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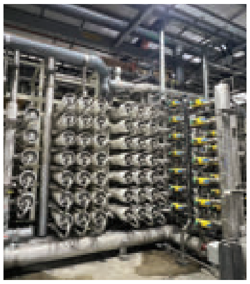

City of Santa Monica (California) Arcadia Water Treatment Plant retrofitted with flow-reversal reverse osmosis.

Photo courtesy of City of Santa Monica.

Winter 2025 Volume 32 Number 1

Features

Departments

Calendar of Events

Association Events

2025 Technical Training Seminar
March 26–29, 2025
Embassy Suites Dallas-Frisco
Frisco, Texas

2025 Annual Convention and Exposition
November 12–15, 2025
The Broadmoor Hotel
Colorado Springs, Colorado

2026 Annual Convention and Exposition
September 16–19, 2026
Oklahoma Convention Center and Omni Hotel
Oklahoma City, Oklahoma

2027 Annual Convention and Exposition
September 8–11, 2027
Cleveland Convention Center
Cleveland, Ohio

Also, please note that the following AWT committees meet on a monthly basis. All times shown are Eastern Time. To become active in one of these committees, please contact us at (301) 740-1421.

Second Tuesday of each month, 11:00 am—Legislative/Regulatory Committee
Second Tuesday of each month, 2:30 pm—Convention Committee
Second Wednesday of each month, 11:00 am—Business Resources Committee
Second Friday of each month, Noon—Pretreatment Subcommittee
Second Friday of each month, 10:00 am—Special Projects Subcommittee
Second Friday of each month, 11:00 am—Cooling Subcommittee
Third Monday of each month, 10:00 am—Certification Committee
Third Tuesday of each month, 3:30 pm—Young Professionals Task Force
Third Tuesday of each month, 11:00 am—Women of Water (WOW) Committee
Third Monday of each month, 3:00 pm—Education Committee
Third Friday of each month, Noon—Boiler Subcommittee
Third Friday of every other month, 10:00 am—Technical Committee
Third Friday of each month, 11:00 am—Wastewater Subcommittee
Fourth Friday of each month, 1:00 pm—Education Resources Committee

Other Industry Events

WateReuse Symposium, March 16–19, 2025, Tampa, Florida

Electric Utility and Cogeneration Chemistry Workshop, June 16–18, 2025, Champaign, Illinois

AWWA ACE '25, June 8–11, 2025, Denver, Colorado.

2025 Industrial Water Solutions, June 23–25, 2025, Columbus, Ohio—Sponsored by the WateReuse Association and Water Environment Federation.

Industrial Water Week (a virtual celebration), October 6–20, 2025, Details available at www.industrialwaterweek.com.

UltraFacility 2025, Fall 2025 (date pending), Austin, Texas.

International Water Conference, November 9–13, Orlando, Florida

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President's Message

By John D. Caloritis, CWT

Happy 2025! We are all looking forward to a prosperous year ahead for AWT.

Leadership Meeting

At the end of last year, the AWT board, committees, subcommittees, task forces, and Related Trade Organization (RTO) liaisons got together to review our goals for 2025. I am pleased to report that work continues on our updated critical outcomes and goals: Thriving Members, Influential Representation, Industry Impact, and continuing our good work with Charity.

The AWT Board of Directors is scheduled to meet in Fort Lauderdale in early-February, where we will be focused on setting priorities and ensuring a positive year of growth success for our organization and its members.

AWT Training

AWT Tech Training will be held February 25–28 in San Diego, California, and March 26–29 in Frisco, Texas. Every year, the sessions are revised and updated based on feedback received from attendees. Programs include sessions on Sales, RO Training, Fundamentals and Applications, ASSE/IAPMO/ANSI 12080 Training and Recertification (San Diego only), Wastewater (Frisco only), and Water Treatment Training.

This year, AWT is proud to feature a new 3-day training course as part of our Tech Training curriculum, Program Design and Operation. The course was developed for the intermediate water treatment professional (2-4 years experience) and focuses on applying water treatment industry knowledge to the sales process to create solution-drive programs. You will not want to miss it! Registration is open - sign up now at www.awt.org.

Volunteer Today

My goal for my term as AWT president is to effectively engage our volunteers and to increase volunteerism. There are so many opportunities to get involved in our organization. Whether through a committee, subcommittee, or task force, your contributions will make a meaningful impact on the AWT and our industry. I challenge all of you to volunteer your time and talents with the AWT. I guarantee you will get more out of your participation than you put in.

Thank you for the opportunity to serve. I can be reached at jcaloritis@metrogroupincc.com.

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Pressure: Up to 362 PSIG (25 BAR)

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- Foot valve with integrated low tank level switch: Prevent your pump from running dry.
- Optional Remote Communication: Modbus, RS-485.
- Wide range of control modes: Stock one pump and solve for many different applications, or future changes in the application.
- Complete with everything for installation: NextStep includes foot valve strainer with integrated low tank level switch, all I/O cables, mounting screws, etc.

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Message From the President-Elect

By Kyle J. Rossi, CWT

We are hard at work planning the 2025 AWT Annual Convention & Exposition, November 12–15, in Colorado Springs, Colorado! It is exciting to return to Colorado Springs, which was the site of our 2007 convention. Headquartered at The Broadmoor, we are certain this year's convention will prove to be another memorable event.

Educational Programs

The program for the 2025 convention is being developed. In addition, the Convention Committee has reached out to members to better understand what sessions they want to see at the meeting. Based on your feedback, we are introducing some new topics and creating sessions to ensure all are up to date on the latest techniques and trends in our industry.

Golf Tournament

This year's golf tournament will be a truly unique experience for participants and sponsors alike – details are coming soon. If you'd like to help shape this year's tournament into one for the record books, please contact me to volunteer on the golf task force. We would love your participation and engagement.

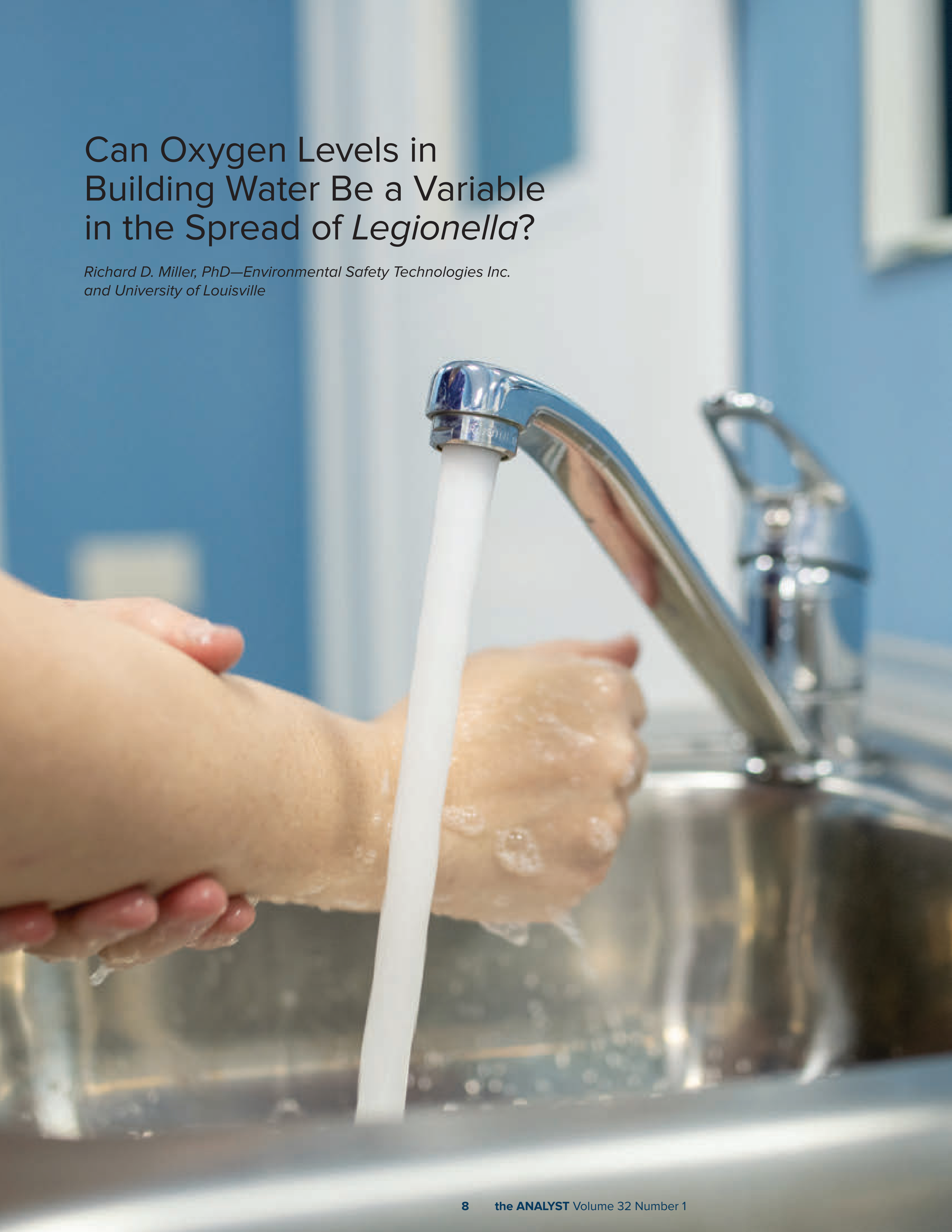
Visit Colorado Springs

Nestled at the foot of the majestic Rocky Mountains, Colorado Springs is an outdoor lover's paradise, bursting with adventure, stunning landscapes, and vibrant culture. Home to iconic attractions like Garden of the Gods, Pikes Peak, and the U.S. Air Force Academy, the city offers a perfect blend of natural beauty and rich history. Whether you're hiking scenic trails, exploring charming downtown boutiques and breweries, or soaking in the breathtaking mountain views, Colorado Springs delivers an unforgettable experience. You may want to extend your stay to experience the huge variety of restaurants, museums, and recreational activities in the area.

As we continue to plan the 2025 Annual Convention & Exposition, I welcome your feedback. I can be reached at krossi@gwt-inc.com. Thank you for the opportunity, and I look forward to serving as your convention chair this year.

Can Oxygen Levels in Building Water Be a Variable in the Spread of *Legionella*?

Richard D. Miller, PhD—Environmental Safety Technologies Inc. and University of Louisville



Background

Legionella is defined metabolically as an obligate aerobe, where it acquires all its energy (and ATP [adenosine triphosphate] synthesis) through metabolism of amino acids via aerobic respiration using oxygen as a required terminal electron acceptor for this metabolism, in much the same way that oxygen is used for human respiration.

Legionella is unable to grow anaerobically on glucose or other carbohydrates, having neither fermentation pathways for ATP synthesis (i.e., like the glycolytic pathway common in many bacteria and yeasts), nor will it use anerobic respiration (e.g., using nitrate or sulfate as a terminal electron acceptor) as, for example, does the aerobic bacterium *Pseudomonas aeruginosa*.

As a result, within building water environments containing sufficient dissolved oxygen, *Legionella* replicates vigorously inside of free-living amoebae, who also use oxygen for mitochondrial respiration. *Legionella* intracellular growth within monocytes and macrophages during Legionnaires' disease in the human lung is also understandably aerobic. However, because of this oxygen restriction, *Legionella* will only grow well in building water with high dissolved oxygen concentrations, such as cooling towers, decorative fountains, whirlpool spas, and fresh city potable water, assuming other conditions are favorable. As a result, *Legionella* will compete poorly in less aerobic environments such as at the base of an oxygen gradient in plumbing biofilms, and in building plumbing dead legs and areas of stagnation where competing facultatively aerobic bacteria use up all the limited oxygen supply while switching from aerobic to anaerobic metabolism.

The objective of this article is to discuss the scientific basis for, and the public health significance of, dissolved oxygen as an important environmental factor (along with temperature and disinfectant concentrations) for *Legionella* proliferation in building water systems, and then to consider possibilities for using oxygen restriction in *Legionella* control.

Understanding of *Legionella* Nutrition and Metabolism

Isolation and initial characterization of *Legionella*. It is widely recognized that the bacterium now known as *Legionella pneumophila*, was first observed and isolated in laboratory studies by McDade, Shepard and co-workers (1) at the Centers for Disease Control (CDC), several months following the nationwide attention to a large outbreak of pneumonia and deaths in the summer of 1976 among persons attending an American Legion convention in Philadelphia, Pennsylvania. As a result of this association, the new pneumonia has been widely known as Legionnaires' disease.

Once the conditions for in vitro growth of the Legionnaires' disease bacterium (LDB) were characterized in early 1977 (2), the CDC made cultures of the LDB widely available to researchers in the United Staes and around the world (including my laboratory at the University of Louisville). What little was known about LDB at the time, was that it was a slow-growing, weakly staining Gram-negative rod-shaped bacterium that did not grow on any traditional agar media used for culturing bacterial pathogens, unless the medium was supplemented with the amino acid L-cysteine and soluble inorganic ferric iron (2). The official naming and taxonomy of the LDB as *Legionella pneumophila* was published by CDC the following year (3).

Over time, additional species of *Legionella* were isolated and identified from patients with Legionnaires' disease, or from aquatic environments. Currently there are more than 60 species of *Legionella* (4). While there are many genetic variations among these *Legionella* species, including some metabolic variations, they all seem to maintain the same overall intermediary metabolism. Unless specificity is needed, this article will refer to these bacteria as *Legionella*.

Biochemical basis for the *Legionella* requirement for oxygen. The relationship of *Legionella* with oxygen was examined by the CDC very early after it was isolated. Studies showed that *Legionella* did *not* grow when the agar plates were incubated anaerobically (2, 5), indicating a requirement for oxygen. For a more complete understanding of what this means, it is useful to understand how bacteria are classified and put into different categories according to their oxygen requirements and metabolism. For the purpose of this *Legionella* discussion, the three major categories (and sub-categories) are shown in Table A.

When compared to these oxygen requirement and metabolism categories, *Legionella* are Obligate Aerobes,

Table A: Bacterial Oxygen Requirements and Metabolism Categories

Category 1

Obligate aerobe: These bacteria require oxygen to live, with metabolic pathways that use aerobic respiration via the electron transport system for the formation of a proton gradient to drive ATP synthesis and use oxygen as the terminal electron acceptor. Obligate aerobes have no ability to generate ATP via anaerobic respiration using nitrate or some other terminal electron acceptor instead of oxygen. Additionally, they have no ability to grow anaerobically using fermentation metabolic pathways for generating ATP.

- **Microaerophiles:** These bacteria are a sub-category of Obligate aerobes. They require oxygen for metabolism and generation of ATP but are poisoned by the atmospheric 21% oxygen. They grow in environments where the oxygen concentration is reduced (e.g., 2 to 10%).

Category 2

Obligate Anaerobe: These bacteria grow only anaerobically (in the absence of oxygen) as a result of not using oxygen for metabolism, but also being killed by oxygen's well-known inherent toxicity (6). Obligate anaerobes use either anaerobic respiration (using nitrate, sulfate, or some other compound as the alternative terminal electron acceptor) and/or use *fermentation* reactions (inherently anaerobic) in order to generate ATP.

Category 3

Facultative Anaerobe: These bacteria can grow equally well in the *presence* or *absence* of oxygen, using aerobic respiration when oxygen is present, but switching to anaerobic growth, using either anaerobic respiration and/or fermentation for ATP generation and growth when oxygen becomes limiting or absent. The ability to switch their metabolism according to the oxygen availability makes them very versatile in terms of their growth habitats. Many human pathogens fall into this category.

- **Aerotolerant Anaerobes:** These bacteria are a sub-category of Facultative Anaerobes, since they also grow well in the *presence* or *absence* of oxygen. However, they never use oxygen, even when it is present (i.e., never switch to aerobic respiration). Rather they tolerate the oxygen toxicity, while always growing using anaerobic fermentation for generation of ATP.

since their metabolism is entirely based on aerobic respiration. *Legionella* are not capable of anaerobic respiration using alternative electron acceptors other than oxygen, such as nitrate as used by *Pseudomonas aeruginosa* (7), or *Escherichia coli,* and many other bacteria (8). Furthermore, *Legionella* does not produce any acid when growing on solid or liquid media with glucose or any other carbohydrate as a fermentable carbon source (5).

Thus, *Legionella* clearly is unable to carry out anaerobic fermentation reactions (e.g., glycolysis pathway) to generate ATP, as do many facultative anaerobic bacteria and yeasts. As a result of its obligate aerobic metabolism, *Legionella* will only grow where there is a sufficient concentration of dissolved oxygen (DO; usually > 2 milligrams per liter [mg/L]) in order to carry out aerobic respiration. This oxygen requirement will obviously restrict their versatility in aquatic growth habitats, compared to the many competing facultative anaerobes in water.

Additionally, since *Legionella* growth in the environment is restricted primarily to intracellular amoebae habitats (see "Growth of *Legionella* in their Natural Aquatic Environmental Habitat" section later in the article) they will tend to be found in biofilm amoebae such as Acanthamoeba and Hartmanella (9) that have these same oxygen requirements.

***Legionella* requirement for amino acids.** The actual carbon compounds that are metabolized (i.e., oxidized) by *Legionella* were identified first in early nutritional studies on *Legionella* that were carried out during the development of chemically defined media for growing *Legionella*, including those at the CDC (10), U.S. Army USAMRIID (11), and at the University of Louisville (12). These studies showed that *Legionella* can grow in liquid media using only amino acids as sources of energy and carbon, as long as certain specific amino acids were present.

Legionella, it turns out, is auxotrophic for (i.e., is unable to synthesize and thus has a requirement for) certain amino acids, including L-arginine, L-leucine, L-isoleucine, L- valine, L-serine, L-threonine, L-methionine, and L-cysteine (13-15). Based on oxygen utilization (i.e., aerobic respiration) experiments, the only rapidly metabolizable substrates used as respirable energy sources for *Legionella* were the amino acids glutamate, serine, threonine and tyrosine (16). Taken together, these results demonstrated the absolute reliance on large amounts of specific amino acids for *Legionella* growth, including for both biosynthesis of proteins and other organic material, and also for energy/ATP generation.

***Legionella* metabolism of glucose.** Interestingly, while glucose (and other carbohydrates) are not required for growth of *Legionella*, glucose is not fermented for energy. *Legionella* does have glucose fermentation pathways in order to metabolize glucose and use the metabolites for biosynthesis of structural organic compounds in the cell. Radiorespirometry studies with differential radioactively labeled glucose have shown that glucose was clearly metabolized, but via the Entner-Doudoroff and pentose phosphate pathways (not the more common glycolysis pathway) with the radiolabel ending up in both carbohydrate and lipid-containing cell factions (16). Similar studies by Harada, et al. (17) also showed a role for the Entner-Doudoroff pathway for the metabolism of glucose in *Legionella*.

Availability of amino acids in the aquatic environment – the role of free-living amoebae. It is clear from the discussion earlier in this section that *Legionella* have a voracious appetite for amino acids (and oxygen); and would require a continuous diet of the specific amino acids in order to proliferate in environmental water locations. One can imagine that this would be a difficult task to find such a continuously large supply of these specific types and quantity of amino acids, not only free in the water, but also within a growing biofilm on surfaces where they would be competing with other bacteria for those nutrients.

Legionella solved this nutrient problem by developing a unique intracellular amoebic habitat (e.g., *Acanthamoeba* and *Hartmanella* species) (19), and a mechanism using *dot/icm* virulence genes coding for a Type IV Secretion System to initiate, among other things, triggering of the ubiquitination of cellular amoebae proteins for proteasomal degradation within the cytoplasm of the host cell, providing a continuous and exclusive supply of amino acids to the growing population of intracellular *Legionella* within the phagosome (20, 21). Thus, *Legionella* will proliferate wherever there are susceptible amoebae (or other protozoa) to grow inside of; and will increase in numbers accordingly (9,21).

Growth of *Legionella* in their Natural Aquatic Environmental Habitat

The unique intracellular habitat used by *Legionella* was first described in the clinical field as a result of the landmark publication by Horowitz and Silverstein (22), showing that the new Legionnaires' disease bacterium (*L. pneumophila*) multiplied intracellularly within human mononuclear phagocytic cells (monocytes and macrophages) in the human lung.

Soon thereafter the same intracellular multiplication mechanism was documented in environmental free-living phagocytic amoebae (23). The rest, as they say, is history. Since the highest concentrations of amoebae are usually found migrating through the aerobic water/surface biofilms as they graze for food (i.e., bacteria to eat), the highest concentration of *Legionella* will be in the same locations (at appropriate temperatures), as they infect the amoebae, inhibit intracellular killing, and convert the amoebae into their amino acid-producing food supplies for replication. After completing their intracellular replication, they exit the amoebae and get released into the biofilm matrix and eventually the water bathing the biofilm in their search to find other amoebae hosts.

***Legionella* growth and availability of oxygen in the aquatic environment.** Soon after the initial isolation of *Legionella pneumophila* from patients in early 1977, *Legionella* was isolated from environmental water sources associated with outbreaks of disease (24). Subsequently, Dr. Carl Fliermans (DuPont) along with collaborators from CDC, detected *Legionella* from 90% of 200 samples from 23 different natural lakes across the southern US (25). All lakes had significant exposure to the atmosphere, resulting in dissolved oxygen (DO) concentration of 5.8 to 6.9 mg/L in samples where *Legionella* was isolated. A follow-up study by Fliermans, et. al. (26) involving 793 surface water samples from across the eastern US showed the same results, with *Legionella* observed in virtually all of the samples.

The results suggested that *Legionella* is part of the natural surface waters aquatic environment and is capable of surviving a wide range of physical and chemical conditions. Dissolved oxygen was present in all 793 samples, although the concentrations in the samples with *Legionella* had DO concentrations that varied from a very low of 0.3 to a high of 9.9 mg/L. The DO in samples with no *Legionella* were not recorded.

Fliermans (26) also looked at DO concentrations in cooling towers and make-up water, finding that cooling towers with make-up water coming from deep wells had lower DO (usually anoxic) and had *Legionella* densities substantially lower than cooling towers that were receiving make-up water from more aerobic surface water from lakes, rivers or streams. Once in the cooling towers, the circulating water would be, as expected, always well-aerated, showing DO numbers in the range of 7 to 11 mg/L and very favorable for *Legionella* growth.

At the time that Dr. Fliermans was running his large environmental surveys, the intracellular nature of *Legionella* had not been fully described. Thus, we now know that the wide geographic distribution of *Legionella* in oxygenated surface waters is also a reflection of the similar distribution and requirements of their amoebae hosts.

Growth of *Legionella* in Building Water Systems

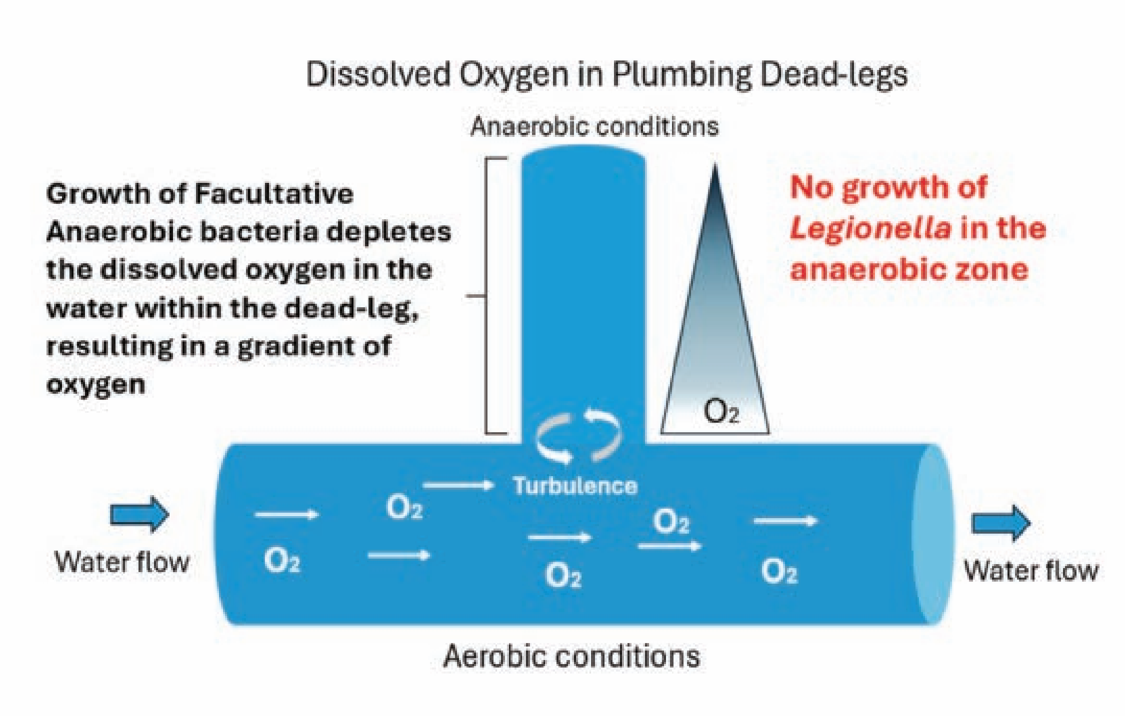
Despite the widespread prevalence of *Legionella* in environmental surface water (lakes, rivers, streams, etc.), Legionnaires' disease in humans is transmitted primarily by contact with aerosols from building water sources and systems where *Legionella* may proliferate and spread. The building water systems that have this *Legionella* colonization and transmission potential are described in the ASHRAE Guideline 12-2020 (29) and ASHRAE Standard 188-2021 (30) documents, and they include building potable water systems (especially the hot loop), heated whirlpool spas/hot tubs, cooling towers and evaporative condensers, decorative water features, direct evaporative air coolers, misters, air washers, and cool-mist humidifiers.

