- Pre-boiler filtration, 320–326
  - activated carbon filters, 323–325
  - bag filters and related technologies, 325–326
  - multimedia filters, 322–323
  - sand filters, 321–322
- Pre-boiler purification by ion-exchange, 345–359
  - basics of IX resins, 347–351
  - basics of IX system designs, 351–353
  - practical functions of IX systems, 353–359
- Pre-boiler purification technologies, 341–376
  - ion-exchange, 345–359
- Pre-boiler section, 70
  - oxygen removal, 480
  - water/steamside problems, 191–213
- Pre-boiler section equipment, corrosion problems affecting, 209–211
- Pre-boiler section waterside problems, 191–215
  - feedwater contamination from makeup water, 193–203
  - feedwater contamination from returning condensate, 203–206
  - overview of pre-boiler section waterside problems, 192
  - problems associated with final feedwater blend, 205–215

- Pre-boiler water subsystems, 45
- Precipitation softening (PS), 310–313
- Precision control phosphate program, 472
- Precommission cleaning, 625, 651–653
  - and alkaline boil-outs, 651–653
- Precipitants, 166
- Precipitated iron binder, 214
- Precipitating phosphate programs, 224, 425, 545
- Precipitation program chemistries, 411, 440
- Precipitation softening, 306, 310–313
- Precision control phosphate programs, 464, 472
- Precoat filter, 299
- Pre flame zone, fireside, 669
- Pre flame zone problems, 670–673
  - problems with fuel oils, 671–673
  - problems with solid fuels, 670–671
- Preheater tubes, in boiler deposits, 634
- Preheaters, feedwater, 20
- Pre-operational cleaning of new boilers, 50, 123, 625
- Pressure
  - absolute, 81
  - atmospheric, 81
  - head, 88
  - hydrostatic, 81
  - maximum allowable working, 79
  - static, 85
- Pressure aerators, 309
- Pressure-equalizing line, 73
- Pressure gauges, 73, 81
- Pressure leaf filters, for condensate conditioning, 376
- Pressure reducing stations, 71
  - inspection of, 621
- Pretreatment, 304
  - alternative technologies, 333–341
  - definition, for MPHW/HPHW systems
  - lack of control, cause and effect problem, 174
  - requirements for MPHW/HPHW systems, 186
    - using greensand, 326
    - using natural zeolite, 326
    - using synthetic resins, 326
- Pretreatment equipment, *see* Water, pretreatment plant system
- Pretreatment need
  - example for deep-well supply, 308
  - example for tropical surface water, 308
  - example for variable quality surface water, 309
- Pretreatment processes, basic types, 307–341
- Pressure aerators, 309–310
- Pressure gauges, 81
- Pretreatment using natural zeolite, greensand, and synthetic resins, 326–332
  - iron and manganese removal using greensands, 327–328
  - Pretreatment using natural zeolite, greensand, and synthetic resins (continued)*
    - multifunctional water conditioners, 331–332
    - organic traps (organic scavengers), 330–331
      - softening by ion-exchange, 328–330
- Primary air, 82
- Primary circuit coolant water, treatment of, 477–478
- Primary superheater tube bundle (WT), 47
- Prime movers, 605
- Priming, 155, 283, 284, 296, *see also* Surging
- Priming control, as functional area requiring chemicals, 387
- Problem-specific polymer, function of all-organics, 443
- Problem-specific polymers, as adjuncts, 389
- Problems with fuel oils, 671–673
- Problems with solid fuels, 670–671
- Process chemicals, causing foaming, 549
- Process contaminants, 136, 141, 204, 218
  - cleaning need, 631
- Process contaminants and deposits, cleaning processes, 651
- Process contaminants control, as functional area requiring chemicals, 387
- Process leaks, 202, 298–301
- Process particulate pickup, 283
- Product breakdown temperatures, of amines, 511
- Product water, in ED technology, 374
- Products for boosting alkalinity, 548
- Professional Water Technologies, 371
- Program primary support chemicals, 385, 389
- Propenamide, 446
- Propenoic acid, 446
- Propylene glycol, 402
- Propylene glycol monstearate, in cleaning formulations, 651
- Protection of idle boilers (longer-term offline), 608–612
  - waterside dry lay-up, 610–611
  - waterside wet lay-up, 608–609
- Protection of standby boilers (short-term offline), 606–608
- Protective colloid, 438
- Proteinaceous foams, 550
- Protonation of amines, 538
- Pulse-echo-pitch-catch technique, 622
- Pulverized fuel, 16, 41
  - treatment formulation, 687
- Pulverized fuel coal burners, 83
- Pulverizer
  - bowl mill, 83
  - impact mill, 83
- Pump
  - feedwater, 88–89
  - multistage centrifugal, 88

- Pump (continued)*  
single stage centrifugal, 88  
steam-driven reciprocating, 88, 89  
turbine, 88, 89  
power requirements, 88  
reciprocating, 89
- Pure water  
definition of basic pure water, 344  
definition of very pure water, 344
- Purge cycle, 16
- Purification by electrodeionization, 372–376  
electrodeionization, 374–376  
electrodialysis, 373  
electrodialysis reversal, 373–374
- Purification, by RO membrane process, 308
- Purification of MU water  
by ion-exchange, 345–359  
by membrane technologies, 359–372
- Purification processes, 304
- Purification technologies for pre-boiler, 341–376
- Purolite, 352
- Pyridazine, 504
- Pyridines, in cleaning processes, 647
- Pyrite, in scales, 646
- Pyrocatechol, 506  
from tannins, 406
- Pyrogallol, 506  
from tannins, 405
- Pyrogallol, 237, 501, 506  
from tannins, 405  
in gas analysis, 693
- QR-1086, 447
- Quality management systems, 43
- Quartz, 145  
in scales, 645
- Quaternary ammonium compounds, 517
- Quebracho, 237, 444, 505  
historical perspective, 392
- Quebracho tannins, 171, 405, 484, 693  
historical perspective, 393
- Quercus* sp. tannin, 405
- Quick lime  
in fuel additives, 680  
for lay-up programs, 610
- Quinic acid, 506  
from tannins, 405, 406
- Quinol, 499–501
- Quinolines, in cleaning processes, 647
- Quinone, 499  
as catalyst, 505
- Radiation, 47
- Radiographic testing, 623
- Radionuclides, 266
- Rapid action intermittent BD arrangement, 77–78
- Rare-earth metals, as slag modifier, 682
- Ratio  
alkalinity to tannin, 407  
cation to anion resin, 536  
caustic to silica, 413  
distribution of amines, 527  
fuel/excess air, 673  
of Na to  $PO_4$ , 474  
oil/grease to millscale, in cleaning processes, 652  
of sulfonated styrene to maleic anhydride, 451  
silica content to caustic alkalinity, 585  
silica to sodium oxide, 398  
sodium to TDS in steam, 603
- Reaction stage turbines, 114
- Real-time remote monitoring, 132
- Reboilers, 536  
to reduce amine exposure, 533
- Reciprocating FW pumps, 89
- “Recommendations for Treatment of Water for Land Boilers,” 343
- Redeposition of scale and corrosion debris, 204, 296–298
- Redox process, corrosion as, 647
- Redox tendencies  
effect of chelant or oxygen, 263  
effect of chelants, 436
- Reducing conditions, maintenance of, 150
- Reduction of oxides, by hydrazine, 298
- Reduction reactions, 149
- Red-water, 398
- Refinery gas, as fuel, 51
- Refractory integrity, 617
- Refractory surfaces, inspection of, 620
- Refuse-derived fuel, 59
- Regeneration, of ion-exchange resin bed, 329
- Regenerative FW heating, 98
- Reheater (WT), 44, 47
- Reheaters, 71, 90–91  
non-drainable, 608
- Relative amine basicity cost effectiveness, 526
- Relative humidity, 690
- Relative neutralizing capacity, of amines, 521
- Relative volatility, of amines, 511, 526–530
- Removal of copper/copper oxides, 641–643
- Reodorants, for fuels, 671
- Residual heat, 20
- Residual oils, 685
- Residual sulfite, sampling for, 605
- Resin  
acrylic bead, in multifunctional water conditioners, 332  
ceramic bead, in multifunctional water conditioners, 332  
gel type, 200  
isoporous, 200  
macroporous, 200

