

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 II

*Treatments, Program Design,  
and Management*



# **Boiler Water Treatment Principles and Practice**

Volume II

*Treatments, Program Design,  
and Management*

**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*

# CONTENTS

---

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	II

---

# 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



AVT	All-Volatile treatment
Barg	bar (pressure), gravity
BD	blowdown
BDHR	blowdown and heat recovery system
BF	blast furnace
BOF	basic oxygen furnace boiler
BOOM	build, own, operate, maintain
BOP	balance of plant
BS&W	basic sediment and water
BSI	British Standards Institution
BTA	benzotriazole
Btu/lb	British thermal unit(s) per pound
BW	boiler water
BWR	boiling water reactor
BX	base-exchange water softener
CA	cellulose acetate
CANDUR	Canadian deuterium reactor
CDI	continuous deionization
CFH	critical heat flux
CFR	Code of Federal Regulations
CHA	cyclohexylamine
CHF	critical heat-flux
CHZ	carbohydrazide
CI	cast iron boiler
CIP	clean-in-place
CMC	carboxymethylcellulose
CMC	(sodium) carboxy-methylcellulose
CMC	critical miscelle concentration
COC	cycle of concentration
cogen	cogeneration boiler
CR	condensate return
CTTD	condenser temperature terminal difference
CW	cooling water

d	distance
DA	deaerator
DA	dealkalization
DADMAC	polydiallyl-dimethylammonium chloride
DAE	1,2-diaminoethane
DBNPA	2,2,-dibromo-3-nitrilopropionamide
DC	direct current
DCA	deposit control agent
DCHA	dicyclohexylamine
DEA	diethanolamine
DEAE	diethylaminoethanol, AKA diethylethanolamine
Dealk	dealkalization
DEEA	diethylethanolamine, AKA diethylaminoethanol
DEG	diethanoglycine
DEHA	diethylhydroxylamine
DEHA	N,N-diethylhydroxylamine
DEHA	diethylhydroxylamine
DETPMP	diethylenetriaminepenta (methylene phosphonic acid)
DT	differential temperature
DHA	dihydroxyacetone
DI	deionization
DMAE	2-dimethylaminoethanol, AKA N-N-dimethylethanolamine
DMAEP	dimethylaminoethylpropanol
DMAP	dimethylamino-2-propanol
DMEA	N,N-dimethylethanolamine, AKA 2-dimethylaminoethanol
DMIPA	dimethylisopropanolamine
DNB	departure from nucleate boiling
DO	dissolved oxygen
DOT	Department of Transportation
DR	distribution ratio
DSP	(anhydrous) disodium hydrogen phosphate

DTPA	diethylenetriaminepentacetic acid
DVB	divinylbenzene
DVGW	Deutsche Vereinigung des Gas-und Wasserfaches e.V
EC	erosion-corrosion
ED	electrodialysis
EDG	ethanoldiglycine
EDI	electrodeionization
EDR	equivalent square feet of steam radiation surface
EDR	electrodialysis reversal
EDTA	ethylenediaminetetraacetic acid
EMF	electromagnetic filtration
EMS	electromagnetic separation
EPIDMA	epichlorohydrin-dimethylamine
ESA	ethoxylated soya amine
ETA	ethanolamine
<i>f</i>	force
FB	firebox boiler
FBC	fluidized bed combustion boiler
FBR	fast breeder reactor
FCC	fluid catalytic cracking
FD	forced draft
FFCPP	full-flow condensate polishing plant
FGD	flue gas discharge
FSHR	flash steam and heat recovery
FT	fire tube boiler
FTA	Federal Technology Alert
FW	feedwater
GAC	granular activated carbon
$g_c$	proportionality constant
GCV	gross calorific value
gph	gallon per hour
GRAS	generally regarded as safe

GRP	glass reinforced plastic
GTM	gas transfer membrane
HAD	hexadecylamine
HAN	heavy aromatic naphtha, AKA solvent naphtha
HE	hydrogen embrittlement
HEDP	1-hydroxyethylidene-1,1-diphosphonic acid
HEDTA	N-hydroxyethylenediaminetriacetic acid
HEIDA	hydroxyethyliminodiacetic acid
HLB	hydrophile-lipophile balance
HMDTMP	hexamethylenediaminetetra (methylene phosphonic acid)
hp	horsepower (boiler)
HP	high pressure
hph	horsepower per hour
HQ	hydroquinone
HQC	3-hydroquinuclidine
HR	heat recovery
HRT	horizontal return tubular boiler
HV	high voltage
HVAC	heating, ventilation, air conditioning
HW	hot water
HWR	heavy water reactor
Hyfor	hydroxyacetic acid (glycollic acid)/formic acid
I & I	industrial and institutional
IBA	isobutanolamine, AKA 2-Amino-2-methyl, 1-propanol
ID	induced draft
IDA	iminodiacetic acid
IP	intermediate pressure
IPA	isopropyl alcohol
IX	ion exchange
$K_a$	acidity dissociation constant
$K_b$	basicity dissociation constant
kcal/min	kilocalorie per minute

kg	kilogram
kPa	kiloPascal
kW	kiloWatt
kW/hr	kiloWatt per hour
lb	pound
LP	low pressure
LPHW	low pressure hot water
LSI	Langelier saturation index
LTHW	low temperature hot water
LV	low voltage
LWR	light water reactor
<i>m</i>	mass
m	meter
M	mega
3-MPA	3-methoxy-N-propylamine
MAWP	maximum allowable working pressure
MB	mixed bed ion exchange
MBT	(sodium) mercaptobenzothiazole
MCR	maximum continuous rating
MEA	monoethanolamine
MEKO	methylethylketoxime
MIC	microbiologically induced corrosion
$\mu\text{S/cm}$	microSeimen per centimeter
mm	millimeter
MM	multimedia filtration
MN	mega Newton
MOPA	3-methoxy,n-propylamine
MPHW	medium pressure hot water
MSP	anhydrous sodium dihydrogen phosphate
MT	mixed treatment
MTHW	medium temperature hot water
MU	makeup water
NaMBT	sodium mercaptobenzothiazole

NC	neutralizing capacity
ND	not detectable
NDT	nondestructive testing
NF	nanofiltration
ng	nanogram
NOWL	normal operating water level
NO <sub>x</sub>	nitrogen oxides
NPSH	net positive static head
NRV	non-return valve
NTA	nitriilotriacetic acid
NTU	nephelometric turbidity unit
NVAT	Non-Volatile alkaline treatment
°C	degrees Celcius
ODA	octadecylamine
°F	degrees Fahrenheit
OH	hydroxyl radical
°K	degrees Kelvin
OS&Y	outside steam and yoke (valve)
OSHA	Occupational Safety and Health Administration
OT	oxygenation treatment
OVGW	Österreich Vereinigung des Gas-und Wasserfaches e.V
P	pressure of gas
PAA	(sodium) polyacrylate
PAA/PAM	acrylate/acrylamide copolymer
PAA/VS	acrylic acid/vinyl sulfonate copolymer
PAC	polyaluminum chloride
PAG	polyalkyleneglycol, AKA polyetherglycol
PAGMBE	polyalkyleneglycol-monobutylether
PAM	polyacrylamides
PBTC	2-phosphonobutane-1-2-4-tricarboxylic acid
PCA	phosphinocarboxylic acid
PCA type 16	phosphinopolycarboxylic acid

PCC	precommission cleaning
PEG	polyethylene glycol
PEL	permissible exposure limit
PF	pulverized fuel
PHWR	pressurized heavy water reactor
PLC	programmable logic controller
PLWR	pressurized light water reactor
PMA	polymaleic acid
PMAA	polymethacrylic acid
POC	preoperational cleaning
POE	polyoxyethylene
POP	polyoxypropylene
PS	precipitation softening
psi atm	pounds per square inch, atmospheric
psia	pounds per square inch, absolute
psig	pounds per square inch, gravity
PV	pressure vessel
PVA	polyvinyl alcohol
<i>R</i>	universal gas constant
RDF	refuse derived fuel
RNC	relative neutralizing capacity
RO	reverse osmosis
RW	raw water
SAC	strong acid cation
SBA	strong base anion
SCC	stress corrosion cracking
SCR	selective catalytic reduction
SG	steam generator
SHMP	sodium hexametaphosphate
SHR	sodium heated reactor
SM	Scotch marine boiler
SNCR	selective noncatalytic reduction processes
SS	stainless steel

SS/MA	sulfonated styrene maleic anhydride
SSU	Saybolt seconds universal
STMP	sodium trimetaphosphate.
STPP	(anhydrous) sodium tripolyphosphate
SV	safety valve
<i>T</i>	temperature
<i>t</i>	time
TDS	total dissolved solids
TFC	thin film composite
TH	total hardness
THM	trihalomethane
TOC	total organic carbon
TQM	total quality management
TSP	(anhydrous) trisodium phosphate
TSPP	(anhydrous) tetrasodiumpyrophosphate
TTA	tolyltriazole
UF	ultrafiltration
USDA	United States Department of Agriculture
UT	ultrasonic testing
<i>v</i>	volume of gas
v	volt
VB	vinylbenzene
VCI	volatile corrosion inhibitor
VOC	volatile organic compound
VOS	volatile oxygen scavenger
VPI	vapor phase inhibitors
W	work
WAC	weak acid cation
WBA	weak base anion
WH/HR	waste heat/heat recovery boiler
WT	watertube boiler
ZST	zero solids treatment





# **Boiler Water Treatment Principles and Practice**

Volume II

*Treatments, Program Design,  
and Management*



---

# PRE-BOILER AND POST-BOILER TREATMENT PROCESSES

---

As has been discussed earlier in this book, boiler plants can only continuously and economically transfer heat to water and effectively produce steam of satisfactory purity if the feed water (FW) and boiler water (BW) quality is properly controlled and appropriate for the particular boiler design and mode of operation. This, in turn, requires that makeup (MU) water and condensate return (CR) qualities are also controlled.

For simple HW and LP steam heating applications, employing perhaps a Scotch marine or firebox FT boiler, the water quality requirements are unlikely to be onerous, but as pressure ratings and heat-flux densities increase (and other factors such as special boiler designs and steam usage applications are taken into consideration) water quality becomes increasingly important. Thus, in general:

- FW and BW qualities are related to boiler pressure and heat-flux density, such that increasingly higher pressure or highly rated boilers tend to require increasingly higher quality and higher purity FW.
- Higher pressure and highly rated boilers often are larger and more complex; consequently, larger boilers usually demand FW of higher quality and tighter water chemistry control ranges than smaller boilers.
- Where boilers are particularly compact or of special design, for any given pressure or heat-flux rating, they are apt to require a higher quality FW than would otherwise be generally provided.
- Where process applications demand particularly high quality or high purity steam, FW and BW quality must conform to a higher standard and water chemistry must be tightly controlled.

- Owners and operators should always provide the highest possible quality of MU water that makes economic sense for their particular boilers, because improving the quality of MU water (and CR) leads to higher quality FW and BW. This in turn provides a payback of reduced heat and treated water losses caused by blowdown (BD), lower “polishing” treatment requirements, cleaner steam, and, for most plants, reduced risks of internal fouling, deposition, and corrosion. Thus, the provision of good to high quality MU water is an essential starting point to the achievement of effective heat transfer and pure steam generation. In practice, it is not uncommon for system designers or owners of some smaller and lower pressure boiler plants to ignore the need for basic pretreatment, believing perhaps that the available water quality is adequate for MU and that any deficiencies can always be compensated for simply by the use of additional chemicals. This assessment is not always true, and although internal chemical treatments are always required, they should generally be regarded as water chemistry “polishers” and added only in small concentrations.
- A further consideration is that boiler plants operate most effectively when the FW and BW chemistry is constant and predictable. Thus, irrespective of a facility’s size (or lack of size), a key objective should be to produce FW of a *consistent* composition. Pretreatment equipment processes can often be particularly useful in ironing out variations in the quality of both MU and CR.

Most raw water sources considered for use as boiler MU have been treated or conditioned either by a water utility (providing *city water*) or in-house (providing *industrial water*). They are supplied to the boiler plant clean and relatively free of **suspended solids, colloidal material, organics, and iron**. In hard water areas there also may be some reduction in **hardness** and **alkalinity** provided. Where boiler plant raw water (RW) quality is still unacceptable for the particular boiler plant needs, additional **pretreatment** (*pre-boiler conditioning* or *external treatment*) may be required.

If a higher quality MU water is required, it passes through one or more **purification processes** as part of the pretreatment.

The term *higher quality* generally means FW with significantly lower levels of **TDS** than typically employed in lower rated boilers. Additionally, it implies the reduction of certain specific minerals or ions (such as **silica, sodium, or alkalinity**) and **noncondensable gases** to meet very low or extremely low concentration specifications.

When the term *higher quality* is applied to CR, it refers to a reduction in **iron** and **copper**. For large industrial or utility WT boilers, this may also include **nickel** and **chromium**. A **polishing process** may be required to achieve this quality.

External treatment does not end with the provision of filtration, softening, demineralization, or polishing, because for all but the most basic of HW heating systems (where MU requirements are minimal), the effective removal of oxygen from FW is also critical. For this process, depending on the overall economics and ultimate use of the HW or steam, a combination of FW heating and chemical oxygen scavenging is generally employed.

Small boiler plants often supplement the heat derived from CR by employing **steam coils**, **steam sparge pipes**, or **electric heaters**, whereas larger facilities use **economizers**, **closed FW heaters**, and **deaerators** (as discussed in Chapter 3).

Although heaters, deaerators, and chemicals are traditionally used for O<sub>2</sub> removal, new **membrane** and **carbon catalyst technologies** have evolved and are discussed in this chapter.

Chemical oxygen removers such as **sulfite**, **hydrazine**, or **diethylhydroxylamine** (DEHA) are added, as appropriate, to the FW line, deaerator storage tank, FW tank, or other receiver. Although oxygen scavengers are typically fed to *external* treatment equipment, they are generally considered to be part of the *internal* treatment program, together with the balance of the chemical treatments (*chemical polishers*).

Most external treatment processes involve the use of large items of capital equipment (although some consumable chemicals also may be used to aid or improve the process, such as *coagulants*, *flocculants*, *filter-aids*, *dispersants*, and the like).

The available range of pretreatment options has widened considerably in recent years, and different methodologies have come to be viewed not as competing technologies but rather as complementary to each other. Consequently, it is now the norm to design pretreatment and purification system trains by blending various primary technology equipment units (or their subsets) together in any of a wide number of permutations to achieve the most cost-effective solution for any specific problem.

Traditionally, the mix of pretreatment equipment required to meet a specific FW volume and quality specification is provided as a permanent installation under a capital project, although today there is a growing global market in **outsourced water services**. Typically, vendors such as **Ecolochem, Inc.**, a world leader in this type of service, provide trailer-mounted, mobile water-processing equipment that can be

hooked up directly to the boiler plant. Standard equipment trains may be provided on long-term lease, processes custom-designed and delivered to fit existing facilities, or, quite simply, treated water purchased to supply all boiler plant needs. See Figure 9.4d for a schematic layout of a mobile plant.

## 9.1 OVERVIEW OF COMMON EXTERNAL TREATMENT PROCESS TECHNOLOGIES

The term *external treatment* is used to describe all of the different types of essential nonchemical processes employed to condition or remove some or all impurities in water before it reaches the FW pumps. There is often considerable overlap in the scope of common water treatment process technologies, and each of the primary processes can be divided into several subsets, giving rise to a wide range of impurity removal efficiencies for each process.

Where higher quality water is required, there is no single technology that can provide all the answers to impurity removal requirements. Consequently, it is common practice to employ two, three, or even more processes in sequence. In view of the different water sources, final quality requirements, and permutations of technologies and subsets, there is no universally agreed upon order in which the technologies are sequenced. Nevertheless, there are some purification processes that, because of specific technical or economic advantage, enjoy popular appeal and are commonly specified.