Control of *Legionella* in building water with chemicals. Many of these *Legionella* colonization water systems contain added chemical disinfectants (including chlorine in the potable water, halogens in heated spas, and a variety of different oxidizing and non-oxidizing chemical biocides in cooling towers). for the purpose of eliminating or controlling the proliferation of equipment-damaging and/or hazardous bacteria, (including *Legionella*) in the water. Thus, these building water systems with a *Legionella* risk are incorporated into Water Management Plans (WMP) for control, as described in ASHRAE Standard 188-2021.

Control of *Legionella* in building water with oxygen. Many of these *Legionella* colonization water systems are highly aerated by virtue of their function, such as cooling towers, heated whirlpool spas with their air jets, etc. Additionally, cold potable water entering a building is also well-aerated from its processing by the city water utility. As potable water is heated in the hot loop, it would have a lower concentration of dissolved oxygen compared to cold water. However, if the hot water remains in a pressurized state within the pipes, the dissolved oxygen will remain in the water and will support the growth of *Legionella*.. Thus, based solely on the dissolved oxygen concentrations, these building water systems are all well suited for *Legionella* proliferation, and help to explain the need for chemicals for *Legionella* control for these systems.

Wadowsky and colleagues (31) confirmed this relationship with oxygen as part of their study of

Figure 1: Dissolved oxygen in potable water plumbing and a dead-leg.



naturally occurring *Legionella* growth in a tap water model. As expected, *Legionella* grew well under aerobic water conditions containing 6.0 to 6.6 mg/L of dissolved oxygen. However, *Legionella* multiplication ceased in tap water with less than 2.2 mg/L of dissolved oxygen. Thus, oxygen can be a very limiting factor in potable water systems. The following are limiting factors impacting oxygen levels in building water systems:

- **Natural areas of hypoxia in plumbing systems.** Hypoxic conditions (dissolved oxygen < 2.2 mg/L) occur naturally in potable water systems where the regular flow of the tap water (with high dissolved oxygen) encounters *stagnation* or *dead-legs* in plumbing systems.

- **Stagnation.** The slow or inconsistent water flow in areas of stagnation is often insufficient for maintaining a continuous supply of dissolved oxygen to a natural microbiome-containing *Legionella*. The growth of aerobic and facultative anaerobic bacteria in the water will use up much of the oxygen, with the facultative anaerobes then continuing to multiply as they switch to anerobic metabolism. Such a stagnation environment with loss of dissolved oxygen, would be unfavorable for *Legionella* proliferation. The effect of stagnation on *Legionella* was shown in a laboratory study by Liu, et al. (32), using a model plumbing system with different flow rates and turbulence. As might be expected based on oxygen availability, the lowest *Legionella* counts were found in the water from the pipes with the stagnant flow, with the highest *Legionella* counts in the pipes with the highest flow rates and turbulence.

- **Dead-legs.** These are plumbing dead ends where there is no longer any water flow through some sections of pipe (shown in Figure 1). The length of the pipe in the dead-leg can vary considerably, with a very long dead section providing a large section of pipe that remains anaerobic and will encourage the growth of obligate and facultative anaerobic bacteria.

Unlike areas of stagnation, a dead-leg has no natural flow, but rather has only the oxygen that would be supplied by the turbulence at the entrance to the dead-leg. With the obligate aerobes and facultative anaerobes using up all of the oxygen within the depths of the dead-leg, an oxygen gradient would be established, with *Legionella* multiplication being restricted within the dead-leg and multiplying only near its entrance where the oxygen supplied by the turbulence would achieve a dissolved oxygen concentration above 2.2 mg/L.

Dead-legs would also have a similar gradient established for chlorine in potable water, which would actually be more favorable for *Legionella* at the lower chlorine concentrations deeper into the dead-leg. Thus, the optimal zone for *Legionella* multiplication in potable water dead-legs is typically very narrow, and near the entrance.

Creating hypoxia (i.e., removal of oxygen) in plumbing systems. The potential for the control of *Legionella* in building water systems by limiting dissolved oxygen has been championed in a review publication publications by Krause (33). This publication provides excellent coverage of *Legionella* and the role of dissolved oxygen in its growth and inhibition. Thus, this article is strongly recommended for more in-depth exploration of *Legionella* and oxygen for those readers who are interested in the topic.

As Krause explains: "Most chemical processes that remove dissolved oxygen from water can leave it unpalatable or toxic. In the past 20 years, membrane contactors using gas transfer membranes (34) have been developed to degas fluids for sensitive manufacturing processes, to prevent corrosion in boilers and radiant heat systems, for bottled beverage production (wine, beer, and juice), and in pharmaceutical manufacturing. A membrane contactor system is capable of removing dissolved oxygen and other dissolved gases through physical mechanisms of vacuum and rapid diffusion that do not adversely impact water potability."

Conclusions

Understanding the essential role that oxygen plays in the aerobic respiration and growth of *Legionella*, helps to provide an understanding of the building water system environments where *Legionella* and its amoebae hosts will multiply (creating a risk of Legionnaires' disease transmission) and where it they will not (e.g., dead-legs, stagnation). More important, is the indication that oxygen deprivation could be used as a tool to inhibit the colonization of *Legionella* in these high-risk water systems. As a proof of principle, a new study by Krause (35) has shown that in a model hot water system colonized by *Legionella*, the *Legionella* numbers were reduced by 90% over 7 days when the dissolved oxygen was lowered to < 0.3 mg/L. Whether this oxygen reduction approach is scalable to an entire hospital hot water loop is exciting to think about, but yet to be answered.

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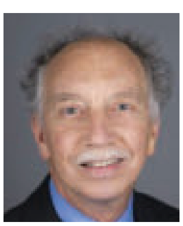

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Can Flow-Reversal RO Solve Silica Fouling and Scaling Problems?

Dor Tal, Sapir Regev, Bruce Alderman—ROTEC

Background

Silica scaling damages reverse osmosis (RO) systems by shortening membrane life and increasing operational costs due to increase in pressures (feed pressure and pressure drop), decreased flux, chemical dosing, and down time for clean-in-place (CIP). For facilities that depend on RO systems for water treatment, silica remains a persistent obstacle. However, advancements in RO technology are emerging to address these challenges. This article will delve into the complexities of silica, its effects on RO systems, and technology developments that promise to improve operations and overcome silica-related issues.

Background

Silica, also referred to as silicon dioxide (SiO_2), is considered the second most abundant material on earth. Silica takes up many forms and is widely found in rocks, sand, and materials such as silt and clay.

Water Treatment Challenges

In water, silica is an umbrella term used to refer to three different forms: soluble (dissolved), colloidal, and particulate or granular. Silica is found in the different brackish water sources used by treatment plants—groundwater, surface sources and seawater. Reactive and colloidal silica content in groundwater and surface water typically can range anywhere from 1 up to 100 parts per million (ppm).

Reactive (soluble) silica is found in surface sources and is often a major contaminant found in groundwater. This type forms yellow silicomolybdic acid in the molybdenum blue test method via the reaction of ammonium molybdate and silica at a low pH. Soluble silica has short molecular chains of three base molecules or less.

The polymerization of silica itself has a long duration (more than a few hours). However, when magnesium or iron ions are present in the water, the induction time is reduced significantly. Specific RO membrane antiscalants interfere with the polymerization mechanism, increase the induction time required for formation of the first polymer chains, and slow the overall reaction. When the antiscalant interferes with the polymerization mechanism, the structure of the material formed can be likened to the salt-lattice formation (an example of such a formation is the calcium carbonate salt [$CaCO_3$]).

Unreactive or colloidal silica is a form of silica that is hard to detect in water and is slow to react to the molybdenum blue test. Colloidal silica has longer molecule chains of three or more base molecules and is often combined with other substances such as iron, aluminum, or organics. Colloidal silica is often found in surface water.

Particulate or granular silica is tiny particles of silica compounds such as clays, silts, and sand that are normally 1 micron (µm) or larger and suspended in water. This type of silica is measured by the silt density index (SDI).

Table A provides a summary about the different silica forms, while Figure 1 shows the end of a silica-scaled RO membranes.

Table A: Silica Overview

Type	Characteristics	Size	Where Found?	Removal	RO System Concerns
Particulate or granular	Silica particles from sand, silt, and clay.	1 µm or larger	Surface water	Filtration	Silica particles can foul RO membrane pores.
Reactive or soluble	Dissolved form of silica that tends to have an anionic charge.	Molecular	Groundwater, surface water	Chemical softening, RO, IX	Can precipitate and form scales.
Colloidal or unreactive	Suspended polymerized chains of molecules that contain tiny particles of silica. Commonly combined with other organic or inorganic compounds. Difficult to detect and remove from water.	10-100 nm	Surface water	RO, UF	Silica particles can foul RO membrane pores.

Figure 1: A scaled RO element.
Photo courtesy of DHP Inc. (Farmington, New Mexico).

Silica Removal from Water

In water treatment, silica can scale RO and nanofiltration (NF) membranes to the point they must be replaced, which can become expensive. For example, RO elements can cost $500 or more. If a system has 150 membranes for example, the price of the replacement membranes alone would be at least $75,000, this does not include the cost of downtime, and the labor involved.

Pretreatment systems are the most important step water treatment designers take to protect RO, NF, and other treatment equipment. These systems are designed based on the source water quality and water source assumptions. Pretreatment steps can include oxidation, coagulation/flocculation, filtration (e.g., multimedia and cartridge filters), activated carbon, and softening.

End-User Concerns about Silica

In addition to the danger silica poses to RO equipment, silica remaining in process fluids is also a concern for some industries. Therefore, it is important that RO systems are highly effective in removing these silica contaminants. For example:

In power stations, silica scaling can insulate boiler tubes or heat exchanger tubes, reducing efficiency. Silica can also carry over steam sent to electrical generating turbines and deposit on the turbine blades as a glass-like substance.

Semiconductor fabs use ultrapure water for rinsing off chemicals used in microchip manufacturing. It is critical that this water is free from ionic and particulate contaminants that can cause product defects if they precipitate or settle on the semiconductor chips.

Treatment Solutions

While silica can endanger effective operations and shorten RO membrane life, there are steps water plant operators take to minimize problems from the three types of silica. Table B lists common methods used to reduce silica in water systems.

Table B: Methods Used to Reduce Silica

Soluble	Non-Reactive	Granular
Cold chemical softeners	Cold chemical softeners	Conventional filtration
Hot chemical softeners	Hot chemical softeners	Clarification
Reverse osmosis	Coagulation and conventional filtration	
Ion exchange	Crossflow microfilters Ultrafiltration	

RO and ion exchange are two ways to remove soluble silica from water. RO removes contaminants from the molecular range (greater than 0.001 µm) to the ionic range. Ultrafiltration, which removes contaminants in the molecular (less than 0.01 µm) and macro molecular (between 0.01 and 0.1 µm) ranges, is considered an effective way to remove colloidal silica. For granular silica, microfilters and particle filters are two approaches used for removing particles sized 1 µm and larger.

Membrane Cleaning

In addition to the methods outlined in Table B, several types of RO treatment chemicals are used to protect RO membranes, including cleaning agents and pretreatment chemicals to protect against fouling, scaling, and biofouling. These membrane treatments include those that target silica fouling and scaling. These silica-specific treatments aim to maintain supersaturated silica levels dissolved in the water. The silica is then disposed in the concentrate stream without depositing within the membrane element.

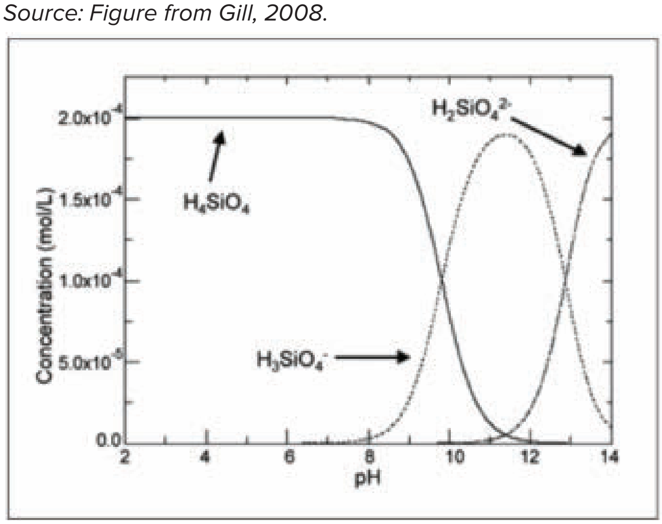
Another provision is CIP, where the membrane system is taken offline. Two basic types of CIP systems are skid-mounted and integral mounted, where the CIP is connected directly to an RO system. Major CIP components include a chemical mixing tank, RO cleaning pump, cleaning cartridge filter, tank heater or cooler, tank mixer, sample points, and a permeate and concentrate return line. RO cleaning uses different types of chemicals, including high- and low-pH cleaners. The chemical solution is prepared in the cleaning solution tank and then cycled through the RO membranes. When the feedwater contains high-silica levels, agents that target silica can be a part of the continuous process. Unfortunately, unlike $CaCO_3$, once silica has polymerized on the RO membrane, efficient CIP usually includes non-traditional cleaning agents.

Conventional RO

In traditional RO, the water flows in a single direction. Pressure vessels commonly have anywhere from three to six 8-inch RO membranes and are arranged in stages where the vessels in each stage are installed in parallel and the feed to each downstream stage is the combined concentrate of the upstream stage. During operation, typically the first RO element in the first stage has the least amount of scaling, while the last membrane in the last stage is the most impacted. This occurs because by the time process water reaches the final stage more than half of the permeate water (salt free) has been produced, leaving the last membrane of the last stage with highly concentrated water that can be full of super-saturated salts.

During operation, plant technicians keep track of their system performance to determine its condition and when to initiate membrane cleanings. The roadmap they follow includes the feed source water analysis and operational parameters, including the SDI, differential pressure, normalized permeate flow, and % rejection. These factors indicate membrane fouling potential, and the extent of fouling and/or scaling. Close attention to these factors can help determine the state of an RO system and when maintenance should occur.

Figure 2: Speciation curve of silicates calculated with the PHREEQC software program for an initial concentration of $2.0x10^{-4}$.
Source: Figure from Gill, 2008.



To enable operation of conventional RO with moderate levels of soluble silica in the feedwater, antiscalant chemicals are used to control silica polymerization. They typically allow silica to reach up to 200% of the unaltered saturation concentration in the brine (specific to chemical manufacturer specification).

For even higher concentrations of silica, plants often increase the pH of the feedwater due to silica's increased solubility in higher pH environments (Figure 2). However, in most waters, the presence of calcium and magnesium salts will limit the pH to lower levels in order to prevent scaling from those sparingly soluble salts. This limits the possibility of increasing pH to deal with high silica concentrations, for the risks of mineral scaling at high pH from calcium and magnesium salts far outweighs the gains that can be achieved in silica solubility at those levels.

Taking this approach a step further is another application of conventional RO aiming to increase recovery despite the presence of both silica and calcium and magnesium salts, termed the High-Efficiency RO (HERO) process. This process has been developed to remove salts like calcium carbonate from the treated water through ion exchange (IX) upstream of an RO unit. The process can typically involve lime softening and weak-acid cation (WAC) treatment steps in advance of the RO unit. The RO can then be operated at higher pH values allowing for increased recovery due to the higher silica solubility.

In addition to the high capital expense (CAPEX) and footprint required for the integrated IX and RO design and installation, this approach also results in high operating expense (OPEX) due to the use of chemicals for decreasing and increasing pH upstream and downstream of the IX. The RO unit in these systems typically operates at a very high pH to maintain silica solubility. Thus, the WAC unit requires long periods of rinsing to prevent even minute levels of hardness from entering the RO unit, which can result in immediate and severe mineral scaling.

For the remainder of this article, we will examine an alternative to conventional RO that can improve operations. This technology can minimize scaling, decrease membrane cleaning frequency, and under the right conditions, extend membrane life.

Flow-Reversal RO

Flow-Reversal RO technology (FR-RO) was invented by Professor Jack Gilron and Professor Eli Korin (both of Ben Gurion University)[A]. The essential idea behind FR-RO is to periodically reverse the flow direction in the RO system. This change can disrupt formation of scales and fouling and in so doing reduce the frequency of membrane cleanings, lengthening the life of RO elements exposed to high salt concentrations. Other benefits to FR-RO include the following.

- Increased total recovery and an associated reduction in concentrate flow.
- Lower demand for RO cleaning chemicals and less CIP downtime.
- Greater operational efficiency creates energy savings because pumps and pretreatment systems do not need to work as hard per volume of product water produced.
- Reduced concentrate flow lowers money spent on brine disposal, which can run from $5.00 to $7.00 per cubic meter for methods such as thermal evaporation, deep-well injection, or offsite trucking.
- FR-RO is more environmentally friendly.

Regarding reactive silica, FR-RO slows and can even prevent silica gel formation that results from the super-saturation and polymerization of soluble silica due to flow reversal before induction time is reached. The induction time is the amount of time it takes for mineral scaling to form crystals in the membrane.

The decision about when to change the flow direction is mainly determined by the salt solubility/saturation index and previous experience with similar water quality. Operation above the limits of the saturation index will result in scaling, but at a reduced rate in comparison to conventional systems. Induction time is determined during initial design for mineral formation based on water quality and has been shown to follow Equation 1.

$$\ln(\tau)= \frac{\ln(\tau)=}{A/[\ln(S)]^2} + B \qquad \text{Eq. 1}$$

Where:

A and B are thermodynamic constants related to the salt

Constant A includes the effect of the surface energy at the nucleating surface and molar volume of the salt.

Constant B includes the frequency factor for the nucleation rate.

Values of A and B for some salts have already been determined and may also be readily obtained experimentally.

S is the molecular Van-Der-Waals surface of the salt.

Knowledge of the facility's water quality analysis history, the scaling index, and induction time is used to determine when the water flow direction should be reversed to prevent silica scaling.

Factors that impact induction time include:

- Ions present in the water (iron, aluminum, hardness ions) significantly shorten the induction time.
- RO operation at higher recovery rates increases concentration in the brine and shortens induction time.
- Antiscalant type and dosage.
- Ambient water temperature (for example higher temperature increases the silica scale induction time).
- The concentration polarization factor (commonly referred to as beta factor) acts as an artificial increase in silica concentration on the membrane surface.

When the direction change occurs in an FR-RO, the last membranes in the pressure vessel become the first membranes to receive the water. So long as the flow reversal occurs within the induction time at the given recovery rate, it is still possible to postpone the start of scale formation.

Figures 3 and 4 show schematics that illustrate the flow directions in FR-RO.

Figure 3: FR-RO with the water flowing leftward.

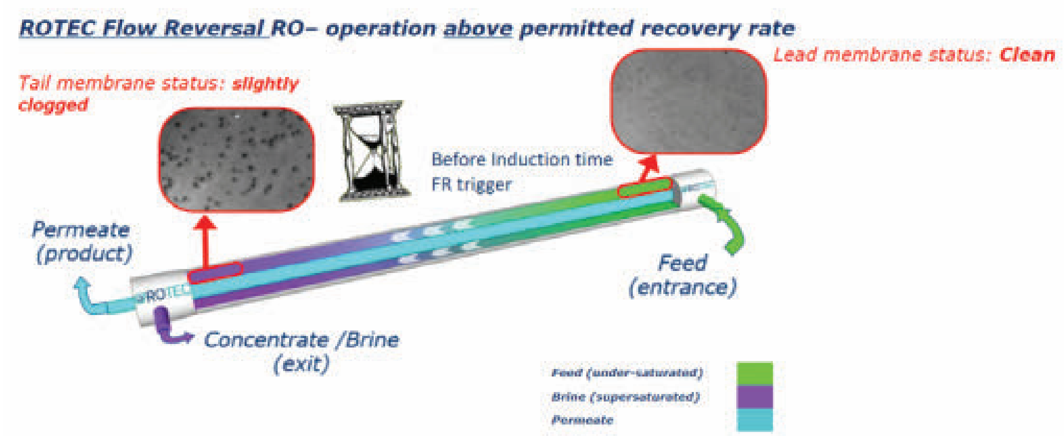
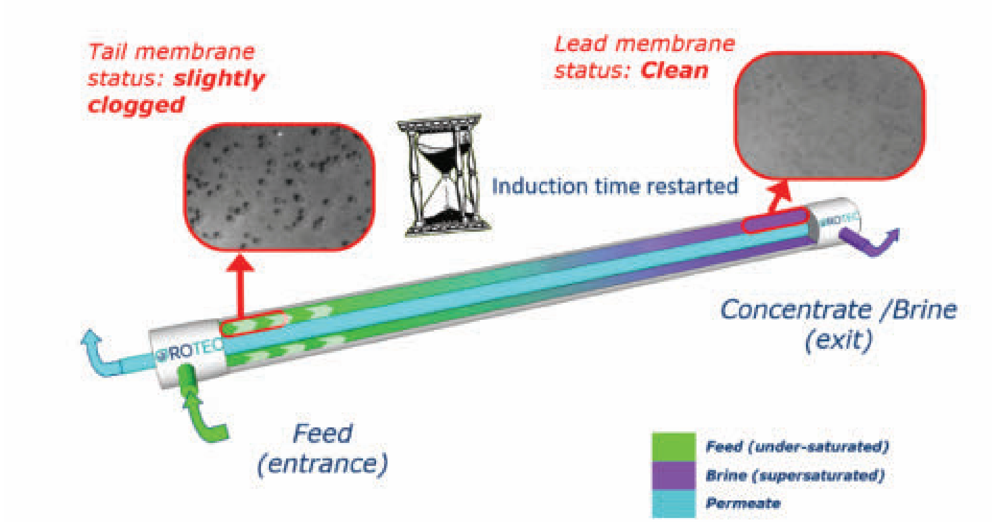


Figure 4: FR-RO water flow direction after it has been changed to flow to the right.



Industrial Application

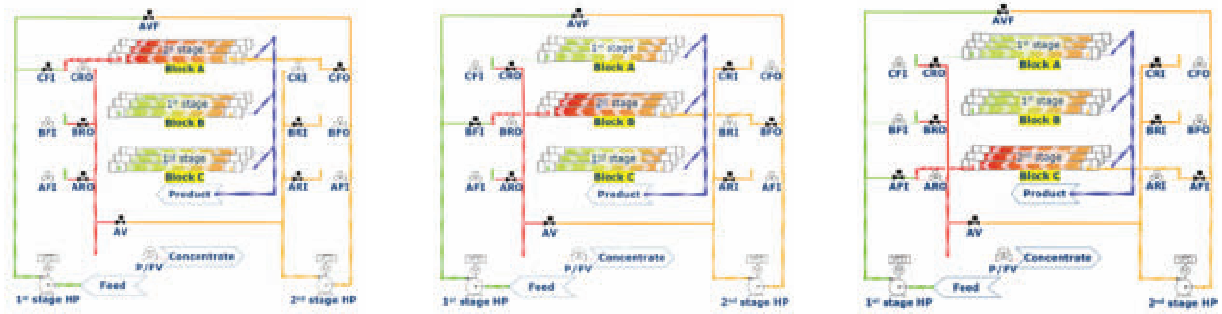
FR-RO technology is applicable to a wide range of end-uses and systems have been installed worldwide. Examples of plants where FR-RO has been placed include drinking water, food and beverage, semiconductor, power, general industry, wastewater recovery, and seawater desalination. An installation can involve the use of new equipment, or it can involve retrofitting an existing RO system with changes that may include replacing pipe sections, a booster pump addition and valving upgrades. These modifications will permit the RO to produce with water flowing in either direction.