- Resin breakdown, 197
- Resin loss from softener, 197
- Restorative preoperational passivation, 171
- Restrictor tube, cleaning, 625
- Resultant by-products, of amines, 511
- Return tube, blisters and deformation, 617
- Reversal of potential, 150
- Reverse osmosis, 199, 324, 360–372
  - application to reduce TDS, 162
  - automatic periodic membrane flush, 366
  - chemical for antiscaling/antifouling, 368–372
  - chemical treatments for RO antiscaling and antifouling duty, 368–371
  - chemical treatments for RO cleaning duty, 371–372
  - clean-in-place, 366
  - conversion factors, 363
  - design considerations for, 364–366
  - energy recovery turbine systems, 366
  - high permeate TDS water reject system, 366
  - to limit silica, 294
  - membrane cleaners, 371
  - membrane cleaning processes, 372
  - membrane storage, 372
  - membranes
    - aramid type, 363
    - aromatic polyamide type, 363
    - cellulose acetate type, 363
    - thin film composite type, 363
  - permeate flush tank, 366
  - pretreatment requirements for RO, 367–368
  - primary components of RO, 361–364
  - programmable logic control, 366
  - pumps, 366
  - as purification technology, 342
- Reversion, of phosphates, 400
- Rippled magnetite, 508
- Riser tubes (WT), 43, 46
- RO, 51
- Rodine 51, 52, 85, 648
- Rohm and Haas Company, 352, 404, 441, 662
- Roof header (WT), 47
- Roof tubes (WT), 47
- Rosin-amine ketone, in cleaning processes, 647
- Rotor unbalancing, in steam turbine, 116
- Ruptures, 259
- Rust
  - in boiler deposits, 634
  - removal during cleaning, 640
- Sacrificial anode, 167
- Sacrificial zinc sheet anodes, historical perspective, 393
- Safety issues, of amines, 511
- Safety valves, 79
- SAG<sup>®</sup> 10, 30, 555
- Saline corrosion, 250
- Salinity and adverse chemical reactions, control over, 169–170
- Salinity in the boiler, limiting, 169
- Salt cake, historical perspective, 393
- Salt density index, 363
- Salt splitting, 358
- Salting rate, of softeners, 328
- Salts
  - as combustion catalyst, 681
  - as fuel additive, 678
  - as slag modifier, 682
- Sample coolers
  - see also* Sampling coils
  - temporary, 602
- Sample points, for superheated steam, 601
- Sample probe, double-walled type, 602
- Sampling coils (sampling pots/sample coolers), 93–94
- Sampling and testing steam and condensate, 599–605
  - sampling for carryover and steam purity tests, 602–604
  - sampling steam and condensate in higher pressure boiler systems, 600–601
  - sampling steam and condensate in lower pressure boilers, 602
  - steam quality and purity and general sampling requirements, 604–605
  - superheated steam, using isokinetic multiport nozzle, 601
- Sampling for carryover and steam purity tests, 602–604
- Sampling nozzle
  - multiport, 601
  - single-port, 600, 602
- Sampling pots, *see* Sampling coils
- Sampling procedures for water and steam, 599
- Sampling station, 111
- Sand filters, 321–322
- Sandwich polisher, design of resin bed, 353
- Saponifiable oil, 549
- Saponification
  - as cleaning processes, 637
  - of fats, as deposit binder, 154
  - of soaps, 205
- Sarcosinates, 444,
  - as iron chelants, 406
- Satellite feeding stations, for amines, 535
- Saturated steam, 600
- Saturation point, of BW TDS, 74
- Saturation ratio, in RO systems, 369
- Save-all tank, 72, 93
- Saw dust, as fuel additive, 678
- Saybolt Seconds Universal, 83
- Scale and corrosion debris transport, 296–298

- Scale control, as functional area requiring chemicals, 387
- Scale and hardness control, nonchemical technologies for, 338–341
- Scale heat conductivity, measurement, 623
- Scale resolubilization, 146
- Scales, 218
  - amorphous, 144, 218
  - analysis of, 632–635
  - carbonate, 182
  - crystalline, 144, 218
  - eggshell thickness, historical perspective, 392
  - mineral salt, 144
  - removal by cleaning solvents, 645–647
- Scaling
  - fouling and deposition, in boilers, 217–235
  - silicate, 37
- Schinopsis* tannin, 405
- Schwebbett™ design, of resin bed, 352, 353
- Scion®, 353
- Scion-Hipol®, deionizer design, 353
- Scope of BW treatment and control of steam/waterside chemistry, 134–140
- Scotch marine boilers, 32–33, *see also* Boiler, fire tube, Scotch marine
- Screens, 325
  - for condensate conditioning, 376
- Scrubber
  - dry, 678
  - wet, 678
- Seawater, as source for RO, 365
- Seawater evaporator, 56
- Seaweed, historical perspective, 393
- Secodyne™, 318
- Secondary air, 82
- Secondary circuit working fluid, treatment of, 478
- Secondary precipitation, 313
- Sedimentation, 306
  - definition, 314
  - historical perspective, 390
- Sediments, 73
- Semipermeable RO membrane, 363
- Sensible heat, 15, 97
- Separation of steam and water, 7–10
- Sequacel® HD, 449
- Sequestrants
  - function of all-organics, 442
  - lignins as, 445
- Sequestration, using phosphate, 419
- Serpentine, 148, 214, 229, 412, 413
  - in boiler deposits, 634
  - in scales, 646
- Settling period, of dry polymer, 320
- Settling rate, of floc, 320
- Shell and tube heat exchangers, 100
- Shell floor, inspection for excessive sludge, 616
- SHMP, 421, *see also* Sodium hexametaphosphate
- Short cycle deionizer design, 353
- Short-term overheating, 260–261
- Siderite, 236
- Sieves, 325
  - for condensate conditioning, 376
- Silica, 217
  - amorphous, deposit in steam-condensate systems, 295
  - carryover, 276
  - cleaning in RO plants, 371
  - colloidal, 199
  - contaminant in steam purity, 603
  - control in supercritical boilers, 476
  - conversion in condensate polishers, 380
  - in fuel additives, 680
  - in higher quality water, 304
  - in scales, 646
  - in steam/condensate, 344
  - ionic, 199
  - limits in steam, 589
  - managing high levels in raw water makeup, 658
  - rejection rate with RO, 361
  - removal, 214
  - removal from water, 311
  - removal by RO, 360
  - testing in steam/condensate, 602
  - vaporous, in steam, 293–295
- Silica adsorption, by magnesia addition, 309
- Silica and magnesium, as mutual precipitants, 412
- Silica and silicate deposition, 227–231
- Silica in BW, maximum concentrations, 588
- Silica control
  - as adjunct requirement, 389
  - with AVT programs, 475
  - as functional area requiring chemicals, 87
- Silica deposit control agents, 360, 370
- Silica deposition, 198
- Silica deposits, 214
- Silica dispersants, 162
- Silica dissociation, 347
- Silica gel, for lay-up programs, 610
- Silica in steam, maximum concentrations, 588
- Silica leakage, 198–199
  - into feedwater, 198–200
- Silica levels, after ion-exchange, 359
- Silica limitation processes, 294
- Silica limits, 588
- Silica micelles, 549
- Silica polymer, for RO pretreatment, 371
- Silica precipitants, 294
- Silica reduction and removal technologies, 163
- Silica removal, 162–163
  - by ferric/magnesium hydroxide absorption, 412