Leaving aside **FW deaeration** (which is usually provided as the final type of external treatment in the pre-boiler section), the primary forms of treatment processes commonly employed can be conveniently categorized into three areas:

1. **MU water pretreatment** provides for a basic good quality water. The scope for potential treatment of impurities is consequently extremely wide because it is concerned with an entire spectrum of raw water sources. Commonly, however, we are concerned with removing *suspended solids* and *colloidal material*, *organics*, *iron*, and *manganese*. Pretreatment also covers the partial or total reduction of *hardness*. Processes employed include **aeration** or **oxidation**, *hardness conditioning* or *removal* by **nonchemical treatments**, **precipitation softening** and **ion-exchange**, **natural zeolite treatments**, and *clarification* by **sedimentation** and **media filtration**.

2. **MU water purification:** is concerned with providing higher quality waters. There are many interpretations as to what constitutes “high quality” water, and consequently there are also a seemingly endless number of related specifications. Purification processes include **ion-exchange, membrane technologies, and electro dialysis**, together with the many subsets available for each technology.
3. **Post-boiler external treatment** is essentially concerned with restoring condensate to a previous high purity condition by removing contaminants resulting from corrosion and steam utilization processes. Processes include **CR purification (polishing) by media filtration and ion-exchange, plus strainer technologies and electromagnetic filtration/separation (EMF/EMS)**.

## 9.2 BASIC PRETREATMENT PROCESSES

Control of waterside chemistry starts in the pre-boiler section because the lack of, or inappropriate methods for, water treatment creates significant operational difficulties and impacts the economics of the entire process from start to finish.

All boiler plants, irrespective of design, size, pressure, or location, need as a *minimum* to be supplied with RW of a basic good quality that is consistently clean and clear throughout the seasons. Further treatment may be necessary.

**Raw water essentially should be free of suspended matter, natural organics, iron, manganese, and sulfur gases. Ideally, it should also be low in hardness, alkalinity, silica, and bacteria and have a pH level of approximately 7 to 8.**

- Where RW of basic good quality is supplied as MU for **HW heating boilers**, no other form of pretreatment is usually necessary. However, an *internal, corrosion inhibitor* treatment-based program should be provided, and periodic **boil-outs** may still be necessary.
- Where RW of basic good quality is supplied for **LP steam boilers** (that is, *firebox, Scotch marine, cast-iron sectional boilers*, etc. at operating pressures below 15 psig) and where the MU water volume demand exceeds 5% of the FW, pretreatment by ion-exchange softening should be additionally provided. This rule also applies to **electrical resistance boilers, electrode boilers, vertical boilers, and coil boilers**.



- For all LP steam operations in which the total hardness of RW exceeds, say, 10 to 20 ppm  $\text{CaCO}_3$ , the use of a softener is preferable to control solely via internal precipitation treatment. Oxygen scavenging and other internal treatment programs should also be provided. Some MPHW/HPHW and lower pressure steam boiler designs may require additional purification beyond simple water softening.
- Where RW of basic good quality is supplied as MU for boilers operating at over 15 psig, irrespective of the CR contribution to FW, additional pretreatment and/or purification treatment is required. At the very least, full softening of MU water is needed.
- Where RW quality is below a basic good quality standard, pretreatment *must* be provided before the water can even be considered as potential boiler MU water.

Pretreatment processes should not be regarded as impurity-specific, stand-alone methodologies because, typically, each form of water impurity may be removed by more than one type of process and individual technologies can be modified to deal with particular RW chemistries.

In practice, for any specific boiler application, the various pretreatment and purification techniques employed are incorporated in a sequential train to provide the most cost-effective or operationally effective treatment solution.

Examples of pretreatment process trains are:

1. **Treatment of a tropical surface water to provide MU for a 75 psig vertical boiler** (rice grower, South America). The water is naturally very soft (only 5 ppm hardness) but colored brown because of organics. A two-stage pretreatment process is carried out in pressure vessels (PV) and involves iron removal using a *BIRM*<sup>®</sup> *catalyst*, followed by *zeolite treatment* for organics removal. No separate *deep-bed sand filtration* stage for suspended solids removal is employed because both PV processes effectively provide filtration capacity in addition to their primary functions.
2. **Provision of MU water for 100 to 150 psig FT boiler from a deep-well supply** (large hotel complex, Caribbean). The water often contains iron and sulfur and is seasonally contaminated with salt water. Total dissolved solids (TDS) vary between 1,200 and 2,500 ppm. The process used is **a. aeration** for iron oxidation and

sulfur gas removal; **b.** iron removal via polymer-assisted *flocculation*; **c.** *clarification* by *sedimentation* and subsequent *deep-bed sand filtration*; **d.** *ion-exchange softening*; and **e.** purification by *reverse osmosis (RO) membrane process* to achieve a 90% TDS reduction.

3. **Supply of MU water for a medium-pressure (450 psig) WT boiler, from a surface water source with very variable suspended solids and hardness** (sugar refinery, South Africa). The process used is **a.** carbonate removal using *hot-lime precipitation softening* coupled with silica adsorption by magnesia addition; **b.** *clarification* in anthracite filters; and **c.** *cation ion-exchange* for the balance of hardness removal.

Notes on some common pretreatment processes are provided in the following sections.

## 9.2.1 Aeration and Oxidation

Aerators are often used for iron and manganese removal from deep well waters. Dissolved sulfur gases and some carbon dioxide are also removed, resulting in a slight elevation in pH levels. There are various designs but **pressure aerators**, **aeration towers**, and **spray ponds**, are common.

### 9.2.1.1 Pressure Aerators

**Pressure aerators** employ a vertical, **volcanic lava media**-filled PV and receive water at pump pressure. The water is mixed with blown air and fed to the bottom of the bed. Excess air is discharged through an air valve to atmosphere, and the aerated water is collected at the top of the column and then fed to a sand filter for removal of insoluble **ferric hydroxide**.

Improved results may be obtained by substituting the volcanic lava for BIRM<sup>®</sup> at a bed depth of 30 to 36 inches (76–91 cm) and a flow rate of 4 to 5 gpm/sq ft of media bed surface area. BIRM<sup>®</sup> acts as a catalyst and normally requires only a periodic backwash to remove surface debris (backwash rate in pressure filter tank is 10 gpm/sq ft).

Optimum catalytic conversion of iron to insoluble ferric hydroxide is achieved when the following conditions are met:

1. Raw water total alkalinity  $> 2 \times$  (sulfate + chloride)
2. pH level  $> 6.8$

# Appendix II

---

## GLOSSARY

---

*The intention of this glossary is to provide a water treatment technology definition that is practical rather than always wholly scientific.*

*Note: BD = blowdown, BW = boiler water, CR = condensate return, FT = firetube boiler, FW = feedwater, HW = hot water, PF = pulverized fuel, PV = pressure vessel, SV = safety valve, TDS = total dissolved solids, WT = watertube boiler.*

### **Absolute pressure:**

The sum of boiler gauge pressure and atmospheric pressure (14.696 psia).

### **Accumulation test:**

Test used to determine the relieving capacity of boiler safety valves.

### **Acid-Base:**

Various theoretical definitions. Acid is the opposite of a base. Essentially, an acid is a compound or ion containing hydrogen with a tendency to be a *proton donor* to a base or *electron acceptor* from a base. In practice, an acid dissociates in water ( $H_2O$ ) to form  $H_3O^+$ , not  $H^+$  as generally believed. Some acids accept electrons with the formation of covalent (shared) bonds, stronger acids accept complete transfer of electrons and are thus *oxidizing agents*. Bases and *reducing agents* are forms of electron donor chemicals.

### **Acidity:**

The concentration of acids or acidic salts in solution that can be measured by titration with a standard alkali to a selected pH endpoint.

### **Acid smutting:**

Staining or discoloration (such as to motor vehicle paint-work), as a result of acid fallout. Acid fallout is soot particles containing

adsorbed sulfuric acid, and resulting from incomplete combustion, exiting the flue gas system and falling to earth.

**Adiabatic expansion:**

The process occurring when steam is expanded by conversion to work without external heat loss or gain. Steam expanding behind the piston of a steam engine after the cutoff point approaches adiabatic expansion.

**Admiralty brass or Admiralty metal:**

Specific types of brass that resist *de-zincification corrosion* and are widely used in heat exchanger fabrication. Typically, Admiralty brass consists of greater than 70% Cu, 1% Sn, small amounts of either As, Sb or P (to prevent de-zincification), and balance is Zn.

**Air:**

Dry air has a composition of 20.947% oxygen (O<sub>2</sub>), 78.086% nitrogen (N<sub>2</sub>), 0.934% argon (Ar) and 0.033% carbon dioxide (CO<sub>2</sub>) by volume. However, air usually has some moisture and at 60% relative humidity (RH) and 80 °F (26.7 °C) air contains 2.09% water (H<sub>2</sub>O).

**Air cock (Boiler vent):**

Device used to vent noncondensable gases from a boiler during start-up and shutdown procedures.

**Air ejector:**

A steam driven device fitted to surface condensers and other items of equipment that removes oxygen and other noncondensable gases, thus maintaining a vacuum.

**Air flow switch:**

A switch that proves primary air is supplied to a boiler.

**Air heater:**

An heat exchanger located in the exit-gas system. Air heaters preheat combustion air and may be of several different types including *convection* air heaters of either *tubular* or *plate* design and *regenerative* air heaters.

**Air to fuel ratio:**

Ratio used to ensure the complete combustion of fuel. The ratio changes over the range of high and low fire.

**Alkaline hardness:**

Hardness in water (soap-consuming scum and scale-generating salts) is caused by the presence of bicarbonates, carbonates, and

hydroxides, of primarily calcium and magnesium. In natural waters, alkaline hardness is principally bicarbonates.

**Alkalinity:**

Primarily the sum of carbonate, bicarbonate and hydrate ions in water, but phosphate, silicate etc. may also contribute partially to alkalinity. Normally expressed as ppm (mg/l)  $\text{CaCO}_3$ . Phenolphthalein alkalinity (P Alk.) is that portion of alkalinity titrated with acid to pH 8.2 end-point, while total alkalinity (T Alk. or M Alk.) is that titrated with methyl orange indicator to pH 4.2 end-point.

**Alloy:**

Metal with additional elements designed to provide beneficial properties, such as brass or stainless steel.

**All volatile treatment (AVT):**

A form of *low solids treatment* program whereby there is no apparent addition to the total dissolved solids in the BW.

**Ambient air:**

The atmospheric open air, not in any confined area.

**Ambient temperature:**

The temperature of the surrounding air.

**Amines:**

A class of chemicals derived from ammonia employed to treat steam and condensate.

**Amphoteric metal:**

A metal, such as zinc, that forms salts with potentially weak acidic or basic properties. Limits the applicability of the metal as an inhibitor against water treatment problems. Examples are aluminum salts in water, which produce a weak base  $[\text{Al}(\text{OH})_3]$  and zinc, which may corrode at either low or high pH.

**Anhydrous:**

Meaning “without water” and describing salts that do not contain any water of crystallization.

**Anion:**

Negatively charged ion in aqueous solution, e.g., chloride ( $\text{Cl}^-$ ) or sulfate ( $\text{SO}_4^{2-}$ ). Certain chemicals may therefore be *anionic* and exhibit anionic properties.

**Anion exchange:**

The replacement of negative ions of soluble salts (such as  $\text{Cl}^-$ ) by hydroxyl ions ( $\text{OH}^-$ ) by passage through a basic resin bed (as in one half of the *demineralization* process).

**Annunciator:**

An audio alarm. The sound is produced electronically.

**Anode:**

Positive electrode (+) of electrolytic cell where oxidation occurs and electrons are donated.

**Anodic inhibitor:**

Chemical that reduces the tendency of iron to oxidize (rust) to ferrous ion, such as *chromate* which suppresses that part of the electrolytic corrosion process occurring at the anodic sites on a metal surface.

**Anthracite coal:**

A hard type of coal with a high calorific value.

**Antifoam:**

A chemical treatment added to prevent the possibility of foaming occurring in the boiler and reduce the risk of BW carryover. Commonly also known as a **defoamer**, although this type of treatment is designed to stop foaming *after* it has already occurred and may involve different chemistries.

**Antiprecipitant:**

A chemical that retards the precipitation of insoluble salts. Mechanism is usually by inclusion within the crystal structure.

**Appurtenances (fittings):**

Equipment fitted directly to a boiler primarily for safety reasons.

**Ash:**

The powdery residual matter remaining after combustion.

**Ash fusion temperature:**

The temperature at which ash particles change from a liquid to a solid. A high ash fusion temperature indicates that the ash particle will quickly change to a solid after burning and is less likely to adhere to a boiler fireside surface (as slag).

**Ash hopper:**

A storage receiver for combustion ash.

**ASME code:**

One of several codes written by the American Society of Mechanical Engineers. Some codes provide controls for the construction, repairs, and the operation of boilers and other types of PV and boiler appurtenances in the United States.

**Atmosphere:**

A unit of pressure. 29.92 inches of mercury at sea level at 45° latitude. Equal to 1,000 g/cm<sup>2</sup>.

**Atmospheric pressure:**

The pressure at sea level. Taken to be approximately 14.7 psia.

**Atomize:**

To convert a liquid into a fine mist by mechanical means.

**Attemperator (desuperheater):**

An apparatus for reducing and controlling the temperature of superheated steam. Typically, a spray attemperator design is employed.

**Attrition:**

A form of erosion especially relating to the frictional wear of ion exchange resins, such as that of water softener resin, causing loss of capacity.

**Austenitic:**

Describes certain types of stainless steels and other metals that consist of nonmagnetic iron containing face-centered cubes of carbon or other elements in solid solution.

**Automatic blowdown system:**

One of several different types of BW blowdown systems that automatically controls the frequency and duration of the BD period. Some systems provide continuous BD.

**Automatic non-return valve:**

A type of valve located in the steam line and elsewhere that automatically cuts the boiler in and out, thus providing for online and offline operation. This valve protects the steam system in the event of a loss of pressure from a boiler, caused perhaps by a large steam leak.

**Auxiliaries:**

Any item of equipment fitted to a boiler to improve control or a major component within one of the many boiler plant systems and sub systems.

**Azeotrope:**

Two or more compounds that when mixed together provide a constant boiling point, distilling off without decomposition and in a constant ratio (e.g., isopropyl alcohol and water).

**Back pressure:**

The pressure exerted against a flow.

**Backwash:**

Part of the operating cycle of water filters or softeners. It involves the upward flow of water to lift up the media bed to release and wash away dirt and other unwanted particulate matter and to reclassify the media.

**Baffles:**

Equipment located inside the boiler furnace area to direct the path of hot combustion gases and thus gain maximum heat absorption.

**Balanced draft:**

A system of balancing induced draft and forced draft to a large WT boiler controlled primarily by dampers. In fact, large WT boilers tend to be specifically designed to operate at a slightly *negative* furnace pressure.

**Bar:**

The cgs system unit of pressure.  $1 \text{ bar} = 1 \times 10^6 \text{ dynes/cm}^2, = 1 \times 10^5 \text{ N/m}^2, = 29.531 \text{ inches of mercury (Hg)}, = 753 \text{ mm Hg, at } 32 \text{ }^\circ\text{F (0 }^\circ\text{C), and at a latitude of } 45^\circ.$

**Base:**

Alkaline chemical, opposite of acid, as in the equation: Acid + Base = Salt + Water.

**Base exchange softening:**

Ion-exchange softening.

**Base load boiler:**

A utility boiler that operates at constant output in order to generate base-load electricity.