The FR-RO can be applied with both 4-inch and 8-inch membrane elements. Typical systems have anywhere from four to eight elements per pressure vessel and can work with membranes made by standard RO element manufacturers.

This technology can be applied to systems that have staged RO. The stages are modified to work in blocks so that the water flow direction reverses in each block. Figure 5 shows an example of a two-stage RO with three blocks.

Additionally, where a HERO process has been used, the RO unit can be retrofitted or replaced to operate as an FR-RO system. The FR-RO may accept lower pH feed water compared to a conventional RO installed within the HERO process, resulting in significant reduction of chemical consumption. Further, the FR-RO unit will allow greater levels of hardness into the system, dramatically reducing the amount of rinse time required on the WAC unit. And finally, the FR-RO system will produce permeate at higher recovery rates than the conventional RO unit.

Figure 5: FR-RO illustration of block rotation.



(A) **(B)** **(C)**

RO installations using this technology can see better productivity from their membrane system. It is common to see the % recovery of permeate go from 75% to even 91 to 92% recovery.

FR-RO "Blocks"

In typical RO systems, the second stage has fewer pressure vessels (PVs) than the first stage, and the subsequent water flow in the second stage is less. So to keep the water hydraulics balanced, it is necessary to divide how the water flows in an FR-RO system, otherwise the feed flow to the First Stage would be too high, and the concentrate flow in the Second Stage would be too low.

To address this problem, a "block staging" approach is used to main hydraulic balance in the RO system[B]. As an example, a two-stage RO system would be divided into three blocks—A, B, and C. In the example shown in Figure 4, the First Stage would have Blocks B and C, and the Second Stage would become Block A.

During operation two blocks would always serve as the First Stage, and the Second Stage would have a single block. As the water flow direction alternates, one of the two blocks from the First Stage will team with Block A when Block A becomes part of the First Stage. In this way it is possible to ensure that all the PVs are continuously changing their flow directions and that the hydraulics of the FR-RO system are kept in balance.

Successful block operation that allows for intermittent flow reversal of all PVs in the FR-RO system is accomplished through an array of valves and valve sequencing. During FR-RO operation, as the flow directions change, the blocks will alternate so that Blocks A, B, and C change their flow directions and RO Stage service. This is illustrated in Figure 4, where Blocks B and C initially work as the First Stage and Block A acts as the Second Stage (Schematic (A)). Schematics (B) and (C) show alignment changes when Blocks A and C work as the First Stage, and then Blocks A and B become the subsequent First Stage.

In Figure 5, Schematic (A) shows a two-stage FR-RO with the addition of valves and pipes. The first stage is divided into Block C and Block B. The second stage is Block A. Blocks B and C act as the first stage and flow from left to right, while Block A acts as the second stage and flows right to left. In the middle schematic (B), Blocks A and C act as the first stage of the FR-RO and flow left to right, while Block B acts as the second stage of the FR-RO and flows right to left. In the third schematic (C), Blocks A and B act as the first stage FR-RO and flow left to right and Block C is the second stage and flows right to left.

Case Studies

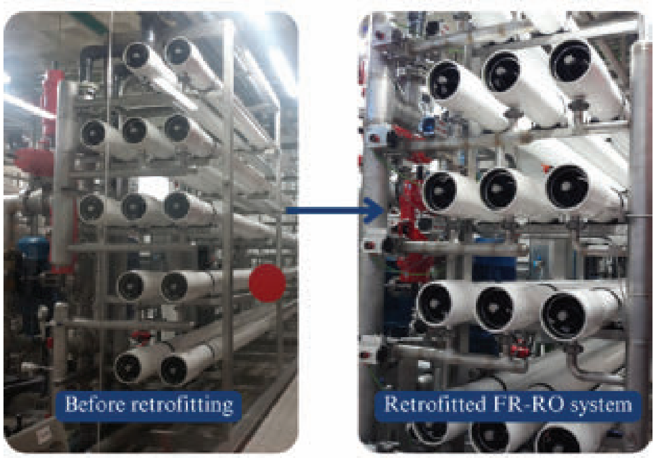
Successful installations using the FR-RO technology have been installed in the United States, South America, Europe, the Middle East, and Asia (China, Malaysia, and Singapore). End-user applications include municipal drinking water, wastewater reuse, microelectronics, food and beverage, pharmaceuticals, oil and gas, agriculture, and general light and heavy industry.

In the case of silica, the FR-RO technology experience at multiple end-user sites has shown this technology can minimize scale formation. In this section, we will look at two examples of plants with high-silica source water that switched from traditional RO to FR-RO.

Table C: RO System Performance from Before and After the Retrofit

	Drinking Water Conventional RO System (before retrofit)	Drinking Water Retrofitted FR-RO System
Type	**Conventional system**	**Retrofit system**
Feedwater TDS level (ppm)	457	
Feedwater silica level (ppm)	67	
Feedwater silica saturation (%)	63.8	
RO system recovery rate (%)	75%	86-88%
Concentrate TDS level (ppm)	~1,785	~3,986
Concentrate silica level (ppm)	262	507
Concentrate silica saturation (%)	227	380
Feed flowrate	80 m^3/h, 352 gpm	68 m^3/h, 300 gpm
Product flowrate	60 m^3/h, 264 gpm	60 m^3/h, 264 gpm
Membrane cleaning frequency	Information unavailable	3-4 times/yr

Figure 6: RO system before conversion (2 stages 8:4 array at 75% recovery) (left). The right photo shows the system after retrofit (3 stages 8:4:2 array at 88% recovery).



Case Study #1: Soft Drink Bottling Plant

In Case Study 1, an existing RO system (80 cubic meters per hour [m^3/h] feed) was retrofitted into the FR-RO process at a European bottling plant. After installation in January 2019, the facility saw its recovery rate increase from 75 to 88%. In this case, a two-staged 8:4 PVs array system was retrofitted to a three-stage 8:4:2 system with minimal interference to plant operations during installation. The flow reversal process was monitored over the course of 10 months, demonstrating a significant increase in permeate production, while reducing operational costs, mainly lowering the waste brine production by up to 52% and also lowering the net energy consumption and feedwater draw, due to same product production from less feedwater.

One challenge this project faced when seeking to increase the recovery rate was mineral scaling, primarily silica with a measured concentration of about 67 ppm in the feedwater.

Figure 6 shows a picture of the beverage plant's RO system before and after retrofitting to the FR-RO technology. Table C shows operational results from the RO system before and after the retrofit.

Case Study #2: Greenfield Beverage Plant

This case study highlights a new beverage plant in Latin America that had a newly designed UF-RO treatment system using the flow-reversal technology. The facility achieved an RO recovery rate of 85%. The UF unit can operate up to a capacity of 90 m^3/h and the RO

Table D: Greenfield Beverage Plant RO System Performance Data

	Greenfield FR-RO
Type	**New FR-RO system**
Feedwater TDS level (ppm)	828
Feedwater silica level (ppm)	58.5
Feedwater silica saturation (%)	55.7%
RO system recovery rate (%)	85%
Concentrate TDS level (ppm)	5,453
Concentrate silica level (ppm)	385
Concentrate silica saturation (%)	366%
Feed flowrate	48 m^3/h, 211 gpm
Product flowrate	41 m^3/h, 179 gpm
Membrane cleaning frequency	1-2 times/yr

unit can operate up to a capacity of 60 m^3/h feed flow. This FR-RO system is a 2-stage design (4:2 PV array configuration). The FR-RO technology reverses the flow between the two PVs in the 2nd stage with 4 PVs in the 1st stage[C]. The FR-RO technology helps prevent carbonate and silica scaling in the system at a high recovery rate. Raw water used at the plant has 58.5 mg/L SiO_2 and a concentrate of 384.9 mg/L SiO_2 at 85% recovery. Table D provides RO system operational data.

Figure 7 shows the new plant's FR-RO and UF treatment equipment.

Figure 7: UF-FR-RO unit pictures at the beverage facility.

Case Study #3: Recovery RO System Retrofit

A bottling plant in the Western United States faced significant challenges with raw water quality, which contained silica concentrations exceeding 60 ppm. The facility operated two conventional RO systems, each with a capacity of 250 gallons per minute (gpm) and a recovery rate of 71%, and a 95-gpm recovery RO system, supplied by the concentrate from the primary RO systems, which dealt with silica levels exceeding 250 ppm. This high silica concentration resulted in severe membrane scaling, leading to frequent cleanings and constant flushing. Although the recovery RO system was designed for a 30% recovery rate, the high operational costs associated with maintaining the system far outweighed the marginal gains in water production. These systems are often termed 'sacrificial ROs' and are expensive to use.

The FR-RO retrofit included the installation of additional pressure vessels, a booster pump, upgraded valves, real-time analytical equipment, and an automated flush system for brine concentrator applications. Additionally, the old membranes were replaced with high-performance ones designed for high-recovery and high-silica environments. These enhancements pushed the total system recovery rate to more than 85% recovery. Table E provides system operational data for the retrofit.

TABLE E

RO Recovery Unit Retrofit System Performance Data

	RO Recovery Unit (before retrofit)	Recovery Unit Retrofitted FR-RO System
Type	**Recovery Unit**	**Retrofitted System**
Feedwater TDS level (ppm)	1,094	
Feedwater silica level (ppm)	259	
Feedwater silica saturation (%)	260	
RO system recovery rate (%)	30%	54%
Concentrate TDS level (ppm)	~1,240	~2,227
Concentrate silica level (ppm)	354	540
Concentrate silica saturation (%)	363	550
Feed flowrate	34 m^3/h, 150 gpm	22 m^3/h, 95 gpm
Product flowrate	10 m^3/h, 45 gpm	12 m^3/h, 51gpm

Figure 8 shows the retrofitted Recovery RO unit.

Figure 8: Additional valves and piping added to the RO recovery unit.

Conclusions

Silica occurs in three forms in water—soluble, colloidal, and granular. Soluble and colloidal forms can cause scaling in RO systems and impact end-user products or operations equipment. Granular silica in water can leave water marks and cause scratches on smooth surfaces. In RO equipment, silica can damage membranes so that they must be cleaned or replaced more often.

To protect against silica, a water treatment plant can use membrane treatment chemicals, as well as pretreatment technologies to remove it from the water before the source water moves to the primary treatment plant.

A new design for RO has been developed known as FR-RO. It can better protect against the damage silica can do to membrane elements. Unlike traditional RO, which has the water flow in a single direction, the flow-reversal technology will alternate the direction the water flows through the system. By having the water flow both ways through the RO membranes it is possible to minimize silica scaling.

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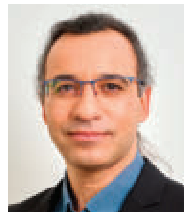
Endnotes

A. The FR-RO technology mentioned in the text has been further developed under work conducted by ROTEC.

B. The Block Rotation technology discussed in the text (called "block staging approach") was developed by ROTEC.

C. The FR-RO technology discussed in the text was developed by ROTEC.



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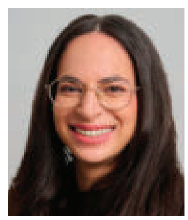

Sapir Regev is the process engineering lead at ROTEC. Ms. Regev has 5 years of experience at ROTEC, working across diverse roles, including process engineer, project engineer, and project manager. In her current role as process engineering lead, she has worked to improve process engineering work-flows and established engineering quality standards across the organization. Through her various positions, Ms. Regev has contributed to global projects in the water treatment sector. She holds a BSc in chemical engineering from the Israel Institute of Technology (Technion).

Bruce Alderman is the CEO of USA ROTEC. He has almost 30 years of experience in the water and wastewater business. Mr. Alderman previously served as VP Sales of Desalitech. In that role, he was instrumental in the sale of Desalitech to DuPont, later becoming the North American industrial sales director for DuPont Water Solutions. Mr. Alderman holds a BS in mechanical engineering from Trenton State College, an MS in environmental engineering from Clarkson University, and an MS in applied physics from Princeton University.

KEYWORDS: COLLOIDAL SILICA, FLOW REVERSAL RO, FOULING, PARTICULATE SILICA, REACTIVE SILICA, REVERSE OSMOSIS, SCALING, SILICA, TECHNOLOGY DEVELOPMENT

How Does a Bio-Sourced Antiscalant Compare to Conventional Treatments?

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Introduction

An important challenge facing the water treatment industry is to find environmentally friendly products that are as effective as conventional products used to control corrosion and scaling issues in industrial applications.

One particular focus has been placed on developing natural or bio-sourced scale inhibitors. Currently, the available products for industrial water conditioning are mainly derived from mining (phosphates) or petrochemicals (polyacrylates). However, around 75% of the world's phosphate production is concentrated in just three countries: Morocco, China, and the United States. These resources, primarily used in agriculture, are considered critical, and their depletion could potentially disrupt the global food balance. Polyacrylates are sourced from petrochemicals, which some believe present long-term environmental concerns.

While studies on natural scale inhibitors have been conducted since the 1950s, it has only been in the last decade or so that research in this area has intensified. Belarbi et al. (1, 2) initiated research into new natural scale inhibitors for industrial water treatment. They hypothesized that plants traditionally used in the treatment of urinary lithiasis could also act as inhibitors of scale formation. Through electrochemical methods, they notably demonstrated that aqueous extracts of *Paronychia argentea* exerted an inhibitory effect on the formation of calcium carbonate precipitates. Additionally, Cheap-Charpentier et al. and Horner et al. (3, 4) have shown the potential effectiveness of plant extracts from *Herniaria glabra*, *Spergularia rubra*, or *Parietaria officinalis* in preventing scaling.

Based on these observations, previous published works by a water treatment company[A] focused on selecting plant sources and a specific eco-extraction method (5). After many years of research, a bio-sourced antiscalant substance[B], was developed. Its development required overcoming various challenges, such as identifying and quantifying active substances, ensuring continuous quality control of plant raw materials, developing an eco-responsible industrial extraction process, and optimizing formulation.

After highlighting the importance of identifying tracers correlated with the antiscalant effectiveness of a plant extract, this article will address the major challenge inherent in using a natural raw material of agricultural origin, namely, the variability in the quality of the supply. The article will discuss the optimization approach of the industrial extraction process[C] developed by the treatment company to reduce the environmental impact of the bio-sourced antiscalant treatment, as well as the regulatory limitations regarding the use of bio-sourced chemicals. Finally, we will discuss the experience gained from transitioning from a polyacrylate-based antiscalant treatment to the plant-based antiscalant treatment in cooling towers (CT).

Materials and Methods

Characterization of the plant extracts is carried out using two methods:

- Quantification of dry residues
- Quantification of an active molecule referred to as the "tracer active"

The measurement of dry residues is performed by evaporating 2 milliliters (mL) of filtered plant extract in an aluminum dish with a diameter of 7 centimeters (cm) placed on a hot plate set at 130°C.

Quantification of the "tracer active" is carried out by UV-visible spectrophotometry. The optimized method allows quantification over a range of 0 to 100 milligrams per liter (mg/L) with a precision of ± 3 mg/L.

Extraction of the active material and yield. The eco-extraction method of plant dry matter (DM) developed was compared to conventional protocols for plant material extraction in a previous publication (5).

In the context of a single-step extraction, the yield can be calculated using the formula shown in Equation 1.

$$\text{yield} = \frac{[C]^{*}V(\text{extract})}{m(\text{plant})} \quad \text{Eq. 1}$$

Where:

[C] = the mass concentration of extracted molecules
V(extract) = the total volume of the extract
m(plant) = the dry mass of the added plant material

In the context of this study, extractions in multiple steps (by exhaustion or by enrichment) are performed (see the "Extraction" subsection later in the article). The yield at Step n can then be calculated as seen in Equation 2.

$$yield_n = \frac{([C]_n - [C]_{n-1}) * V(extract)_n}{m(plant)_n} \quad \text{Eq. 2}$$

Where:

$[C]_n$ = the mass concentration of extracted molecules at Step n
$[C]_{n-1}$ that at Step n-1, , $_n$ the total volume of the extract at the end of Step n, and $m(plant)_n$ the mass of plant material added at Step n.

Characterization of the efficiency of a scale inhibitor. The efficiency measurement is conducted using chronoamperometry (1, 6).

The experiments were conducted in a three-electrode cell. The reference electrode is a saturated calomel electrode (SCE), and the counter electrode is a platinum grid. The working electrode is a rotating disk electrode (RDE) with a carbon steel tip with a specific surface area of 1 square centimeter (cm^2). The rotation speed of the RDE is 1,000 revolutions per minute (rpm), and the temperature is maintained at 35°C. The electrolyte is osmosed water containing 0.500 g/L of calcium sulfate ($CaSO_4$), 2 H_2O; 0.60 grams per liter (g/L) of magnesium sulfate ($MgSO_4$), 7 H_2O; 0.420 g/L of sodium bicarbonate ($NaHCO_3$). This results in a total hardness (TH) of 315°F and a total alkalinity (TAC) of 25.0°F. The measurement is performed using a Biologic SP-150 potentiostat, and the control and processing software is EC-Lab. The measurement is conducted over 120 minutes. The efficiency is calculated as seen in Equation 3:

$$Efficiency(\%) = \frac{\text{Time of scaling without inhibitor} - \text{Time of scaling without inhibitor}}{120\text{min} - \text{Time of scaling without inhibitor}} \quad \text{Eq. 3}$$

Results and Discussion

Technological Barriers

Quantification

Traditional methods for quantifying active principles mainly rely on measuring dry residues (DR) or on chemical oxygen demand (COD) measurement.

In the absence of a purification phase, the extraction of plant materials leads to obtaining an extract containing a large number of molecules (proteins, fats, mineral salts, sugars, phenolic compounds, terpene compounds, etc.), not all of which necessarily contribute to scale inhibition (7).

In this context, the water treatment company[A] has developed a protocol to quantify the so-called "Tracer Active" in each plant extract (see Figure 1).

Figure 1a shows that the efficacy of Sources P and B reaches 100% at 5 mg of dry residue per liter (DR/L), while Source N reaches 100% at most at 50 mg DR/L.

Figure 1b indicates that, regardless of the source, efficacy is achieved for at most 4 mg/L of "active tracer"

Figure 1: The inhibitory efficacy of three antiscalant products as a function of dry residue concentration (a) or of a "Tracer Active" principle (b). The graphs show the efficacy of three types of antiscalant products: petro-based (P), bio-based (B); and natural (N).

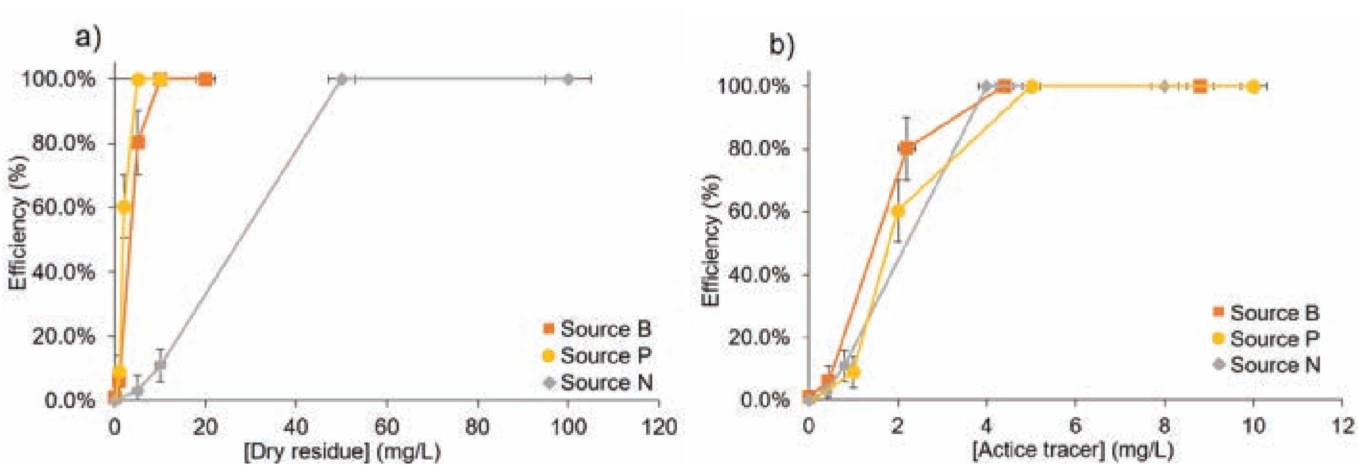
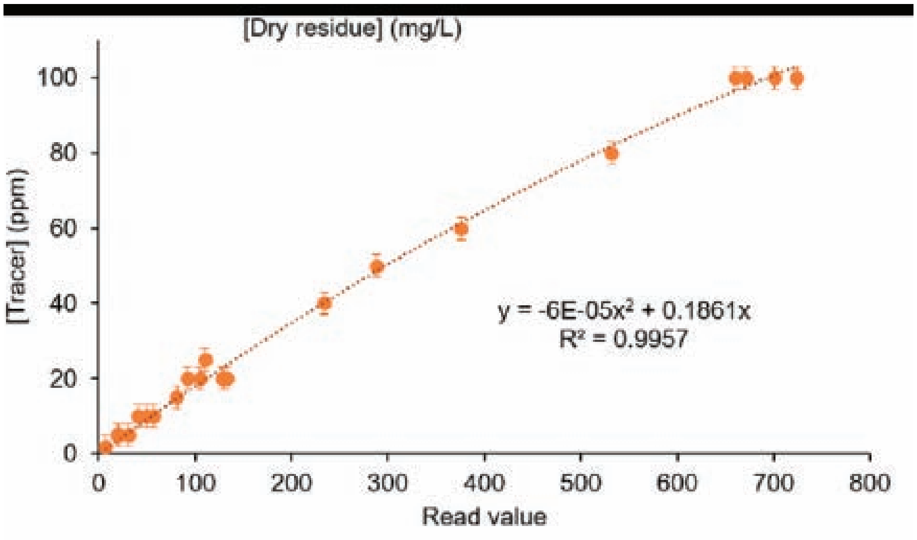


Figure 2: Calibration curve for the quantification method of the "active tracer" in the bio-sourced antiscalant.



(or equivalent concentration in petro-sourced active molecule). The efficacy of a source is therefore correlated with its concentration of "active tracers".

Figure 2 represents the calibration curve of the quantification method of the "Active Tracer", according to the method optimized by the treatment company[A].

Figure 2 highlights a strong correlation ($R^2 > 0.99$) between the measured value and the theoretical concentration of the "active tracer".

Its simplicity and precision allow its use both in quality control, in laboratory research and development (R&D) analyses, and in "field" monitoring (post-harvest, monitoring of on-site installations, etc.), just like other classic water analyses. This method allows, on the one hand, control of the content of "active tracers" at each stage of the life cycle of the organic antiscalant and, on the other hand, ensures optimal inhibitory effectiveness against scaling.

Furthermore, this method allows for adjusting the proportion of plant extracts in the final organic antiscalant product formulas based on their "active tracer" content, thus ensuring consistent product quality.

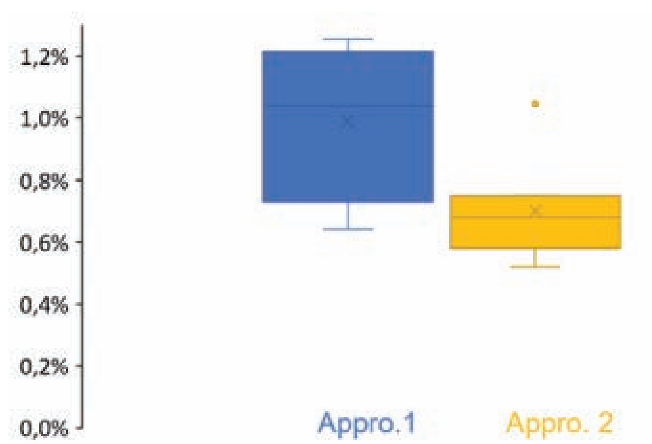
Supply control. The use of plant-based raw materials lead to a high variability in composition, depending on growing conditions (soil, climate, inputs, etc.), variety, harvested part, growth stage, among other factors (8-10).

Figure 3 shows the variability of mass concentrations of the "Active tracer" observed for two successive supplies of the same raw material (Source M) that made up the organic antiscalant.

Figure 3, derived from six samples per supply, indicates a higher proportion of "Active Tracer" in Supply #1 (~10%) compared to Supply #2 (~7%). Additionally, a significant dispersion around the mean is observed, particularly for Supply #1, indicating that the raw material harvested within the same plot and at the same time may exhibit significant heterogeneity.

