# Real-time Monitoring of Legionella in Casthouse Water Cooling Systems

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**Abstract**

The Direct Chill (DC) casting process uses water to extract typically 95 % of the heat from the molten aluminium and control the solidification process. When the casthouse is equipped with an open recirculation system (i.e. cooling tower, lubricant separation unit, etc.), it represents a high risk for the growth of *Legionella spp* because the overall conditions are favourable. In addition, the cooling tower are prone to generate aerosol that will disperse and could transport the contaminated water. *Legionella spp* is a family of pathogenic bacteria that is responsible for Legionellosis. In Europe, Australia, and the USA there are about 10–15 cases detected per million population per year. The transmission is observed by inhalation of contaminated bioaerosols.

The owner of the casthouse may have legal obligation to manage and monitor the presence of *Legionella spp* in their water-cooling system. The detection must be addressed quickly with curative actions that will affect the water chemistry and related quality and stability. The water chemistry variation of the cooling water could also significantly influence the water quenching power and impact DC casting performances. Real-time monitoring allows a better control of the water chemistry (e.g. no shock treatment) and quenching power that reduces variation on the overall DC casting process.

This paper will present the advantages of real-time monitoring that can detect the presence of *Legionella* by measuring the concentration of a specific bacteria namely the *Legionella pneumophila*. The measurements can be done directly on site with results available within 4 hours compared to 14 days traditionally. This makes possible quicker corrective actions and eliminate the risk of outbreak. ,

Rio Tinto Aluminium was the first industry to demonstrate the feasibility to measure the presence of *Legionella*, using the BioAlert$^{TM}$ technology, in an industrial environment. The applicability of this technology to establish a control chart based on the daily results improved considerably the water stability and lowered the risk of *Legionella* exposure. In addition, it also contributed in better understand the bacteria metabolism, and its influencing factors, to improve operational practices and reduce the overall impact on production.

**Keywords:** Legionella, BioAlert$^{TM}$, Real-time monitoring, Quenching power DC casting, Water treatment system.

## 1. Introduction

It is a common misconception that water used to feed a process system is pure and safe. It is not sterile, though. Because waterborne bacteria like *Legionella* can spread and become dangerous for human health, water management program is essential.

*Legionella* bacteria are at the cause of Legionnaires' disease, a severe, acute lung infection with pneumonia-like symptoms, which can be fatal for immunodeficient individuals. The *Legionella* genus (*Legionellaceae* family) numbers 59 species and 70 serotypes, of which nearly half have been linked to human diseases [1]. *Legionella* is found in most natural and engineer water system such as cooling tower. They typically grow in humid conditions with temperatures between 25 and 45 degrees Celsius, which makes contaminated water cooling systems prevalent. The *Legionella pneumophila (Lp)* genus is associated with over 85 % of all infections. They belong to 15 different serotypes, and serotype 1 represents more than 61 % of reported cases [2]. In the United States, reported *Legionella* cases have increased ninefold since the year 2000 (Figure 1) [3].