- Silica removal (continued)*
  - by ion-exchange, 349
    - need for, 162
- Silica scaling, 440
- Silica solubilization, 546
- Silica volatiles, 154
- Silica volatilization, 230
- Silicate anions, 228
- Silicate-based boiler compounds, 411–413
- Silicate-based inhibitor, to prevent free hydroxyl ion, 241
- Silicate chemistries, as anodic inhibitors, 388
- Silicate ion, in steam, 294
- Silicate precipitation, seeding points, 228
- Silicate scale, 228
  - eggshell thickness, 230
- Silicate scaling, from hardness breakthrough, 661
- Silicate zeolites, historical perspective, 391
- Silicates, 145, 227–231, 395, 398–399, 635
  - amorphous, in steam, 293
  - in boiler deposits, 635
  - in cleaning formulations, 649
  - complex scales, 229
  - contributor to stress-corrosion cracking, 240
  - corrosion inhibitor, 183
  - glassy, in steam, 293
  - role in caustic-induced stress corrosion cracking, 466
  - in scales, 646
- Silicates and other common minerals,
  - deposition by, 227–237
  - deposits from inorganic salts and organics, 233–237
  - iron oxide and other corrosion debris deposition, 231–233
  - silica and silicate deposition, 227–231
- Silicic acid, 380
  - in steam, 294
  - volatile, 116
- Silicone-block copolymers, 552
- Silicones, 554–555
  - as antifoams, 551
- Siloxane glycol/PAG copolymer, 555
- Silt, in fuel oils, 672
- Single gas analyzer, 693
- Single-phase boiler, *see* Boiler, single phase
- Sintering temperature, of slag, 682
- Slag, 42
- Slag deposits, 674
- Slag modifiers, 682–683, 684
  - examples, 682–683
  - for fireside cleanliness, 611
  - formulation, 687
  - as fuel additives, 675, 680
- Slagging, 673
  - of furnace area, 681
  - of superheater, 681
- Sling psychrometer, 693
- Slow rinse, of ion-exchange resin bed, 329
- Sludge, 73, 176, 218,
  - coarse magnetite, 178
  - hematite, 178
  - iron, 180
  - in LP boiler vessel, 182
  - managing problems in LP boilers, 657
- Sludge blanket precipitation softening, 311
- Sludge conditioners, 440
  - as adjuncts, 85
  - historical perspective, 392
  - tannin as, 404
- Sludge conditioning, via tannins, 388
- Sludge control, as functional area requiring chemicals, 387
- Sludge dispersants, 237
  - tannins and lignin-based, 444
- Sludge dispersion, of polymers, 413
- Sludge fluidizer, function of all-organics, 442
- Sludging
  - due to hardness breakthrough, 196
  - general, 236
  - grease, caused by oily surfaces, 298
- Smaller steam turbine generators, 114–115
- Smelt, 58
- Smoke suppressant, 681
- Smoke test set, 693
- Smutting, 681
  - acid, 680
  - dry, 680
- SNF S.A., 318
- Soap
  - as combustion catalyst, 681
  - as slag modifier, 682
- Soda ash, 30, 411
  - in cleaning solutions, 652
  - condensate corrosion induced by, 289
  - historical perspective, 391
  - as a softening agent, 311
- Soda pulping process, 58
- Sodalite, 229, 234
- Sodaphos<sup>®</sup>, 422
- Sodium
  - carryover, 276
  - contaminant in steam purity, 603
  - control in supercritical boilers, 476
  - in fuel oils, 671
  - in fuels, 673
  - in higher quality water, 304
  - in steam/condensate, 344
  - levels in steam, 603
  - testing in steam/condensate, 602
- Sodium acid sulfite, 487–488
- Sodium alginates, 444
- Sodium aluminate, 411
  - historical perspective, 391
- Sodium aluminosilicate zeolites, historical perspective, 391