In this case, for the same quantity of raw material produced and extracted, Supply #1 yields an extraction

Figure 3: Boxplots of active tracer grams per grams of RS as a function of the supply of Source M.



efficiency of active principle 30 to 40% higher, compared to Supply #2.

Thus, for the same amount of energy expended to extract a given source, the higher the extraction efficiency of the active principle, the greater the economic and environmental impact reduction.

Life Cycle and Ecotoxicity

Extraction

Previous studies have shown that the choice of eco-extraction method affects its yield (5).

In this new study, the objective is to investigate if the environmental impact of the extraction process can be improved. Two extraction methods were tested:

- Progressive depletion of the raw material and complete renewal of the extraction solvent at each step.
- Enrichment of the extract by complete renewal of the material to be extracted at each step.

Figure 4: Diagram of the extraction process known as exhaustion or enrichment.

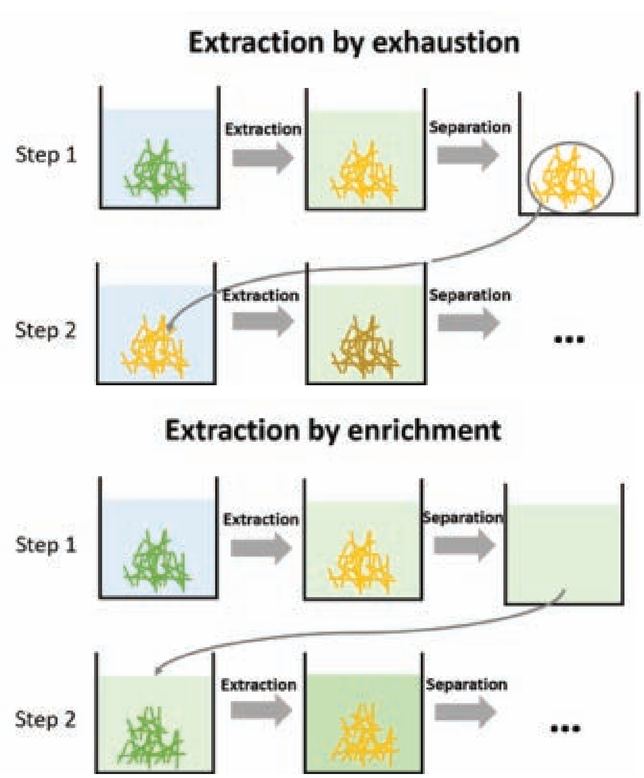


Figure 4 illustrates the two extraction methods described here.

In the exhaustion extraction method, the solvent is renewed at each stage, while in the enrichment extraction method, it is the dry matter that is renewed at each stage. Regardless of the method or extraction stage, the Solid/Liquid ratio is 10% by mass.

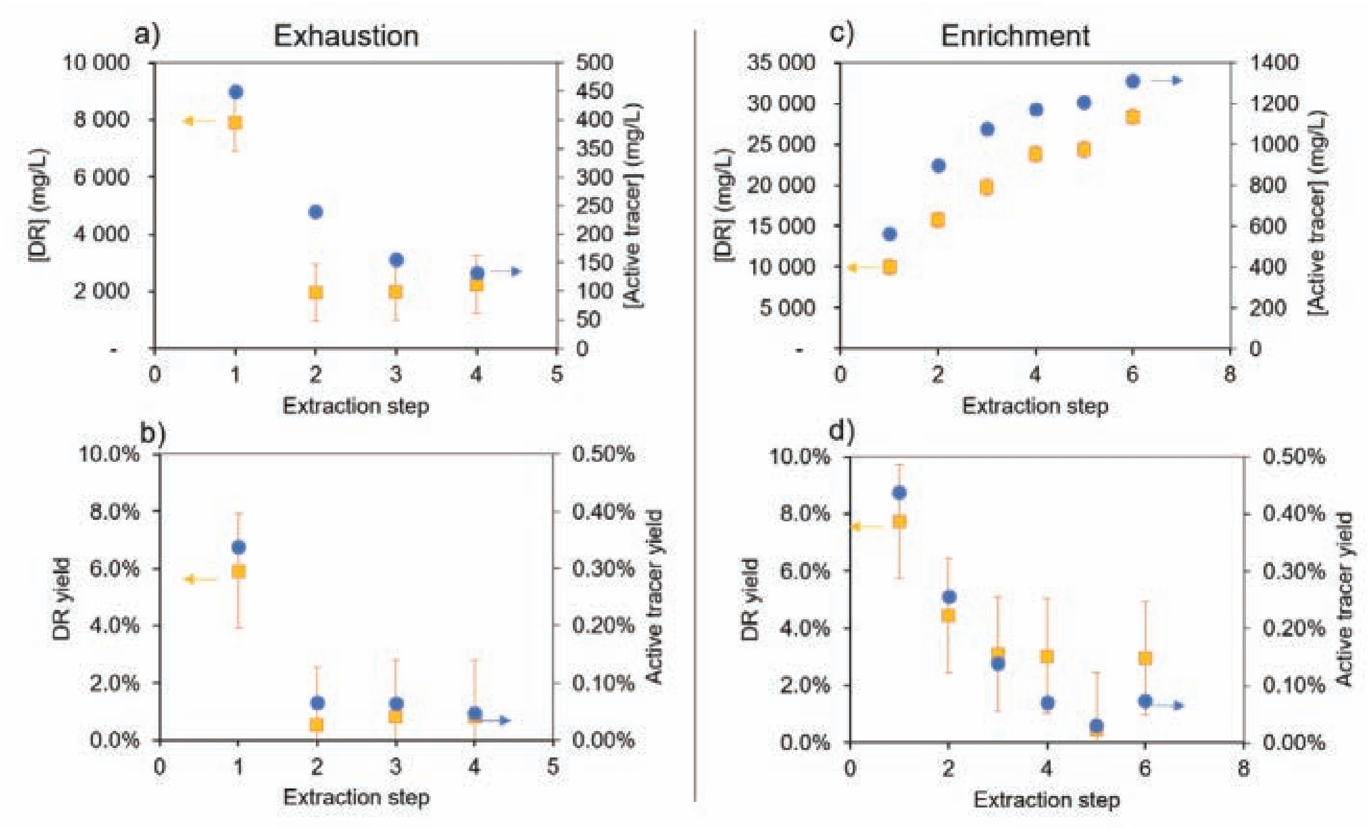
Figure 5 shows the evolution, stage by stage, of various parameters measured during an exhaustion extraction (a) and (b) and during an enrichment extraction (c) and (d).

Figure 5a shows that during an exhaustion extraction, the first step allows extracting approximately 450 mg/L of "active tracer," compared to only 250 mg/L in the second step. The extraction yield, as shown in Figure 5b, then decreases from 0.35% in Step 1 to 0.07% in Step 2. The discrepancy between the evolution of "active tracer" and DR is explained by the significant uncertainty in the measurement of residual solids due to the low concentrations measured, and the difference in solubility between the tracer compound and other constituents of the raw material. The "active tracer," easily extractable in the extraction solvent, is more rapidly "exhausted" during extraction than other compounds in the raw material.

Figure 5c shows that during an enrichment extraction, the concentration of "active tracer" increases rapidly between Steps 1 and 4 (from 564 to 1171 mg/L), reaching a plateau beyond the 6th extraction (1,310 mg/L). Additionally, the yield decreases from 0.44% in Step 1 to 0.07% in Step 4, then remains between 0.03% and 0.07% between Steps 4 and 6.

Thus, from the second step of an exhaustion extraction, the yield is divided by 5. The majority of active principles are extracted during the first step. During an enrichment extraction, there is a change in slope in the curves of "active tracer" concentration and DR yield evolution from Step 3 or 4. Beyond this inflection point, the extraction yield stabilizes. This stabilization of the extraction yield observed from Step 4 onwards is probably due to the progressive saturation of the solution. Conducting a second series of enrichment extractions confirmed this inflection point around Steps 3 and 4 and the attainment of a plateau from Step 6 through Step 9 (data not shown).

Figure 5: a) and b) show step-by-step evolution of the concentration of DR and "Active Tracer" and the yield of DR and "Active Tracer" during an exhaustion extraction; c) and d) highlight the step-by-step evolution of the concentration of DR and "Active Tracer" and the yield of DR and "Active Tracer" during an enrichment extraction.



The environmental impact of the extraction process is mainly related to the energy required for heating the solvent during extraction and for the solvent evaporation to obtain a stable concentrate.

Regarding the extraction phase, enrichment appears to be more efficient as it allows for the reuse of the solvent and therefore the recovery of the heat it contains. However, one may question the profitability of enrichment extraction at each step. Therefore, Figure 6 presents the evolution, step by step, of the volume of water used per mg/L of "active tracer" during an enrichment extraction.

Figure 6: Evolution, step by step, of the cumulative volume of water (L) used per mg/L of "active tracer" extracted during an enrichment extraction.

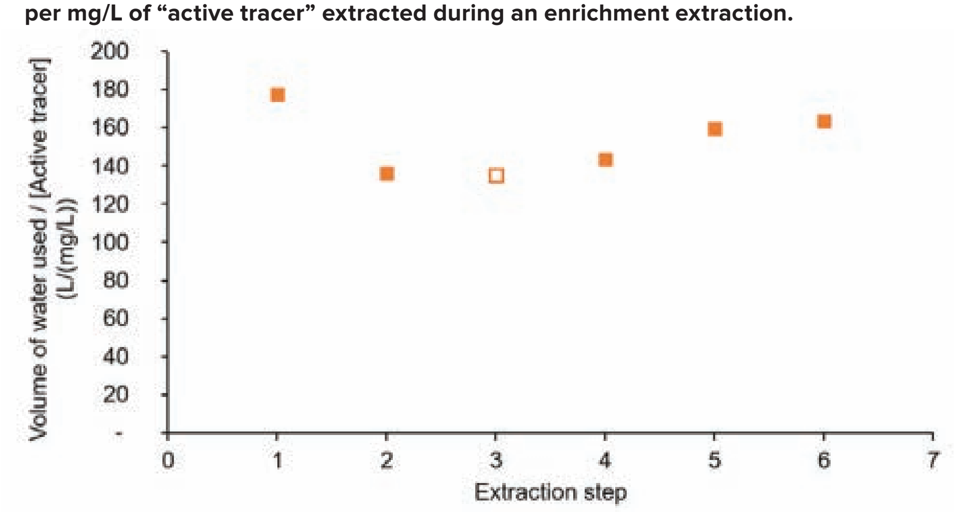
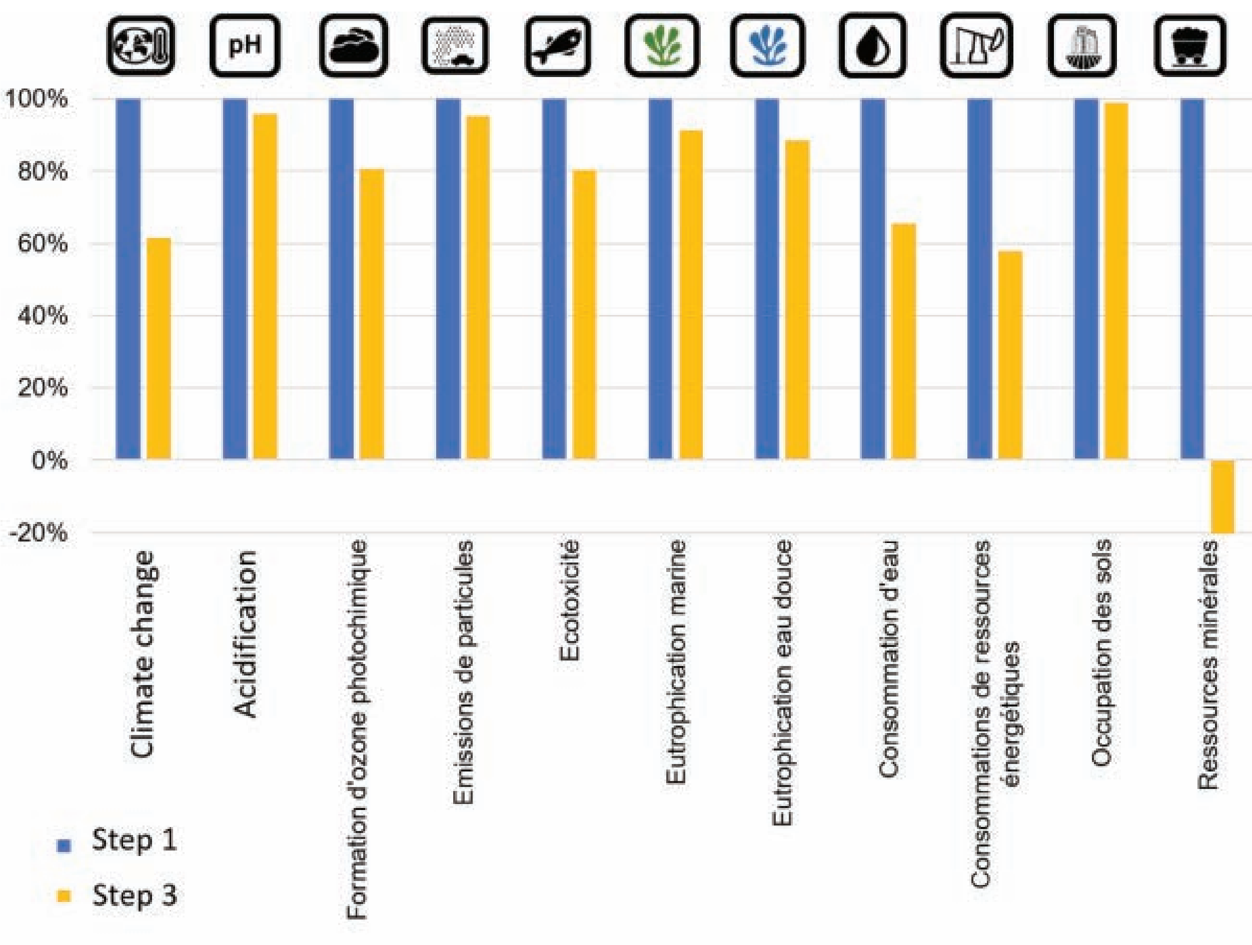


Figure 6 shows a decrease in the volume of water (L) per mg/L of "active tracer" extracted from Stage 1 to Stage 3 (177 L/(mg/L) and 135 L/(mg/L) respectively), followed by an increase in this value up to Stage 6 (163 L/(mg/L)). The minimum of the curve is reached at Stage 3, where the least amount of water is used to extract the maximum amount of active ingredient.

Regarding the concentration phase, the more concentrated

Figure 7: Comparison of LCA between extraction by single-step enrichment and three successive steps (%).



the initial extract, the less energy is required for the concentration process. Therefore, Stage 3 appears to be the most interesting as it leads to a more concentrated extract while minimizing the amount of water used. It is estimated that enrichment extraction could reduce energy consumption by 50% during the concentration stage, and by approximately 25% during the extraction stage.

Life Cycle Analysis (LCA)

The environmental impact of a natural extract is not limited to the volume of solvent needed for extracting the raw material or the amount of energy required to heat it. It must be studied comprehensively across the entire life cycle of the product. Based on mid-point indicators for an analysis scope ranging from agricultural production attributable to the organic antiscalant to factory output (cradle-to-gate), we compared, as shown in Figure 7, the life cycle of an extraction based on the number of enrichment extraction steps (1 step or 3 steps).

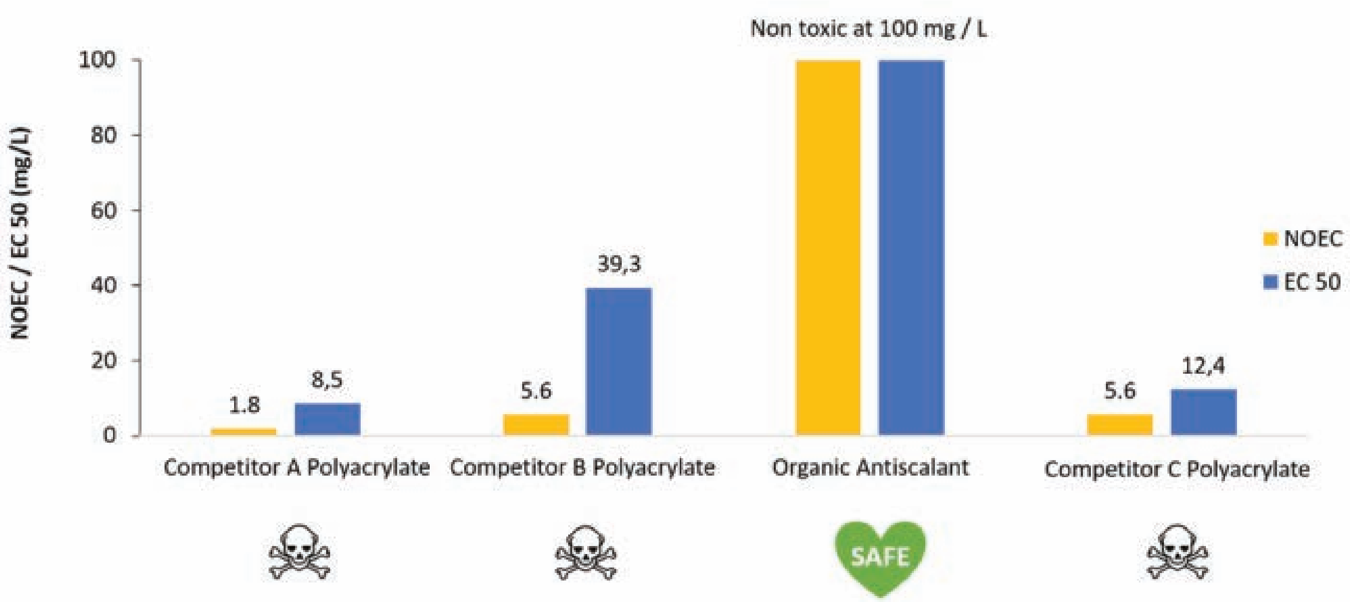
Figure 7 shows an overall decrease in the environmental impact of the organic antiscalant when transitioning from one to three extraction steps. This reduction is primarily due to the optimization of the amount of water needed to extract the active ingredients.

Ecotoxicity

The natural origin of the organic antiscalant does not imply its safety (11). Ecotoxicological tests were conducted to study the ecotoxicity of the antiscalant on the embryo-larval development of bivalves (oysters). Figure 8 represents the no observable effect concentration (NOEC) and the median effective concentration (EC_{50}) for chemical solutions based on polyacrylates made by different manufacturers, as well as the organic antiscalant.

Figure 8 indicates that products based on polyacrylates have a NOEC and an EC_{50} lower than 5.6 mg/L and 39.3

Figure 8: Ecotoxicity test on the embryo-larval development of bivalves (oysters) for products based on polyacrylate or the organic antiscalant.



mg/L, respectively. In contrast, the organic antiscalant shows no toxicity over the entire range of tested concentrations (up to 100 mg DR/L). It appears to be more than 20 times less impactful on the embryo-larval development of bivalves than polyacrylate-based products.

Furthermore, as the organic antiscalant is derived from a natural source, unmodified chemically, and non-toxic, according to REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) Regulations, it is exempt from a safety data sheet. *Note: REACH is a European Union regulation that governs the production and use of chemical substances to protect human health and the environment. It requires manufacturers and importers to register chemical substances in quantities of one ton or more per year with the European Chemicals Agency (ECHA) and to manage the risks associated with these substances.*

In conclusion, the industrial (commercial) production of the required the development of a specific method for characterizing the active ingredient representative of the scale inhibition efficacy. This allowed for the characterization of raw materials and the selection of plant sources rich in active molecules, optimizing the environmental impact. Similarly, industrial scaling provided an opportunity to optimize the extraction process established previously in the laboratory, making it more ecological and economical by choosing a three-step enrichment extraction. Finally, ecotoxicological tests demonstrated the safety of the organic antiscalant and its exemption from Safety Data Sheets under REACH regulations.

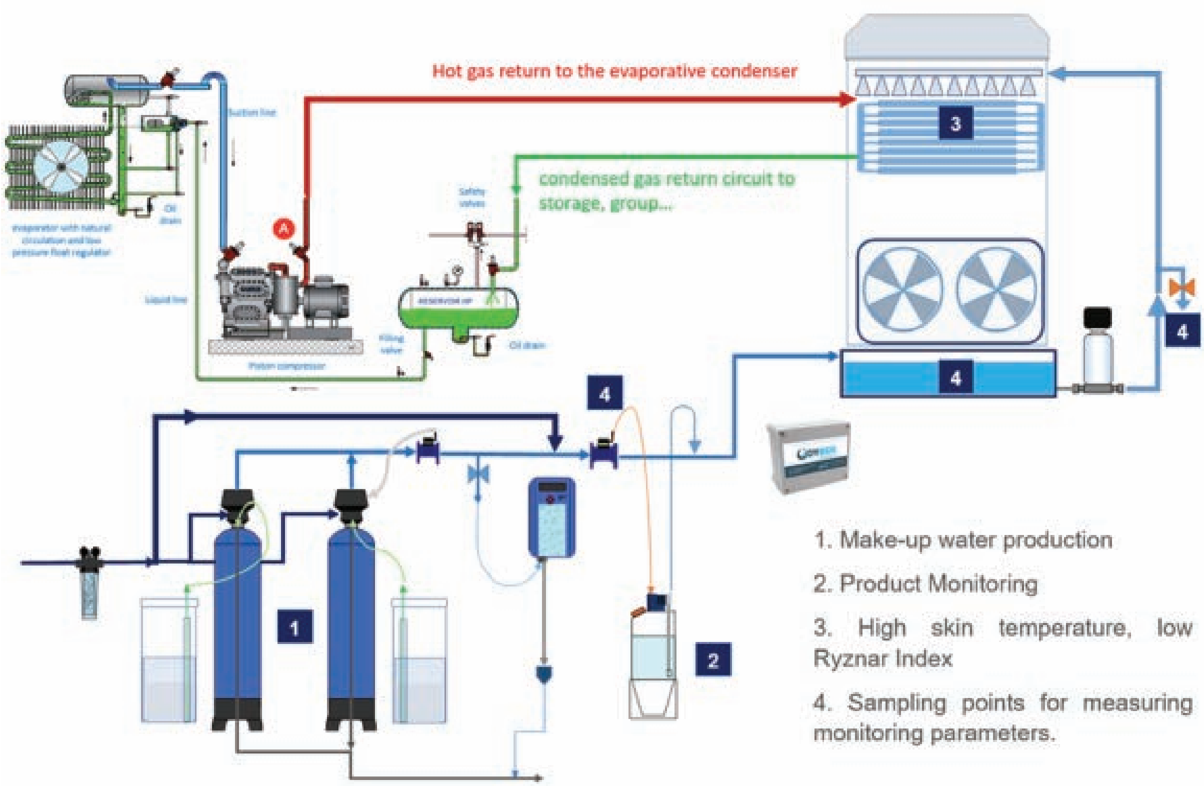
On-Site Testing

Site selected. The next step after research and validation in the R&D lab, was to test the organic antiscalant at a 1:1 scale in operating cooling towers. To do this, we began by substituting the organic antiscalant for its "operational" equivalents in formulations to validate the compatibility of the solutions. The substitution led to the presence of a very low proportion of fine particles in solution but did not alter the stability of the different formulations containing the organic antiscalant, nor their aspect.

Several sites in France with water cooling applications and different water qualities have been chosen to deploy the organic antiscalant industrially. The selected installations all have circuits that can be assimilated to the schematic diagram represented in Figure 9. On each of the tested circuits, the same observations were made, leading to the same conditions. Therefore, this article will focus on one site only, Site G.

The conditioning strategies follow the guidelines of the regulatory French framework ICPE 2921, which

Figure 9: Schematic diagram representing the installations tested at Site G.



emphasize the need to maintain surface cleanliness, performance, and equipment integrity while controlling microbial activity in the fluid.

As monitoring indicators, the Ryznar Index (RI) and the Saturation Index (SI) were used. Although highly debated, the RI is often indispensable in the profession as an indicator, and its association with SI provides a very good characterization of water's scaling potential.

The temperature used for calculating the two indices is the most important measurement taken from the water network. Generally, it is located at the top of the evaporator, where a high skin temperature induces parameters particularly favorable to scaling (low RI).

Water analyses were conducted every two weeks, from 13 weeks before the switch from the conventional product to the organic antiscalant until 11 weeks after the substitution. Surface conditions were also regularly monitored. Analytical monitoring was reinforced and supplemented by the surveillance of key parameters (measurement of additional parameters such as biological oxygen demand (BOD_5), COD, etc.) continuously and remotely using on-line monitoring technologies.

Table A presents the characteristics of the installation at Site G.