**Bed:**

The volume of carbon, sand, ion-exchange resin, or other media contained in a pressure tank and used as pre-treatment process for water. Requirements for bed depth, expansion and support, etc. are governed by the design criteria for each process.



**Bed volume (BV):**

A volume measure of the permitted flow rate of water through ion exchange resins and sometimes other media, such as sand. Typically, ion-exchange resins used for water softening will tolerate 8 to 40 BV/hr.

**Bent-tube boiler:**

A multiple-drum WT boiler design that allows for more flexibility in the internal arrangement of boiler surfaces.

**Bituminous coal:**

A soft coal with a high volatile content.

**Black liquor:**

The liquid remaining from the cooking of pulpwood. It is used as a fuel in specially designed pulp and paper industry WT boilers.

**Blowdown:**

A portion of the circulating BW that is removed, either intermittently or continuously, to limit the concentration of soluble and insoluble salts in the water.

**Blowdown tank:**

A PV that receives boiler BD prior to any final discharge to waste.

**Blowdown valve:**

One of various types of valve employed to enable BD of a boiler. Main BD valves are located at the bottom of all boiler drums, shells, and headers.

**Boiler capacity:**

The potential output of a boiler, normally given as lbs/hr or kg/hr *maximum continuous rating* (MCR).

**Boiler explosion:**

A waterside expansive force that can be caused by a sudden drop in steam pressure without a corresponding decrease in temperature (especially in a FT boiler). Or a furnace expansive force due to the ignition of highly inflammable gas, vapor or dust. Minor furnace explosions are called *puffs*, *flarebacks*, or *blowbacks*.

**Boiler horsepower:**

A boiler steam generating rate of approximately 34.5 lb./hr. *from and at* 212 °F (33,475 Btu per hour) and today, typically provided by 5 sq. ft. of boiler heating surface.

**Boiler layup:**

The removal of a boiler from service for an extended period. A layup (wet or dry) requires the boiler to be stored under controlled conditions to avoid corrosion.

**Boiler room log:**

A book into which all notable events, problems, and requirements identified during the operation of a boiler are recorded.

**Boiler surfaces:**

The various tubes, connecting headers (manifolds), and drums within the *steam/water circulation system* that collectively provide primary heat transfer and steam generation.

**Boiler shutdown:**

A set of procedures undertaken to remove a boiler from service (“*going off-line*”).

**Boiler startup:**

A set of procedures undertaken to prepare a boiler for service (“*going online*”).

**Boiler tube:**

Any of a number of steel tubes used simultaneously as heat transfer devices for both steam generation and boiler furnace cooling. Boiler tubes may be straight or bent.

**Boiler vent (air cock):**

Device used to vent non-condensable gases from a boiler during startup and shutdown procedures.

**Bottoms:**

The portion of petroleum crude left after lighter fractions are distilled. Today, much of the bottoms that goes into residual fuel oil (No. 6 oil) is simply asphalt or asphaltines.

**Bourdon tube:**

The coiled-tube component of a pressure gauge that coils or uncoils dependent upon pressure inside the tube.

**Box header:**

A box shaped, steam-water receiving vessel employed in older WT boiler designs. Box headers required *staybolts* to prevent bulging.

**Boyles Law:**

Under constant temperature conditions, the volume of a gas varies inversely as the pressure:  $p_1V_1 = p_2V_2$

**Brass:**

One of several corrosion resistant *copper/zinc* alloys (e.g. 70% Cu + 30% Zn). See **Admiralty brass**.

**Breakthrough (endpoint):**

The point reached in the service cycle of an ion exchange resin where the exchange capacity has been exhausted and the ion to be exchanged breaks through the bed.

**Breeching:**

The exit-gas duct connecting a boiler to its chimney.

**Brining:**

Part of a softener regeneration process whereby the cation ion exchange resin is converted to the sodium form by the application of a, typically, 10 to 15% W/V strength of brine (sodium chloride).

**British thermal unit (Btu):**

A measurement of heat energy. One Btu is the quantity of heat required to increase the temperature of one pound of water by one degree Fahrenheit (F). Also, one Btu is lost when one pound of water is reduced by 1 °F.

**Brittle fracture:**

The separation or cleavage of a metal with little or no resulting *plastic deformation*.

**Bronze:**

One of several types of high-chloride resistant, copper/tin alloys (e.g. 90% Cu + 10% Sn), usually 11% Sn maximum and also containing small amounts of Zn and P. Also bronze alloys, whereby Sn is replaced by Al, Si, or Be.

**Brownian movement:**

Movement of colloidal suspended particles due to forces resulting from collision of colloids and molecules of suspended medium (usually water).

**BS&W:**

Or S&W. Basic sediment and water. The paraffin, sediments, and salt water impurities in crude and oil fuels that need to be removed prior to further processing or use.

**Burning in suspension:**

The combustion of a fuel in air without visible support. PF coal is burnt in suspension within the boiler combustion chamber.

**Butterfly valve:**

A balanced valve employed to control gas flow in gas-fired boilers.

**Bypass damper:**

A type of damper used to control the air temperature in air heaters. It also provides a means of minimizing air heater corrosion.

**Bypass line:**

A pipeline that passes around an injection point, valve, control point, heater, steam trap, or other device in order that repairs or other work can be carried out on the bypassed item of equipment as and when required.

**Calibrate:**

To adjust a pressure gauge or other measuring device in order to conform closer to a test gauge or set of standards.

**Carbon steel:**

A two-phase mixture of *ferrite* and *pearlite*.

**Carbonate control:**

A virtually defunct form of chemical treatment program employed in older design, low heat-flux boilers, whereby the risk of BW scale formation is managed by means of a controlled reserve of carbonate ions.

**Carnot cycle:**

An early concept of the cycle of thermodynamic processes as relating to steam engine heat-energy performance.

**Carryover:**

BW containing some level of contaminant that is entrained and passes with the steam into the main steam-header. Carryover is always detrimental to the steam cycle process and is primarily caused by BW *priming* (*surging*), *gulping*, *misting*, or *foaming*.

**Cast iron:**

*Iron/ carbon* alloy, poured as a hot molten liquid into a mold. Usually produced as either *gray iron* (where flakes of graphite are embedded in an iron matrix) or *nodular iron* (spheroids of graphite in the matrix).

**Cathode:**

Negative electrode (–) of an electrolytic cell where reduction occurs and electrons donated.

**Cathodic inhibitor:**

Any chemical (such as zinc hydroxide) that suppresses the reduction of oxygen to hydroxyl ion. A cathodic inhibitor suppresses that part of the electrolytic corrosion process at the cathodic sites on a metal surface.

**Cathodic protection BW programs:**

Cathodic protection equipment has been used very successfully in water tanks and HW and steam boilers as anticorrosion devices for 100 years or more. Such equipment comes in many shapes and sizes, and comprises a sacrificial anode of either zinc or magnesium alloy, either bolted directly to a suitable internal water-wetted (cathodic) metal surface, or self-contained by enclosing the anode with a suitable cathode (such as a silver plated base metal). Usually several devices are required for any boiler, more for larger units and less for smaller ones, and these require replacement every one to two years.

Cathodic protection is a useful supplement to other forms of water treatment, as a general corrosion inhibiting device in HW boilers, or where specific design configurations can lead to inadequately protected localized metal in steam boilers. Where BW makeup demands are minimal and boiler output is fairly constant, cathodic protection devices can also provide some measure of protection against hardness scales. Calcium carbonate salt is formed as a flocculant or soft sludge rather than a hard scale, due to the peptizing effects of a zinc hydroxide complex formed from zinc ions in alkaline BW.

Claims are sometimes made that the use of cathodic protection devices eliminates the need for any type of water treatment chemical, including oxygen scavengers (on the basis that oxygen in the FW increases the rate of zinc anode corrosion, producing both zinc ions and hydroxide ions and resulting in the removal of O<sub>2</sub> from the BW electrolyte). Such claims that corrosion protection devices provide a complete program are spurious.

*NOTE: Butler Engineering Associates, Inc. of New Jersey, USA, provide cathodic protection devices suitable for boilers of up to 150 psig, and promote them as a complete alternative to chemicals with no messy mixing, pouring or testing being required. Nevertheless, it is noted that this com-*

pany also markets a liquid, color-coded BW treatment chemical formula-tion under the brand name COR-EX.

**Cation:**

Positively charged ion in aqueous solution such as hydrogen ( $H^+$ ) or calcium ( $Ca^{2+}$ ) ions. Certain chemicals may therefore be *cationic* and exhibit cationic properties.

**Cation exchange:**

Replacement of positive ions of a soluble salt by passing sodium through a cation resin (*softening* or *base exchange*) or hydrogen through an acidic resin (as in one half of the *demineralization* process).

**Caustic cracking:**

A form of boiler waterside, *caustic stress-corrosion cracking corrosion* affecting carbon steels and austenitic stainless steels (300 series). Particularly associated with high localized concentrations of deposited *sodium hydroxide* (caustic soda).

**Caustic embrittlement (caustic stress corrosion cracking):**

A general term for those types of corrosion induced by caustic and accelerated by stress and moderately high temperatures (200–250 °C).

**Caustic gouging (ductile gouging):**

A form of corrosive attack on boiler steel by a very high concentration of sodium hydroxide in which hydrogen is evolved and *ferrite* and *hypoferrite* ions are formed.

**Cavitation:**

Formation of vapor bubbles in rapidly flowing or turbulent water causing risk of pumping failure and erosion and/or corrosion. Due to an increase in velocity at the pump head resulting in a localized pressure reduction and the subsequent collapse of the vapor into *voids* or *cavities*. Where FW temperatures are high (over perhaps 195–205 °F) the pump velocity can reduce FW vapor pressure below that corresponding to the temperature of the liquid and cavitation can occur accompanied by some noise. Warning of severe pump cavitation is often indicated by a heavy noise.

**Cementite:**

*Ferric carbide*. A compound of iron and carbon having the approximate formula  $Fe_3C$ .

**Centrifugal force:**

The force created by a rotating impeller that builds up in a centrifugal pump.

**Centrifugal pump:**

A popular design of boiler FW pump that employs centrifugal force to create pumping pressure.

**Chain grate stoker (traveling grate stoker):**

A *cross-feed stoker* employed with high capacity boilers because of its ability to feed solid fuel at a faster rate than other stoker designs.

**Channeling:**

The short-circuiting or taking the least line of pressure resistance of a flow of water in a resin bed.

**Check valve:**

An automatic valve that controls the flow of a liquid by permitting it to travel only in one direction.

**Chelant:**

Organic compound (such as ethylenediamine-tetraacetic acid (EDTA) or nitrilo-triacetic acid (NTA) having the ability to take metal ions in water and produce soluble, coordinate-bond complexes. Chelants are commonly used in BW deposit control treatments and various cleaning formulations.

**Chelonate:**

A coordination complex formed by the chelation of a metallic ion.

**Chemical compound:**

A chemical formed from a reaction of two or more elements.

**Chemical concentration:**

The amount of chemical in a given amount of water. Normally given as *parts per million* (ppm), *parts per billion* (ppb), or *milligram per liter* (mg/l).

**Chemical mixture:**

Two or more chemical compounds or elements mixed together and usually capable of easy separation.

**CHEMTREC:**

USA Chemical Transportation Emergency System.

**Chimney:**

The vertical flue part of an exit-gas system. Designed to induce draft in order to exhaust the gases into the atmosphere.

**Classes of fire:**

The three classes of fire are: **A**: those started from wood paper or rags; **B**: those started from oil, grease, or flammable liquids; **C**: those initiated by electricity.

**Classification:**

The backwash and rinse cycle part of a filtration or ion exchange process that permits a media bed to resettle in a graduated manner so that the largest grains or beads are at the top and the smallest at the bottom.

**Clinker:**

Commonly also known as cinder or slag. Clinker is the mass of fused ash that results after the incombustible residual material from combustion cools down from a molten state.

**Coagulate:**

To bring together small particles into a single larger mass that can be filtered or flocculated and subsequently removed from a water.

**Coal bunker:**

A storage container for coal, often an overhead hopper.

**Coal conveyor:**

A continuous rubber belt used to transport coal from the coal yard to a fuel preparation and storage area.

**Coalesce:**

To bring together small droplets of oil into a larger volume that can then be separated from water.

**Coal feeder:**

A mechanism used to control the rate of feed to a stoker or pulverizer.

**Coal gate:**

A device used to control the depth of coal entering the boiler furnace in a stoker feed system.

**Coal ram:**

A device to evenly distribute the coal into the center retort of an underfeed stoker and force it to the top of the stoker from where it can be fired.



**Coal scale:**

A coal measuring and recording device for stoker fired or PF fired boilers.

**Cocurrent:**

A design feature of an ion exchange plant whereby service flow and regenerant flow are in the same direction. The opposite of *counter-current* (*counterflow*).

**Cogeneration (combined cycle):**

The production of electricity and industrial process steam in the same boiler plant system.

**Cold work:**

The permanent deformation of a metal produced by a press, hammer, or other external force.

**Colloid:**

Extremely small particle, typically  $10^{-5}$  to  $10^{-7}$  cm in diameter. Colloidal solutions or *hydrosols* contain colloidal particles that are electrically negatively charged, which contributes to their fine dispersion and the difficulty of sedimentation and clarification. Coagulation is usually carried out by causing the particles to adsorb positively charged ions, such as aluminum from alum.

**Combustible material:**

Any material that burns when exposed to oxygen and heat at its ignition temperature.

**Combustion:**

The rapid *exothermic* (heat generating) chemical process that occurs when oxygen reacts with a fuel.

**Combustion control:**

The regulation of the combustion process in a boiler furnace. Control takes place by regulating the access of fuel or air.

**Complete combustion:**

The total burning of a quantity of fuel supplied ideally with the minimum of excess air necessary.

**Compressive stress:**

The stress that occurs when equal and opposite forces act upon an object. All FT boiler tubes are subject to compressive stress.

**Condensate:**

Steam that has lost heat and *condensed* (reverted to liquid water).

**Condensate polisher:**

A type of high-temperature operation, ion-exchange plant. It can remove contaminants from condensate by both exchange and filtration mechanisms.

**Condensate tank:**

A receiver for the collection of condensate prior to being pumped to an *open FW heater* (deaerator).

**Condensing turbine:**

A design of turbine whereby the driving force is provided by exhaust steam condensing in a surface condenser.

**Conditioning:**

The process of adding chemicals to a water to “condition” it, in order prevent any subsequent deposition or corrosion taking place.

**Conduction:**

The transmission and transfer of heat without bulk motion of the conductor.

**Conductivity:**

The phenomenon of transmitting electrons through a body (an electric current). Usually associated with the measurement of electrical conductivity through water and measured in *microSiemens per centimeter* ( $\mu\text{S}/\text{cm}$ ) or *micromho per centimeter* ( $\mu\text{mho}/\text{cm}$ ).  $1 \mu\text{S}/\text{cm} = 1 \mu\text{mho}/\text{cm}$ . The *mho* is equivalent to a *reciprocal ohm* (the unit of resistivity).

**Congruent phosphate conditioning:**

One of several phosphate-conditioning programs for high pressure WT boilers, (*coordinated* and *equilibrium phosphate conditioning* are others). Congruent phosphate conditioning is used to provide a precisely controlled and limited range of boiler water pH and total phosphate. The program involves the careful blending of various alkaline phosphate buffers with a view to avoiding the formation of free hydroxyl alkalinity.

**Contact heater:**

A FW heater into which “live” steam is injected.

**Convection:**

A mechanism of heat transfer in which heat energy is transmitted by convection current motion through gases and liquids. Part of the heat-transfer process in a boiler is by convection whereby the circulation of water carries heat from the tube near the fire to the drum and surrounding areas.