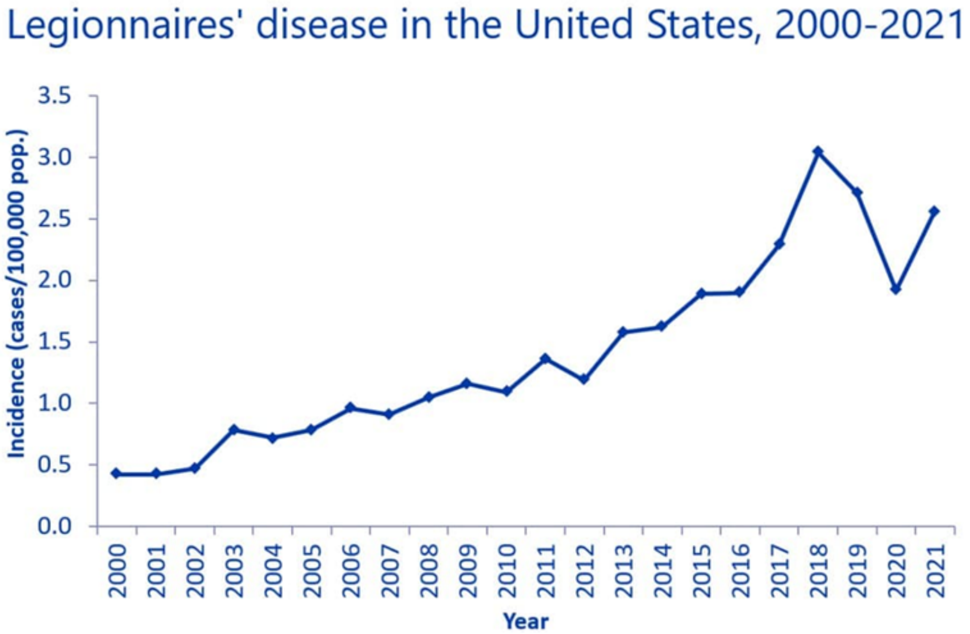



**Figure 1. Increase in cases of Legionnaires' disease in the United States, 2000-2021.**

In direct chill (DC) casting, the solidification phase requires process water in order to extract heat from the molten aluminium. Quenching power can be defined as the heat-extracting ability of the water [12]. Cooling tower is a recommended equipment for the casthouse water cooling system due to their overall performance within the operational temperature range (from 70 ºC down to 27 ºC). Aerosolized water can be released into the atmosphere by cooling towers. At Rio Tinto Aluminium Quebec, the majority of the water casthouse designs are open loop recirculation system (i.e. cooling tower, lubricant separation unit, etc.) as opposed to closed loop cooling system with heat exchangers and chillers that separate cooling and process water (Figure 2). The same procedures for operation and maintenance apply to both kinds of loop circuits. Closed-circuit cooling towers, on the other hand, prevent atmospheric exposure of the DC process cooling water. Open recirculating system represents a higher risk for the growth of *Legionella* because the overall conditions are favourable (same casting process water circulating through the cooling tower, more complex chemistry water due to a diversity of contaminants, complexity of the chemical treatment strategy, biofilm easily developing in the cooling tower, etc.). In addition, the cooling towers are prone to aerosol generation, which can disperse and transport the contaminated water with *Legionella.*. They have the potential to expose a large number of people to contaminated aerosols over long distances (up to 10 km) [4, 5].

