Boiler Water Treatment
Principles and Practice

Volume I

Boiler Basics and Steam-Water Chemistry

Colin Frayne

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ABOUT THE AUTHOR

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

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

PREFACE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Colin Frayne
New York City, 2002

CONTENTS

MODERN BOILER WATER TREATMENT PRACTICE

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

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

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

INTRODUCTION: THE FUNCTION OF BOILER WATER TREATMENT AND ITS MARKETING

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SYMBOLS AND ABBREVIATIONS

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

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