**Convection superheater:**

A type of superheater that is located within the convective pass section of a boiler and receives heat by convection.

**Corrosion:**

Oxidation of a metal or alloys to its (lower energy state) oxides or cations. In effect, the wastage or other damage to a metal caused by one or more of several types of chemical or electrochemical reactions. Takes many forms such as galvanic, crevice, pitting, under-deposit, and biologically induced corrosion.

**Corrosion current:**

Stream of electrons flowing (by convention) from anodic (+) to cathodic (-) areas of a metal. Part of the overall corrosion mechanism.

**Corrosion debris:**

Corrosion product. Rust, oxide, or other result of corrosion process.

Corrosion fatigue:

A form of corrosion resulting in the *transgranular cracking* of a metal in an corrosive environment under a cyclical pattern of stress.

**Countercurrent (counterflow):**

A design feature of ion-exchange plant whereby the regeneration flow or backwash flow are in the opposite direction to the service flow. Also, a principle used in heat exchangers whereby the medium being heated flows in the opposite direction to the medium supplying the heat.

**Cracking open:**

A term meaning to slowly open a valve in order to allow pressure to equalize on both sides of the valve.

**Creep:**

The high temperature and stress-induced deformation of a metal, the extent of which is time-induced.

**Critical pressure:**

The pressure at which there is no separation of phase in a liquid. The critical pressure of water is 3203.6 psia.

**Cross-linkage:**

The tie between polymer chains to link them together, producing added strength and other benefits. As exemplified by *divinylbenzene* (DVB).

**Cross “T”:**

A connection fitted to water columns and other items of equipment permitting easy inspection and cleaning of the equipment.

**Cyclone separator:**

A steam-water separation device that functions by the use of centrifugal force and changes in direction.

**Damper:**

A device used to control the flow of air and other gases.

**Data plate (name plate):**

A plate attached to boilers, valves, and other equipment containing officially required data pertaining to operational rating and safety issues.

**Day tanks:**

Tanks employed to hold diluted water treatment chemicals or regenerants and used as a reservoir to be pumped or educted into a water system as part of a treatment process.

**Deadweight tester:**

A device used to test and recalibrate a pressure gauge.

**Dealkalization:**

Any of various processes for reducing the alkalinity content of water, especially the use of ion-exchange processes for dealkalizing boiler MU water.

**Deaerating feedwater heater (deaerator):**

A type of steam-heated open FW heater containing a vent and vent condenser and employed for the elimination of non-condensable gases. Depending upon deaerator design and operation, it is sometimes possible to reduce FW dissolved oxygen (DO) levels to below 0.005 cc/l (7.2 ppb).

**Dealloying (selective leaching):**

A form of corrosion in which of one or more elemental constituents of an alloy is leached, often leaving a porous structure. Examples are *dezincification* of brass and *denickelization* of nickel alloys.

**Decarburization:**

A form of corrosion induced by the oxidation of carbon in the *ferrite* phase of carbon steel to carbon dioxide.

**Defoamer:**

See **Antifoam**.

**Deionize (DI):**

To *demineralize* or remove ions from solution by means of an ion-exchange plant.

**Demineralization (deionization):**

The process of removal of both cations and anions from waters by ion-exchange, evaporation, or other means.

**Density:**

The mass of a given volume of matter. The density of water is 1.0 g/cm<sup>3</sup> at 20 °C, or 62.5 lb. per cu ft.

**Deposit:**

Any of a number of crystalline or non-crystalline scales and other insoluble materials laid down in a boiler system by a variety of mechanisms. Usually on a heat-transfer surface.

**Deposit control agent (DCA):**

Any of a number of modern, polymer-based chemical formulation additives having one or more deposit-inhibiting effects when applied to water as part of a prescribed treatment program.

**Desuperheating:**

The process of removing heat from superheated steam in order to control high pressure steam temperature and to tailor the steam for different, lower temperature and/or pressure applications.

**Dewpoint:**

The temperature at which water vapor (steam) condenses. The dew-point temperature is important in boiler fuel combustion processes, as whenever a metal surface is cooler than flue gas, condensation occurs. If sulfur gases are present and the acid dewpoint (the tem-

perature at which  $\text{H}_2\text{SO}_4$  vapor is in equilibrium with liquid  $\text{H}_2\text{SO}_4$ ), cold-end corrosion will take place.

**Dezincification:**

Form of corrosion of brasses whereby the zinc is selectively leached out of the brass. Prevented by either reducing the zinc content to below 15% or by the addition of trace amounts of inhibiting elements, such as arsenic (As).

**Discharge pipe:**

The piping attached to the outlet side of a BD or safety valve to convey steam/water to an external environment.

**Dispersant:**

A chemical agent having the ability to lift, separate, and maintain in suspension a variety of mineral particles for a limited period.

**Dissociation:**

The process of ionization in water of an electrolyte or a salt, whereby cations and anions are formed.

**Distribution ratio:**

The ratio of a concentration of an amine chemical treatment in steam solution compared to that in condensate solution under a given pressure and temperature.

**Divinylbenzene (DVB):**

A difunctional monomer commonly employed to cross-link ion-exchange polymers.

**Downcomer:**

A pipe that transports BW down and away from the top drum, usually to a *waterwall bottom header*.

**Draft:**

A pressure difference between two points that provides the impetus for air or other gases to flow.

**Drip feed:**

A means of adding liquid chemical treatment to a FW tank by means of an overhead dripping container rather than by use of a dosing pump. From a control viewpoint, drip feed is most usually unsatisfactory as the feed rate reduces over time with decrease in treatment head pressure, and ultimately the device tends to gum up.

**Dry-bulb temperature:**

Temperature of ambient air as measured with a dry-bulb thermometer (DB °F or °C).

**Dry pipe separator:**

A steam-water separation device consisting of a horizontal closed pipe, perforated at the top and with drain holes at the bottom.

**Ductile fracture:**

A metal fracture characterized by considerable plastic deformation, the tearing of metal and an appreciable expenditure of energy, as occurs with repeated bending of a strip of metal.

**Ductility:**

The ability of a metal (or other substance) to be drawn by plastic deformation without fracturing.

**Economizer:**

A type of FW heater located in the exit-gas pass of the boiler system.

**Eductor:**

A device through which water flows creating a vacuum that is employed to draw a solution (such as a coagulant or flocculant) into the stream of water.

**Effluent:**

The flow of water out of a tank or water system. The opposite of *influent*. A waste stream.

**Electric boiler:**

A type of boiler that produces heat via electric resistance coils or electrodes.

**Electrostatic precipitator:**

A device used to remove *fly-ash* from boiler exit-gases in order to reduce the atmospheric pollution load. It places an electric charge on the dust particle and removes the particle onto a collecting plate.

**Emulsion:**

A colloidal dispersion of oil-in-water. In BW systems where oil contamination has occurred, emulsifying agents from the oil can produce an emulsion which further adds to the total foulant load and impedes heat-transfer. Specific organic emulsifiers have both *hydrophilic* (water loving) and *lipophilic* (oil loving) groups in the same molecule.

**Enthalpy:**

The total heat content of a body. The sum of *sensible heat* and *latent heat*.

**Entrainment:**

The transport of water (and associated TDS) into a gas steam, e.g. *carryover* in a boiler.

**Entropy:**

Theoretical mathematical expression of energy measurement related to the second law of thermodynamics. Essentially a measurement of relative quantities of energy distribution, and reported in units of Btu/lb. or J/kg.

**Equilibrium:**

The point of balance at which there is no driving force in a reversible reaction.

**Equalizing line:**

A steam heating line used to warm up the main steam line and equalize the pressure around the main steam stop valve.

**Equivalent mineral acidity:**

The total concentration of neutral salts in water, each expressed in terms of calcium carbonate.

**Erosion:**

A type of metal wastage caused by the mechanical action abrasion of the metal surface by high velocity steam, air bubbles or solid particles. Often part of a larger erosion-corrosion process.

**Eutectic mixture:**

A mixture of salts having a minimum melting point less than any of the individual constituents.

**Eutectic structure:**

The microstructure of a metal resulting from the solidification of liquid metal such that two or more distinct solid phases are formed.

**Evaporation test:**

A test employed to check the effectiveness of the low-water, fuel-cutoff valve.

**Excess air:**

The amount of air needed for complete combustion over and above the theoretical requirement. In practice, excess air requirements typically may range from 5 to 30%.



**Exfoliation**

A form of corrosion exhibited by the throwing off of thin slivers or chips from the surface of a metal such as cupro-nickel.

**Exhauster:**

A device that discharges a mixture of coal and warm air to the burner.

**Expansion bends:**

A piping design feature that permits the expansion and contraction of lines to occur without risk of damage to the lines, valves, or other system components.

**External treatment:**

A general description for a wide range of pre-boiler FW and MU water treatment processes.

**Extraction steam:**

Steam extracted from one or more controlled pressure points on an *extraction steam turbine* and used for various process applications. Extraction steam may be delivered to an *extraction heater*.

**Feathering:**

The action that may occur at the point when a safety valve is about to lift.

**Feedwater:**

The water supplied to a boiler by the FW pump and consisting of a combination of CR and MU water.

**Feedwater heater:**

One of several different types of heater used to raise the FW temperature so as to avoid boiler thermal shock and gain improved efficiency and economic benefit.

**Feedwater pump:**

One of several different types of pump including turbine and centrifugal pumps used to convey FW to the boiler inlet at the correct pressure.

**Feedwater regulator:**

A device used to maintain the normal operating water-level (NOWL) in a boiler.

**Feedwater treatment:**

That part of a chemical treatment program applied directly to the boiler FW. Some chemicals may additionally be applied direct to the BW, steam, condensate, or MU water.

**Ferrite:**

A term applied to iron in the *alpha state* ( $\alpha\text{Fe}$ ) containing approximately 0.2% carbon together with other elements in solid solution.

**Ferritic stainless steel:**

A magnetic form of stainless steel that contains an  $\alpha\text{Fe}$  microstructure.

**Field erected boiler:**

A boiler that must be erected in the field rather than supplied as a packaged unit, due to its large size and complexity.

**Filming amine:**

A long-chain amine usually fed to the steam header and employed to prevent steam and condensate line corrosion by a surface-filming process.

**Filtration:**

In this context it is the separation of solids from water by forcing the water through a porous filter media. The objective is typically to reduce the level of TDS in the water and often to reduce both the size of the particle remaining and the turbidity of the water. Filtration efficiency and quality is a function of many variable factors, although filtration is usually carried out at relatively low velocities, where velocity and pressure drop are directly related to each other. Typically a sand filter will remove a high percentage of particles above a diameter of 20 to 30  $\mu\text{m}$ , whereas dual or multimedia filtration is required to remove particles down to a diameter of 10 to 20  $\mu\text{m}$ .

**Fines:**

The debris resulting from the attrition or other breakdown mechanism of filtration or exchange media. Typically, fines are particles of under 50 mesh.

**Firebox:**

A boiler furnace. The part where fuel is combusted.

**Fire point:**

The temperature at which a fuel will burn continuously when exposed to a flame, as measured in a *flash-point apparatus*.

**Fire tube (FT) boiler:**

A design of boiler where BW is on the outside of heat exchange tubes and the hot gases of combustion are on the inside.

**Firing rate:**

The quantity of fuel that can be burnt per unit time.

**Fish-mouth rupture:**

The bursting of a boiler tube resulting in a rupture having the appearance of a fish mouth.

**Fittings:**

Boiler appurtenances.

**Flame scanner:**

A boiler device that proves the pilot and main flame continuity.

**Flareback (puffs or blowbacks):**

A boiler explosion of limited intensity. It may still cause flames to be thrown several feet beyond the boiler.

**Flash economizer:**

The heat exchanger component of a boiler blowdown, flash steam, and heat recovery system (FSHR).

**Flash-point:**

The temperature at which a fuel emits sufficient vapor to flash when exposed to an open flame.

**Flash steam:**

Steam generated from HW that is subjected to a sudden pressure drop.

**Flash vessel (flash tank):**

A PV that permits flash steam from BW blowdown to separate from the hot water.

**Flat gauge glass:**

A type of glass used for gauge glasses operating at over 250 psig.

**Flocculant:**

A chemical agent that causes the agglomeration of small, pinhead sized particles to larger flocs for the purposes of settlement and water clarification.

**Flue gas analyzer:**

One of several different types of flue-gas analysis equipment (such as *electronic*, *Fyrite*, or *Orsat* types). They are used to determine boiler fuel combustion efficiency.

**Flux:**

A substance (usually liquid) employed to remove surface metal oxides in preparation for soldering, brazing or other metal fusion techniques. Also, the rate of energy transfer across a given surface area.

**Fly ash:**

Small particles of (mostly combusted) material suspended in the gases of combustion and carried out of the furnace flue with these gases.

**Foaming:**

The formation of small, stable, non-coalescing bubbles at BW heating surfaces that rise to the steam/water interface. With relatively pure water larger bubbles develop and break easily to release the steam, however, where either excessive suspended solids or excessive TDS are present, the water film around each bubble is toughened and stabilized by the impurities. Smaller bubbles develop and the final eruption of steam (*steam surging*) encourages *priming* (*surging*) and *carryover* to take place.

**Forced draft:**

Mechanical draft produced by a fan supplying forced air to the furnace.

**Fouling:**

General term for any impediment to a flow of water in a system. Fouling is caused by insoluble matter.

**Fouling factor:**

Reciprocal of *heat transfer coefficient* multiplied by 1,000. A term employed when designing *surface condensers*.

**Free blowing drain:**

A drain line used to remove condensate from the main steam line.

**Freeboard:**

The space above a media bed in a closed vessel that permits bed expansion and backwashing to take place. The allowance typically is 25 to 60% of the volume occupied by the media.

**Free mineral acidity (FMA):**

The sum of mineral acids in a solution.

**Gagging:**

The application of a clamp on a SV spindle to keep the valve in a fully-closed position, especially during a hydrostatic test.

**Galvanic corrosion:**

A form of corrosion resulting from the presence of two dissimilar metals such as steel and copper in an electrolyte such as water forming a galvanic couple, whereby the less noble *anodic* metal (in this case steel) corrodes.

**Galvanic series:**

A list of metals and alloys arranged for the purposes of water treatment to show their relative potential for *nobility* or resistance to corrosion.

**Gas calorimeter:**

An instrument used to determine the heat content of a fuel gas.

**Gas cock:**

A manual, rapid-action gas shutoff valve.

**Gas mixing chamber:**

A low-pressure air and fuel gas mixing chamber located prior to the boiler furnace.

**Gas porosity:**

The development of a porous structure in a solidifying metal caused by the evolution of dissolved or entrapped gases.

**Gate valve:**

A valve that operates either in the fully open or fully closed mode. Widely used especially as a boiler stop valve.

**Gauge glass:**

A sight glass to indicate the BW level and capable of being blown down to remove any sludge or sediment that may impair reading the correct level.

**Gauge pressure:**

The pressure inside a PV. The contribution to *absolute pressure* beyond that provided by atmospheric pressure.

**Globe valve:**

A type of valve often used to take an item of equipment out of service. An inline globe valve is typically installed with a bypass line and bypass valve.

**Grain:**

One seven thousandth of a pound. 1 grain per U.S. gallon (grpg) as  $\text{CaCO}_3 = 17.1$  ppm (mg/l). Also, describes a particulate crystal in a crystalline metal or alloy.

**Graphitic corrosion:**

Selective form of iron corrosion, primarily in *gray cast iron* but also less commonly in *nodular cast iron*, whereby the (*anodic*) iron matrix converts to *iron oxide* while the (*cathodic*) graphite remains intact. The casting retains its shape but loses all strength and can be cut with a knife.