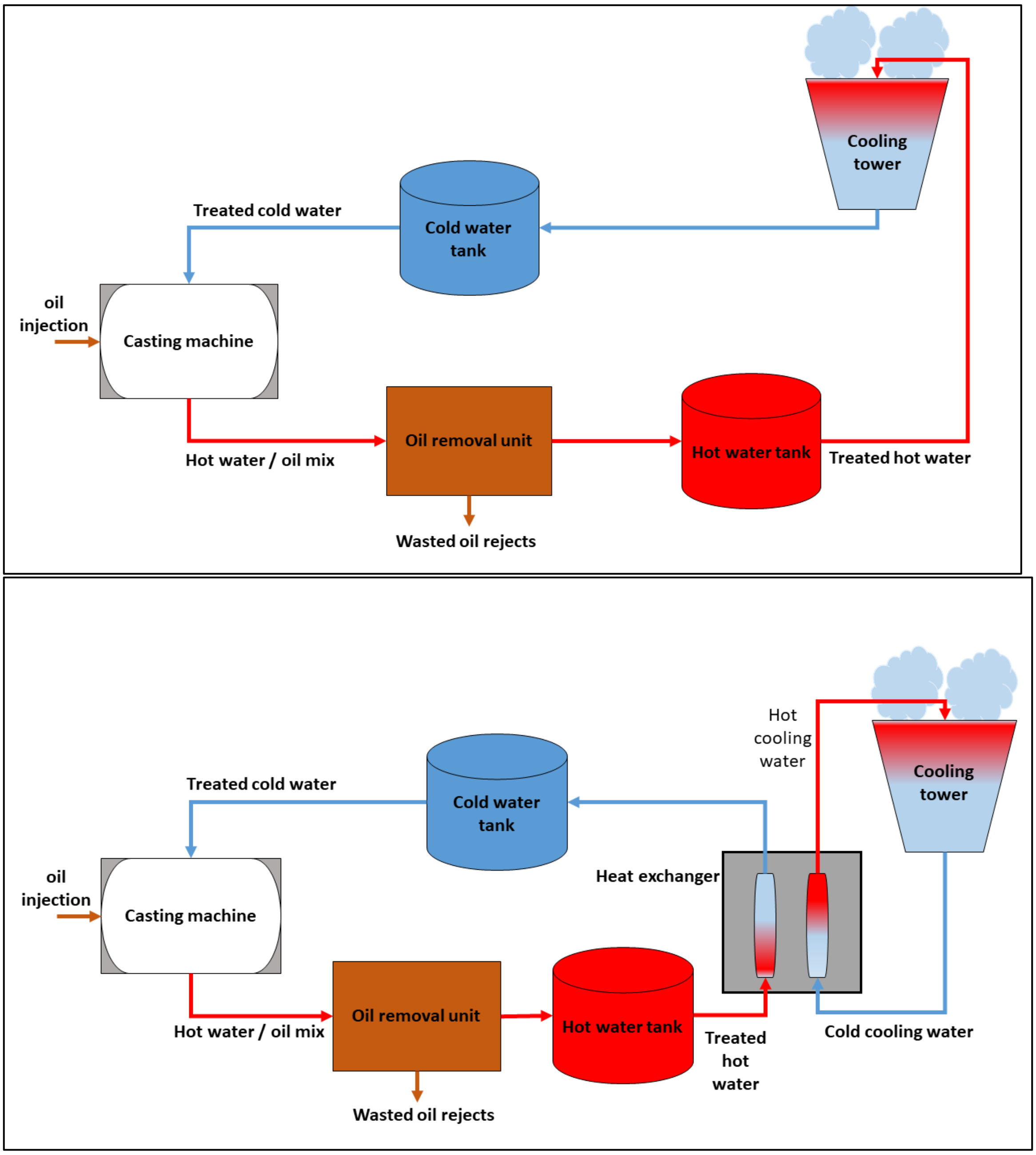



**Figure 2. Two types of cooling recirculation systems.**
**Top: Open-loop cooling, Bottom: Close-loop cooling (Original figure).**

*Legionella* monitoring guidelines are constantly evolving with new knowledge discovered in the last 10 years. Many countries are adopting policies or standards to help achieve *Legionella* control and target the global operation of cooling towers. Monitoring procedures and actions should be implemented to address the presence of *Legionella* and reduce the risk of exposure to the bacteria.

Owners of water-cooling facilities with cooling towers may be required by law to monitor and manage *Legionella* levels in their systems in accordance with existing public health standards. Table 1 presents the mandatory legal compliance in Quebec [6]

**Table 1. Legal compliance regarding the control of *Legionella* contamination in water cooling systems in Quebec.**

| Legionella pneumophila contamination level | Risks | System condition | Specific action |
|---|---|---|---|
| < 10 000 CFU/L | Negligible | Under control | Normal operation |
| 10 000–100 000 CFU/L | Low | Under monitoring | Process optimisation |
| 100 000–1 000 000 CFU/L | High | Early contamination | Preventive actions: identify causes, apply corrective actions, effectiveness check |
| > 1 000 000 CFU/L | Critical | High contamination | Immediate corrective actions required: shut down airflow (fans), apply emergency decontamination (12-72 h), effectiveness check |

*Note: CFU = Colony Forming Units*

In order to reduce *Legionella* contamination hazards and their negative repercussions, on-line quantitative polymerase chain reaction (qPCR) detection and monitoring system can lead to improved risk control. In order to evaluate the advantages and limitations of the technology in a heavy industry setting, three monitoring instruments were deployed in three separate aluminium smelters in the Saguenay-Lac-Saint-Jean region of Quebec, as part of the technological showcase project [7]. This patented technology, BioAlert Lp15$^{TM}$ [8], measures quantities of *Lp* bacteria from serotypes 1-15, living or dead and whose form is intact, by capturing them in a filter and quantifying the genetic material (DNA). Therefore, the qPCR method tends to overestimate *Legionella* counts, and even though the results are not directly related [9] to Legionnaires' disease risk; it can be an indicator of the effectiveness of control measures and water treatment efficiency in the cooling water system.

The objective of on-line monitoring is to trigger a problem-solving process to quickly identify the root cause of *Lp* detection. The primary objective is to make minor process adjustments with minimal disruption to the chemistry and the quenching power. The advantage will be consistent and stable process water for casting.

## 2. Method

The standard method, which is also the reference method herein, is the culture method (AFNOR NF T90-431) [19]. Water-cooling system samples, with or without dilution, are deposited on specific culture media to foster the development of *Legionella spp*., the full range of *Legionella* species. The colonies are counted, and the results are expressed in CFU (Colony Forming Units)/L. Subsequent steps are needed to confirm the presence of *Legionella pneumophila*. Bacteria development requires several days and, consequently, results are usually only available in 5-10 days' time. In theory, only viable *Legionella* cells can develop in a culture environment.