Table A: Characteristics of the Site G Installation

Tower Power	Network Volume	Half-Life Time (T ½)	Materials
800 kW	2.5 m3	8 to 9 hours	Galvanized steel

Table B presents the water analysis of the makeup water and the circuit with the conventional product for Site G.

Surface condition before and after substitution.
On this site, the towers are cleaned twice a year, this biannual scheduling ensures a detailed monitoring of the evolution of surface conditions. The switch from the conventional product to the organic antiscalant took place on March 16, 2020. Technical shutdowns occurred in early December 2019 (4 months before the change of conditioning product) and early June 2020 (3 months after). The evolution of surface conditions during the

Table B: Water Analysis of the Makeup Water and the Tower*

	pH	TH (ppm)	M-Alk (ppm)	Conductivity (µS/cm)	Chlorides (mg/L)	Iron (mg/L)	Copper (mg/L)	N	RI	IS
Make-up	7.8	31	204	608	32,8	< 0,1	< 0,1	-	-	-
Cooling Tower	8.7	57	380	1,098	63,9	< 0,1	< 0,1	~2	~5	~50

Notes: *Data based on normal operation of cooling tower with conventional treatment products.

The calculations of RI and SI in the TAR depend on the fluid temperature, which was considered to be 60°C (140°F), the maximum value recorded in the network.

technical shutdowns at Site G is presented in Figure 10.

We observe in Figure 10a (November 2019) and 10b (June 2020) the maintenance of surface conditions, with no deposition formation observed on the upper tubes. In Figure 10c (November 2019) and 10d (June 2020), surface conditions are maintained with no deposition formation on the nozzles (historical deposits, in place, non-evolving). Figure 10e (November 2019) and 10f (June 2020) show very clean surfaces with no deposition formation and absence of salts between the trickle lamellas of the packing.

In conclusion, three months after switching from the conventional product to the organic antiscalant, there is no significant modification in surface conditions. The system's integrity is maintained.

Monitoring

Water quality at the installation was monitored throughout the in-situ test. In addition to standard parameters, concentrations of sulfate, nitrate, BOD_5, and COD were measured. Table C shows the evolution of water quality based on the analysis date.

Figure 11 shows the evolution a) of the concentration factor (TH, TAC, chlorides, sulfates), b) of the RI and SI, over time for Site G. The central vertical line corresponds to the switch from the conventional product to the organic antiscalant (March 16, 2020).

We observe the constant values for the makeup water in Table C. Between the first and second analysis, the client decreased the concentration in the tower, which explains the decrease in concentration factors (N) (Figure 11a) between early December and early January. During the analyses with the conventional product, the concentration factors were around 1.5 to 2.0 when switching to the organic treatment. Despite the increase in system concentration between February 25th and April 9th, the system integrity was preserved with the organic antiscalant conditioning. Additionally, in Figure 11b, we see an RI oscillating between 4.8 and 5.8 for the TAR. The SI, on the other hand, oscillates between 20 and 80.

The tests show that a simple substitution of the petro-sourced antiscalant with the organic treatment, without changing the operating conditions of the network, remains transparent to operation. The next step for this site will be to increase the concentration rate to reduce the RI to values close to 4.2.

Figure 10: Surface condition evolution between the technical shutdown in November 2019 (left) and June 2020 (right) at Site G. a and b: View of the upper tubes (Point 3 on the schema in Figure 9); c and d: View of the spray ramps and a set of nozzles (Point 3 on the schema in Figure 9); e and f: View of the packing's trickle lamellas.

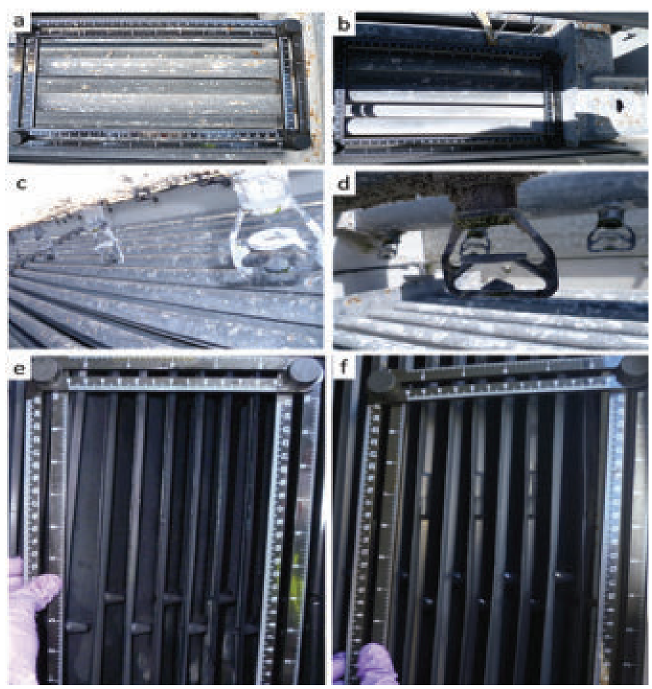
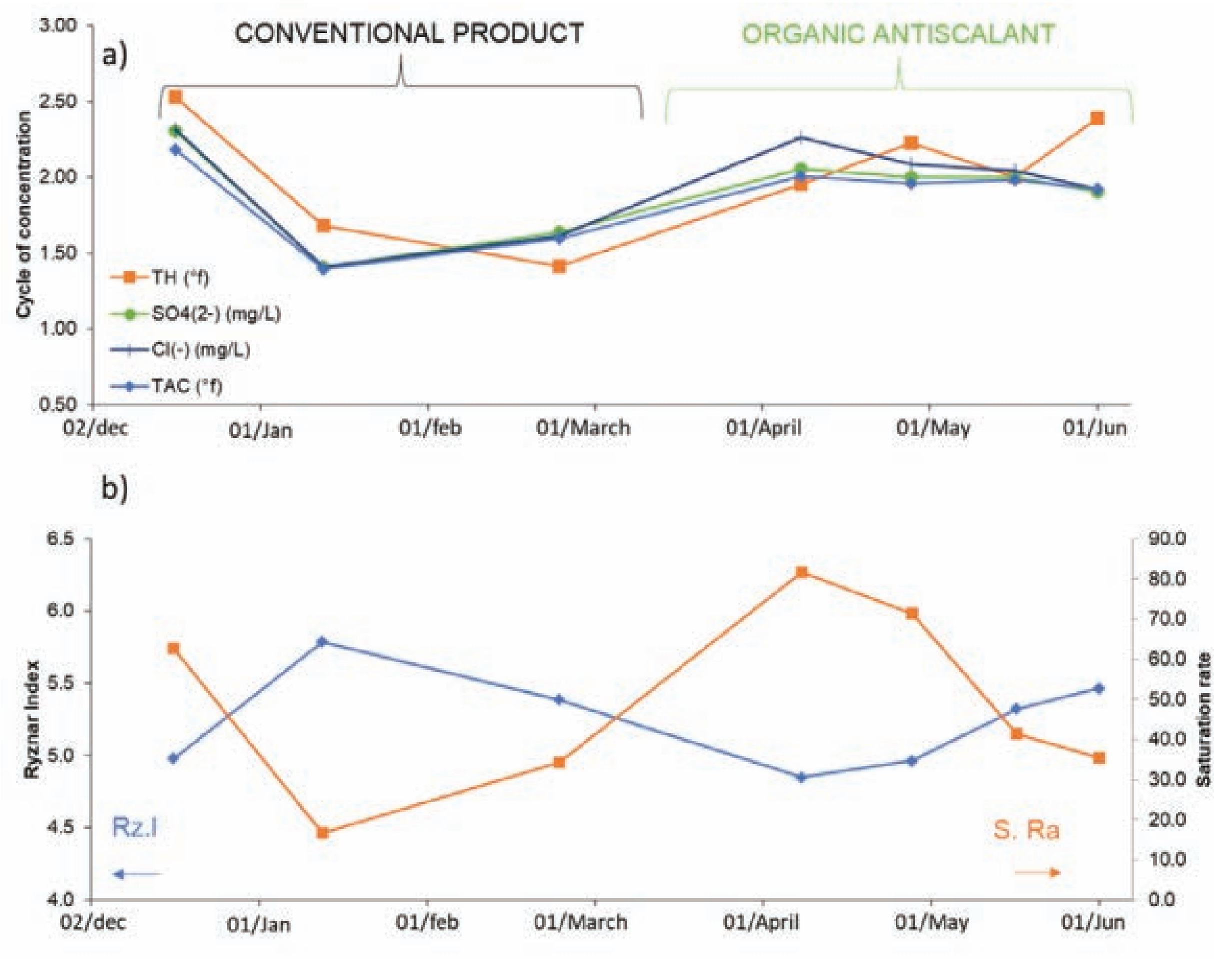


Figure 11: Evolution of a) concentration factor, b) RI and SI, over time for Site G. The central vertical line corresponds to the switch from the conventional product to the organic antiscalant.



Conclusion

After establishing the formula of the organic treatment in the laboratory, its commercialization required the development of a specific quantification method, based on the detection of active tracer molecules by spectrometry. The correlation between the concentration of the tracer and the inhibitory effectiveness of scale formation was verified for different selected sources.

Furthermore, the evaluation of the inhibitory potential of a plant source (through quantification method) allowed for improving the quality of plant raw materials by using the sources richest in active principles (increasing from 7 to 10% mass of active molecules per dry residue), thereby enhancing the ecological and economic efficiency of the organic antiscalant. Similarly, the environmental impact was reduced by an average of 20% by transitioning from a single extraction stage to three successive extraction stages by enrichment. Finally, due to its nature, the organic treatment is exempt from REACH regulations (no SDS required), and it poses no environmental hazards compared to conventional products.

During the deployment of the organic treatment at industrial sites, the integrity of the networks was maintained despite an increase in the concentration factor. Surface conditions are also preserved, even in the most vulnerable areas. One difference, resulting from the substitution of conventional products with the organic treatment, is the slight increase in the proportion of readily biodegradable DBO_5 in the effluent water.

The deployment of the organic treatment is part of a concept that respects industrial ecology: offering industrial facilities a technical solution that is equivalent but in line with today's environmental challenges.

Table C: Water Quality for the Makeup Water and the Cooling Tower at Site G

Date		12/17/19	01/13/20	02/25/20	04/09/20	04/29/20	05/18/20	06/02/20
Product		Conventional			Organic Antiscalant			
Temperature fluid (°C)		60	60	60	60	60	60	60
pH	Make-Up	7.7	7.5	7.7	8.3	7.8	7.8	7.6
	CT	8.7	8.4	8.6	8.8	8.8	8.7	8.7
TH (ppm)	Make-Up	32	34	42	37	29	23	21
	CT	69	50	59	71	64	46	40
	N	2.2	1.5	1.4	1.9	2.2	2.0	1.9
M-Alk (ppm)	Make-Up	185	205	201	209	212	208	209
	CT	404	286	321	420	415	413	402
	N	2.2	1.4	1.6	2.0	2.0	2.0	1.9
Cl^- (mg/L)	Make-Up	31.3	32.5	33.3	33.2	33.1	33.0	33.0
	CT	72.5	45.7	53.8	75.1	69.1	67.4	63.4
	N	2.3	1.4	1.6	2.3	2.1	2.0	1.9
SO_4^{2-} (mg/L)	Make-Up	36.0	37.0	36	38	40	40	41
	CT	83.0	52.0	59	78	80	80	78
	N	2.3	1.4	1.6	2.1	2.0	2.0	1.9
Conductivity (µS/cm)	Make-Up	559	587	591	651	631	612	626
	CT	1189	806	925	1203	1223	1176	1167
	N	2,1	1,4	1,6	1,9	1,9	1,9	1,9
NO_3^- (mg/L)	Make-Up	15,0	13,6	12,4	13,0	13,8	13,6	14,0
	CT	34,8	19,2	20,1	27,6	33,4	27,8	27,3
	N	2,3	1,4	1,6	2,1	2,4	2,0	2,0
Na^+ (mg/L)	Make-Up	160	120	120	130	140	136	140
	CT	250	160	190	260	270	278	270
	N	1.6	1.3	1.6	2.0	1.9	2.0	1.9
DOB_5 (mg O_2/L)	Make-Up	< 0.5	<0.5	1.7	0.6	<0.5	0.7	0.9
	CT	0.9	0.5	1.4	0.5	0.7	1.2	1.3
COD (mg O_2/L)	Make-Up	11	<10	<10	<10	<10	10	<10
	CT	44	22	20	19	19	20	17
RI	CT	5.0	5.8	5.4	4.8	4.9	5.3	5.5
SI	CT	62.6	17.2	34.9	81.5	70.9	44.8	35.1

Note: The highlighted delineation corresponds to the switch from the conventional product to the organic antiscalant four right columns.

These sectors are founded and organized according to the principles of the circular economy, and it is this approach that has enabled the networking of French actors, ranging from farmers to users of the commercial product.

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Endnotes

[A] ODYSSEE Environnement in Requeil, France, is the water treatment company mentioned in the text.

[B] ODYLIFE is the bio-sourced antiscalant treatment mentioned in the text. It is also referred to as the "organic antiscalant" in the article.

[C] The optimization approach of the industrial extraction process discussed in the text was developed by ODYSSEE Environnement.

Fabrice Chaussec is the co-founder and current General Director of ODYSSEE Environnement. As a water treatment expert with 30 years of experience in the field, he has played a key role in the design and development of innovative technologies aimed at preventing corrosion, scaling, and biofilm formation. Before founding ODYSSEE Environnement in 2006, he gained significant experience in the sector while working at Concorde Chimie, where he contributed to the development of film-forming amine products. He may be contacted at f.chaussec@odymail.fr.

Frédéric Bertrand joined ODYSSEE Environnement in 2010. He currently serves as Technical Director and an important role he plays is to ensure the operational links between R&D and ODYSSEE's field teams. His work includes leading the deployment of large-scale industrial trials and providing support to technical and commercial functions. Mr. Bertrand holds a water management and control diploma earned in 1994. He began his career in industrial water applications with Concorde Chimie as a technical sales representative and now has more than 20 years of experience in water treatment. He may be contacted at f.bertrand@odymail.fr.

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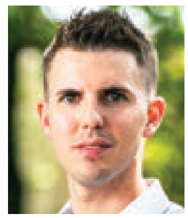

Logan Manaranche joined ODYSSEE Environnement in 2013, initially serving as a technical engineer in France and later transitioning to provide technical support for the American continent as VP of ODYSSEE USA INC. Mr. Manaranche is a chemical engineer who graduated from the National Institutes of Science and Technology of Toulouse, France, and the University Center of Exact Sciences and Engineering (CUCEI), a part of the University of Guadalajara in Mexico. He may be contacted at l.manaranche@odymail.com.

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Lessons Learned from the Design and Operation of a ZLD System

Adam Kortan—FCT Water Treatment

Introduction

A power plant in Colorado has recently undergone a drastic transition that is shared by many older plants across the country. The plant was originally built as four coal-fired conventional units and operated that way for 50 years. Condenser cooling came from river water that ran through large cooling towers, eventually to be treated for ash removal and discharged back to the South Platte River.

Starting in late 2020, plans came together to modernize the plant and use it as a figurehead for the clean energy transition. Three of the coal units were decommissioned completely and one was converted to natural gas firing. A state-of-the-art combined-cycle generator was built, bringing the total plant output up to nearly 1 gigawatt (GW). The wastewater treatment plant across the river started to supply the plant with a guaranteed source of water in the winter months, giving the power plant some certainty for full year operations as well as a guaranteed customer for the purple-pipe plant that otherwise had no winter users.

On top of all these physical transformations came the regulatory changes to the National Pollution Discharge Elimination System (NPDES) permit the plant used to send out its wastewater. Standards change over time to generally include more and stricter limits, and removal of coal from the site also tightened many of the limits that couldn't feasibly be met while treating coal waste. In particular, the state-proposed limits to common anions— sulfate, chloride, and total inorganic nitrogen (TIN: nitrate + nitrite + ammonia)— that were impossible to meet with the existing treatment system.

About this time I started working as a chemist at the plant and was quickly brought into the process of figuring out how we would meet the new limits proposed by the state.

The remainder of this article will focus on the story of the design and build of a state-of-the-art zero liquid discharge (ZLD) wastewater system. We did many things right in the project, or at least the best we could, but we also made more mistakes than we were owed. Every project is going to be different but throughout this article, I will strive to give the reader a broadly relevant document on how to learn our lessons and avoid the consequences in your own future projects.

Figure 1: Power plant aerial views showing the plant changes during the decommissioning of coal units (left) and transition to a ZLD facility (right).

Figure 1 shows power plant aerial views of the plant changes during the decommissioning of coal units in 2015 (left) and transition to a ZLD facility in 2023 (right).

Avoiding the New Limits

Implementing a new ZLD system was not the utility's first choice. A study done nearly a decade earlier in anticipation of these changes had put the price in the ballpark of $100 million, and as such we attempted a few things to avoid or reduce building a system with that price tag. Steps that were taken included the following:

1. **Permit variance.** With the help of lawyers familiar with environmental law, the utility tried to convince the state that meeting some of the proposed limits was not feasible or necessary. Unfortunately, this plan did not work.

Figure 2: Carbon dioxide tank and vaporization skid for cooling tower pH control.

Figure 3: Power plant and POTW located across the South Platte River from one another.

2. **Elimination of specific parameters.** While most of the limits the plant could not meet were due to concentration of makeup water, there were some contributions from the plant. In particular, the plant trial tested carbon dioxide (CO_2) acidification of the main cooling tower to replace sulfuric acid and remove any sulfate contributions, even though they were minimal compared to the total sulfates. This technology had worked at another plant in the fleet but after a near total failure of the trial, it was determined their makeup quality was vastly superior and it had no chance of working at this plant. See Figure 2 for a picture of the CO_2 tank and vaporizer skid from the trial.

3. **Discharge to POTW.** Changing from a direct discharger under a NPDES permit to an indirect discharger going straight to a publicly owned treatment works (POTW) was investigated. The POTW was just across the river from the plant as can be seen in Figure 3 below and the POTW was excited for the chance to work with the plant. However, the tap fee on the table was nearly $100 million and meeting their constituent limits would have necessitated building a more robust wastewater system at the plant, defeating most of the gains of discharging to the POTW in the first place.

With these avenues exhausted it was determined to go down the path of a detailed exploration of plant operations in the future and potential ZLD technology options.

The Study Phase

On our own time, the plant chemists had been acquiring as much chemistry and operational data as possible. We were able to compile several years' worth of detailed data on the plant makeup sources, plant flows under existing operations, and wastewater quality both pre- and post-treatment in the existing wastewater system.

The plant then hired an engineering firm to model the current and future plant operations, establish a hypothetical water balance and quality, and evaluate existing technologies available.

As a part of this process we tried to gather input from every possible stakeholder to the system. As the plant chemists, we would be the ones in charge of the water quality and any operations that affected the NPDES permit held under our names. We consulted any operator willing to talk about experience at this plant or others they had transferred from. Management at the plant level and above was consulted to determine what they wanted from a reliability, operational difficulty, operations and maintenance (O&M) costs, and headcount. Every plant in the fleet was consulted, including several that already had ZLD facilities of one kind or another. The Transmission and Commercial Operations groups were consulted to determine as best as possible the expected capacity factors of each unit and when the coal-to-gas converted unit would be retired.

As a result of this study the engineering firm came up with four potential options for the plant to pursue.

1. Retire the converted conventional unit seven years early and operate the combined-cycle cooling tower at two cycles of concentration to stay under the new limits.

Table A: Wastewater Quality Data Used for Design Basis for Potential ZLD Systems

Water Quality Data				
Parameter	**Minimum (1)**	**Typical (2)**	**Maximum (3)**	**Units**
Chloride	99.48	266.76	496.56	mg/L
Fluoride	0.66	1.78	3.32	mg/L
Nitrate	3.01	8.06	15.00	mg/L (as N)
Sulfate	121.50	442.28	882.98	mg/L
Field conductivity	665.00	1,783.15	3,319.30	µmho/cm
Field pH	8.00	8.0	8,0	SU
Ammonia	0.36	0.97	1.80	Hg NH_3-N/L
Total phosphorus	0.05	0.14	0.27	mg/ P/l
TDS	449.50	1,205.30	2,243.55	mg/L
TSS	10.00	26.81	49.91	mg/L
Calcium hardness	115.42	309.48	576.09	mg/L as $CaCO_3$
Total hardness	162.92	436.85	813.09	mg/L as $CaCO_3$
Aluminum	0.18	0.49	0.91	mg/L
Barium	0.03	0.07	0.13	mg/L
Copper	0.01	0.02	0.03	mg/L
Iron	0.05	0.14	0.25	mg/L
Manganese	0.01	0.03	0.06	mg/L
Zinc	0.03	0.09	0.16	mg/L
Cadmium	0.50	1.34	2.50	mg/L
Selenium	0.94	2.52	4.70	mg/L
Calcium	46.58	124.91	232.52	mg/L
Magnesium	11.36	30.46	56.69	mg/L
Silicon	3.83	10.26	19.09	mg/L
Alkalinity (P)	20.0	53.63	99.83	mg/L as $CaCO_3$
Alkalinity (total)	99.48	130.13	172.24	mg/L as $CaCO_3$

Sources:

1) The minimum (best case) water quality assumes U4 and U7 offline. Wastewater flow would be essentially storm water in this scenario or miscellaneous plant service water uses. We've assumed the wastewater quality to be equal to the Reuse Water quality.

2) The typical (normal operating case) water quality assumes that U4 is offline, U7 cooling tower operating at 12 cycles of concentration, with the typical Reuse Water as makeup and the balance of the 700 gpm as Reuse Water quality.

3) The maximum (worst case) water quality assumes U4 and U7 cooling towers operating at 12 cycles of concentration with the typical Reuse Water as makeup and the balance of the 700 gpm as Reuse Water quality.

4) Reuse Water quality is calculated from 9 samples, collected throughout 2017 and 2018.

2. Install a ZLD system utilizing a thermal evaporation system.

3. Install a smaller membrane-based ZLD system and makeup water softening system.

4. Install a more complicated membrane-based ZLD system with no makeup pre-treatment.

Option 1 was included to directly address some concerns of upper management at the utility, and it was thrown out as existing electrical generation could not meet expected demand without the unit. Option 2 was ranked low due to extremely challenging operations of a thermal system at another fleet power plant and the desire to avoid the extremely high parasitic load that such a system requires, directly impacting the utility's ability to sell the power generated from the plant. Option 3 was also ranked low due to the size of the makeup water softening system that would be required as the total plant makeup flow could theoretically reach as high as nine million gallons of water per day. That left Option 4, and several possible technologies were examined by the engineering firm.

The firm also supplied a design basis for the expected makeup water quality and wastewater quality that incorporated historical makeup data and expected plant operational changes. That design basis is highlighted in Table A.

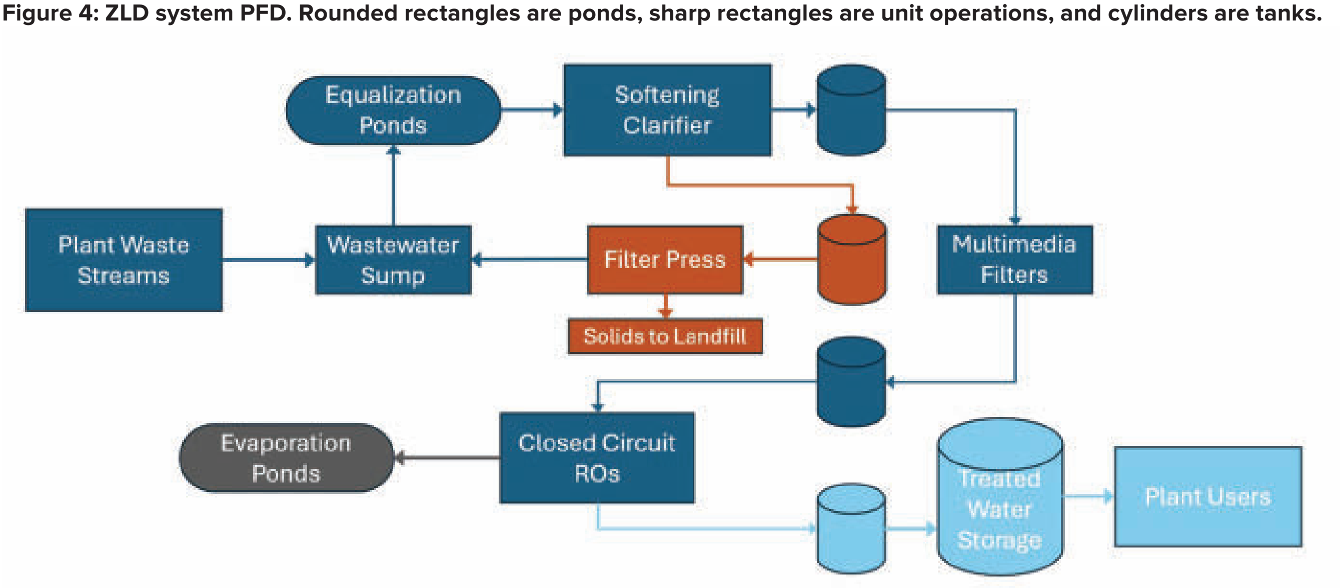
The end of the study phase transitioned into the bid phase where the proposed system from the engineering firm was sent to a handful of large wastewater technology firms for them to base proposals on. In the end, three full proposals were evaluated. The main reasons for the choice were cost, perceived simplicity of the system (had the fewest number of unit operations), and the highest proposed total system recovery. The last point was particularly impactful due to the limited real estate available on the plant site for evaporation, every additional gallon of water returned to the plant for reuse was one that didn't go to filling up a pond that would be at capacity in ten years given our projections (until such point the old unit was retired and total plant flows were halved). Figure 4 shows the process flow diagram (PFD) for system that was selected and built.