**Graphitization:**

High temperature, long-term phenomenon whereby the *iron carbide* component of steel changes to graphite and pure iron.

**Grate:**

That part of a solid-fuel furnace on which the fuel is held and the combustion process starts.

**Gravimetric:**

Measurement by weight.

**Gulping:**

An intermittent form of BW carryover caused by variable water levels. Especially carryover into WT boiler superheaters.

**Handhold:**

An internally positioned, removable steel cover for boiler shells and other types of PV. It enables inspections and cleaning to take place.

**Hardness:**

Primarily the sum of Ca and Mg salts in water, although it may include other metal salts such as Al, Mn, Sr, and Zn. *Temporary hardness (carbonate hardness)* is that portion of the total hardness that can combine with  $\text{CO}_3$  or  $\text{HCO}_3$ . The balance is *non-carbonate* or *permanent hardness* and is caused by Ca or Mg nitrates/sulfates/chlorides, etc. Permanent hardness is equivalent to the excess of hardness over alkalinity.

**HAZMAT:**

Hazardous materials and an international coding system for identification. Many water treatment chemical formulations contain hazardous materials, which need special handling and transportation.

**Head:**

The energy per unit of fluid ( e.g. lb.).

*Potential head:*

Refers to the energy of position, measured by the work possible in dropping a vertical distance.

*Static pressure:*

Energy per unit of fluid due to pressure, it is the height to which a liquid can be raised by a given pressure.

*Velocity:*

Refers to the kinetic energy per unit of fluid; it is the vertical distance a liquid would have to fall to acquire the velocity  $V$ .

*Total head:*

Refers to the net difference between total suction and discharge heads.

*NPSH:*

See **Net positive suction head**.

**Head loss:**

The reduction in driving pressure of a flow of water through a plant due to frictional and fouling losses.

**Heat energy:**

The energy of a fuel potentially available as heat.

**Heat exchanger:**

Any of various types of heat transfer equipment, whereby relatively cold water flowing over a surface will, by conduction and convection means, transfer heat away from a process. The most common types of heat exchangers are *plate and frame* and *shell and tube* designs. A boiler is also a type of heat exchanger.

**Heat flux:**

The rate of flow or transfer of heat in a heat exchanger.

**Heat flux density:**

The quantity of heat transfer per unit surface area, per unit time.

**Heat transfer coefficient: (U).**

Rate at which heat is transferred through a heat-exchanger (Btu/sq. ft/hr/°F).

**Heat value:**

The heat energy potentially available from a unit mass of fuel. Typically measured as Btu/lb coal or Btu/gal oil.

**Helmholtz double layer:**

The layers of opposite charges formed on the surface of individual electrically-charged particles in water, causing mutual repulsion.

**Hematite:**

A form of rust. Magnetic, gray-to-red colored iron oxide ( $\text{Fe}_2\text{O}_3$ ) offering no protection from further corrosion; usually, red hematite is the first signs of steel corrosion and often followed by the formation of *magnetite*. Hematite occurs in the presence of high levels of oxygen.

**Hideout:**

The apparent loss of BW phosphate and other salts in high pressure WT boilers operating under high-load conditions. The salts reappear and can be determined when the load is reduced.

**High and low water alarm:**

A water-level alarm system located inside the BW column.

**High fire:**

The point of a firing cycle at which the burner is combusting the maximum amount of fuel per unit time.

**High pressure boiler:**

A legal definition that varies from country to country. In the USA it refers to any boiler generating steam at or above 15 psig. In practice, a boiler is commonly only referred to as “high pressure” if it generates steam at over perhaps 350 to 650 psig.

**Horizontal return tubular boiler (HRT boiler):**

An early design of FT boiler.

**Hot well:**

A reservoir to receive recovered condensate, located at the bottom of a surface condenser. Also any other tank or basin that receives water from flash steam recovery.

**Huddling chamber:**

A design feature on some types of SV that permits steam to collect in a chamber, providing an increased total upward force that causes the valve to pop up.



**HVAC:**

Acronym for *heating, ventilation, and air conditioning*.

**Hydrogen bond:**

A property of water whereby attractive forces cause linking of hydrogen in one molecule to oxygen of another. Due to the energy input required to break the hydrogen bond, steam has a high energy content.

**Hydrogen embrittlement:**

A form of corrosion whereby cracking of steel occurs, caused by the pressure generated from the reaction of hydrogen (from water) and carbon (from steel) producing hydrocarbons.

**Hydrology:**

The science dealing with the properties, distribution, and circulation of water.

**Hydrolysis:**

Any decomposition involving the addition of water. Specifically, a double decomposition reaction between water and another substance.

**Hydrometer:**

An instrument to measure the specific gravity (SG) of fluids. Typically a small, calibrated, and bottom-weighted glass or metal cylinder that floats to a level indicating the SG.

**Hydronic heating system:**

A HW heating system whereby heat is typically supplied by pumping HW through pipes at 160 to 200 °F.

**Hydrophilic:**

Having an affinity for water, such as the sulfonate component of a detergent molecule.

**Hydrophobic:**

Having no affinity for water (non-water wettable or water soluble).

**Hydrostatic pressure:**

The water pressure exerted at the base of a water column, equivalent to 0.433 psia per vertical foot.

**Hydroxyl ion:**

Anionic radical (OH<sup>-</sup>) primary contributor to alkalinity of water.

**Ideal engine:**

A theoretical engine where there is no loss in efficiency due to friction, wiredrawing, leakage, cylinder condensation, or radiation.

**Igniter:**

A burner device used to ignite a fuel and air mixture.

**Impeller:**

The rotating part of a centrifugal pump in contact with the water, converts centrifugal force into pressure.

**Impingement:**

High velocity steam or particles striking a metal surface and causing metal wastage by erosion. Also refers to unburned fuel oil striking a surface and resulting in the formation of carbon deposits and smoke.

**Impulse turbine:**

A turbine design where the expansion of steam occurs entirely in fixed nozzles. The steam jets from the nozzles are directed into disc-mounted buckets on the rotor forcing the shaft to rotate.

**Inclusions:**

Foreign, unwanted insoluble contaminants in a metal (or precious stones). Usually *oxides*, *silicates*, or *sulfides*.

**Incomplete combustion:**

The wastage of fuel caused by an inadequate supply of air, resulting in the formation of soot and smoke, and unburnt particles remaining in the ash.

**Induced draft:**

Mechanical draft developed by a fan located between the boiler and the chimney.

**Inert resin:**

Non-reactive ion-exchange resin. Commonly employed at a specific intermediate density to separate cation and anion resins in a mixed-bed demineralization plant, in order to limit contaminant leakage, especially from regenerants.

**Infra red:**

Light rays situated beyond the red end of the visible spectrum generated during combustion and detected by a flame scanner.

**Inherent moisture:**

The moisture component of coal and other solid fuels that is not available to bond or freeze to other particles.

**Inhibitor:**

A type of waterside maintenance chemical treatment. Any of a very wide range of chemicals that prevent or reduce tendencies of deposition, fouling, scaling, corrosion, or other unwanted phenomena to occur in a water system. Typically for smaller boiler plants, individual inhibitors are blended together to produce various *multifunctional* formulations specific for particular water chemistry and/or operating conditions. Larger boiler plants tend to use individual active component inhibitors.

**Insulation:**

A cladding material applied to boilers, pipes, and all hot surfaces in order to reduce radiant heat energy losses.

**Intergranular corrosion:**

A form of corrosion occurring at the grain boundaries within a metals microstructure.

**Interlock:**

A burner safety control system required to ensure proper operating sequences are employed.

**Internal FW line:**

A perforated pipeline (sparge line) inside a boiler located at the NOWL. It distributes relatively cool FW over a wide area in order to reduce thermal shock and ensure intimate mixing of the FW and chemical treatments with BW.

**Internal furnace:**

A FT boiler design whereby the furnace is fully located within the boiler shell. All modern FT boilers employ internal furnace designs.

**Internal treatment:**

Chemical treatment programs based on the direct addition of chemicals to FW or BW in order to prevent subsequent deposition, corrosion, or other problems from occurring. With precipitating types of internal treatments, the boiler waterside space is employed as a reaction vessel and, where a particular boiler design is unsuitable, inadvertent problems of fouling may occur.

**Internal treatment:**

Chemical inhibitor component of a water treatment program.

**Ion:**

An electrically charged atom, radical, or molecule.

**Ion association:**

Concept used in sophisticated scaling models, whereby certain ions in aqueous solution are said to associate in pairs (e.g.,  $\text{CaSO}_4$ ,  $\text{CaHCO}_3^-$ ). These ion pairs are then deducted from the total analytical value, to provide an estimate of the free ion content available for seed crystal scaling or growth agglomeration and deposition.

**Ion exchange resins:**

Hard, attrition-resistant, insoluble synthetic polymers (typically a copolymer of styrene with divinylbenzene). The resins are manufactured in a spherical bead shape that contain either exchangeable anion or cation portions, capable of exchanging with other anions or cations and usually in an aqueous medium. Typically cation resins for water softening will have a practical operating capacity of 20,000 gpg (at 6 lb NaCl per cu ft) rising to 30,000 gpg (at 15 lb NaCl per cu ft).

**Jackson turbidity units:**

A measure of turbidity of suspended particles. The Jackson turbidity method compares optical obscurity against a series of standards.

**Kinetic energy:**

The dynamic energy of a body or substance that comes from molecular motion.

**Kinetics:**

The branch of science dealing with the effects of kinetic energy, especially the speed of reaction.

**Laminar flow:**

Smooth or streamlined flow of water.

**Langelier saturation index (LSI):**

A derived expression relating to the saturation point of calcium carbonate solubility in water. Used frequently to interpret various water analyses in order to determine the potential for  $\text{CaCO}_3$  super-saturation and deposition (*scaling*) and also by inference, but not always correctly, the opposite nonscaling potential (*corrosion risk*). Used more in raw water and cooling water reviews than FW or BW. Although LSI is scaleless, the industry generally accepts and promotes the following:

LSI = 0.0 rising to +3.0: increasing tendency for scaling to occur.

LSI = 0.0 decreasing to -3.0 increasing

tendency of corrosion risk.  
LSI =  $-0.5$  to  $+0.5$ : “uncertainty”  
zone, some scale and corrosion

Also several other indices, esp. *Ryznar Index* are now used.

*Note: LSI and all derivations (such as Ryznar, Puckorius) are simply based on total analytical values rather than free ion species (those ions remaining after ion association pairs are deducted from the total analytical value (TAV)).*

**Laning:**

The short circuiting of furnace gases, resulting in a different heat distribution pattern.

**Latent heat:**

Heat which, when supplied or removed from a substance, produces a change of state without a change in temperature.

**Latent heat of fusion of water:**

144 Btu/lb. at 32 °F (0 °C)

**Latent heat of vaporization:**

970 Btu/lb. at 212 °F (100 °C)

**Laws of thermodynamics:**

The first law is one of conservation of mass and energy, whereby a balance exists between energy, work, and heat quantities. The second law relates to energy flow, whereby heat can only flow from a hotter body to a colder one.

**Lime and lime soda softening:**

The process of pre-treating hard water with lime and sometimes soda as well, based on standard precipitation methods, to reduce the hardness either to a minimum level or more usually to a preset level of, say, 85 ppm thereby lowering the total treatment costs. Usually carried out in specially designed tanks and followed by clarification and filtration. Calcium bicarbonate is always removed, requiring one equivalent of lime and precipitating as the carbonate. Calcium non-carbonate hardness is removed using one equivalent of soda ash. Magnesium bicarbonate, however, requires two equivalents of lime and precipitates as the hydroxide, while magnesium non-carbonate hardness removal requires one equivalent of soda ash and one of lime.

**Lipophilic:**

Property of substances having an affinity for oil, such as in certain surfactants.

**Low solids treatment:**

A boiler plant water treatment strategy designed to keep BW TDS levels as low as possible, minimizing BE requirements and limiting the potential for carryover. High quality, pre-boiler external treatment processes such as reverse osmosis or demineralization are supplemented by internal treatment programs that may consist of *all volatile treatments* (AVTs) or small amounts of inorganic and organic “*polishing*” treatments.

**Macroporous resin:**

Ion-exchange resin having large pores that reduce the potential for permanent fouling to take place.

**Magnetic device:**

One of many types of boiler and/or cooling water plant equipment variously claimed to control and prevent scaling or in addition, to prevent corrosion (or possibly even algae and sludge in open cooling water systems) in water circuits by nonchemical means. Usually employ external electrical circuits or permanent magnets to provide a magnetic induction (flux density) of perhaps 2,500 gauss. Usually clamped around or inserted into a pipe line.

**Magnetite:**

A form of rust. Magnetic, dark-gray-to-black form of iron oxide ( $\text{Fe}_3\text{O}_4$ ) that forms a protective film on steel surfaces.

**Makeup (MU) water:**

Supplementary treated water required to compensate for losses due to steam consumption, blowdown, and leaks in boiler plant steam/water system.

**Martensite:**

A type of iron or steel exhibiting a needle-like microstructure of solid solution of supersaturated carbon.

**Matrix:**

The primary phase of a substance into which a secondary material is embedded.

**Microstructure:**

The structural appearance of a metal under a microscope.

**Mild steel:**

Carbon steel having a maximum carbon content of 0.25%.

**Misting:**

The development of an aerosol of *microdroplets* of BW into steam at the water/steam interface, caused by the sudden release of pressure *under* bubbles as the steam they contain is released. Typically, improved steam separation equipment is needed if misting persists in a boiler.

**Moderator:**

A substance employed to slow down the neutrons in a nuclear reactor in order that they can be captured by the nuclei. Boron, heavy water (D<sub>2</sub>O) and graphite are commonly used moderators.

**Molecular bridging:**

The joining of particles by polymers as part of the process of flocculation. Usually higher MW polymers produce higher levels of molecular bridging.

**Mud drum:**

The bottom drum of a multiple drum WT boiler. Sludge and muds tend to collect in this drum.

**Net positive suction head (NPSH):**

The net head or pressure measured in ft. or m that causes a liquid to flow through the suction side of a pump, enter the pump chamber, and reach the impeller. When the source of liquid is *above* the pump, NPSH equals the barometric pressure *plus* the static head, *less* the entrance head, frictional losses in the suction piping and vapor pressure of the liquid. When the source of liquid is *below* the pump, NPSH equals the barometric pressure *less* the static head, entrance head, frictional losses in the suction piping and vapor pressure of the liquid. NPSH is specific for each pump design and application and must be supplied by the manufacturer.

**Neutralizing amine:**

A volatile, amine-based chemical treatment usually added to the boiler FW, designed to neutralize the corrosive effects of carbonic acid in steam/condensate and raise condensate pH.

**NTA:**

Nitrilotriacetic acid or its sodium salts.

**Once-through boilers:**

High pressure design of boiler with no BW recirculation.

**Ordinary steel:**

Plain carbon steel containing approximately 2% carbon together with traces of other elements.

**Organic fouling:**

Fouling of pores of ion-exchange resins by the presence of organic contaminants in the water being processed. The resin gradually loses its capacity and requires cleaning.

**Orsat apparatus:**

Portable flue-gas analyzer employing “wet chemical” techniques. Uses a liquid-filled leveling bottle to introduce a measured flue-gas sample into the glass apparatus. The flue-gas sample is then selectively passed into each of several chambers to permit selective absorption and other reactions to take place, resulting in measurable losses of original individual constituent gases. Orsat apparatus measures *carbon dioxide*, *carbon monoxide*, *oxygen* and *hydrogen*, or *water vapor*.

**Osmotic pressure:**

Pressure differential that exists between two solutions separated by a semipermeable membrane.