- Sodium-aluminum silicate, zeolite, 411
- Sodium aluminum sulfate, in scales, 645
- Sodium and silica leakage, 198–199
- Sodium bicarbonate, 226, 515
  - condensate corrosion induced by, 288
  - production, 357
- Sodium bisulfite, 168, 371, 396, 487–488
  - as RO membrane cleaner, 371
  - breakdown in steam-condensate systems, 291
- Sodium borate, 395
- Sodium bromate, in cleaning processes, 645
- Sodium carbonate, 226, 289, 411, 413, 545
  - in cleaning solutions, 652
  - historical perspective, 391
  - as a softening agent, 311, 312
- Sodium carboxylates, 444
  - from hydrolyzable tannins, 406
- Sodium carboxymethylcellulose, 444
- Sodium cation ion-exchange softening, with ED, 374
- Sodium compounds in fuel, 674
- Sodium contamination, in condensate, 382
- Sodium control, as functional area requiring chemicals, 387
- Sodium-cycle ion-exchanger, 161
- Sodium cycle softening, 328–329
- Sodium deposits, in clinker, 684
- Sodium dihydrogen phosphate, 421
- Sodium dioctyl sulfosuccinate, 543
- Sodium disilicate, deposit in steam-condensate systems, 295
- Sodium dodecyl sulfate, in RO cleaners, 372
- Sodium-EDTA, in cleaning processes, 638
- Sodium erythorbate, 61, 485, 486, 497–499
- Sodium erythorbate and erythorbic acid, 497–499
- Sodium ferrite, 249, 257
- Sodium ferroate, 546
- Sodium glucoheptonate, 432
- Sodium gluconate, 432
  - in cleaning processes, 640, 646
  - as passivator, 649
- Sodium heptonate, 432
- Sodium hexametaphosphate, 400, 421, 422
- Sodium humate, 444
  - historical perspective, 393
- Sodium hydrogen sulfite, 487–488
- Sodium hydrosulfite resin cleaner, 349
- Sodium hydroxide, 545
  - adequate concentration of, 240
  - as adjunct, 389
  - buildup in boilers, 236
  - in cleaning processes, 641
  - in cleaning solutions, 652
- Sodium hypoferrite, 249, 257, 546
- Sodium hypophosphite, 452
- Sodium ion-selective electrodes, 603
- Sodium ions, 169
  - measuring in steam, 278
- Sodium iron silicate, in scales, 645
- Sodium lauryl sulfate, in RO cleaners, 372
- Sodium leakage
  - into feedwater, 198–200
  - from polishers, 382
- Sodium levels, after ion-exchange, 359
- Sodium lignosulfonate, 444, 445
  - as decharacterizer, 485
- Sodium mercaptobenzothiazole, 401
- Sodium metabisulfite, 488–489
- Sodium metaborate, 399
- Sodium metaphosphate, 424
  - historical perspective, 393
- Sodium metasilicate, in cleaning solutions, 652
- Sodium metavanadate, 675
- Sodium molybdate, 397
- Sodium nitrate, 387, 395
  - in coil boilers, 595
  - conductivity guide, 595
  - historical perspective, 393
  - as oxidizer in cleaning processes, 641
- Sodium nitrate inhibitor, 256
- Sodium nitrite-based corrosion inhibitors, 580
- Sodium oxide, as slag component, 682
- Sodium polyacrylamide-acrylate, historical perspective, 393
- Sodium polyacrylate, historical perspective, 393
- Sodium polymethacrylates, 446
- Sodium polyphosphate, 399
- Sodium polysilicates, 398, 412
- Sodium pyrosulfite, 488–489
- Sodium pyrovanadate, 675
- Sodium salinity, control over, 169
- Sodium salts, steam distilling, 295
- Sodium silicates, 411
- Sodium slip, 358
- Sodium sulfate, historical perspective, 393
- Sodium sulfite, 168, 483–487, 578
  - breakdown in steam-condensate systems, 291
  - catalyzed, 87
  - in coil boilers, 595
  - feeding, 487
  - historical perspective, 393
  - as primary support chemical, 389
- Sodium tannates, 407
- Sodium tetraborate, 399
- Sodium tetrabromofluorescein, 543
- Sodium trimetaphosphate, 421
- Sodium tripolyphosphate, 399, 422
- Sodium vanadyl vanadate, 675
- Soft water, definition, 217
- Softened makeup, increased demand, 196
- Softener
  - need for, 225
  - need for with HP steam boilers, 308
  - need for with LP steam boilers, 308
  - reduced operating capacity, 197

- Softening
  - by ion-exchange, 328–329, 346
  - lack of capability in feedwater, 193–196
- Softening need, example, 194
- Sokalan® PA20 -PA25, 446
- Solid fuels, problems with, 670–671
- Solubility limit, of BW TDS, 74
- Solubilizer, function of all-organics, 443
- Soluble poison, 477
- Solublizing programs, 658
- Solution polymers, 316
- Solvent degreasers, 649
- Solvent extractable oily matter, 568
- Solvent naphtha, for fuel oils, 686
- Solvent sprays, in cleaning formulations, 650
- Solvents
  - for removing copper and copper oxides, 643–645
  - for removing iron oxides, 637–641
  - for removing organics, 649–651
  - for removing scales, 645–647
- Sonar effect, in nonchemical technology, 334
- Soot
  - in stack, 677
  - inspection for, 620
- Soot blowers, 73, 81–82, 611, 682
  - inspection of, 620
- Soot blowing, affecting steam sampling, 604
- Soot deposition, 674
- Soot emissions, dry, 678
- Soot removers, 649
- Sooting, 680
- Sorbant, 58
- Sorbitan, 544
- Sorbitan-based non-ionic surfactant treatments, 544
- Sorbitan fatty acid esters, 544
- Sorbitan monolaurate, 684
- Sorbitan tristearate, 544, 684
- Sorbitol, 544
- Soya-based filmers, 537
- Soyaalkyl-dimethylamine, 540
- Space heating equipment, 132
- Spalling, 259
  - in FW heaters, 609
- Sparge pipe, 18
- Specific conductance to TDS conversion guide, 570
- Specific humidity, 690
- Specific ion electrode, 9
- Specific usage additives, USDA, 484
- Spherical stack solids, 673
- Spheroidization, 261–262
- Spinels, 642
- Spiral wound cartridge, 363
- Spiral wound RO elements, 364
- Split stream dealkalization, 356
- Spoilage, of fuels, 671
- Sponge ball blasting, 624
- Sponge Ball, Inc., 624
- Spray attemperators, 91
- Spray attemperation water, 586, 589
  - water quality limits, 591
- Spray dryer desulfurizer, 678
- Spray ponds, 309
- Sprayed electrode boilers, 28–29
- Spreading coefficient, of antifoams, 551
- Square-wave generators, 334
- SS/MA, 451, *see also* Sulfonated styrene maleic anhydride
- Stability of treated water, 313
- Stabilization of unstable water, 202
- Stabilizer, function of all-organics, 443
- Stains, 176
- Stand-alone online cleaning formulations, 628–629
- Stand-alone programs, for online cleaning, 627
- Standard hydrogen electrode, 150
- Standard soap solution test, historical perspective, 392
- Standby and idle boilers, management of, 606–612
- Standby boilers (short-term offline), protection of, 606–608
- Stannous chloride, in cleaning processes, 640
- Starches, 237, 438
  - as adjuncts, 386
- Stay bolts, 29
- Steam, 1
  - carryunder, 8
  - delivery system, 45
  - discoloration, 300
  - dry, 8, 9
  - extracted, 115
  - header, 71
  - high heat-content, 274
  - live, 273
  - moist, 9
  - purity, 268, 275–284, 604
  - quality, 274, 275–284
  - superheated, 4
  - throttle, 114
  - valves, 71
  - wet, 9, 282
- Steam accumulator, 281
- Steam analyzer, Larson-Lane type, 278
- Steam and condensate equipment, inspection of, 621
- Steam and condensate purity, 154
- Steam and condensate systems, corrosive gases in, 284–293
  - carbon dioxide carryover, 288–291
  - other corrosive gases and related impurities, 291–293
  - oxygen infiltration, 285–287
- Steam and water problems affecting turbines, 115–116