Planning Phase Retrospective

As the story has been told so far, there may have been a few setbacks, but it hopefully sounds like a process that was thoughtful and thorough. I can assure the reader that we sure thought it was. However, we now have the ability to examine the planning phase of this project with perfect hindsight and there are a host of conclusions we can draw that are applicable to many other projects.

1. **Water conservation.** The plant took on a large effort to reduce sources of waste of "good" water. Despite not being able to fix every source of waste due to plant age and occasional plant inaction, the amount of city water

Figure 4: ZLD system PFD. Rounded rectangles are ponds, sharp rectangles are unit operations, and cylinders are tanks.



going down the drains was reduced by a significant amount. While great for the planet and the plant's water bill this also meant that the wastewater quality was more influenced by cooling tower blowdown and hence had significantly worse quality.

2. **Makeup water modeling.** As discussed above the plant had collected years' worth of makeup water quality data as an input to the design basis. However, changing plant and fleet operations meant that the water that had only been taken in the winter months would be taken year-round. The data appeared relatively stable, so it was thought to be fine but in retrospect the summer saw significant swings in certain constituents that have caused issues. If at all possible, it would be prudent to gather extra water quality information prior to a switch like this.

3. **Missing parameters.** Despite all our data collection we still didn't know what we didn't know. While we were thorough, there were parameters that we had never had a need to test for in the past and did not know were critical to operations of a ZLD system like our selection. In particular, total organic carbon (TOC) was not sampled and thus assumed to be zero by the equipment manufacturers. Any RO membrane manufacturer will tell you that feed water must have somewhere around < 3 parts per million (ppm) TOC and ours had ten times that amount, and due to the contract language there was no consequence to those that designed the system. We would have been well served by requiring a detailed parameter list from the equipment bidders to fill any holes in the bid packages.

4. **Design to typical versus max.** In all the chaos of evaluating multiple large bid packages during the summer of 2020, it was overlooked that the equipment designers used the typical water case in the design basis above to size all the equipment with the max case being the upper limit. There was little extra capacity for anything above the max case, and now that the system is operating with the max case being the minimum much of the equipment was undersized. It was intended to be a balance between current operations and the future when the old, converted unit is retired; however,

Figure 5: Equalization pond with several hundred thousand pounds of sludge filling the bottom three feet of the pond.

it would have likely been better to downsize later rather than overload now.

5. **Flow expectations.** The system was designed well for expected flows. Maximum flows are enough to cover the plant running full out and the minimum flows are appropriate for lower demand winter operations. Designing any larger or smaller would have required multiple equipment trains for the clarifier that would need to be taken in and out of service which would have significantly complicated the system.

6. **Back-end design errors.** Due to the nature of this plant being extremely space limited, much of the equipment design was based on the expected evaporation rate of the brine ponds. In the middle of the bidding phase, it was discovered that the predicted evaporation rate had been overestimated and once corrected the necessary ZLD water recovery was higher and limited our potential choices. For a value that was so critical, it would have been prudent to measure real evaporation rates ourselves or contract that prior to committing to a design.

Table B: Logs available in the manufacturer's O&M manual.

Dates							
Chemical Tests							
Process Water							
Turbidity							
pH							
Effluent Water							
Turbidity							
pH							
Chemical Treatment							
Soda ash							
Sodium hydroxide							
Coagulant ($FeCl_3$)							
Polymer							
Magnesium chloride							
Sodium hypochlorite							
Primary zone sludge (% solids)							
Sludge recycle (% solids)							
Sludge blow=off (% solids)							
Process water flow							

7. **Stakeholder representation.** Throughout the process, we tried to get the right stakeholders involved at the right steps. Utility planning can be very challenging with the constraints of Transmission and Commercial Operations, which we incorporated to the best of their ability to commit. However, some of the plant stakeholders, especially union positions like maintenance and operations, were not adequately involved in the process. While it may be complicated, a serious effort needs to be made to get competent people from every discipline involved if they are going to be operating and managing the system in the end.

8. **Site visits.** This may be common practice for large projects but due to the pandemic (2020), no site visits were made and no lessons, as seen in this article, were learned. If time and resources allow, this isn't a step to skip.

9. **Best possible equipment.** If there is a small difference in the upfront cost that might get equipment better suited to the water being treated, it will likely pay dividends in the future. While presenting this system design at a conference prior to the build, an audience member stood up and said, "this system will never work without ultrafiltration (UF)." Without realizing it, he represented the same company that designed the system with multimedia filtration (MMF) instead of UF, but unfortunately he wasn't wrong. After the fact there was neither the space nor the money for easily adding in another treatment step. If the money can be argued for during the design it is much more efficient to spend it then than after the system has failed and needs fixes.

It is almost painful to limit some of these points to a few sentences rather than tell the whole tale in a few thousand words, but hopefully in their brevity I did not understate the impact of the mistakes we made. While some of them impacted the construction and startup below most were not realized until full operations started, which will need its own story.

Table C: Chemistry Monitoring Program

Sample Point	Parameter	Frequency	Notes
Clarifier Influent	pH	1x/day	
	Conductivity	1x/day	
	Total Hardness	1x/day	
	Calcium Hardness	1x/day	
	P Alkalinity	1x/day	
	Total Alkalinity	1x/day	
	Turbidity	1x/day	If inlet turbidity increases or decreases dramatically, recommend jar testing to confirm chemical feed rates.
	Color	1x/day	Note any noticeable color change in operator logs.
	Sludge Depth in Clarifier	1x/shift	If sludge depth is increasing, increase blowdown rate. If decreasing, decrease blowdown rate.
	Sludge Density	1x/shift	If sludge density is normal but depth is high, increase blowdown. If sludge density lower than normal, perform jar testing and adjust coagulant/polymer dosing.
	Temperature	1x/day	As water gets colder particles will settle slower. Increase coagulant dose to produce heavier and faster settling floc. Confirm dosage rates with jar testing. OR Reduce system treatment rate so the particles have longer to settle. As water gets warmer the particles will settle faster. Decrease the coagulant dose to produce a lighter and slower settling floc and reduce chemical usage.
Clarifier Effluent	pH	1x/shift	Measured online, compare to grab samples.
	Conductivity	1x/day	This will depend on excess alkalinity in the water.
	Total Hardness	1x/day	Hardness will be dictated by chemistry.
	Calcium Hardness	1x/day	Ca Hardness is directly related to soda ash dose.
	P Alkalinity	1x/day	Based on kinetics and soda ash dose.
	Total Alkalinity	1x/day	Based on kinetics and soda ash dose.
	Turbidity	1x/day	Measured with online turbidity meter.
	Color	1x/day	Clarified water should be clear.
	Free Chlorine	1x/day	Increase bleach dosing if not reading 1 ppm free chlorine. Decrease bleach dosing if reading above 1 ppm free chlorine.

Note: This monitoring program was developed by the plant after several months of operation.

Construction and Startup

After rushing through the design and procurement phases of the project, we rushed right into constructing and startup. Schedules slipped due to the supply chain delays of the Covid years and weather, but the system was fired up nearly on time. As with the planning phase, there were more issues than even the staunchest pessimist could have dreamed of and below is the attempt to distill these issues into positive lessons for any project.

Reuse of buildings. Money was saved by reusing an existing building (that had housed a previously failed water resource project), which was great on paper, but in practice ended up costing the plant far more. The building was too small to house everything, so some equipment was placed outside or in a remote building. Freeze protection is now an issue and has caused several extreme plant failures and improvement projects have been submitted to expand the building after the fact. When evaluating cost saving measures be sure to compare the ideal to the savings and really evaluate what a smaller up-front price tag will cost.

Reuse of equipment. The plant had an existing filter press that could handle the load from new system.

However, the plant had been lax on maintenance due to the old plant configuration and no money was budgeted in the new project to overhaul the equipment. The result was numerous failures and hundreds of thousands of pounds of sludge sent back to the ponds (see Figure 5). If reusing critical equipment treat it as new equipment and have the same engineering diligence for operation, maintenance, and budget.

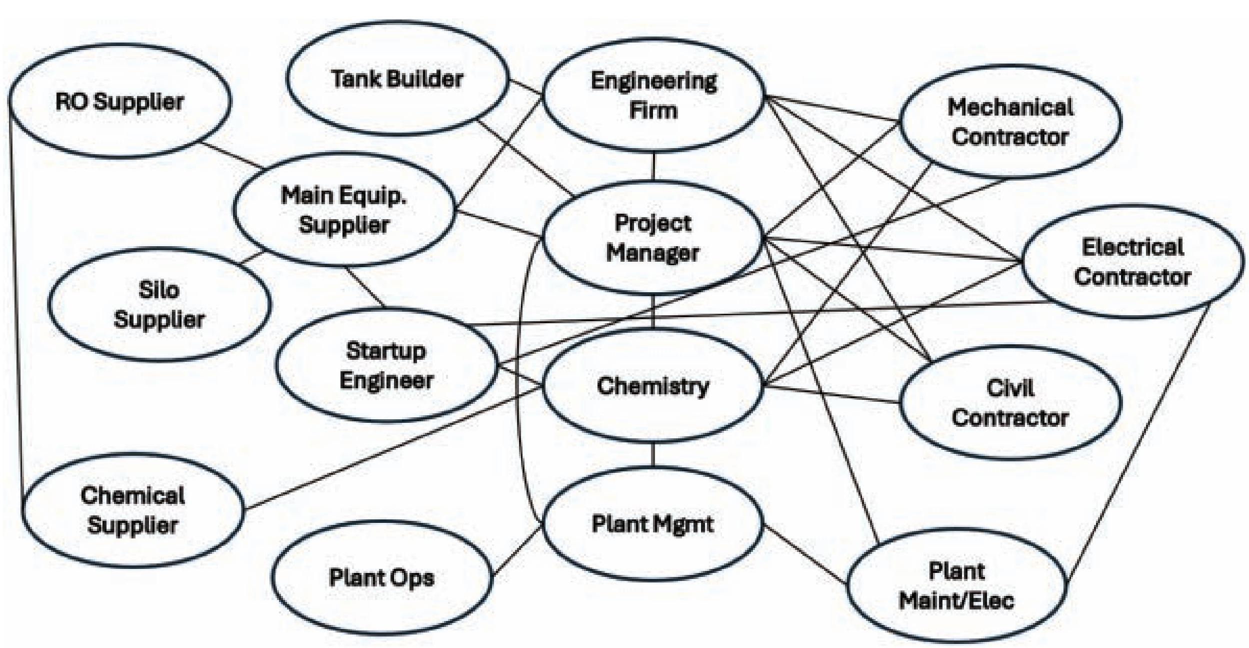
Rounds and logs. Despite many efforts to obtain guidelines for operator rounds, chemistry testing, and critical chemical parameters at various stages of the system the plant had none of this information prior to startup and operation of the system (see Table B for what was provided). Since this was a new technology to the plant and utility, there wasn't the institutional knowledge to do this without expert guidance. As is predictable, this led to numerous issues during startup where chemical feeds or the system balance was wrong, and we did not have the data to identify the issues or help diagnose the exact causes of the problems. At the same time the shovels are going in the ground, the users should have the data they need to develop the operational program with key parameters, frequencies, and troubleshooting. Table C shows the chemistry monitoring program that plant chemists developed after experience with the ZLD system.

Communication. This project involved a host of people from more than dozen different companies (see Figure 6). A single utility project manager was the hub through which nearly everything flowed, but he was not an expert on building a water treatment project. A project of this scale would have benefitted significantly from having more project management manpower involved and including those familiar with construction of similar projects.

Startup engineer experience. For this project, there was one field service engineer assigned to get the system up and running. He did have a few days of help from a chemical engineer but outside of that he was mostly on his own for several months, and it was very obvious he had no real chemistry background. This resulted in several issues such as wild chemical under- and over-feeds, disabling of critical alarms that were thought to just be nuisances, and a lack of ability to train operators and chemists how to monitor the system as discussed earlier (see Figure 7 for examples). Anyone responsible for starting up any system needs to have expert knowledge of the system or have immediate access to those that do and conduct frequent check-ins.

Critical design details. The engineering of the project was quite thorough and many of the critical details such

Figure 6: Sketch of the project communication paths. Lines indicate direct communication between the parties.



as material compatibilities were specified. Due to lack of experience on the startup engineer and mechanical contractor as well as the complicated communication web (Figure 7), there were several of these details that were missed (see Figure 8 for an example). It is strongly recommended that a specific person is assigned to review and check details called out in the detailed design and a pre-startup checklist includes details such as materials used and heat trace setpoints.

Concurrent operations. This project was being installed at an operating power plant that couldn't come offline for the months or years required to perform a clean switch, so the old wastewater system was used while the new system was being constructed. Operation of the old system required different wastewater quality and plant operations, which meant the startup of the ZLD system was done on water that was not representative of the design and the future water quality. As such, many issues were masked until the final changeover to the new

Figure 7: Chemical feed issues causing massive scaling in the rapid mix tank (top), polymer overfeeds causing cartridge filter blinding (bottom right) and disabling of pressure alarms causing cartridge filter implosion (bottom left).

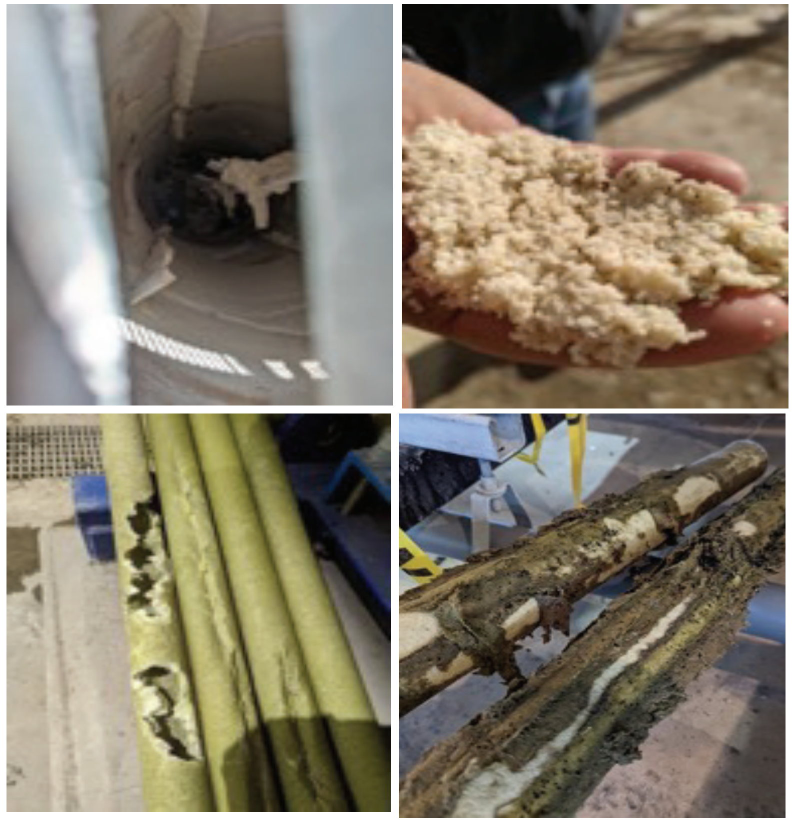


Figure 8: Swollen and degraded EPDM gasket in the polymer feed line that caused pump plugging and damage as pieces broke off

system. The startup plan lacked but should have included how the plant was going to integrate operations of the old and new systems and what the requirements for each would be.

Conclusion

These lessons from the design and build of a unique wastewater treatment plant are not unique to this system. Every issue faced could have been mitigated by proper planning, follow through, and having the right people with the right knowledge in the right spots (disregarding luck of course). It is my sincere hope that our hardship imparted at least one useful lesson to the reader.

Most of these lessons learned were not discovered until attempting to operate the system fully and taking it through the variations in season, plant operations, personnel changes, and maintenance.

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Preventing Hospital-Acquired Waterborne Infections—the Need for Effective Risk Assessment

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Editor's note: This article first appeared in the Winter 2022 issue of *Waterline*, the quarterly journal of the Water Management Society (WMSoc), which is based in the United Kingdom. It is being republished in the *Analyst* as a part of a new cooperative agreement being developed between the AWT and WMSoc to periodically share articles published in each organization's respective journal. One goal of this agreement is to expose members of each group to water knowledge gained by experts from the WMSoc and the AWT. This particular article by Dr. Susanne Lee covers the important topic of waterborne infections and the need to use risk assessment as a tool to prevent their occurrence in hospitals and other healthcare facilities.

Introduction

Readers will all be familiar with *Legionella* and Legionnaires' disease (LD). The first recognized UK hospital outbreaks occurred in Kingston Hospital between 1979 and 1980 (1). It was followed by the Stafford Hospital outbreak in 1985, which affected 101 patients with 28 deaths (2). The reporting to the House of Lords of the Badenoch Report (3) following the Public Inquiry stated:

> *"The report refers to a combination of circumstances that appear to have contributed to this outbreak. These circumstances include* ***defects in the design and construction of engineering services, problems during the commissioning of the air conditioning plant, lack of knowledge and understanding of the sophisticated engineering plant, shortcomings in maintenance, including chlorination,*** *and the weather conditions. The report also points to the inherent difficulty on present knowledge of eliminating the Legionella bacillus in water spray cooling towers used for air conditioning."*

I would like to be able to say we have moved on since then, but more than 45 years later, those listening to the Public Inquiry into deaths associated with the new Queen Elizabeth University Hospital in Glasgow will recognise many of the failings highlighted above as still being a problem today.

Development of Guidance

The Stafford Hospital public inquiry resulted in the publication of the first Guidance Note EH48, upon which the current Health and Safety Executives' (HSE) Approved Code of Practice (L8) and associated guidance (HSG 274 parts 1-3) are based. These specify that *Legionella* risk assessments (RA) are required for all premises where the Health and Safety at Work etc. Act and associated legislation apply. For health care premises, the Water Safety Plan (WSP) approach to managing water safety risks is incorporated into guidance, both by the HSE and Department of Health (DOH). WSPs consider not only the risk from *Legionella* but take account of all forms of hazard and hazardous events and ensures there are the appropriate skill sets to manage any identified risks effectively by a multidisciplinary team, the water safety group (WSG). WSPs should also include supporting programmes and documented processes, to ensure competency checks, training, communication, audit, monitoring, and surveillance are in place. In 2020, BS 8680 (4) was published to help organisations, irrespective of size and complexity, to develop and implement holistic and effective WSPs.

Legionella Risk Assessments

Risk assessments form the core of the WSP, and it is essential that they are carried out by those familiar with the systems to be assessed and take account of the susceptibility of those who might be exposed and carried out with impartiality (i.e., there is no conflict of interest of those carrying out the RA). Before BS 8580 was published in 2010 (5), the standard of many *Legionella* RAs can, at best be described as "of variable usefulness and quality" and often used as a means to generate unnecessary remedial work for the company carrying them out. Registration and auditing by the *Legionella* Control Association (LCA) of members and accreditation of companies providing RAs to BS 8580 (updated in 2019) have significantly improved the quality.

Sadly, whilst the ACOP makes it clear that those employing contractors to carry out risk assessments on their behalf have a duty to ensure the competence of those they employ, this is often neglected and contracts are awarded on a cost rather than quality basis and there remains the problem that having an RA is all too frequently seen as a tick box exercise with recommendations for improvement not completed. It is also of concern that RAs are all too often not treated as living documents or reviewed when there are changes that affect the validity to ensure that the written scheme of control remains effective. This was especially worrying during the time of COVID, when even premises on healthcare sites were not being used to full capacity, with some left empty for long periods of time. In addition, the impact on the risk due to the increased susceptibility to waterborne infections of patients suffering from COVID-19 or the long-term sequalae (i.e., long COVID), resulting from it should be considered and may mean that extra water safety measures are needed in areas treating them.

The prevention of Legionnaires' disease will always be of major concern to Hospital Trusts (Boards in Scotland) as it can affect not just patients, but also staff and visitors, including in non-clinical areas. However, in recent years there has been a growing awareness of the increased risk to patients from other opportunistic waterborne pathogens, particularly *Pseudomonas aeruginosa* the bacteria that resulted in the deaths of the three babies in Belfast in 2012 (6, 7).

> "The risk assessment process should build upon what is already present in terms of processes and procedures for infection prevention and patient safety from waterborne infections."

Pseudomonas aeruginosa

P. aeruginosa (*PA*) belongs to a large group of gram-negative bacteria that are natural inhabitants (not contaminants) of soils, natural waters such as lakes, rivers, constructed water systems and moist environments. *PA,* and other naturally occurring opportunistic pathogens, are likely to be present in biofilms attached to the incoming supply network infrastructure and occur in supply water even when it meets all the regulatory parameters for drinking water.

Free-living microorganisms in the water phase, as opposed to those in biofilms, are much more sensitive to residual biocides in the supply water and as long as there are sufficient residual levels of disinfectant in the supply their numbers will be controlled. At low water temperatures they also have a low ability to cause human infections as the virulence factors required to cause disease are not expressed until temperatures rise to around 37°C (8). However, once within the building water system, *P. aeruginosa*, in common with *Legionella* and other waterborne pathogens, can grow to levels that can pose a risk of infection, if the water systems and/or any equipment that stores or uses water, are not managed effectively.

Transmission

Whilst it is understood that *PA* can cause infections in the normal population when it can gain entry into body areas where it normally doesn't have access for example, via cuts and grazes, through hair follicles, the urinary tract and ear canal during submersion in water, these are relatively rare and not usually life threatening. However, in patients with compromised immune systems, which make them more susceptible to infection, *PA* infections can be difficult to treat and pose a high risk of mortality. Direct and indirect contact are significant modes of transmission for *Pseudomonas aeruginosa* and other gram-negative infections from both contaminated water sources, surfaces, and person to person.

It is generally accepted that areas with water outlets, especially taps with inserts, drains and toilets can play a significant role in transmission to patients. It is nearly 50 years since Chadwick (1976) showed the potential for splash contamination that can reach several feet away from the sink and yet the designs of high-risk areas still do not adequately protect patients. There is much evidence in the peer-reviewed literature that hospital-acquired infections of *PA* have also been associated with a variety of sources other than that the drinking water distribution system and outlets, including systems and equipment used for personal hygiene, diagnosis and treatment (9, 10), including from bottled water and baby feeding bottles (11, 12), etc.. Patient and staff interactions and practices can also contribute to the risk of infection, including poor cleaning practices transferring *PA* from wastewater outlets to taps and the surrounding environment.

PA can also grow on damp items such as face cloth's, tooth and shaving brushes, cleaning cloths and mops etc., within sanitising solutions made up incorrectly or with contaminated water, and items left in the splash zone. Equipment such as blood gas analysers, milk pasteurisers, water baths, ventilators etc. have also been associated with *PA* infections (13-16), etc. It is therefore essential that all potential sources are assessed, not just water.

At-Risk Groups

Those most at risk are patients in augmented care, such as those with an undeveloped skin barrier (e.g., in neonatal intensive care) (6, 7, 17-19), neutropenic patients in transplant units and haematology oncology, burns (20-23), as well as patients with interventions that compromise the skin/tissue integrity (e.g., venous and bladder/urinary catheters) (24-27). Patients with cystic fibrosis (28) are also at high risk of colonisation and infection with *PA*.