**Overspeed trip:**

Device that closes the throttle valve on a turbine should its speed exceed a predetermined value.

**Oxidation:**

Addition of oxygen, removal of hydrogen or loss of electrons.

**Oxygenation Treatment:**

Under some circumstances, corrosion can actually be controlled in high pressure boilers by adding oxygen to the boiler feedwater (FW) rather than by removing it. The process is called oxygenation treatment (OT) and is designed to ensure sufficient oxygen is present in the FW ( $> 5$  ppb  $O_2$ ), in order to ensure the economizer and feed line passivated magnetite film is not disrupted. OT also reduces the risk of erosion-corrosion problems, and limits iron transport to other parts of the boiler system.

**Oxygen scavenger:**

Any of a number of chemical treatments designed to remove traces of dissolved oxygen in boiler FW.



**Package boiler:**

Self-contained, shop-assembled boiler plant complete with FW pumps, fuel system, draft fans, and other auxiliaries.

**Packing gland:**

A device that effectively seals a pump against leakage around the shaft by means of various rubber/fiber packing materials.

**Part per million:**

A unit weight of solute dissolved in one million units of the same weight of solution. Approximately equivalent to mg/liter or  $g/m^3$ . 120 ppm = approx. 1 lb/1,000 U.S. gallon.

**Passivation:**

The conversion of a reactive metal surface into a lower energy state that does not readily further react or corrode. Usually carried out by *anodic inhibitors* producing a passive oxide film on a clean surface. A vital component of any program for long-term protection of a metal waterside surface.

**Peaking boiler:**

A steam generator designed to operate intermittently to meet peak demands for steam and electricity.

**Pearlite:**

An aggregate containing an alternate *ferrite* and *cementite* ( $Fe_3C$ ) lamellae microstructure.

**pH:**

Logarithmic scale for expressing acidity or alkalinity of water (7.0 to 0 indicates increasing acidity; 7.0 to 14 indicates increasing alkalinity). Measured by means of a glass electrode/reference electrode pair immersed in the water sample under test. The potential difference depends upon the pH which is then displayed on a pH meter (high input impedance, millivoltmeter).

**Phosphate conditioning:**

A popular type of internal chemical conditioning, precipitation water treatment program. Relies on the careful management of permanent reserve of phosphate ions in the BW to prevent waterside scale formation.

**Pit:**

Visible sign of metal wastage in the form of a deep crevice resulting from various forms of localized corrosion.

**pK:**

Expression of the extent of dissociation of an electrolyte; the negative logarithm of a compounds ionization constant.

**Plenum chamber:**

A wind box or air chamber that receives and directs pressurized air to a furnace or other item of equipment.

**Pneumatic system:**

A control system that uses air as an operating medium.

**Pollution:**

In this context, pollution refers to the identification and measurement of polluting contaminants in a raw water source (such as organic debris, treated sewage, ammonia, fertilizer, oil, etc.,) that constitute a risk of fouling and can hinder the effectiveness of any chemical treatment program. Tests undertaken to determine the level of pollution include *permanganate value (PV)*, *biochemical oxygen demand (BOD<sub>5</sub>)*, *chemical oxygen demand (COD)*, and *total organic carbon (TOC)*. The COD test, either by a laboratory dichromate reaction/titration or by automatic COD equipment, is probably the most useful for polluting contaminant assessment.

**Polyamine BW programs:**

Certain long-chain polyamines and amine derivatives have long been used as cationic coagulants for waste-water application and biostats for recirculating cooling systems and once-through condenser cooling, however they have also been promoted for use as single-formulation, multi-functional programs for BW and steam/condensate application, especially in France and other European countries (e.g. Polaris® from UCIO S.A.). These polyamines are claimed to provide a film-forming effect in boilers (thus negating the need for oxygen scavengers), yet are sufficiently volatile to provide protection to condensate lines and are suitable for up to 550 °C. Such claims seem greatly exaggerated and practical experience has shown that clogging of dosing pumps and fouling of boiler appurtenances is a problem.

**Polymer:**

General name for a wide range of (mainly organic) chemicals used in BW treatments and other formulation types and produced from linking individual chemical molecules (monomers) to form a chain.

**Polyphosphate:**

One of various molecularly dehydrated orthophosphates.

**Potable water:**

A water meeting drinking water standard quality.

**Potential energy:**

The inherent energy of a body or substance, potentially available in various forms including chemical or heat energy of a fuel.

**Pour point:**

The lowest temperature at which fuel oil will flow. *Residual oil* (No. 6 oil) will not usually flow at ambient temperature and requires heating to reduce the viscosity and raise the pour point.

**Pressure-reducing station:**

A control station employed to reduce high pressure steam to one or more lower pressures, thus rendering the steam suitable for a number of downstream processes.

**Primary air:**

Air mixed with fuel at or in the burner. Used to ensure instant combustion as the fuel enters the furnace.

**Priming:**

See **Surging**.

**Process steam:**

Steam required for a manufacturing or user process and often totally consumed so reducing the available CR.

**Protective colloid:**

A chemical treatment designed to prevent the coagulation of colloids by the provision of a surface coating onto the colloidal particles.

**Pulverizing mill:**

A mill that grinds or pulverizes fuel such as PF coal to a prescribed degree of fineness. Typically, 70% of PF will pass through a # 200 mesh (74 micron) screen.

**Purge period:**

The time period before fuel ignition and after boiler shutdown when explosive combustibles are removed from the furnace area by air purging.

**Quick closing valve:**

A valve that only requires one quarter turn to fully open or close.

**Radiant heat:**

Heat energy supplied by the emission of rays. Thermal radiation travels at the speed of light (186,000 miles per second).

**Radiant superheater:**

A type of tube bundle *superheater* located in the radiant section of a WT boiler.

**Rank:**

The grade of various types of coal based on size, calorific value, and ash content.

**Rankine cycle:**

A concept of the cycle of thermodynamic processes, introduced later than the *Carnot cycle*. Modifications of the Rankine cycle are of practical importance in boiler design, in relating the successive thermodynamic changes as water is converted to steam, expands and converted to mechanical energy in a turbine, then condenses and returns to the boiler.

**Rapping:**

A method used to dislodge ash particles collected by an electrostatic precipitator.

**Raw water:**

Water available on site not subjected to any in-house treatment process. City water, despite being treated at a primary city facility is described as “raw water” when being considered for suitability in industrial processes.

**Reaction turbine:**

A design of turbine in which a partial reduction in steam pressure takes place in fixed nozzles (vanes) and a further steam pressure reduction takes place in “nozzles” created by moving rotor blades. A reactive force is generated that results in the rotation of the turbine shaft.

**Redox:**

(See also **Oxidation, Reduction**). Some dissolved substances in water occur either in an oxidized or a reduced form, and their state can be changed by either the acquisition of electrons (reduction) or the loss of electrons (oxidation). This transfer system is a reduction-oxidation system, or redox. (Red.  $\leftrightarrow$  Oxid.  $n^+ = n^{e-}$ , where  $n$  is number of electrons involved), and can be used to measure and

control such reactions, using an oxidation/ reduction millivolt potential meter (ORP meter), with a platinum and reference electrode. Example is the measurement of effectiveness of a chlorination/ dechlorination program.

**Reduction:**

The removal of oxygen, addition of hydrogen, or gain of electrons.

**Refractory:**

Heat tolerant brickwork used in boiler furnaces.

**Regeneration:**

As applied to ion exchange resins, regeneration refers to the process of restoring spent resin to a condition by which it can continue to exchange either cations or anions. Regeneration of softeners specifically refers to the addition of an 8 to 25% brine solution, typically applied at 2 to 7 BV/hr, at a salting rate of 6 to 25 lb NaCl/cu ft (100–400 g/l NaCl), depending on regional custom and practice. Regeneration has now typically come to mean the inclusion of a cycle of back-washing, brine injection and both slow and rapid rinsing.

**Reheat:**

The process of returning partially expanded steam from the HP stage of a turbine back to a reheat superheater before the steam passes to the turbine IP and LP stages.

**Relief valve:**

A valve designed to protect water system components from excess pressure.

**Resin capacity:**

The quantity of soluble material capable of being exchanged by an ion exchange resin. Expressed as grains  $\text{CaCO}_3$ /cu ft. or  $\text{kg CaCO}_3/\text{m}^3$ .

**Retort:**

The space below the grate of an underfeed stoker.

**Reverse osmosis (RO):**

The thoroughly practical implementation of reversing the natural phenomenon of osmosis, by applying a relatively high pressure to a high TDS content water in contact with one of various types of semi-permeable membrane. This typically results in a 30 to 70% recovery of permeate water, from an original, supply source, containing only 2 to 8% of the original level of TDS. The process requires close

attention to pre-treatment, to extend membrane life, but has become a major technology for world wide application. It is especially used in the treatment of MU water for high pressure boiler plant, usually in combination with ion-exchange demineralization processes.

**Ringelmann chart:**

A smoke density comparison chart.

**Riser:**

A pipe that permits the flow of BW up and towards the top drum. Usually receiving steam/water from a waterwall top header.

**Rotameter (rotometer):**

A variable-area, fluid or gas flow-rate meter. Usually a cone inside a glass measuring cylinder that is suspended by the upward flow of gas or liquid.

**Ryznar Index or Stability Index; (SI):**

A variant on the LSI. SI is generally believed to be more relevant than LSI due to being derived from operational studies of cooling systems. Although SI is scaleless, the industry generally accepts the following;

SI = 7.0 down to 4.0: increasing tendency for scaling

SI = 7.0 rising to 10.0: increasing tendency of corrosion

SI = 6.5 to 7.5: "uncertainty" zone

**SAC Resin:**

Strong acid, cation exchange resin.

**Salt splitting:**

The capability of conversion of a salt solution to caustic by an anion exchanger, or to an acid by a cation exchanger.

**Saponification:**

The hydrolysis of a fat to a soap by reaction with an alkali.

**Saturated steam:**

Steam that is fully saturated with heat and corresponding with a particular temperature and pressure.

**SBA Resin:**

Strong base, anion exchange resin.

**Scale:**

Layer, or layers, of *minerals* (especially *calcium carbonate*) deposited, by the throwing down, or precipitation, onto a heat transfer sur-

face, reducing its  $U$  value. Scales are often hard and dense and difficult to remove. The scale can be *crystalline* in nature (a solid body having a characteristic internal structure, with symmetrically arranged plane surfaces and definite angles), or *amorphous* (lacking any characteristic crystalline shape). Also, scale refers to thick layers of corrosion product on a metal surface that can occur at high temperature.

**Secondary air:**

Air brought in around the burner or wider furnace area, used to ensure complete combustion.

**Sensible heat:**

Heat which when supplied or removed from a substance causes a *sensible effect* on the substance, i.e. a rise or fall of temperature.

**Silt density index:**

A measurement of silt, colloids, bacteria, and other rapid foulants of RO membranes. The SDI test is used to determine the SDI of water and thus its suitability for an RO process. SDI of above 5.0 indicates the water is unacceptable. Ideally the water should have an SDI of below 1.0.

**Sinuuous header:**

A design of WT boiler header that receives tubes in a serpentine (wavy) manner.

**Slippage (leakage):**

The resultant low level of particular salts remaining in a processed water after passing through an ion-exchange plant. Slippage occurs because of a less than totally efficient exchange capability processes.

**Slag:**

Commonly also known as cinder or clinker. Slag is the mass of fused ash that results after the incombustible residual material from combustion cools down from a molten state.

**Sludge:**

Any sedimentary deposit or foulant that fails to form a crystalline scale. Often the result of supersaturation or the binding of biological or other organic material with dust, sand, or other mineral deposits. Also, sludge is not always deposited at point of origin and can additionally bake onto heat transfer surfaces.

**Sludge conditioner:**

A chemical treatment designed to “condition” BW precipitants in order to prevent their coagulation and the subsequent likely accumulation of sludges that can cause fouling problems.

**Slug treatment:**

The intermittent addition of chemical treatments by hand rather than continuous addition by use of a feed pump.

**Smoke:**

Flue gases containing enough unburnt carbon and hydrocarbons so as to cause discoloration and usually measured by comparison with standard color charts.

**Softening:**

Any of a number of processes designed to remove alkaline earth elements (primarily calcium and magnesium) from MU water.

**Soot:**

Carbon deposits resulting from incomplete combustion.

**Sootblowers:**

Nozzles used to inject a medium, such as steam, into the boiler to dislodge deposits. Used to clean the fireside during operation of the boiler.

**Spalling:**

Hairline cracks, flakes, or splinters that can occur out of the surface of a refractory or steel as a result of changes in furnace temperature or *long-term overheating*.

**Specific conductance:**

A measure of ability of water to conduct an electric current and often related to TDS content of water. Typically, one  $\mu\text{S}/\text{cm}$  units of conductivity  $\times 0.65$  equals ppm TDS.

**Specific gravity:**

Ratio of the density of a substance to that of water.

**Spheroidization:**

The thermal transformation of lamellar cementite in the pearlite phase of carbon steel to spherical grains.

**Stainless steel (SS):**

Any of a number of iron alloys containing more than 11.5% Cr and usually exhibiting passivity in water.



Types 304 and 316 and their low carbon equivalents (L) are commonly used as construction materials.

**Types:**

304 = < 0.08% C, 18–19% Cr, 9% Ni, < 0.01% Mo

304 L = < 0.03%, 18–19%, 9–10%, 0%

316 = < 0.08%, 17%, 11–12%, 0.2%

316 L = < 0.03%, 17%, 12–13%, > 2–5%.

Most types of SS used for water treatment have an *Austenitic* crystalline structure (centre-faced cubic). Others are *Ferritic* (centred cubic), *Marstenitic* (quadratic), or *Austeno-ferritic* types, which have superior mechanical strength and are resistant to *stress corrosion*.

**Static suction lift:**

Where a liquid is below the pump, relates to the vertical distance from the center line of a pump *down* to the free liquid source.

**Static suction head:**

Where the liquid is above the pump, relates to the vertical distance from the center line of a pump *up* to the free liquid source.

**Steam:**

Water vapor. Water that is at or near its saturation temperature and pressure where the liquid and the gas phases coexist.

**Steam drum:**

The top drum of a WT boiler that receives FW and chemical treatments, provides both a steam reservoir space and a point from which BD can take place.

**Steam purity:**

A measurement of the contamination of steam by various organic and inorganic materials. Some contamination is inadvertent (e.g. carryover) while some is intentional (e.g., neutralizing amines).

**Steam trap:**

An automatic device that removes condensate and *noncondensable gases* (such as air) from steam.

**Steel or carbon steel:**

Alloy of iron containing up to 2% carbon and other trace elements. It is a common construction material.

**Strainer:**

A metal screen designed to remove particles and sediments that would be detrimental to steam traps and other devices.

**Stratified bed:**

Bed containing resins of sufficient density differences so as to settle into layers within a tank or vessel.

**Stress:**

A measurement of force per unit area on, or within metals and other construction materials. Excess stress can lead to metal failure.

**Stress corrosion cracking:**

Any of a number of corrosion processes whereby in a corrosive environment localized stress accelerates the rate of corrosion and may result in metal failure.

**Supercritical boiler:**

A WT boiler that is designed to operate at a pressure above 3203.6 psia.

**Superheat:**

The increase in steam temperature over and above the *saturated steam temperature* for a specified pressure.

**Surface condenser:**

A type of shell and tube heat exchanger that condenses exhaust steam and creates a vacuum, improving the efficiency of a turbine.

**Surface moisture:**

External moisture that is not bonded to a particle of coal or other fuel. External moisture will ice in cold weather and lump fuel together in a solid mass. Where this occurs, thaw sheds may be used to heat the mass before further transport or use.