- Steam blanketing, 146, 229, 259, 608
- Steam bubble frothing, 296
- Steam bubble nucleation, 6
- Steam coils, 305
- Steam-condensate recovery system, 45
- Steam cycle, 86
- Steam delivery system, 71
- Steam demand, 274
- Steam drums, 8, 41, 45
  - inspection of, 618
- Steam dryers, 280
- Steam flashing, 605
- Steam flow restrictions, 281
- Steam generation, 1–22
  - basics of, 4–10
    - separation of steam and water, 7–10
    - steam tables, 7
  - boiler plant efficiency, 14–22
  - energy, work, and power, 10–14
- Steam generation bank tubes, 44, *see also* Boiler bank tubes (WT)
- Steam generator, *see* Boiler
- Steam heated tracing lines, 19
- Steam load swings, 281
- Steam meter, inspection of, 621
- Steam pH, with hydrazine, 492
- Steam pressure efficiency, 17
- Steam pressure reductions, 281
- Steam purity
  - notes, 604–605
  - testing for, 603
- Steam purity and steam quality, 275–284
  - general sampling requirements, 604–605
  - necessity for steam sampling, 276–278
  - steam sampling problems, 277–278
  - steam–water separation effectiveness, 278–284
- Steam quality, 604
  - notes, 604–605
  - testing for, 603
- Steam raising plants, 67
- Steam release velocities, 14
  - excessively high, 115
- Steam sampling, 276–278
  - in higher-pressure boilers, 600–601
  - in lower-pressure boiler systems, 602
- Steam sampling points, 600, 601
- Steam sampling/testing, 599–605
- Steam saturation temperature, 103
- Steam scrubbers, 280
- Steam separator-water storage drums, 573
- Steam separators, 280
- Steam sparge pipes, 305
- Steam-to-steam heat exchanger, 60
  - to reduce amine exposure, 533
- Steam stripping, 9
- Steam superheating and delivery system, 47
- Steam surging, 283
- Steam system cycle, 132, 134
- Steam tables, 7
  - with amines, 533
- Steam trap efficiency, 10
- Steam traps, 91–92
  - disc, 92
  - efficiency, 19
  - float thermostatic, 92
  - impulse, 92
  - inspection of, 621
  - inverted-bucket, 92
  - thermodynamic, 92
  - thermostatic, 92
- Steam turbine
  - backpressure, 113, 115
  - condensing, 113, 115
  - extraction, 115
  - high-pressure section, 113, 114
  - impulse stage type, 113, 114
  - induction, 115
  - intermediate pressure section, 114
  - large steam, 113
  - low-pressure section, 114
  - noncondensing, 115
  - reaction stage type, 113, 114
  - reheat condensing, 113
  - smaller generator systems, 114
  - water and steam problems, 115
- Steam turbine-driven FW pumps, 89
- Steam volatiles, vaporous silica and, 293–295
- Steam washers, 280
  - limiting silica by employing, 295
- Steam-water
  - different types employed, 137
  - separation of, 7
  - sublayer film, 143
- Steam/water analyzer panels, 661
- Steam-water circulation system, 44, 45–47
  - boiler steam-water circulation system, 45–46
  - steam superheating and delivery system, 47
- Steam-water control limits, 138
- Steam-water separation, 278–284
  - effect of boiler operating variables on, 280–282
  - factors affecting the quality of, 8
  - interface factors, 282–284
  - operating variables, 280–282
  - steam–water interface physicochemical factors, 282–284
  - steam–water separation devices, 279–280
  - surging and carryover, 282–284
- Steam-waterside chemistry, control of, 134
- Steam-waterside problems and water treatment objectives, 140–144
  - interrelationship of waterside problems with boiler design and operation, 142–144
  - treatment objectives, 142

- Stearylamine, 536
- Steel laths, as sacrificial anodes, historical perspective, 393
- Steelworks waste heat boilers, 57, *see also* Boiler, waste heat, steelworks
- Steric repulsion, function of all-organics, 442
- Sticky films, 300
- Stirling boiler, *see* Boiler, water tube, Stirling
- Stockhausen, 318
- Stoichiometric relationships, of hydrazine, 493
- Stokers, 84
  - inspection of, 620
  - mass feed, 84
  - overfeed stokers, 84
  - underfeed stokers, 84
- Stop valves, 79
- Storage of bagasse and similar process residues, 671
- Straight tube NP steam generator, 66
- Strainer technologies, 307
- Strainers, 325
  - for condensate conditioning, 376
- Stratification, 259
  - in feedwater tank, 111
  - of fuel oils, 672
- Stratified packed-bed, design of resin bed, 352
- Stress and high temperature-related corrosion, 254–262
  - chelant corrosion, 262–265
  - copper corrosion, 265
  - overheating effects and high-temperature corrosion, 259–262
  - stress corrosion cracking, 255–258
  - thermal fatigue cracking and corrosion fatigue, 258
- Stress corrosion cracking, 255–258
  - caustic cracking, 255–256
  - caustic embrittlement, 255–256
  - caustic stress corrosion cracking, 255–256
  - hydrogen embrittlement and hydrogen damage, 256–258
- Stress corrosion cracking mechanisms, 169
- Stress rupture, 260
- Strontium, 221
  - as slag modifier, 682
- Styrene, 443
- Styrene divinylbenzene, 327, 347
- Subcooled liquid, 53
- Submerged electrode boilers, 27–28
  - fixed water level, submerged electrode boilers, 28
  - variable water level, submerged electrode boilers, 28
- Substantivity, of amines, 538
- Suez-Lyonnaise, 441
- Sulfur, in combustion chamber, 676
  - Sugar molecules, as tannins, 404
  - Sugar-phenols, from tannins, 405
  - Sugar refinery boilers, 59, *see also* Boiler, sugar refinery
  - Sugars, as process contaminants, 283
  - Sulfamic acid, in cleaning processes, 641, 646
  - Sulfate ions, 169
  - Sulfate leakage, 198
  - Sulfate salinity, control over, 169
  - Sulfate scale, historical perspective, 392
  - Sulfates, 217, 635
    - in boiler deposits, 635
    - cleaning in RO plants, 371
    - effect on nitrite feed rate, 396
    - in RO feedwaters, 370
    - in water supplies, 234
  - Sulfides, removal by slow heating, 646
  - Sulfite, 305, 498
  - Sulfite-based one-drum program formulation, 557
  - Sulfite/bisulfite, 208
  - Sulfite oxygen scavenger, 417
  - Sulfite pulping process, 58, 445
  - Sulfite/sulfite derivatives, as oxygen scavengers, 482
  - Sulfonate groups, 442
  - Sulfonated styrene maleic anhydride, 451
  - Sulfonated vinyl radical, 444
  - Sulfones, as biocides for fuel oils, 686
  - Sulfonic acid group, in ion-exchange resin structure, 327
  - Sulfur, 54
    - as combustant, 691
    - reaction producing sulfur dioxide, 691
  - Sulfur compounds, 673
  - Sulfur dioxide, 682
    - breakdown in steam-condensate systems, 291
    - in combustion chamber, 676
    - in steam-condensate systems, 284–285
    - from sulfite, 486
  - Sulfur gases
    - emissions of, 676
    - in acid rain, 675
  - Sulfur trioxide, 682
    - in combustion chamber, 676
  - Sulfurated ash deposits, 676
  - Sulfuric acid
    - in cleaning processes, 641
    - for RO pretreatment, 367
    - forming under pits, 250
    - from sulfur gases, 680
  - Sulfuric acid regenerant, 349
  - Sulfurous acid, breakdown in steam-condensate systems, 291
  - Superfloc™, 318
  - Superheat, degrees of, 602
  - Superheater deposits, 90