The Importance of Clinical Surveillance

Effective clinical continuous and systematic clinical surveillance should be able to provide timely, accurate, and relevant interpretation of data to establish the trends of hospital acquired *PA* infections and burden of disease on the Trust and in patients. The most serious *PA* infections can cause bacteraemia, pneumonia, urosepsis, wound infection as well as secondary infections of burns (29) with significant impact on both the lives of the affected patients and their families.

Besides posing a serious threat to the survival of these patients, *PA* infections are difficult to treat, owing to the ability of *P. aeruginosa* to readily acquire antimicrobial resistance. This increases the likelihood of the spread of multiple antibiotic-resistant strains throughout the hospital, which may spread further to the community, ultimately contributing to the global increase in multiple antibiotic-resistant microorganisms; identified as of critical concern by the World Health Organization (WHO).

Infections with strains showing antibiotic resistance are relatively easy to detect and it is almost certain that these are but the tip of the iceberg. This theory is borne out as studies have shown that where waterborne pathogens are excluded from high-risk wards either because there is no water in the patient environment or point of use (POU) sterilizing-grade filters are being used, the overall numbers of all gram-negative infections, not just from *PA*, also dropped.

P. aeruginosa Risk Assessments

The WSP should include the processes to be followed by the multidisciplinary WSG for the commissioning of the assessment, agreeing on the scope, defining the competencies and experience required, the areas to be assessed, and identifying the competent in-house personnel to form/support the risk assessment team.

PA risk assessments are much more complex than those required for *Legionella* as *PA* is not just limited to growth in water, distribution, and the associated wastewater system, but equipment and other potential sources that patients may be exposed to both off and on the patient wards. The potential transmission from water used for drinking, including bottled water, thickened drinks for patients with swallowing difficulties, and making up of infusions etc. should also be assessed. The complexity of assessing all potential sources and determining the risks to patients, therefore requires a multidisciplinary group.

Risk Assessment Process

The risk assessment process should build upon what is already present in terms of processes and procedures for infection prevention and patient safety from waterborne infections. As an up-to-date *Legionella* risk assessment is a legal requirement, a starting point then, should be to review the *Legionella* risk assessment and ensure it, the asset register and the schematics are up to date, that it complies with BS 8580-2019, L8, HSG 274 and HTM 04-01, that remedial measures have been completed and the existing controls are effective. Remedial actions, monitoring results and audits should also be appraised. Remedial actions recommended in previous risk assessments, if not carried out effectively could increase the risk of waterborne infections so appropriate checks should be made.

The asset register should be updated to include all systems and items of equipment, fittings and components that might pose a risk from *PA*; the completeness of the asset register should be verified with input from clinical staff and those with practical experience and knowledge of the buildings, patient areas, systems, equipment, activities, and users.

The RA should include all risks from water system design and engineering, any items or equipment used that stores or uses water, the potential for splash contamination from drains and contaminated outlets, cross contamination of items that the patient may come into contact with or exposure to aerosols, potential sources of nutrients that could support the colonization and growth of *PA* and other waterborne pathogens. This includes an assessment of cleaning practices, food and drink preparation, and clinical and patient practices, (such as storing personal items within the splash zone, having food and drink that could be contaminated with *PA* brought in, etc.) that might increase the risk of cross contamination and patient infections.

Environmental Surveillance

The WSP should include the processes by which the WSG validates and verifies that controls are effective. Water microbiology is an inexact science and for many reasons a negative sample does not mean that the target organism is not present. Samples taken for verification that the risk from *P. aeruginosa* at an outlet is controlled should always be first flush and ideally taken when the outlet has not been used for some hours (post-flush samples are only useful during initial investigations to identify systemic failings) as this is the water that will represent the highest risk.

> "Free-living microorganisms in the water phase, as opposed to those in biofilms, are much more sensitive to residual biocides in the supply water."

Even when *PA* is present in the sample, the result may be negative just by chance as *PA* like other waterborne microorganisms is not uniformly distributed but attaches to surfaces, including to scale and particulates to form clumps. So, where there are low numbers, such clumps may not be present in the volume analysed and the result can be a genuine negative for that sample. It is important to remember the target organism may also be lost during the transport, storage and processing of samples and the recognition of colonies.

Even when there is a genuine negative result for a given sample time and date, *PA* can be transferred from patients and staff to outlet immediately after sampling, so an outlet could become contaminated and not be identified as a potential source for several months. For these reasons, intermittent sampling at six monthly intervals does not give any guarantee that the outlet remains safe or allows the build-up data for trend analysis and identification of endogenous v endemic strains. The frequency of sampling then, should be based on risk assessment, agreed by the WSG and provide sufficient data to establish trends.

P. aeruginosa Risk Assessment

A *P. aeruginosa* risk assessment check list could include an assessment of the following areas:

- The relevant microbial hazards (other than *Legionella*),
- The known, likely, suspected or possible sources/routes of microbiological contamination of the water and surrounding environment, taking into consideration the effect of single untoward events as well as the potential for intermittent or continuous low-level ingress.
- If there are conditions likely to support the growth of microbial hazards such as temperature; poor water flow and turnover; nutrients, including scale and corrosion products; materials of construction; and ineffective cleaning practices.
- Whether there have been, or are, failures in the application of effective control measures, including flushing, temperature control and biocides, as well as a history of flooding, poor drainage, backflow, etc.
- The disposal of patient waste and surplus fluids, including intravenous antibiotics, down sink drains.
- The mechanism(s) by which contaminated water could cause infection in those exposed. Examples include splashing, formation of aerosols, direct contact through bathing, indirect contact (e.g., via cross contamination from contact with others), items washed or rinsed in contaminated water, items splashed with contaminated water, food preparation, consumption or aspiration of water or ice either directly or indirectly. Together with an assessment of the mode of transmission, duration, frequency and population size.
- The nature and vulnerability of the exposed population, taking account their susceptibility to infection and/or the presence of potential routes of ingress into the body (e.g., open wounds, burns, indwelling venous, and urinary catheters, among others).

- All water uses and water systems and associated equipment, as well as potential hazardous events.
- The effectiveness of existing controls and any actions that need to be taken to improve control, including an assessment of the effectiveness of cleaning and maintenance.
- The relevance and success of the monitoring and inspection work, including any microbiological tests that have been carried out as these will indicate whether the correct actions have been taken based on the results obtained.
- Results of sampling and monitoring of controls, cleaning and maintenance, supervision, audits and inspections carried out on the patient areas, system/equipment/processes, etc., to see whether these indicate if the risks are minimized.
- Training, competence checks and hygiene awareness, as relevant, for staff, contractors, service providers, patients, visitors and relatives.
- Operational considerations in consultation with relevant staff (e.g., members of clinical, infection control and prevention and cleaning teams) may be required.
- Checks of actual practices, for example, by discussion with, and/or observation of, individuals carrying out their work or activities involving exposure to water, or the aerosols derived from it.
- Where there are projects that involve the construction and commissioning of water systems and equipment (including refurbishments) as well as maintenance and remedial work, that there are processes in the WSP to ensure the risk of ingress from contaminated components, fittings and equipment is minimized.
- The cleaning and maintenance of specialist equipment (e.g., water baths for warming intravenous fluids, baby feeds, etc.).
- All fluids/gels used for patient diagnosis and treatment.
- All specifications, plans, method statements, systems, and equipment to be installed are reviewed and approved by the WSG to ensure they do not pose a risk of contamination.
- That there are processes to identify and manage colonized/infected patients who may pose a risk of cross contamination to others, especially when transferred from other healthcare premises.
- The processes to verify the timely and appropriate reactions to lapses or failures of control.
- The processes to verify that any substantive changes in the at-risk population would be identified, together with any substantive changes to relevant personnel.

“Risk assessments form the core of the WSP, and it is essential that they are carried out by those familiar with the systems to be assessed...“

- Ensuring that the impact of activities by those using water in places with highly susceptible patients are identified and appropriately managed.
- The measures in place to prevent cross-contamination from drains and personnel to patients and the environment.
- Whether there is appropriate clinical and environmental surveillance and the processes in place where increases in the observed isolation of potential waterborne pathogens are detected.
- The processes to verify patients, staff and visitors are kept informed of water-associated risks and how they can help to manage those risks.

For other microbial hazards (e.g., non-tuberculous Mycobacteria, and other gram negatives), the assessors should determine whether there are any hazardous events and significant risks that have not been identified and included.

Note, the points in this section are not all inclusive; it is recommended that the WSG confirm that there are processes within the WSP to ensure all relevant factors applicable to the areas assessed are included in the RA, taking into account the particular susceptibility/vulnerabilities of those who might be exposed.

Closing Thoughts

For some patients, the presence of water and associated drains may be considered too risky when they are at their most neutropenic. Work in the Netherlands has shown an overall decrease in ICU infections from waterborne pathogens where there is a patient water-free environment. For the highest risk patients NTM infections should also be considered. Evidence from other hospitals suggest this is a predictable event. NTMs are inherently resistant to both heat and biocides and treatment regimens for NTM infections such as *M abscessus* are prolonged and often not tolerated by patients. The WSP should include documented procedures for predictable untoward events before they occur, both to try and prevent them from occurring and to ensure there is effective communication and well thought out action plans to reduce the impact. For high-risk neutropenic patients, the WSG, with input from relevant clinical leads, may take the decision that no water (including drains) is safe.

As one can see, risk assessments for *PA* are complex, they cannot be carried out solely by contractors. They require familiarity, not just with the water quality, but also with clinical and patient practices. Assessors need to be able to think on their feet and ask questions and importantly each patient area will need to be taken as a separate exercise. The information in this article is based on BS 8580-2 Water Quality; Risk Assessment for *Pseudomonas aeruginosa* and other Waterborne Pathogens-Code of Practice, which was published in early 2022.

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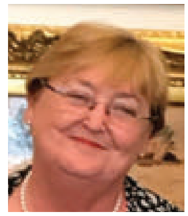

Dr. Susanne Lee has more than 45 years' experience in clinical and public health microbiology and is a former Director of the Health Protection Agency (now Public Health England) Food Water and Environmental Microbiology Laboratory in London. She is now Director and co-owner of Leegionella Ltd., an independent international public health consultancy. She has been involved for almost 20 years with the development of national and international guidelines and is chair of the ESCMID study group for Legionella Infections (ESGLI) working group that has produced a variety of technical guidelines, updated to reflect requirements at the time of the COVID-19 pandemic. Dr. Lee may be contacted at susannelee@leegionella.co.uk.

KEYWORDS: BUILDING WATER, *LEGIONELLA*, MICROBIAL CONTROL, POINT OF ENTRY, *PSEUDOMONAS AERUGINOSA*, REGULATIONS, RISK ASSESSMENTS, WATERBORNE INFECTIONS, WATER MANAGEMENT PLANS

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LMC Enterprises (dba Chemco Products Co., and Flo-Kem)

6401 Alondra Boulevard
Paramount, California 90723
(866) 243-6261
www.chemcoprod.com

Company History: Chemco Products Co., headquartered in Paramount, California, has been developing and supplying specialty cleaning products and solution-oriented programs for more than 60 years. The company founder, Lyman M. "Bill" Cole, started Chemco in 1962 to fulfill a small niche in developing and selling conveyor chain lubricants and cleaners to industry in southern California. He also founded Flo-Kem to manufacture all of the specialty blended chemicals for Chemco. After Mr. Cole passed away, the company was led by his two daughters, Jan Utz and Elaine Cooper, from 1995 to 2020. Chemco remains a privately owned family business and is now led by the third generation—Jamie Utz Thomas and Erica Utz Wochna.

Current Business: Chemco Products is a specialty chemical company that serves the dairy, food and beverage, and water and wastewater business sectors. For more than four decades, Chemco and Flo-Kem have operated as separate businesses, and Chemco was considered to be Flo-Kem's largest customer. In 2013, the two companies merged and are known legally as LMC Enterprises dba Chemco Products Company and Flo-Kem.

Chemco's services include developing custom formulations to meet the individual needs of the client. Examples include specialized membrane cleaners for dairy and juice processes, customized steam boiler and cooling water corrosion and scale inhibitors, or formulations based around the unique food and beverage regulatory requirements faced by the clients of our customers. Chemco is also able to deliver these blends with its tanker trucks.

Chemco has six AWT Certified Water Technologists (CWT) on staff, as well as eight ASSE 12080 qualified persons.

Business Locations: Paramount, Rancho Dominguez, and Ceres, California; and Mesquite, New Mexico. The company now offers nationwide service, but key regions served include the western United States, especially the Southwest and Midwest regions.

Involvement and Recognition: Chemco Products joined AWT in 1986. Michael Bourgeois, VP of Technical Operations, served as AWT president in 2021.

Top Executives: Jamie Utz Thomas, CEO; Erica Utz Wochna, President and Chief People Officer; Julie Petritsch, CFO; Michael Bourgeois, CWT, VP, Technical Operations; Jeff Stanhope, VP, Northern Region; Russell Gaston, VP, Southern Region; and David McCullough, Jr., VP, Sales.

2nd and 3rd generation owners: (left to right): Jan Utz, Elaine Cooper, Erica Utz Wochna, and Jamie Utz Thomas.

Michael Bourgeois, CWT— VP, Technical Operations, past AWT president (2021).

Creative Water Solutions, LLC

13809 Industrial Park Boulevard
Plymouth, Minnesota 55441
(877) 212-6493
www.cwsnaturally.com

Company History: Creative Water Solutions (CWS) was founded in 2003 by David R. Knighton, MD, and Vance D. Fiegel to commercialize their water treatment technology using sphagnum moss. Their previous company, a leader in chronic wound care, went public in 1991. After discovering sphagnum moss's historical use as a World War I wound dressing, Dr. Knighton and Mr. Fiegel conducted extensive research into its unique water treatment properties. CWS initially focused on recreational water treatment before expanding into industrial applications in 2014.

Current Business: CWS manufactures and distributes proprietary sphagnum moss products and delivery systems for both industrial water treatment and recreational water applications (commercial/residential pools, spas, and water features). The sphagnum moss is harvested sustainably from natural bogs, requiring no cultivation or fertilization and containing no additives. This harvesting process maintains the bog ecosystem's hydrology while ensuring self-sustaining moss growth. After harvesting, the sphagnum moss is processed and pressed into various shapes. Each lot is quality control tested prior to being packaged into units of varying dosages. The product is delivered through the use of specially designed contact chambers.

Industrial water treatment products are distributed through our international network of dealers. Recreational water products are sold through dealers and distributors, with select residential products available directly from CWS. These recreational water products are used in swimming pools, spas and decorative water features to reduce organic contamination and harmful disinfection by products, as well as scale and corrosion, while decreasing chemical demands and overall water usage.

Sphagnum moss products for industrial applications are supplied in solid form and are used for water treatment in various applications, including cooling towers, boilers, spray injector systems, and closed-loop systems. The sphagnum moss products are used to reduce organic contamination, control corrosion and scale, and reduce chemical and water demand.

CWS products are listed under NSF Standard 50, Standard 61, and NSF-Registered Proprietary Substances and Nonfood Compounds.

A commercial installation of contact chambers that hold the Sphagnum moss-based treatment products.

Business Locations: CWS and its dealer network service the US, Canada, and the Pacific Rim.

Involvement and Recognition: CWS has been an AWT member since 2014.

Top Executives: David R. Knighton, MD, CEO; Vance D. Fiegel, president and Chief Science & Technology Officer; Paul R. Gramstad, CFO; Doug Workman, director of sales and business development.

Tyler Beck
Seaco Technologies, Inc.
Bakersfield, CA

Question: Why do you feel this credential is important to have?

I think having the CWT certification is a marker of professionalism in the water treatment industry and provides credibility; the results of the exam can also provide a solid indication of what areas in the water treatment industry you are strong in, and where you may need to dig in more.

Question: What do you think are the most prominent issues facing the water industry today?

One of the key challenges in the industrial water treatment industry today is balancing sustainability, economics, and technical expertise. As environmental concerns grow, there's increased pressure to deliver eco-friendly solutions. However, many customers prioritize cost-cutting over sustainability, often opting for cheaper, less efficient methods that can lead to long-term problems. Our industry demands high technical skills to design and implement effective solutions, but this is complicated by clients who sometimes reject our expert advice in favor of substandard approaches. We must balance providing top-tier solutions while managing customer expectations when cost constraints limit our options.This dynamic creates tension as we strive to drive costs down without sacrificing quality or sustainability. The challenge lies in educating clients on the value of sustainable, efficient systems, and navigating the complexity of delivering solutions that meet both economic pressures and technical needs.

Question: What was the most difficult aspect of the exam?

I think the most difficult aspect of the exam is that it challenges you with concepts you may be unfamiliar with. There are a lot of ways to achieve a result in our industry and if you lack experience working with these concepts from the ground up you may find yourself at a loss. If you are given apps and sheets that calculate dosage math for you or have only ever experienced using one type of boiler treatment you will walk into that exam extremely unprepared.

The exam is made up of five broad sections that encompass the water treatment industry. You need to score high enough to show an overall proficiency in those sections, which can be a challenge if your exposure to those different areas of treatment is limited.

Question: What advice would you give those thinking about taking the exam?

I would recommend using the AWT Technical manual and other written resources as not just your test preparation but also to improve your knowledge of the treatment industry. Those resources in addition to the online AWT training can supplement your knowledge well.

However, I think the most important aspect of preparing yourself to take the exam and pass is to make sure you are getting exposure to as many different treatment systems as possible. You need a high level of practical knowledge and experience with these systems. If you are in a role where you are provided with a treatment plan and not involved in surveys or treatment plan design, then I highly recommend you make professional adjustments to be included in those areas. Any areas of the five test sections you lack expertise and experience in, get that experience before attempting the exam.

Allen Clouse
Commercial/Industrial Sales Consultant at Hall's Culligan

What prompted you to start volunteering with AWT?

While attending an AWT technical training event, Angela Pike approached me and asked if I would consider joining the Pretreatment Committee. Initially, I was both excited and honored to be asked, but I assumed I wasn't qualified to serve. However, as I learned more about the committee structure, I realized that AWT committees actively seek members at various stages of their professional journeys.

It became clear that a diverse team with a wide range of experience levels is essential to creating a well-rounded and effective committee. I'm glad Angela encouraged me to take the leap—it's been an incredibly rewarding experience.

What has been the most rewarding thing about volunteering?

Joining a committee has provided me with numerous rewards. The most significant benefit has been the opportunity to build meaningful relationships with other professionals across the water treatment industry. These connections have been invaluable for sharing knowledge, experiences, and best practices.

Additionally, being part of a committee helps me stay actively engaged with my AWT membership, keeping it top of mind and ensuring I remain proactive rather than complacent in my professional growth and contributions.

Finally, and just as importantly, the monthly committee meetings challenge me to bring my best—whether it's presenting well-thought-out technical questions or providing valuable insights to the discussions. This ongoing exchange of ideas pushes me to continuously learn and grow.

Enhance Your Water Work through a Growing Network

Mike Henley—MD Henley & Associates

Prologue

The following conversation is fictional, but the core of the discussion is critical for the story I'm about to share. So…let's begin.

New Water Treatment (WT) Employee (Newbie): *Thanks for hiring me. What would you like me to start working on?*

Old Water Treatment Sage ("The Boss"): *Here is a flier for the National Water Treaters Conference that will be in six weeks in Cleveland. I want you to register and make your travel arrangements. For this afternoon, spend time on the conference website. Download the PDF of the conference program, print a hard copy, and study the different sessions. Tomorrow, I would like you to have a list ready of the sessions that interest you and specific papers you would like to attend. that you can share with me and Smitty* (Newbie's direct supervisor).

Smitty and I will study your list, and then we'll have a meeting to discuss your list and the strategy for attending this conference.

Newbie: *Okay, but don't you have any water treatment system work you would want me to take on?*

The Boss: *Yes, but this is more important. We have high hopes for you and think attending this conference will give you a good foundation for your work with Zephyr Water Treatment.*

Newbie: *Thank you, Sir. I'll talk with you tomorrow about the conference.* (As he walked away, Newbie was somewhat confused. He looked forward to designing state-of-the-art water systems and solving riddles for successfully removing contaminants. And his first assignment was to fly to Cleveland to attend a conference spending time listening to "boring papers" and mingling among strangers in the exhibit hall?)

Introduction

The dilemma one faces when beginning a new job or coming into a different industry is the challenge of becoming established and grounded so that you are valued, confident and able to contribute to the business and be building a career *at the same time*. In this short dialog, Newbie did not appreciate the gift The Boss was wanting to share.

I did not join the water industry until late 1990, but my first journalism job in the late 1970s had somewhat of a similar beginning. After graduating from university in 1978, I began my first position as a reporter for the *Brighton Blade* and *Fort Lupton Press* in communities northeast of Denver (Colorado). The hours were long and involved attending school board and city council meetings, visiting the police station, going to chamber of commerce lunches, and so on. And this was before the widespread use of computers, which meant typewriters were used, and "cut and paste" was a literal part of the job when large chunks of text needed to be rewritten. But enough on the details of work at a weekly newspaper.

The real point of my story is about becoming established in the water industry. But as we segue, there is one important point that my first managing editor, Dick Sides, taught me. Shortly after I began, Dick told me to begin collecting any business cards for my rolodex, and to use blank cards to write down names and contact information for those without a card. (*For those unfamiliar, a rolodex is a rotating filing system designed to hold business cards. It has become outdated with the revolution in digital data storage and various apps available for use on a computer, pad or cell phone to store contact lists.*) Dick's goal—for me to begin developing a network of contacts that could be useful sources of information and be helpful in different ways for newsgathering.

Application to the Water Business

Fast forward to late 1990, when I joined Tall Oaks Publishing as the editor of *Ultrapure Water Journal* (*UPW*) and *Industrial Water Treatment*. At the time, I knew a tad about drinking water treatment because of working three summers on the lawn crew at a Denver Water plant. But "ultrapure water" was new, and not a commonly used term—at least for me. But very quickly I learned that ultrapure referred to particular qualities of treated water used in the semiconductor, pharmaceutical, and power industries. Each industry's treated water had particular attributes based on the end use, but the semiconductor industry has the highest purity standards overall for treated water quality requirements among *all* end uses, including drinking and pharmaceutical water.

One of my first tasks as I began my new job was to attend the ULTRAPURE WATER Expo West, which was conducted in San Jose, California, in November 1990. As it turned out, one of the blessings given to me by Dr. Frank Slejko, publisher and founder of *UPW*, was the opportunity to attend a large number of water industry conferences during my time with *UPW*. During my career with *UPW*, I was involved with helping organize 60+ conferences/meetings, including co-organized conferences in Europe and Singapore. The work involved helping to develop conference programs, working with speakers and moderators, and helping with the actual technical sessions at the conferences.

Additionally, I was given the opportunity to attend multiple other conferences as a part of my work. Besides the AWT, three other examples of conference I've had the honor to attend were sponsored by the American Membrane Technology Association (AMTA), Cooling Technology Institute (CTI), and the International Water Conference.

Working with or attending these different conferences was a gift, because it has provided a foundation and valuable learning about the water industry and the science of water treatment. For this, I am forever thankful for this gift given to me by Dr. Slejko.

Networking 101

The ultimate gift though, was that through these activities, I was able to develop a network of contacts that has sustained my nearly 35 years of work in the water field at *UPW* and now as a water industry consultant. The last part of my consultancy's name is "& Associates." I truly consider the different ones within my network as associates and have shared different names when someone contacts me and is looking for help in a particular area of expertise. For the balance of this story, I would like to offer some helpful tips for network development.

Options for Networking

Conferences/Meetings

If one wanted to, it would be possible to attend one or more conferences or water-related events monthly. This is *not* necessary. Instead, I would recommend selecting one to three conferences related to your water treatment area to regularly go to and to be intentional to make new contacts each time you attend through the technical sessions, exhibits, receptions and other mixers. Of course, the AWT Annual Conference is a worthwhile event, and should be considered as a part of one's yearly schedule.

A characteristic one will find is that conferences can somewhat mirror the atmosphere at a school reunion or a family gathering. By that, I mean that as time goes on, you will develop ongoing friendships with fellow professional water treaters, and attending a particular conference will become an event you look forward to—not just for professional development, but for renewing contacts, who can even become dear friends.

Another important facet of attending a conference is the ability to meet subject matter experts (SMEs) and industry leaders through the technical papers and keynote addresses. One of the fun things to do is to take a seat close to the front of the room, and after a speaker is done during the break times to go up to the different speakers to introduce yourself, and if possible, get their business cards.

Here a few benefits from attending conferences and meetings:

- An easy venue to meet new people, who are also looking to meet others.
- Technical session topics can provide some indication about current industry concerns or new water industry trends.
- The exhibits allow one to learn about different companies and to meet contacts, who can also help expand one's reach into a company.
- Making long-term friendships with fellow water industry professionals.
- Through your contacts, adding individuals to your network who could one day become a future employer, or be helpful in your existing work.
- Discovering potential future business opportunities.
- The opportunity to become a part of the organizing committee, or other support groups. These can be great ways to make worthwhile contacts.