**Surface tension:**

Property of liquid, whereby molecular forces at the surface tend to minimize the contained volume, hence water droplets. Water has high surface tension which makes it poor at wetting thus requiring use of surfactant materials for certain processes.

**Surfactant:**

Surface active agent. Any of a wide range of detergents, emulsifiers, dispersants, defoamers, etc., that tend to reduce the surface tension of water and improve its wetting power.

**Surging (priming):**

The phenomenon of wildly fluctuating and spouting BW levels as a result of poor operational and/or water chemistry conditions.

Adverse conditions include too high a water level, uneven heat distribution, variable load swings, too high a steaming rate, too low a steam pressure, and excessive suspended or dissolved solids, alkalinity, chlorides, etc. The maintenance of any steam generating stability under surging conditions is impossible. Surging is closely associated to problems of *foaming* and *misting*, which can lead to the *carryover* of BW into the steam (*entrainment*).

**Suspended solids:**

Particles of matter suspended in water that can be removed by filtration or prevented from settling for periods of time by the use of dispersants.

**Synergy:**

Enhanced result from the action of two or more chemicals working together and greater than the sum of individual actions.

**Tensile strength:**

The ultimate strength of a metal under test, measured as the ratio of load to cross-sectional area.

**Therm:**

A unit of gas-fuel heat energy equivalent to 100,000 Btu.

**Thermal fatigue:**

A form of metal failure, whereby fracturing occurs under repeated cycles of thermally-induced stress.

**Thermocouple:**

A temperature measuring device that reports data back to a recorder.

**Threshold effect:**

The ability of small concentrations of chemicals such as certain phosphates and polymers to retard relatively large amounts of crystal growth and eventual deposition by incorporation of the chemical into the crystal lattice.

**Titration:**

A method of water analysis allowing the concentration of an unknown dissolved material to be determined. It requires the addition of a liquid titrant of known concentration into a water sample of known volume until an end-point is indicated by a color change.

**Toxicity:**

( $TL_{50}$ ). The concentration of a toxicant, such as a biocide, in which 50% of test animals (typically fish species) survive for 96 hours under prescribed conditions.

**Tuberculation:**

Very visible form of corrosion in which voluminous layers form of brittle, iron oxide corrosion debris, usually covering a pit or deep crevice.

**Tube sheet:**

Usually a circular perforated end sheet, into which heat exchanger tubes are welded, brazed, or rolled.

**Turbine stage:**

A section within a turbine where the steam transfers energy to the turbine blades. As steam pressure drops within a stage, the blade length become larger.

**Ultrasonic testing:**

A form of nondestructive testing in which an ultrasonic beam is applied to sound-conducting materials to locate any discontinuities.

**Vacuum:**

A degree of air pressure below atmospheric pressure.

**Vapor:**

A gas at or near saturation temperature and pressure and coexisting with a liquid phase.

**Vapor phase inhibitor (VPI):**

Or volatile corrosion inhibitor (VCI), are typically aminocarboxylates (the reaction products of an amine or amine derivatives, such as cyclohexylamine, dicyclohexylamine, guanidine or aminoalcohols, and an organic acid). VPIs are generally supplied in solid form for ease of handling and are effective in preventing general, pitting, galvanic and other forms of corrosion of both ferrous and non-ferrous metals. They are volatile materials designed to produce and disseminate vapors within enclosed spaces, that at equilibrium contact metal surfaces and form a protective, micro-crystal barrier film. In the presence of even minute traces of moisture, the crystals dissolve and are adsorbed at the metal surface as highly ionic species that provide corrosion inhibition without interfering with metal conductivity, dimensional tolerances, or other functional requirements.

VPIs can be employed to provide protection to boilers during layup periods, both for dry and wet layup.

**Viscosity:**

The property of a fluid that resists any force such as atmospheric or pump pressure, tending to produce flow. Viscosity is a function of the fluids cohesive forces and generally decreases with increase in temperature. Also, friction losses decrease with increase in temperature.

**Water hammer:**

Instantaneous surges of water under pressure caused by sudden interruptions in water flow in a pipe or water system, producing a hammering sound and leading to metal stress and possible eventual failure. Water hammer can develop where a steam main is incorrectly pitched, has un-drained pockets or where steam flows up and meets draining condensate flowing down causing a temporary interruption in both flows.

**Waterwall:**

Tubes in a WT boiler surrounding the furnace and convective pass sections that are welded together to form a continuous membrane. The waterwall prevents heat-path short-circuiting and provides a cooling mechanism for the boiler.

**WAC resin:**

Weak acid, cation exchange resin.

**WBA resin:**

Weak base, anion exchange resin.

**Wire drawing (throttling):**

The process by which steam forces its way through a narrow opening with a corresponding loss of pressure, as occurs to some extent during the admission of steam to a steam engine.

**Zeolite:**

A natural ion-exchange material used for softening water and other purposes. Typically minerals of hydrated aluminum or sodium silicates.

**Zeta potential:**

The potential between the Helmholtz double layer of a charged particle. Important for assessing the suitability of polyelectrolyte chemicals because it can be easily measured, unlike some other electrokinetic forces.



---

# BIBLIOGRAPHY

---

1. Aalto, J.S. *Steam Turbine Systems for Power Plant Auxiliary Drives*. Journal of the National Association of Power Engineers. NAPE, USA, 1994.
2. ABMA. *Boiler Water Requirements and Associated Steam Purity for Commercial Boilers*. American Boiler Manufacturers Association, USA, 1998.
3. Advanced Separation. *The ISEP Principle*. Technical and marketing literature. Advanced Separation Technologies, Inc., USA, circa 1995.
4. Akzo. *Industrial Surfactants, Nitrogen Derivatives*. Technical literature and catalog. Akzo-Nobel, Inc., USA, 1992.
5. Akzo. *Armohib Corrosion Inhibitors*. Technical and marketing literature. Akzo-Nobel, Inc., USA, 1992.
6. Alamo. *AQA Total Lime Protection Scheme*. Promotional literature. Alamo Water Refiners, Inc., USA, 1999.
7. Albanese, Vincent, M. (Nalco Fuel Tech). *Evaluating the Fuel Treatment Process*. Plant Engineering, USA, October 1994.
8. Amjad, Zahid; Zibrida, John F.; Zuhl, Robert W. *Silica Control Technology for Reverse Osmosis Systems*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, February 1999.
9. Angus. *TB 41: AMP-95 Corrosion Inhibitor in Steam-Condensate Lines*. Technical literature. Angus Chemical Company, USA, 1998.
10. ASB Technical Committee. *The Treatment of Water for Shell Boilers*, 4th edition. Association of Shell Boilermakers, UK, 1998.
11. Ash, Michael and Irene. *Handbook of Water Treatment Chemicals*, 1st edition, Gower Publishers, UK, 1996.
12. ASME Boiler and Pressure Vessel Committee. *Recommended Guidelines for the Care of Power Boilers*, 1986 edition. The American Society of Mechanical Engineers, 1986.
13. ASME Feedwater Quality Task Group. *Consensus on Operating Practices for the Control of Feedwater and Boiler Water Chemistry in Modern Industrial Boilers*. The American Society of Mechanical Engineers, 1994.
14. Atkinson, A. A. *Neutralizing Amine Information* (private communication). Atkinson Chemicals, Ltd., UK, 1992.
15. Babcock & Wilcox (Editors: Stultz, S.C.; Kitto, J.B.). *STEAM: Its Generation and Use*, 40th edition. The Babcock and Wilcox Company, USA, 1992.
16. Bacharach. *Combustion and Environmental Measurement Instruments*. Technical documents and promotional literature. Bacharach, Inc., USA, 1998.
17. Barkley, J. P. (U.S. Bureau of Mines). *Questions and Answers on Boiler Feed-Water Conditioning*. U.S. Government Printing Office., 1942.
18. Bennett, Robert, and Handlesman, Barry. *Solving Cold End Boiler Problems Through Innovative Chemical Technology*. Paper delivered at Southeastern Electrical Exchange, New Orleans, Louisiana, USA, April 1976.

19. Blake, Richard T. *Water Treatment for HVAC and Potable Water Systems*. McGraw-Hill, Inc., USA, 1980.
20. Blake, Richard T. *Fuel Oil Additives. Heating/Piping/Air Conditioning*, Reinhold Publishing Co., USA, September 1975.
21. Boffardi, Bennett P. *Water Treatment for HVAC&R Systems*. "Practical Guide," Association of Water Technologies, USA, 1999.
22. Brandvold, D. C. *Water Treatment: Industrial, Commercial and Municipal*, 3rd edition. DCB Enterprises, Inc., USA, 1994.
23. British Standard 2486:1978. *Recommendations for Treatment of Water for Land Boilers*. British Standards Institution, UK, 1978.
24. British Standard 2486:1997. *Recommendations for Treatment of Water for Steam Boilers and Water Heaters*. British Standards Institution, UK, 1997.
25. Buecker, Brad. Wofford, John. (Burns & McDonnell Engineering Co.) Magel, Ron. (San Miguel Electric Copoerative, Inc.). *Chemical Cleaning Clears San Miguel's Boiler Tubes*. Power Engineering, USA, June 1994.
26. Burgmayer, P. R.; Cotton, I. J.; Knowles, G. *Oxygen Scavenging and Passivation in Steam Generating Systems: Fiction, Folklore and Fact*. Betz/NACE Annual Conference and Corrosion Show, USA, 1992.
27. Cavano, Robert. Panel Discussion on Oxygen Scavengers Non-Sulfite Alternatives. Association of Water Technologies 5th Annual Convention, USA, 1992.
28. Cavano, Robert. *Amine Volatility and Flammability*. "The Analyst," Association of Water Technologies, Winter 1998.
29. Celgard. *Liqui-Cel Extra-Flow Membrane Contactors*. Technical literature. Celgard, Inc., USA, 2000.
30. Chatterjee, S.K. and Sharma, P.D. *Review of Water Chemistry Treatment and Corosion Problems in Nuclear Steam Generators*. Presented at the Bombay All India Symposium on Water Treatment. Indian Centre for Training and Development, November 1979.
31. Chattopadhyay, P. *Boiler Operations Questions and Answers*, 1st edition. McGraw-Hill, Inc., USA, 1994.
32. Chettle, Brent W. (West Inc.). *Water Treatment Mathematics Workshop Reference Manual*. Regional Training Seminar Handbook. Association of Water Technologies, USA, 1999.
33. Clayton, Dennis (Utility Chemicals, Inc.). *Amines: Demand, Selection. Prediction, Compliance*. Presented to Association of Water Technologies, Traverse City, Michigan, USA, October 1997.
34. Cleaver Brooks. *Boiler Plants and Deaerators*. Technical documents and promotional literature. Cleaver Brooks Division, Aqua-Chem, Inc., USA.
35. Cotton, I. J. *Chemistry of Oxygen Corrosion Control*. Betz/NACE Corrosion 87. National Association of Corrosion Engineers, USA, March 1987.
36. Cuisia, Dionisio G. *Diethylhydroxylamine for Corrosion Protection in Industrial and Utility Boilers*. Dearborn/44th Annual Meeting International Pittsburgh Water Conference, U.S. A., 1983.
37. Cutler, Frances; Casar, Douglas. *Effectiveness of iron Removal by Deep-Bed Polishers*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, September 1998.
38. Dearborn. *Polyamide Antifoam Treatments*. Technical publication. Dearborn Chemical Company (now a division of G.E. Betz), USA 1950.



39. Dardel, François de. *Some Principles of Ion-Exchange Plant Design*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, October 1999.
40. Degremont. *Water Treatment Handbook*, 5th and later editions: John Wiley & Sons, USA, 1979.
41. Department of Energy (UK). *Fuel Efficiency Booklet 6: Flash Steam and Vapour Recovery*. Her Majesty's Stationary Office, UK, 1997.
42. Dilcer Jr., Samuel B.; Dromgoole, Jim C. *Waterside Inspecting Techniques for Industrial Boilers*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, November 1998.
43. Dooley, R.B.; Paul, L.D. *Phosphate Treatment and Corrosion Fatigue*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, February 1997.
44. Dow. *A Guide to Glycols*. Technical literature. Dow Chemical Company, USA, 1992.
45. Dow. *A Guide to Condensate Polishing*. Technical literature. Dow Chemical Company, USA, 1979.
46. Ecolochem. *The World of Ecolochem*. Marketing literature. Ecolochem, Inc., USA, 1994.
47. Electro-Steam. *Electrical Steam Generators*. Various marketing publications. Electro-Steam Generator Corp., USA.
48. Elf Atochem. *Pennad 150 (Dimethylaminoethanol), Dimethylamino-2-Propanol*. Technical publications, No. 00150 and No. 02368. Elf Atochem North America, Inc., USA, 1993.
49. Elonka, Stephen Michael & Kohan, Anthony Lawrence. *Standard Boiler Operators' Questions and Answers*. TMH Edition. Tata McGraw-Hill Publishing Company Ltd. India, 1973.
50. FMC. *Phosphorus Chemicals*. Technical literature. FMC Corporation, USA.
51. Frayne, Colin (ANCO). *Overview of Combustion and Related Problems Associated with Various Fuels, and Their Technical Solutions*. Technical Bulletin. Anderson Chemical Company, Inc., USA, 1992.
52. Frenier, Wayne E. (Hydrochem Industrial Services). *20 Years of Advances in Technology for Chemically Cleaning Industrial Equipment: A Critical Review*. Paper 338, presented at the NACE International Corrosion Conference, USA 1998.
53. Fulton. *Vertical Boilers*. Promotional literature. Fulton Boiler Works, Inc., USA.
54. Gandhi, Ashish (Cortec Corporation). *Volatile Corrosion Inhibitors: Unique Water Treatment Applications*. "The Analyst," Journal of the Association of Water Technologies, USA, Fall 2000.
55. George, A. M. *Chemical Control of Slagging in Incinerators and Other Combustion Equipment*. Marston-Bentley technical literature. Canning Group, P.L.C., UK, 1993.
56. Gestra (UK) and Highveld Instrumentation (South Africa). *Boiler Blowdown and Flash Steam Recovery Systems*. Technical and promotional literature. Gestra Aktiengesellschaft, Germany, 1990.
57. Gonzalez, William J.; Rondum, Kaj D. *Implementing the Proper Procedure for Removing a Boiler from Service*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, November/December 1994.
58. Gonzalez, William J. *Proper Layup Procedures for Industrial Boilers and Their Auxiliaries*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, March/April 1996.