- Superheaters, 71, 90–91
  - convection (WT), 44
  - convection type, 90
  - horizontal arrangement, 90
  - interdeck arrangement, 90
  - nondrainable, 608
  - pendant arrangement, 90
  - platen arrangement, 90
  - radiant (WT), 43, 90
  - secondary (WT), 47
  - wet lay-up by flooding, 609
- Superheaters and reheaters, 90–91
- Superior<sup>®</sup>, nonchemical technology, 338
- Supersaturation, 144
- Surface acting agent, antifoam/defoamer chemicals as, 549
- Surface-acting properties, of process contaminants, 550
- Surface adsorption reaction, of hydrazine, 492
- Surface cleaner, PEG as, 553
- Surface condenser, 114
  - operational problems, 117–119
- Surface shielding, in corrosion processes, 247
- Surface (skimmer) BD arrangement, 76–77
- Surface spreading action, of antifoams, 551
- Surface tension, increase due to impurities, 283
- Surfactant antifoam/defoamer chemicals as, 549
- Surfactant properties, of amines, 543
- Surfactants, in fuel additives, 680
- Sur-gard<sup>™</sup>, 497
- Surging, 33, 115, 154, 155, 183, 282, 284, 294, 296
  - from excess softener chlorides, 661
- Surging control, as functional area requiring chemicals, 387
- Surging, steam–water interface
  - physicochemical factors and, 282–284
- Survival pressure
  - of DEHA, 496
  - of erythorbate, 499
- Suspended iron, 663
- Suspended solids, 306
  - calculations for BD requirements, 580
  - in raw water, 304
- Sweet water, 402
- Synergism, using phosphate, 419
- Synperonic<sup>®</sup> L62LF, 552
- Synthetic tannins, 388
  
- Tag-out/lock-out rules, 599
- Tagged polymers, 662
- Tallow-based filmers, 537
- Tallow propylenediamine, 540
- Tallow alkyl-dimethylamine, 540
- Tamol<sup>®</sup> 850 -960, 446
- Tank sludging, 672
  
- Tannic acids, 505, 568
  - historical perspective, 393
  - sodium salts, 405
- Tannin application notes, 406–410
- Tannin-based corrosion inhibitors,
  - degradation of, 582
- Tannin-based one-drum program formulation, 557
- Tannin-based products, as oxygen scavengers, 483
- Tannin blend concentrates, 405
- Tannin blends, 171
- Tannin chemistries, 405–406
- Tannin Corporation (Peabody, MA), 445
- Tannin extracts, historical perspective, 392
- Tannin index/value, 407
- Tannin programs, 388, 403–410
  - tannin application notes, 406–409
  - tannin chemistries, 405–406
  - tannin program formulations, 409–410
- Tannins, 168, 184, 208, 237, 283, 394, 395, 438, 443, 444, 498, 505–506, 550
  - mixing with amines, 485
  - lignin-based sludge dispersants and, 444–445
  - liquid single types, 445
  - multibled inhibitors, 405
  - natural, 404
  - spray-dried, 445
  - synthetic, 404
  - thermal decomposition limits, 591
  - wattle, 30
- Tap water, as source for RO, 364
- Tar, 237
- TDS levels, in higher quality water, 304
- Tea bush, 408
- Technical supervisory service, 127
- Teflon<sup>®</sup>, 534
- Temperature
  - condenser terminal difference, 118
  - saturation, 4
- Temporary hardness, 223, 311
- Terminalla chebula*, tannin, 405
- Terminology
  - boiler, 1
  - boiler plant, 1
  - steam generator, 1
  - steam-raising plant, 1
- Terpolymers, 442, 446, 447
  - as adjuncts, 389
  - use of to control iron fouling, 197
- Tetradentate ligand, 431
- Tetrahydro-*p*-isoxazine, 520
- 1,3,4,5-Tetrahydrocyclohexane-carboxylic acid, 405, 506
- Tetrapolymers, 442
- Tetrapotassium pyrophosphate, 123
- Tetrasodium-EDTA, in cleaning processes, 646
- Tetrasodiumpyrophosphate, 422

- Tetrazines, 505
- Texaco Corporation, 519, 520, 686
- Thermal aging, of oxides, 297
- Thermal breakdown, 219
  - inspection for, 620
  - of treatment chemicals, 237
- Thermal conductivity, 148
- Thermal cycling, 665
- Thermal cycling stress, 258
- Thermal decomposition, of fuels, 673
- Thermal fatigue cracking and corrosion fatigue, 258
- Thermal fluids, 1
- Thermal gradients, effect at boiler surfaces, 468
- Thermal oxidation, 91, 261
- Thermal shock, 98
  - to ion-exchange resin, 327
- Thermal sleeve, 601
- Thermal stability of amines, 511, 530–531
- Thermo-compression evaporator, *see* Evaporator, thermo-compression
- Thermodynamic steam traps, 92
- Thermo-expansion FW regulator, 80
- Thermohydraulic FW regulator, 80–81
- Thermostatic steam traps, 92
- Thin film composite polyamide cartridges, 365
- Thinning of vertical tubes, condensate corrosion producing, 289
- Thiocarbamide, in cleaning processes, 643
- Thiols, in cleaning processes, 647
- Thiomorpholine, in cleaning processes, 647
- Thiourea, in cleaning processes, 637, 642, 647
- Thorium232, 62
- Thorium233, 62
- Threshold agents, 166, 176
  - function of all-organics, 443
- Threshold effect, 398
  - function of all-organics, 443
  - by phosphate action, 400
  - of polymers, 413
- Threshold mechanisms, 432
  - for RO pretreatment, 369
- Threshold phosphate, 202
- Throttling calorimeter, 9, 278
- Tin, 210
- Toluol, 686
- Tolyltriazole, 395, 401
- Top drum, inspection of, 618, *see also* Steam drum
- Top water-wall headers (WT), 46
- Total alkalinity, 546
  - requirements with phosphate, 420
- Total hardness, definition, 223
- Total organic carbon, 457
  - rejection rate with RO, 361
- Total solids, control with AVT programs, 476
- Total volatiles, of fuels, 670
- Tough gel, in bead resin deep-bed polishers, 380
- Tracer dye polymer, 662
- Tracer dyes, 179, 662
- Transgranular cracks, 465
- Transport
  - of boiler water solids, 202, 203
  - of iron oxides, 662
  - of metal oxides, problems caused by, 297
  - of scale and corrosion debris, 204, 211, 285, 296–298
- Transport agent, function of all-organics, 443
- Transport-Plus™, 455
- Transported iron, 663
- Transported iron and copper oxides, 550
- Transported metal, 508
- Transported silt, 550
- TRASAR®, 441
- TRC® 233, 447
- Treatment of NP primary circuit coolant water, 477
- Treatment of NP secondary circuit working fluid, 478
- Treatment processes, pre-boiler and post-boiler, 303–383
- Treatment programs, optimizing in HP industrial boilers, 661–662
- Tri-Act®, 544
- Triaminoguanidines, 505
- Triammonium-EDTA
  - in cleaning processes, 638
  - oxidizer mix, in cleaning processes, 645
- Tricalcium phosphate, 145, 422, 423
  - in boiler deposits, 635
  - historical perspective, 392
  - scale, 235
- Trichloroethylene, in cleaning formulations, 650
- Triethanolamine, 498
  - in cleaning processes, 644
- Trihalomethanes
  - contaminant in steam-condensate systems, 291
  - removal by carbon filters, 323
  - removal of by membrane technology, 360
- 1,2,3-Trihydroxybenzene, 506
  - from tannins, 406
- 3,4,5 Trihydroxybenzoic acid, 405, 506
- Trio-bed, design of resin bed, 353
- Trion-3™, 332
- Triple bed, design of resin bed, 353
- Triple condensate polisher, 380
- Triple-membrane process, for high-purity water, 374
- Triple-membrane purification, 345
- Trisep, Inc., 361
- Trisodium phosphate, 123, 399, 421
  - historical perspective, 392
  - in cleaning solutions, 652
- Triton N101, 686