Genetic material quantification (qPCR) in genomic units (GU/L) has gained in popularity as it yields faster results. However, the method quantifies the full range of genetic material in the samples: living bacteria, dead bacteria (free cell DNA), and viable but nonculturable bacteria (VBNC). The on-line technology showcase was conducted in 2020 and the result are available in an earlier publication given at The Minerals, Metals & Materials Society (TMS) in 2022 [7, 9]. The industrialization phase is completed, and the operational teams are using all three installed units on a daily basis. They are still regularly performing plate culture controls to ensure equivalence between the two methods or a change in the microbial matrix for the water system. To ensure the strength and validity of the technology during the showcase in 2020, the BioAlert Lp15$^{TM}$ (Figure 3) results were compared weekly with the results of culture tests (AFNOR NF T90-431) [19] by an ISO/CEI 17025: 2005 accredited laboratory (Genochemia, Saguenay) [7].

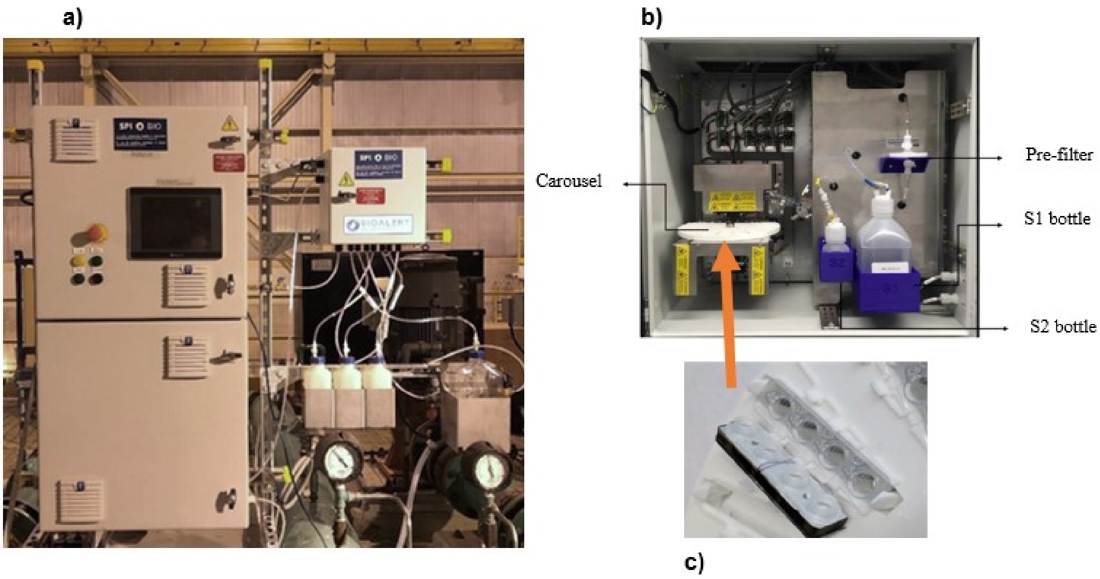



**Figure 3. Presentation of the BioAlert Lp15$^{TM}$ system. Left: a) Outside view, including the power supply housing (top), sampling and analysis housing (bottom), and external module, Right-Top: (b) Inside view, including the pre-filter, reagent bottles, and carousel, Right-Bottom: (c) test cartridge.**

The conductivity measures the dissolved ions and molecules in water, which affect its ability to conduct electrical current (SM 2510-B) [20]. Free chlorine refers to both hypochlorous acid (HOCl) and the hypochlorite (OCl-) ion or bleach (SM 4500-Cl G) [21].

For most of the laboratory chemistry tests conducted on the casting water system from the Grande-Baie site, especially those related to conductivity and free chlorine laboratory tests, the grab water sample were taken at the same sampling point as the on-line qPCR units which is after the cooling tower.

At the Laterrière site, the sampling point for the qPCR on-line is located after the cooling tower A. Tower A and B are connected on the same water system for this site. However, at the Alma site, the sampling point for the on-line qPCR is before the cooling tower.

## 3. Challenges

The casting of various aluminium products requires treated and cooled water, to which casting oil is added to lubricate the casting molds. The water used in casting is heated and charged with oil. It travels through an oil-removal equipment. After receiving a chemical treatment, the process water is sent through cooling towers, pipes, tanks, and pumps back to the casting machine.

For decades, the aluminium industry has been very interested in how heat transfer occurs during DC casting and how the temperature of the casting and the water chemistry affect this process. Numerous studies have attempted to demonstrate the relationship between water chemistry and heat transfer [11-16]. These studies seek to demonstrate and assess how each water indicator, in its own distinct manner, can influence the heat extraction ability, defined as the quenching power.