Your Work

Duh…okay Captain Obvious you think. *"I already knew that."*

Okay, that is true enough. But seriously, this is the primary place to launch a network from. Sources include the following:

- Your supervisor and coworkers. They know you and can share ideas.
- Through work projects or contacts you make while on the job. With the different companies you work with it can be possible to develop a list of several names besides your primary contact. And again, if asked, your primary contact will likely be willing to act as a referral point.
- Let your supervisor and higher ups know of your willingness and interest to join with organizing committees or other support groups with conferences and other professional organizations. Getting such permission can provide opportunities to expand your own network but also provide the opportunity to give a "face" to your company. This can give your business further credibility and give it visibility with SMEs, water business influencers, and within the particular organization.

Special Interest Groups

Through virtual meeting tools like Zoom, Google, Teams, and others, it is possible to easily attend group sessions. For example, in Colorado, there is a group called Water Reuse Colorado (WRCO) that meets by Zoom and in-person. The AWWA also has a Colorado Water Utility Council chapter that meets monthly. Regulatory agencies also will conduct meetings, often with a virtual attendance option to learn about pending regulation changes or to give updates on water-related topics. Through all of these, one can learn about individuals that it could be important to reach out to and add to your professional network.

National groups like the AWWA and WateReuse Association have similar groups elsewhere in the US, and state regulators elsewhere also have similar outreaches like those sponsored by the Colorado Department of Public Health and the Environment (CDPHE).

LinkedIn/Other Social Media

Social media like LinkedIn, Facebook, or others can also be useful tools for networking. I personally like LinkedIn and have found it a useful way to meet fellow water treatment professionals. Also, it is possible to join special interest groups related to specific water interests. For example, corrosion, industrial water or wastewater, electrodeionization, membranes, among others. One great example is the Industrial Water Treatment interest group, which AWT member James McDonald very ably manages.

On LinkedIn it is possible to create a network that can be searched not only by names, but by other criteria like company affiliation, industry, and region, among others.

Tours

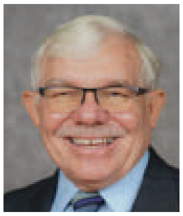
When attending conferences and other meetings, sometimes there can be the opportunity to visit an industrial site. When offered, these are worthwhile to join. For example, at the Spring 2024 American Boiler Manufacturers Association conference in Aurora, Colorado, the organizers arranged for tours of the host resort's boilers. It was a good learning experience, plus it gave the opportunity to meet not only hotel staff who run the system, but other conference attendees.

Volunteer

Some organizations work to develop standards or guidelines for different water treatment areas. Often the organizers are looking for SMEs to join and help with their work. This can be a great opportunity to meet others to invite to join your network.

Final Thought

Success in the water business comes from various aspects, including training, knowledge, competence and professionalism. However, a well-developed network is also integral because the contacts can provide different types of support and also be helpful when one needs a subject expert or is looking for wise counsel. One word of caution, the temptation when developing a network is to view those in your network as tools for *your* advancement/gain. A healthier view is to see those in your network as relationships meant for mutual benefit.



Mike Henley is a Water Industry Consultant through MD Henley & Associates, whose work includes serving as the Technical Editor for the Analyst. Mr. Henley has nearly 35 years of experience in the water industry and was the editor of the old Ultrapure Water Journal for 27 years. As a water journalist, his background includes water types used for a number of applications, including ultrapure (semiconductor, pharmaceutical, power), industrial, cooling, wastewater, desalination, water reuse, and natural resources (oil field and mining). He may be contacted at mdhenleywater@gmail.com.

KEYWORDS: BUSINESS DEVELOPMENT, NETWORKING, PROFESSIONAL DEVELOPMENT, WATER TREATMENT

Advertising Index

How Can Biocide and Dehalogenation Monitoring Improve Cooling Water Treatment?

Brad Buecker—Buecker & Associates

Introduction

Cooling water systems, and especially open-recirculating designs that have a cooling tower as the core component, allow the introduction of many microorganisms to the cooling water. The warm and wet conditions can induce exponential growth of microbiological colonies and protective slime that foul equipment and cause massive problems. Figure 1 (1) shows a heat exchanger fouled with microbial slime.

Figure 1: A heat exchanger fouled with microbiological slime and silt.
Source: Reference 1.

Properly designed and conscientious operation/maintenance of biocide feed systems are critical for minimizing microbial fouling. The author and a world-class colleague addressed this subject in a previous article published in *Water Technology* (2). A key issue for microbiological control is precision monitoring of biocide concentrations in the recirculating water and, per environmental issues and regulations, biocide residuals and dehalogenation agent concentrations in cooling water discharge. This article highlights a new, innovative technology for monitoring these chemical parameters.

A Brief Review of Oxidizing Biocides

Following the discovery in the late 19th century that chlorine was highly effective for killing water-borne microorganisms, water treatment personnel hastened to install chlorine feed systems at the many emerging drinking water production plants. Chlorine gas supplied in one-ton cylinders became the workhorse for drinking water and then cooling water treatment. (Subsequent safety concerns regarding gaseous chlorine storage and handling led to a changeover to liquid bleach at many industrial plants.)

When chlorine is added to water the following reaction occurs as shown in Reaction 1:

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl \qquad \text{Reaction 1}$$

HOCl (hypochlorous acid) is the killing agent, and it functions by penetrating microbial cell walls and then oxidizing internal cell components. During the middle of the last century, when acid/chromate programs were in vogue for cooling water scale and corrosion control, chlorine was an ideal oxidizing biocide. However, with the elimination of chromate in the 1980s (per health concerns regarding hexavalent chromium), the replacement scale/corrosion inhibitor programs operated at a pH near or even slightly above 8.0. The efficacy and killing power of chlorine are greatly influenced by pH due to the equilibrium nature of HOCl in water, as shown in Reaction 2.

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad \text{Reaction 2}$$

The hypochlorite ion (OCl^-) is a much weaker biocide than HOCl, probably because the ionic charge does not allow hypochlorite to effectively penetrate cell walls. These factors led to the development and increased use of alternative oxidizers, including bromine (typically generated as hypobromous acid (HOBr)), chlorine dioxide (ClO_2), and monochloramine (NH_2Cl), among others. Regardless of the oxidizing compound, accurate monitoring is very important for chemistry control, which leads to the heart of this discussion.

The Evolution of Monitoring Technology

While several monitoring techniques evolved over the decades, the most common was the DPD (N,N-diethyl-p-phenylenediamine) method, where this indicator turns pink in the presence of chlorine or similar oxidizers. The color intensity, which can be determined by standard spectrophotometry, correlates to the oxidizer concentration. Note that DPD will react with free and total oxidizers. The latter is an oxidizer that has reacted with water impurities such as ammonia or organic molecules to produce less potent compounds. DPD testing originated as a bench-top procedure, but years ago was incorporated into on-line instrumentation.

In clean water supplies, such as purified drinking water, DPD monitoring can provide accurate results. However, for cooling tower systems, of which hundreds of thousands exist around the globe, debris brought in with the makeup water, and particulates that enter via the air flowing through the tower, produce a less-than-pristine environment. Impurities may significantly influence the accuracy of existing analytical technologies. This can be problematic when calculating biocide concentrations, which in turn can lead to poor chemistry control. The worst-case scenario is under-reporting and subsequent fouling from out-of-control microorganisms.

The need for accuracy led to the development of robust electrochemical technology that has been incorporated into sample panels similar or identical to that shown in Figure 2.

The core component of this system is a multi-parameter sensor that simultaneously and directly analyzes oxidizing biocide concentration (as parts-per-million (ppm)), pH, oxidation-reduction potential (ORP), and temperature. Specific conductivity is another, and often very important, instrument that can be added to monitoring panels. Also included in the configuration

Figure 2: Photo of an electrochemical sampling system.
Source: **Pyxis Lab, Inc.**

is an ultrasonic flowmeter with regulating valve for flow measurement and automatic adjustment to a user defined setpoint. Real-time data is available on the panel display screen and can be transferred to remote terminals and computers in a variety of formats. Cloud transfer capabilities are also standard. Essentially, the continuous analyses allow plant personnel or remote monitoring software and operators to obtain a comprehensive picture of cooling water conditions. Examples include:

- Ability to instantaneously monitor oxidizing biocide levels. A drop in concentration suggests chemical feed system problems.
- Continuous specific conductivity (SC) monitoring. This is the typical measurement to control cooling tower blowdown.
- Changes in pH may come from water chemistry fluctuations, but often are seen in cooling-tower systems with sulfuric acid feed to control pH. Numerous examples have been documented of upsets that allow very low pH conditions to develop in the cooling water, which in turn can cause severe corrosion. On-line monitoring can alert plant personnel to these and other pH issues.
- ORP can be a good backup to oxidizer monitoring. A change in one but not the other suggests a possible probe malfunction.

A key to the technology is the straightforward ability to select or change out the sensor based on the oxidizing biocide to be monitored (i.e., free chlorine, total chlorine, bromine, chlorine dioxide, ozone and per-acetic acid [PAA]). The special feature is the highly sensitive bare-gold electrode, which replaces the more maintenance-intensive membrane sensors of other analyzers.

Gold is an extremely noble metal that is not attacked by any normal water species. The sensor flow reservoir compartment includes a motor-driven brushing assembly— which operates whenever sample water is flowing— to mechanically clean the sensor of particulate build up. Supplementing that feature is a chemical injection port that allows introduction of cleaning agents at the brush head to remove oil or grease that may have accumulated on the sensor.

Accordingly, the applications for this technology continue to grow and include process/effluent stream monitoring at food and beverage plants, refineries and organic chemical facilities, and wastewater treatment plants, among others. An interesting twist regarding wastewater plant effluent monitoring comes from the increasingly common selection, often mandated, of municipal wastewater effluent as an alternative to freshwater makeup at industrial facilities (3). Organic compounds and nitrogen species in these streams impart a halogen "demand" that can decidedly reduce the efficacy of the biocide. Accurate monitoring is important to comprehensively evaluate system conditions.

An added feature of the newest systems is a probe for analyzing ultra-low concentrations of sulfite in the sample stream. Bisulfite (or similar sulfite-based reducing agent) feed is often required to dechlorinate wastewater streams prior to discharge. Precise chemistry control can be very important in this regard. In fact, this new aspect of the technology reminded me of the following case history, per a makeup water treatment application, that illustrates the potential benefits of simultaneous oxidizer/sulfite analyses.

Case History

For two years in the late 1990s, the author served first as a process specialist and then as the acting water/wastewater manager at a chemical plant. A few months before I arrived, plant management had purchased a reverse osmosis (RO) unit to pretreat makeup water ahead of an existing cation/anion demineralizer. The unit was shipped to the plant in a semi-trailer, from whence it operated with hose connections to and from the makeup water treatment building. Through an agreement with a neighboring power plant, one of their personnel, a mechanical engineer, served as the prime service and troubleshooting manager for the RO. His incomplete chemistry knowledge leads to the following narrative.

Raw water for the chemical plant came from three sand point wells located on the banks of a large river. While this groundwater was essentially free of suspended solids, as is common with sand point wells, the dissolved iron concentration ranged from 2 to 3 ppm. Accordingly, raw water pretreatment included chlorine injection followed by passage through an atmospheric spray tower to oxidize the iron. The particulates settled in a pit that had an entrance and exit ramp for a "bobcat" operator to drive through and scoop out the precipitates. Sodium bisulfite ($NaHSO_3$) injection at a point approximately 30 feet from the RO inlet protected the RO membranes from chlorine attack. The water system operators set bisulfite feed at a high rate to cover all projected chlorine concentrations.

At the time of this incident, the operators were cleaning the RO membranes every three days to maintain the necessary output. Note that the normal membrane cleaning interval for a reverse osmosis unit should be months not days. The supervising engineer had concluded that the problem was iron fouling of the membranes, and he was in the process of having a greensand filter installed to remove this "iron." We immediately analyzed the makeup stream with a standard test kit and found the dissolved iron concentrations to be no greater than 0.25 ppm. This data raised questions about the need for a greensand filter, but we were too late to stop purchase and installation.

During the next RO shutdown, just a day or two later, we opened the cartridge filter housing. The filters and internal vessel walls were covered with microbiological slime. The microbes and slime, not iron, were what had fouled the RO membranes and drastically increased the cleaning frequency. It was clear that some organisms had survived the chlorination step, came out of hibernation following bisulfite injection, and then multiplied in the biocide-free environment. An analysis of colony-forming units (CFU) from a slime sample showed bacteria counts

in the millions. Given that the water had a distinct sulfite/sulfate concentration from feed of the bisulfite reducing agent, undoubtedly some of the bacteria in the slime were sulfate reducers. The hydrogen sulfide that these organisms produce through their metabolic processes can be highly corrosive to many metals.

The upshot of this case history is that now, for processes requiring simultaneous analyses of oxidizer and sulfite concentrations in real time, the technology is available.

Conclusion

Measurement of oxidizing biocide concentrations and related parameters can be difficult and subject to errors in "dirty" waters. Yet, these analyses are critical for microbial control or to potentially prevent release of residual biocides in excess of concentrations allowed in the plant's discharge permit. The technology highlighted in this article is rapidly being adopted at plants that have process or waste streams that challenge conventional oxidizing biocide analytical technology.

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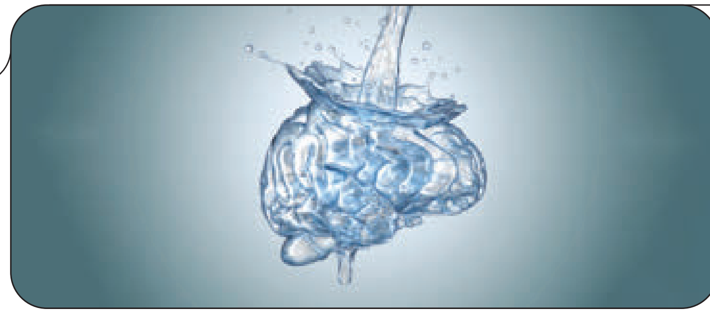
KEYWORDS: BIOCIDES, BIOFOULING, CHLORINE, COOLING TOWERS, COOLING WATER, MONITORING, WATER QUALITY



What Can Cause Low Conductivity in Medium-Pressure Boilers?

Compiled by James McDonald—Chem-Aqua.

Note: The following water treatment discussions come from the Industrial Water Treatment interest group on LinkedIn.

Question: *What could cause a low-to-medium-pressure boiler not to cycle up as high as it should (i.e., have a low conductivity)?*

Tom: If running sample/cycle-based control, the sample time may be too long, and the time between samples (the cycle) too short.

Ron: The boiler water must cycle up unless there is a loss of boiler water somewhere, allowing dissolved solids to escape. Check all blowdown lines for open or cracked valves. Look for carryover too. Steam must be very low with regards to conductivity. Ask for help from your qualified water treatment company.

Todd: The conductivity sensor needs calibration or the sensor needs replacement.

Andrew: Low or little load.

Chris: Poor or non-existent wet chemistry testing. Especially when automation is being used.

Joel: Leaking blowdown valves. Poor controller programming and/or inaccurate calibration. Excessive carryover.

Gene: Boiler tube leak.

Brian: Have we checked the feedwater conductivity!? Sometimes this isn't a problem, and we have outstanding condensate return greater than 95%! In cases like these, our feedwater tank can be at or below 20 microohms.

Steve: Leaking BFW (boiler feedwater) check valves. I have seen caustic overfeed result in low level carryover, lowering the cycles of concentration.

Question: *Do the multi-parameter colorimeters require calibration, and, if so, how often?*

Chris: I have to admit—we don't like the "field cowboys" doing calibrations. That's just dangerous! We offer an "Accuracy Check Kit" to evaluate the colorimeters. The rep uses the standards in the kit to check absorbance levels of each wavelength. If the device doesn't pass, the unit is sent in for professional service.

Dick: Chris, I agree with your comment about doing "field" calibrations on these instruments.

Reggie: Valid point.

Dave: Yes, every three months.

Question: *What can cause a water softener's eductor not to function properly during the brine draw of a regeneration cycle?*

Doug: Plugged educator, loose tube fitting allowing an air break, plugged flow control valve not allowing enough flow to pull brine, plugged or pinched blowdown line not allowing enough flow to pull brie, stuck overflow float, and faulty brine valve…to name a few.

Bain: Lower raw water pressure feeding educator, badly oxidized resin, and valve problems on the softener.

Reggie: Most probably an obstruction in the eductor, low water pressure, or an air leak.

Steve: Obstruction, temperature (viscosity), pressure, flow, among others.

David: Low water pressure on the brine draw part of the cycle. No water in the salt bin or saturator. Blocked eductor. Snorkel stuck down.

Lawrence: Drain obstructed or plugged.

Ron: Lots of good answers already. My all-time favorite was a brine tank full of salt *without* water!

Question: *How did you get your start in this profession? What advice would you give someone considering joining or someone new?*

Ron: I got my start in this profession from a request by management as a chemical engineer to help investigate the water treatment performance of 50+ installations by one water treatment company that had air washers, boilers, cooling towers, and chilled water loops. Once the systems were ranked by various factors, it became apparent a lot of opportunities emerged. As I gained water treatment experience working with various suppliers, I found a great deal of value investing in our plant personnel and helping to evaluate and improve our unit operations from a chemical engineering background, doing calculations and testing pinks and blues.

We were able to support beneficial operating best practices and uniform standards for performance. I learned the value of joint assessments with corporate technical managers at water treatment companies to support our reps and putting some plants up for competitive bids on strong performance standards between companies and I saw how this helped raise the bar. It was a very fun journey to help save our company lots of money. For anyone interested in entering the water treatment business, I would recommend chemical engineering (sorry I'm biased) and building and strengthening relationships.

Question: *What is a chemical injection quill and what are the design options?*

Chris: It is used to inject water treatment chemicals into the bulk water in a pipe. Make sure you use an injection quill metallurgy compatible with the chemical. Also, put a sign on that valve that says: "Don't close this valve!"

Question: *What is your favorite place to eat when you're on the road servicing accounts?*

Loren: The favorite lunch place of my clients. They typically meet the expectation of a hole-in-the-wall restaurant. Then, make certain you overtip their favorite waitress.

Chris: This reminded me of the rib joint at one of my customers' favorite place in Ponca City, Oklahoma. They couldn't take me my first time visiting because "I was dressed too nicely!"

Craig: I always try to pack something to eat. I have a big yeti cooler that can keep things cold for 48 hours. I commuted back and forth to Winnipeg for a bit last year (28-hour drive) and would just pack my food. Favorite food on the go is crispy bacon.

Steve: Gas station (you know the clean rest rooms and acceptable food). Then consume on the commute.

Question: *What are some possible uses for reverse osmosis (RO) reject?*

Jay: It all depends on the quality and system metallurgy where you want to use. We have one account where we put a water softener before our RO and then use the concentrate as make-up to a cooling tower, but the tower and system had to have the right metallurgy. We also have 5 minutes of the backwash from the water softener going to the tower and 10 minutes of the fast rinse. We have also used RO reject in once-through cooling of another process operation. So it is like anything else, you must know full water quality analysis and completely about the system where you are going to use this water.

Alfonso: Other potential uses are:

- Ethanol fermentation
- Aquaculture/habitat/brackish wetlands
- Recovery of specific chemicals that can be used by various industries (KCl, $NaCl$, Na_2SO_4, Na_2NO_3, $MgSO_4$, K_2SO_4, $Mg(OH)_2$, and others).
- Use of the brine in an industrial process (electrolytic production of Cl_2 and $NaOH$)
- Production of electricity from a solar brine pond
- Brine shrimp production
- Algae production
- Irrigation of halophytes for animal feed
- Toilets and urinals
- Dust control

Bill: Add a storage system and pump on a float switch and use the concentrate water for irrigation as long as the salt concentrations are low.

Faheem: I had worked in a company where there was a three-stage RO plant. The first stage was used as boiler feed water, the second stage as process water and in PHEs for heat transfer, and the third stage (TDS 5,000 ppm) considered as a reject stream was used in gas washers/scrubbers and for various cleaning purposes.

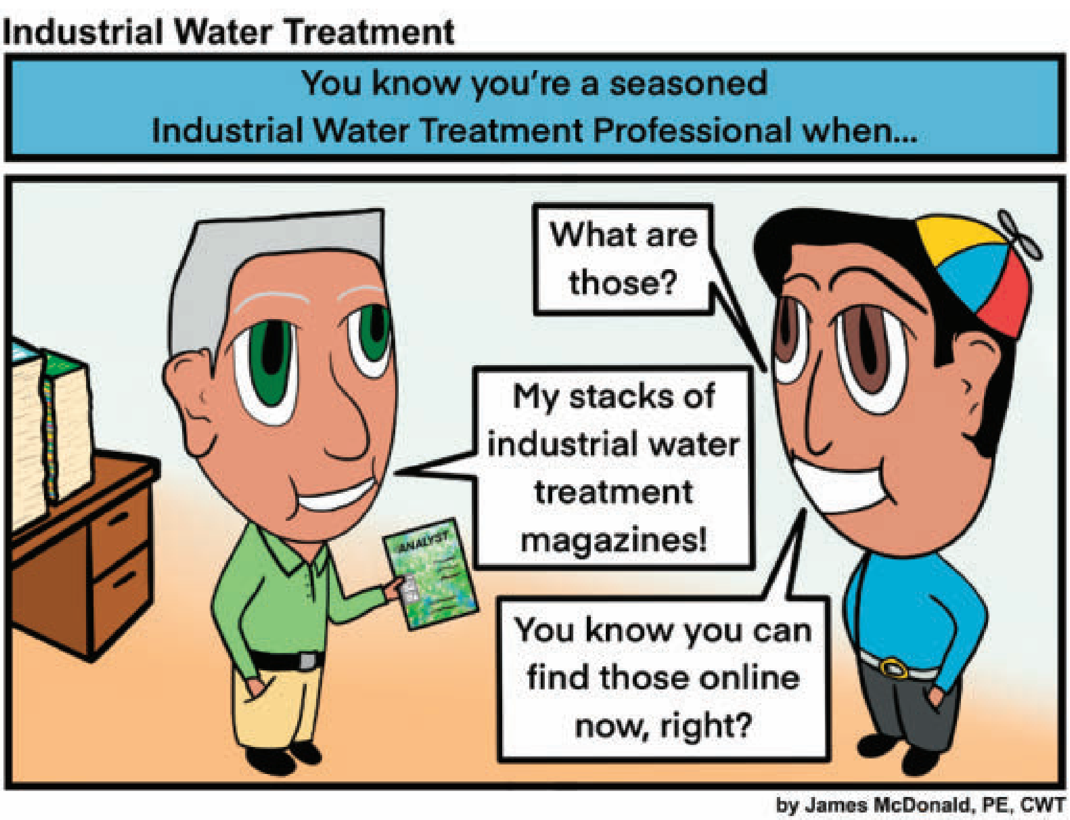
John: From my dark past in the paper industry, reject water went to the pulpers or the pulp mill.

Dennis: Our Carwash Customers use a second tank, float, and pump to collect the concentrate and send it back to the wash. Since most carwashes use a municipal supply to feed the RO system (spot free rinse). The water is still clean enough coming out of the reject line for the initial part of the wash. It is not wasted at all.

Question: *What can cause overflow conditions in a cooling tower?*

Shawn: So many things, ha-ha. I feel like I've seen it all over the years, but I'm sure something will surprise me again at some point. Luckily, we're fortune to live in the day and age of remote monitoring. This has helped me alert many of my plants and catch water overflow quickly, saving water, chemistry, and protecting assets, especially with systems and applications feeding off "real time" sensors/probes (ORP, PTSA, and others).

Zahid: I am very well aware about this issue and facing



on my site from last 3 years. The partial load of plant can cause the extra consumption of chemicals, water loses, and power loses due to a little mistake during the commissioning. The cooling tower is still over flowing. The make line was installed at a lube oil cooler of a turbine and after cooling it was connected with return header of a cooling tower due to temperature demand. We are not able to minimize raw water flow so that this excess amount of water can cause over flow, water loss, chemicals loss, and energy loss.

Syed: I think condenser water pumps used that are oversized can cause overflow in a cooling tower.

Phil: My favorite is when the operator puts a fire hose or garden hose in tower to keep usually undersized machines cooler.

Ric: Uncontrolled make up.

Tim: Scale clogging the nozzles on the hot deck.

Darius: The ball float is no longer attached to the valve arm.

Dennis: Faulty make up water diaphragm.

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