- Troubleshooting boiler operations, 657–667
  - identifying high water losses in HW
    - heating and other closed-loop systems, 659–660
  - managing high silica levels, in raw water makeup, 658
  - managing high sludge problems in lower pressure boilers, 657–658
  - optimizing treatment programs and control parameters in high-pressure industrial boilers, 661–665
  - significance of hardness breakthrough in lower pressure boilers, 660–661
  - significance of high iron levels when operating a chelant program, 658–659
- Try cocks, *see* Gauge cocks
- Tube bifurcation, 55
- Tube failure, 168
- Tube flare, inspection of, 619
- Tube hanger, inspection of, 620
- Tube heat transfer rate, measurement, 623
- Tube rupturing, 257
- Tube sheet, inspection, 617
- Tuberculation, 246–247
- Tubercules, as binding agent, 232
- Tubes
  - bent, 41
  - inspection for dusting, 616
  - inspection for thinning, 617
  - inspection of deterioration, 616
  - inspection of leaks, 616
  - inspection of surface, 616
  - leaking in condenser, 118
- Turbine and condenser operation efficiency, 20–22
- Turbine efficiency, effect of condenser, 116
- Turbine overspeed, 282
- Turbine pumps, 89
- Turbines, 71
  - extraction, 21
  - noncondensing, 21
  - operating efficiency, 20
  - reheat condensing, 21
- Turbining boilers, 623
- Turbulent flow, in bulk boiler water, 143
- Turndown ratios, 16, 19
- Turner gauge, 623, 631
- Tuyeres, 84
- Tween™, 545
- Two-drum programs, 555
- Two-phase boiler, *see* Boiler, two-phase
- Two-phase nucleate boiling, 465
- Two-phase systems, fundamental problems, 140
- Two-pipe heating system, 133
- U value, 218
- Ucon®, 686
- Ucon® 50-HB-5100, 553
- Ultraclean Technology, 624
- Ultrafiltration, 324, 359
  - as purification technology, 342
- Ultrasonic testing, 622
- Unburned carbon, 677
- Undercutting of rolled ends, 619
- Underdeposit corrosion, 248
- Underfeed stokers, 84
- Uniform general corrosion, historical perspective, 393
- Uniform rate corrosion, 245
- Unihib® 106 -305, 449
- Union Carbide Corporation, 519, 520, 553, 555, 686
- United States Department of Agriculture, 484
- Unshared electron pairs, due to basicity, 524
- Unstable treated water, 202
- Upcore™ design, of resin bed, 352
- Upflow precipitation softening, 311
- Uptake funnel precipitation softening, 311
- Uranium232, 62
- Uranium235, 62
- Uranium238, 62
- Urea, 684
  - in steam-condensate systems, 292
- U.S. Department of Health, 484
- U.S. Energy Federal Technology Alert, 333
- U.S. Filter, 353, 375
- Use of glycols, problems associated with, 177
- Utility power boilers, 53–55
- U-tube manometer, 86
- Vacuum deaerators, 108
- Vacuum pumps, in condensers, 117
- Valve
  - automatic non-return, 73, 80
  - blowdown, 73, 74
  - blowdown for coil boiler, 74
  - blowdown for firetube boiler, 74
  - blowdown for marine boiler, 74
  - blowdown for vertical firetube boiler, 74
  - blowdown for watertube boiler, 74,
  - blowoff, 73, *see also* Valve, blowdown
  - drum safety, 73
  - feed line check, 73
  - feed line stop, 73
  - outside stem and yoke, 79
  - pop type safety, 79
  - safety, 79
  - safety relief, 73
  - shut-off, 73
  - side-action lever, rapid opening, 75
  - slow-opening angle, 75
  - steam huddling chamber, 79
  - steam line stop, 73
  - stop, 73, 79
  - super-jet safety, 79
  - superheater safety, 73
- Vanadate complexes, as fireside deposits, 676

- Vanadium, 681
  - in clinker, 684
  - compounds in fuel, 674
  - in fuels, 673
- Vanadium pentoxide, 674, 675
  - as fireside deposits, 676
  - as slag component, 682
- Vanadium sulfate, as slag component, 682
- Vapor compression evaporator, *see*
  - Evaporator, vapor compression
- Vapor-phase amine, 526
- Vapor phase inhibitors, 389
  - as program primary support chemicals, 385
- Vapor phase programs, 464, 474–476
- Vaporizing oil burners, 83
- Vaporous silica and other steam volatiles, 293–295
- Variable water level, submerged electrode boilers, 28
- Varnish, 205, 300
- VCI materials, for lay-up programs, 610
- Vented receiver, inspection of, 621
- Vents, boiler, 80
- Versa® TL-3, TL-4, TL-7, 451
- Versene®, 432
- Vertical boiler, *see* Boiler, fire tube, vertical
- Vertical recirculating inverted U-tube NP steam generator, 66
- Vinylbenzene, 443
- Vinylformic acid, 446
- Viscosity improver, 672, 685
- Viscosity of fuel oils, 672
- Vitamin C, 497
- Vivendi, 353
- VOC removal, using multifunctional water conditioners, 332
- Volatile corrosion inhibitors, for wet lay-up, 609
- Volatile neutralizing amine, with AVT programs, 475
- Volatile organic scavengers, 483, 489, 511, 521
  - with AVT programs, 474
- Volatility, 521
  - of amines, 511, 526–520
- Volatility, relative volatility, and distribution ration or partition coefficient, 526–530
- Volcanic lava media, 309
- Volumetric heat release rates, 14
- VPI, 389, *see also* Vapor phase inhibitors
- Vulcan Chemical Technologies, 318
- Vyncke special-purpose boilers, 59
  - Waste heat and other special purpose boilers (continued)*
  - carbon monoxide boilers, 57
  - combined cycle boiler systems, 59
  - enhanced oil recovery boilers, 58
  - fluidized bed combustion boilers, 58
  - steelworks waste heat boilers, 57
  - sugar refinery boilers, 59
  - Vyncke special-purpose boilers, 59
  - waste-to-energy boilers, 59
- Waste heat boiler, *see* Boiler, waste heat
- Wastewater treatment system, 72
- Waste-to-energy boilers, 59, *see also* Boiler, waste-to-energy
- Water
  - boiling by heat transfer, 4
  - dipolar nature of, 2
  - entrained, 9
  - in fuel oils, 671
  - pretreatment plant system, 69–70
  - triple point of, 7
- Water analysis records, 631
- Water chemistry control limits, tables and supporting notes, 566–598
- Water chemistry, control of, 157–158, 559–598
- Water column gauge glass, 73, 75, 82
- Water columns, 82
- Water conditioners
  - multifunctional, 331–332
  - multifunctional booster unit, 332
- Water conditioning, *see* Water, pretreatment plant system
- Water content, of fuels, 670
- Water hammer, 5, 91, 183, 276
- Water in steam, 604
- Water levels, 281
- Water losses
  - excessive or uncontrolled, 180–182
  - prevention of in MPHW/HPHW systems, 186
  - identifying in closed loop systems, 659–660
- Water meter, need for, 179
- Water pretreatment plant system, 69–70
- Water softening, need for, 160–161
- Water-soluble surfactant, in cleaning formulations, 651
- Water treatment capital equipment, need for, 158–163
  - need for deaerators and other equipment, 161–162
  - need for water softening, 160–161
  - need for silica removal, 162–163
- Water treatment management reviews, 126–127
- Water treatment for nuclear powered steam generators, outline of, 477–478
- Water treatment practice, effective, 156

