Boiler Water Treatment
Principles and Practice

Volume II

Treatments, Program Design, and Management

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

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

Printed in the United States of America

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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-nitriloproprionamide
DC	direct current
DCA	deposit control agent
DCHA	dicyclohexylamine
DEA	diethanolamine
DEAE	diethylaminoethanol, AKA diethylethanolamine
Dealk	dealkalization
DEEA	diethylethanolamine, AKA diethylaminoethanol
DEG	diethanolglycine
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-dimethy-laminoethanol
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
f	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
m	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
μS/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_x	nitrogen oxides
NPSH	net positive static head
NRV	non-return valve
NTA	nitrilotriacetic 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
R	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
T	temperature
t	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
v	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

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9

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_2 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 **electrodialysis**, 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 $CaCO_3$, 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® 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® 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® 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_2), 78.086% nitrogen (N_2), 0.934% argon (Ar) and 0.033% carbon dioxide (CO_2) 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_2O).

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) $CaCO_3$. 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 [$Al(OH)_3$] 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 (Cl^-) or sulfate (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 Cl^-) by hydroxyl ions (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^2.

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 bar = 1×10^6 dynes/cm^2, = 1×10^5 N/m^2, = 29.531 inches of mercury (Hg), = 753 mm Hg, at 32 °F (0 °C), and at a latitude of 45°.

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_2 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 promotes 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 formulation 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 *countercurrent* (*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* (μS/cm) or *micromho per centimeter* (μmho/cm). 1 μS/cm = 1 μmho/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, underdeposit, 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^3 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 dewpoint 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 H_2SO_4 vapor is in equilibrium with liquid H_2SO_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* (αFe) containing approximately 0.2% carbon together with other elements in solid solution.

Ferritic stainless steel:
A magnetic form of stainless steel that contains an αFe 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 μm, whereas dual or multimedia filtration is required to remove particles down to a diameter of 10 to 20 μm.

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 $CaCO_3$ = 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 it 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 CO_3 or 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 (Fe_2O_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^-) 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., $CaSO_4$, $CaHCO_3$-). 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 $CaCO_3$ 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 (Fe_3O_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_2O) 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_5)*, *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 an 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 $CaCO_3$/cu ft. or kg $CaCO_3/m^3$.

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.

Sinuous 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 μS/cm units of conductivity x 0.65 equals ppm TDS.

Specific gravity:
Ratio of the density of a substance to that of water.

Spheroidization:
The thermal transformation of laminar cementite in the pearlite phase of carbon steel to spherical grains.

Stainless steel (SS):
Any of a number of irons 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.

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