59. Gottlieb Michael, C. *Fundamentals of Ion Exchange*. Technical literature. ResinTech, Inc., USA, circa 1990.
60. Gottlieb Michael, C. *The Practical Aspects of Ion Exchange in the Service DI Industry*. "Water Technology", Vol. 11, February/March 1989.
61. Great Lakes Chemical Corporation. *Products for Industrial Water Treatment*. Various technical/promotional literature. (Formerly FMC Corporation [UK] Ltd. and prior to that the Process Additives Division of Ciba-Geigy), UK, 1983–1995.
62. Gunnerson, Gary. *Using Activated Carbon for Pretreatment in the Power Industry*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, October 1998.
63. Hampshire. *Chelate Specifications*. Technical literature. Hampshire Chemical Division of W.R. Grace, Inc., USA, 1970.
64. Hann, W.M.; Keller, L.H.; Sanders, T.W.; Weinstein, B. *Towards Field-Friendly Traceable Polymeric Dispersants*. 58th International Water Conference, USA, Nov 1-5, 1997.
65. Hansen, Annegrethe; Subramanian, Ravi (Enersave Engineering Systems). *Packed-Bed Versus Hold-Down Ion Exchange*. "Ultrapure Water." Tall Oaks Publishing, Inc., USA, July/August 1996.
66. Hare, Michael D. *Automatically Controlled Skimmer Blowdown in Steam Boilers*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., September/October 1994.
67. Hargrave, Robert E. *The Influence of Inadequate Water Circulation on Boiler Tube Failures*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, September/October 1994.
68. Harris, Norman C. *Modern Air Conditioning Practice*, 3rd edition, McGraw-Hill Inc., USA, 1983.
69. Heslop, R.B. and Robinson, P.L. *Inorganic Chemistry*, 2nd edition. Elsevier Publishing Company, USA, 1963.
70. Hollander, Orin B. *Chelants in Water Treatment*. "The Analyst." Association of Water Technologies, USA, Spring 1998.
71. Hollander, Orin B. *Oxygen Control in Boiler Circuits*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, March 1994.
72. Hollander, Orin; Krager, Richard. *Selection Criteria for Amines Used in High-Pressure Boilers*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, November 1997.
73. Hollander, Orin.; Freedman, Arthur J. *Monitoring and Control in Industrial Water Systems: Part 2*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, February 1997.
74. Hollander, Orin. *Controlling the Chemistry of Coordinated Phosphate Programs in High-Pressure Boilers*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, September 1998.
75. Houseman. *The Good Water Guide: Chemical Cleaning*. Technical and marketing notes, Houseman Ltd., (now a member of ONDEO Nalco, a division of Suez Lyonnaise), UK. 1980.
76. Houseman. *Boilerplan*. Technical reports. Houseman Ltd., (now a member of ONDEO Nalco, a division of Suez Lyonnaise), UK. 1990.
77. Houseman. *Did You Know? The Use of Amines in Steam Condensate Return Lines*. Technical and marketing notes, Houseman Ltd., (now a member of ONDEO Nalco, a division of Suez Lyonnaise), UK. 1980.

78. Industrial Water Society. *Corrosion Control in Steam Raising Plant Through the 80's*, 1st edition. Water Management Society, UK, 1982.
79. Jarvis, Preston. *Chelates and Their Uses: An ENCEE Product Review*. American Industrial Chemical Corporation, USA, 1993.
80. Johnson, Peter R. (Ametec Inc). *Fundamentals of Fluid Filtration: A Technical Primer*. Tall Oaks Publishing, Inc., USA, 1990.
81. Kasper, Joel (Aquagenics). *A Look at Steam Systems, Carbon Filters and Condensate Polishers*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, February 1998.
82. Kemmer, Frank N. (editor). *The NALCO Water Handbook*, 2nd edition, McGraw-Hill Inc., USA, 1988.
83. Ketrick, Bruce T. (Guardian Chemical Specialties Corp.). *Objectives of Water Conditioning*. Regional Training Seminar Handbook. Association of Water Technologies, USA, 1999.
84. Kinghorn, Patrick H.; Haas, William E. (Ecolochem, Inc.). *Low Level Deoxygenation of Boiler Makeup Water Using Gas Transfer Membranes*. Pittsburgh International Water Conference, USA, 1999.
85. Knight Corporation. *Filters and Strainer Vessels*. Promotional literature. Knight Corporation, U.S.A.
86. Kramer, Andrew W. *Power Plant Primer*. Power Engineering, USA, 1983.
87. Laronge, Thomas M. *Water Reuse via Condensate Polishing*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, September/October 1996.
88. Laronge, Thomas M. *Boiler Cleaning Boilers Without Mistakes*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, March/April 1995.
89. Laronge, Thomas M. *Boiler Water Treatment Need Not Pressure You*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, November/December 1995.
90. Liang, C.H.; Huang, T. Chen. *Boron-Lithium Chemistry in PWR Primary Coolant*. "Ultrapure Journal," Tall Oaks Publishing, Inc., USA, November 1992.
91. McCoy, James W. *The Chemical Treatment of Boiler Water*, 1st edition, Chemical Publishing Co., USA, 1981.
92. McCoy, James W. *Industrial Chemical Cleaning*, 1st edition, Chemical Publishing Co., USA, 1984.
93. McCoy, James W. *Chemical Analysis of Industrial Water*, 1st edition, Chemical Publishing Co., 1969.
94. Maringer, Luis V.; Saavedra, Claudia T.; Selby, Anthony K.; Haberman, Charles E. *Boiler Failure Due to Acid Phosphate Corrosion*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, January/February 1993.
95. Meckler, Milton. *Electrostatic Descaler Testing: An Evaluation*. "Heating/Piping/Air Conditioning Journal". USA, 1974.
96. Meltzer, Theodore H. *High-Purity Water Separation for the Semiconductor, Pharmaceutical and Power Industries*, 1st edition. Tall Oaks Publishing, Inc., USA, 1993.
97. Miller, William S. (Ecolochem, Inc.). *Oxygen Removal By Catalyzed Carbon Beds*. EPRI Condensate Polishing Workshop, Electric Power Research Institute, USA, October 1985.
98. Molnar, T. L. *Boiler System Equipment Inspection Techniques*. Mogul Applications Discussion Document. Mogul Corporation (Dexter), USA, 1982.

99. Molnar, T. L. *Removal from Service and Storage of Industrial Boilers*. Mogul Applications Discussion Document. Mogul Corporation (Dexter), USA, 1982.
100. Mommaerts Guy J. *A Review of Packed-Bed Technology Design Parameters*. "Ultrapure Water," Tall Oaks Publishing Inc., USA, July/August 1999.
101. Monsanto. *Cyclohexylamine and Dicyclohexylamine*. Publication No. 143. Monsanto Chemical Intermediates Co., USA, 1983.
102. Monsanto. *Phosphates for Industry*. Publication N. 9181. Monsanto Company, USA, 1993.
103. Nalco. *How to Protect Your Boiler During Shutdowns*. Technifax TF-23, ONDEO Nalco (Division of Suez Lyonnaise/Degrémont), USA, 1983.
104. Nalco. *An Introduction to Fuel Treatment*. ONDEO Nalco (Division of Suez Lyonnaise/Degrémont), USA, 1987.
105. NBIC. *National Board Inspection Code*. ANSI/NB-23. National Board of Boiler and Pressure Vessel Inspectors, USA, 1998.
106. Nunn, Robert G. *Water Treatment Essentials for Boiler Plant Operation*. McGraw-Hill Companies, Inc., USA, 1997.
197. Obrecht, Malvern F. PhD. *Steam and Condensate Return Line Corrosion. Factors That Accelerate It, Retard It, with Emphasis on Oxygen*. "Heating, Piping & Air Conditioning," USA, August 1964.
108. Obrecht, Malvern F. PhD. *Steam and Condensate Return Line Corrosion. How to Employ Filming Amines for Its Control*. "Heating, Piping & Air Conditioning," USA, October 1964.
109. Olin. *Phosphates*. Technical literature. Olin Mathieson Chemical Corporation, USA, 1964.
110. Osmonics. *Electrodeionization*. Technical documents and promotional literature. Osmonics, Inc., USA, 1999.
111. Owens, Dean L. *Practical Principles of Ion Exchange Water Treatment*. Tall Oaks Publishing Inc., USA, 1995.
112. Painter, John C. (Ecolochem). *Benefits of Non-Capital Makeup Systems*. NUS Clearwater Florida Makeup Water Technologies Seminar, USA, 1993.
113. Parker Amchem. *Rodine Acid Inhibitors for Industrial Cleaning and Steel Pickling Operations*. Technical and marketing document. Parker Amchem, Inc. (Henkel), USA.
114. Paul, David H. *Back to Basics: Understanding a Water Analysis Report. Parts I & II*. "Ultrapure Water," Tall Oaks Publishing Inc., USA, January/March 1998.
115. Permutit. *A Reflection of Quality*. Pre-treatment equipment marketing information. The Permutit Company, Ltd., UK (now part of Vivendi/US Filter Corp.).
116. Peter-Hoblyn, J.D. (Nalco Fuel Tech UK). *Fuel Treatments for the Middle East*. Private communication to C. Frayne, Aquassurance, Ltd. UK 1992.
117. Pfizer Corporation. *Industrial Uses for Erythorbates and Ascorbates*. Information Sheet 2042. Pfizer Chemical Division, USA.
118. Pipe, Sue, General Editor. Various "Waterline" and "Waterscan" reports. The Water Management Society, UK.
119. Port, Robert D.; Herro, Harvey M. *The NALCO Guide to Boiler Failure Analysis*, 1st edition, McGraw-Hill Inc., USA, 1991.
120. Powell, Sheppard T. *Water Conditioning for Industry*, 1st edition, McGraw Hill, Inc., USA. 1954.

121. Price, Tim. *AVT to OT Conversion on a Drum Boiler Unit at Thomas Hill Energy Center*. Associated Electric Cooperative. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, November 1997.
122. Reardon, P. A.; Kelly, J. A. *New Oxygen Scavengers and Their Chemistry Under Hydrothermal Conditions*. Nalco/NACE International Corrosion Forum, 86. NACE International, USA, March 1986.
123. Reardon, P. A.; Bernahl, W.E. *New Insights into Oxygen Corrosion Control*. Nalco/NACE International Corrosion Forum, 87. NACE International, USA, March 1987.
124. Robinson, Jim. *Internal Water Treatment for Industrial Steam Plants*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, November/December 1992.
125. Robbins, C. J. (Elf Atochem North America). *Condensate Line Control/Humidification Considerations*. Presented to Association of Water Technologies, Franklin Plaza, Philadelphia, Pennsylvania, USA, April 1994.
126. Rohm and Haas. *Optidose Traceable Polymer System*. Technical publication. Rohm and Haas Company, USA, 1998.
127. Rohm and Haas. *Amberlite Engineering Manual*. Rohm and Haas Company, USA, 1983.
128. Romero, Matilde F.; Pérez, Orlando; Navarro, Alfredo. *Phosphate Attack as Caustic Corrosion in High-Pressure Boiler Tubes*. "Material Performance". NACE International, USA, March 1999.
129. Rondum, Kaj D. *Traditional and Advanced Approaches to Boiler Water Deposition Prevention*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, January/February 1994.
130. Ross, Sydney. *Chemical Defoaming Agents*. Chemical Industries. Maclean-Hunter Publishing Corporation, USA, May 1949.
131. Rudolph, John W.; Reid, Robert W.; Cuisia, Dionisio G. *New Oxygen Scavenger for Boiler Systems*. "NACE Corrosion 83". National Association of Corrosion Engineers, USA, April 1983.
132. Russum, Stephen A. (Nalco Chemical Co.) *Maintaining Steam/Condensate Lines*. "Plant Engineering", USA, March 1992.
133. Salaices, Maria; Waterhouse, Bert; Waddams, A.L.; Kamatari, O. *Chelating Agents*. Technical product review, CEH, Inc., USA.
134. Schofield, W.R.; Lutzman, John; Patterson, Gene W. *Use of Chemical Additives to Reduce The Impact of Slag Formation in Hazardous Waste Incineration*. Hazardous Materials Control Journal, USA, 1992.
135. Schuck, Joseph. *Boiler Water Treatment, A Discussion of the Basic Control Programs*. Technical Document No. 84-01 ChemLink (now Baker Petrolite), USA, 1984.
136. Schwieger, Robert G. *Heat Exchangers*. "Power" special report, Power Publishing Co., USA, June 1970.
137. Schwieger, Robert G. *Industrial Boilers—What's Happening Today, Part II*. "Power" special report, Power Publishing Co., USA, 1978.
138. Shimura, Y.; Uchida, K.; Sato, T.; Taya, S. *The Performance of New Volatile Oxygen Scavenger and Its Field Application in Boiler Systems*. Kurita/NACE Corrosion 2000. NACE International, USA, April 2000.
139. Short, W.B. *Learning from Past Experience—45 Years With Boilers*. "Waterline" Industrial Water Society (now Water Management Society), U.K. , June 1991.

140. Singh, Rajindar (M.A.E. Environmental Technologies). *A Review of Membrane Technologies: Reverse Osmosis, Nanofiltration and Ultrafiltration*. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, March 1997.
141. Steingress, Frederick M., Frost, Harold J. *High Pressure Boilers*, 2nd edition. American Technical Publishers, Inc., USA, 1994.
142. Stewart Richard, G. *Partial Oxygenated Feedwater Treatment at the Paradise Fossil Plant Unit 1*. Tennessee Valley Authority. "Ultrapure Water," Tall Oaks Publishing, Inc., USA, November 1997.
143. Stodola, Jan. Silbert, Marvin D. *Enhanced Phosphate Treatment for Drum-Recirculating Boilers*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, January/February 1996.
144. Streatfield, E.L. *Scientific Basis of Organic Boiler Water Treatment*. Paper delivered in Oslo to the Research Society for Norwegian Industry. Norway, 1962.
145. Suchower, Andrew; Jain, Dr. Kiran. *ANCO Chemical Cleaning Manual*. Internal publication, Anderson Chemical Company, USA.
146. Tanis, J. N. *Procedures of Industrial Water Treatment*, 1st edition, Ltan, Inc., USA, 1987.
147. Thate Sven. Specogna Nicola. Eigenberger Gerhart. *A Comparison of Different EDI Concepts Used for the Production of High-Purity Water*. "Ultrapure Water," Tall Oaks Publishing Inc., USA, October 1999.
148. Tvedt Jr., T. J.; Holloway, Robert T. *Control of Industrial Boiler Water Chemistry: A New ASME Consensus*. "Industrial Water Treatment," Tall Oaks Publishing, Inc., USA, May/June 1996.
149. Ultraclean. *Cryojet Physical Blasting Cleaning Services*. Marketing information. Ultraclean Technology, USA
150. Union Carbide. *Silicone Antifoams*. Technical publication. Union Carbide Corporation, USA, 1979.
151. U.S. Department of Energy. *Non-Chemical Technologies for Scale and Hardness Control*. Federal Technology Alert, [http://www.pnl.gov/fta/11\\_non.htm](http://www.pnl.gov/fta/11_non.htm), 1999.
152. U.S. Filter Corporation. *Permutit Water and Waste Treatment Data Book*, 18th printing, U.S. Filter Corporation, USA.
153. Various authors and editors. *BETZ Handbook of Industrial Water Conditioning*, 8th edition, Betz-Dearbon (now G.E. Betz), USA, 1980.
154. Various authors and editors. *Principles of Industrial Water Treatment*, 9th edition, Drew Industrial (division of Ashland Chemical Corporation), USA, 1987.
155. Wabash Power Equipment Co. Various internet sourced, product information notes. <http://www2.thomasregister.com>, 1998.
156. Water Management Society (formerly The Industrial Water Society). *Corrosion Control in Steam: Raising Plant Through the 80's*. Water Management Society, UK, 1982.
157. Weisler Fred; Sodaro, Rick (Hoechst Celanese Corp.). *Degasification of Water Using Novel Membrane Technology*. "Ultrapure Water," Tall Oaks Publishing Inc., USA, September 1996.
158. Welden. *Direct Fired Steam Generator*. Promotional literature. Weldon Steam Generators, Inc., USA.
159. Wiltsey, D.G. *Carbohydrazide as a Hydrazine Replacement*. Missouri Valley Electric Association Conference '86. Nalco Chemical Company, USA, April 1986.

160. Wisman, Joe. *Preventative Maintenance for Steam Generators*. "Modern Baking," USA, October 1991.
161. Woodruff, Everett B.; Lammers, Herbert B.; Lammers, Thomas F. *Steam Plant Operation*, 5th edition, McGraw-Hill, Inc., USA, 1984.
162. Wyandotte. *Foam Control with Wyandotte Surfactants*. Technical Publication. Wyandotte Chemical Corporation (now BASF AG), USA 1970.





---

# 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-Aminobutanol, 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 dealcalization, 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
- Antiscalents, 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
- Glycolic 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
  - decarburation, 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
- Pyrogallic acid, 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