- Water treatment program management, 125–129
  - chemical treatment additions, 125
  - chemical treatment testing and interpretation, 125–126
  - full-service and outsourcing programs, 127–129
  - water treatment management reviews, 126–127
- Water treatment programs
  - need for internal chemical types, 165
- Water treatment recommendation
  - perspectives, 560–566
    - ABMA Commercial BW Requirements and ASB BW Guide*, 563–565
    - ASME Consensus*, 561
    - BS2486*, 562–563
    - McCoy BW, 565–566
- Water tube boiler plant sections, 43–45
  - water tube convection-pass section, 44
  - water tube exit gas section, 45
  - water tube furnace section, 43–44
- Water tube boilers, 39–61
  - high-purity steam generation, 60–61
  - steam-water circulation system, 45–47
  - types of WT boiler, 47–59
    - cogeneration boilers, 52–53
    - coil boilers, 49
    - industrial WT boilers, 49–52
    - marine boilers, 55–56
    - utility power boilers, 53–55
    - waste heat and other special-purpose boilers, 56–59
  - water tube boiler plant sections, 43–45
- Water tube convection-pass section, 44
- Water tube exit gas section, 45
- Water tube furnace section, 43–44
- Water tube steam generators, 50–52
- Water-jet electrode boilers, 28–29
- Water-team appurtenance checks, 120
- Water vapor
  - in air, 689
  - determination, 693
- Water-wall headers, inspection of, 618
- Water-wall tubes (WT), 43, 45, *see also* Membrane wall tubes
- Water Wizard, 332
- Waterline evaporation, 250
- Waterside dry lay-up, 610–611
- Waterside fouling, 194
- Waterside problems
  - interrelationship with boiler design/operation, 142
  - in hot water heating and low-pressure steam systems, 180–185
    - excessive water loss, 180–182
    - lead and lag boiler operation, 184–185
    - maintaining inhibitor levels and controlling BD and surging, 182–184
  - Waterside problems (continued)*
    - limiting potential for, 156–172
      - controlling corrosion, 167–172
      - effective water treatment practice, 156–158
      - limiting deposition, 163–167
      - need for water treatment capital equipment, 158–163
    - in MPH and HPHW systems, 185–189
- Waterside and steamside problems, 131–301
  - basics of, 131–172
    - contamination, 154–155
    - corrosion, 149–153
    - deposition, 144–148
    - fouling, 153–154
    - fundamental steam-waterside problems and water treatment objectives, 140–144
    - hot water and steam system cycles, 132–134
    - limiting potential for waterside problems, 156–172
    - system of BW treatment and control of steam/waterside chemistry, 134–140
  - boiler section specifics, 217–271
    - boiler scaling, fouling, and deposition, 217–237
    - nuclear powered steam generators, corrosion in, 265–267
    - other forms of corrosion, 262–265
    - passivation and common corrosion problems, 237–254
    - stress and high temperature–related corrosion, 254–262
  - hot water heating and low-pressure steam boiler specifics, 173–189
    - problems of corrosion in hot water and LP steam heating systems, 178–180
    - problems associated with use of glycols, 177
    - other waterside problems, 180–185
    - problems with heating coils, 175–177
    - waterside problems in MTHW and HTHW systems, 185–189
  - post-boiler section specifics, 273–301
    - corrosive gases in steam and condensate systems, 284–293
    - oil and process contamination, 298–300
    - scale and corrosion debris transport, 296–298
    - steam purity and steam quality, 275–284
    - vapor silica and other steam volatiles, 293–295
  - pre-boiler section specifics, 191–215
    - feedwater contamination from makeup water, 193–203
    - feedwater contamination from returning condensate, 203–206

- Waterside and steamside problems*  
(continued)  
overview of pre-boiler section waterside problems, 192  
problems associated with final feedwater blend, 205–215
- Waterside surfaces, operational control of, 599–667  
boiler cleaning, 623–657  
boiler inspections, 612–623  
managing standby and idle boilers, 606–612  
sampling and testing steam and condensate, 599–605  
troubleshooting notes, 657–667
- Waterside wet lay-up, 608–69
- Wattle tannin, 237, 405
- Waxes, 685
- Weld defect problems, 174
- Wet chemistry analysis, 622
- Wet desulfurization system, 54
- Wet lay-up  
of boiler auxiliaries, 609  
by cascading BD, 609  
programs, 606  
protection of waterside, 608–609
- Wet steam, 604
- Wetback boiler, *see* Boiler wetback
- Wetness/dryness degree of in steam, 604
- Wetting agents, in cleaning formulations, 650
- Wheatstone bridge, 623
- Wick boiling, 14
- Wire drawing, 76
- Wood flour, as fuel additive, 678
- Wood fuel, 17
- Wood, as fuel, 51
- W.R. Grace, Inc., 432
- WT boilers, inspection of, 618–621  
fireside inspections, 620–621  
waterside inspections, 618–619
- Wustite, 233
- X-ray diffraction, 622
- Xenon, in air, 689
- XI™, 375
- Xonolite, 229
- Yellow metal protection, 395
- Zeolites, 326  
historical perspective, 391  
scale, 411  
softening, 391  
treatment, 308
- Zero enthalpy, 2
- Zero solids treatment programs, 464, 474–476, 478, 546
- Zetag™, 318
- Zinc, 210
- Zinc anodes, 167  
with nonchemical technology, 334
- Zinc oxides, 146  
in corrosion debris, 296  
transport of in condensate, 231, 232
- Zinc sludge, as fuel additive, 678
- Zinc transport, 212