The chemical matrix of the process cooling water is also favorable for the proliferation of *Legionella* pathogens due to factors such as operating temperature range, system design, flow rate variations depending on production needs, nutrient availability, biofilm formation, and dead arms or stagnant water. Process water is a complex component for a cooling system. The challenge lies in maintaining keys indicators within a dynamic operational framework. Factors such maintenance, equipment malfunctions or shutdowns and compliance with environmental and hygiene standards all play a role in affecting the chemistry of the water, its quenching power and the potential for *Legionella* growth.

## 4. State of the Art

The system's chemistry baseline must be capable to identifying variation and noise from all maintenance and operational activities. When using standard chemistry applicable to tap and process water such as pH, hardness, alkalinity, conductivity, turbidity, oil & grease content, total suspended solids or total dissolved solids, chlorine, iron, aluminium, sulphate concentration etc., determining which of these dynamic mixes is actually causing the quench to vary will be challenging. With a well-established daily inspection and follow-up analysis, it is easier to minimize variation and process noise when applying corrective actions. The main goal is to achieve as consistent cast water quality as possible [10].

It has been shown that advanced water treatment chemistry, coupled with innovative monitoring and chemical control automation, can improve the consistency of the DC casting process. The success of the program water management strategy may be verified by tracking all the analyses that are carried out. Moreover, it is necessary to identify the factors contributing to *Lp* growth and the effectiveness of corrective actions.

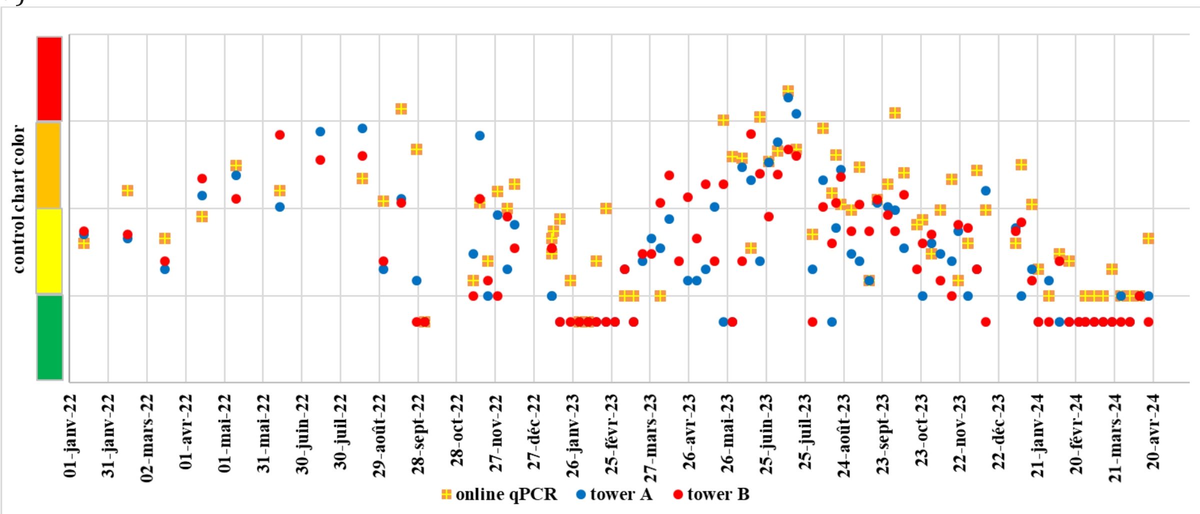
## 5. Results

### 5.1 Plate Culture and on-Line qPCR Results Trends

Numerous research has compared the plate culture and online qPCR methods. [17]. The patterns of qPCR and culture results follow the same trend for the three sites. Figure 4 shows examples from two of the three sites where the on-line qPCR and culture results follow the same trend. For trend in Figure 4a with towers A and B (related to the same water system) when *Lp* was detected by culture (sampling at the outlet of both cooling towers), the pattern of results for on-line qPCR (sampling at the outlet of cooling tower A) followed the same trend. Even though the sampling point of cooling tower B was different from the qPCR sampling point, it is connected to the similar water system as tower A.

Figure 4b shows that after the start-up of the additional cooling tower (connected to the same water system) used only from May to November, the *Legionella* counts increased significantly. Those measurements showed that there was more fluctuation in the system with the two cooling towers operating, and that the counts rose as the machinery started up. The start-up and cleaning cooling tower procedure were the root cause of higher level of detection. This also highlights another finding in both water system, high qPCR results often precede a higher level of culture detection, even when there is no culture detection at the same time frame [17].

a)




(b)

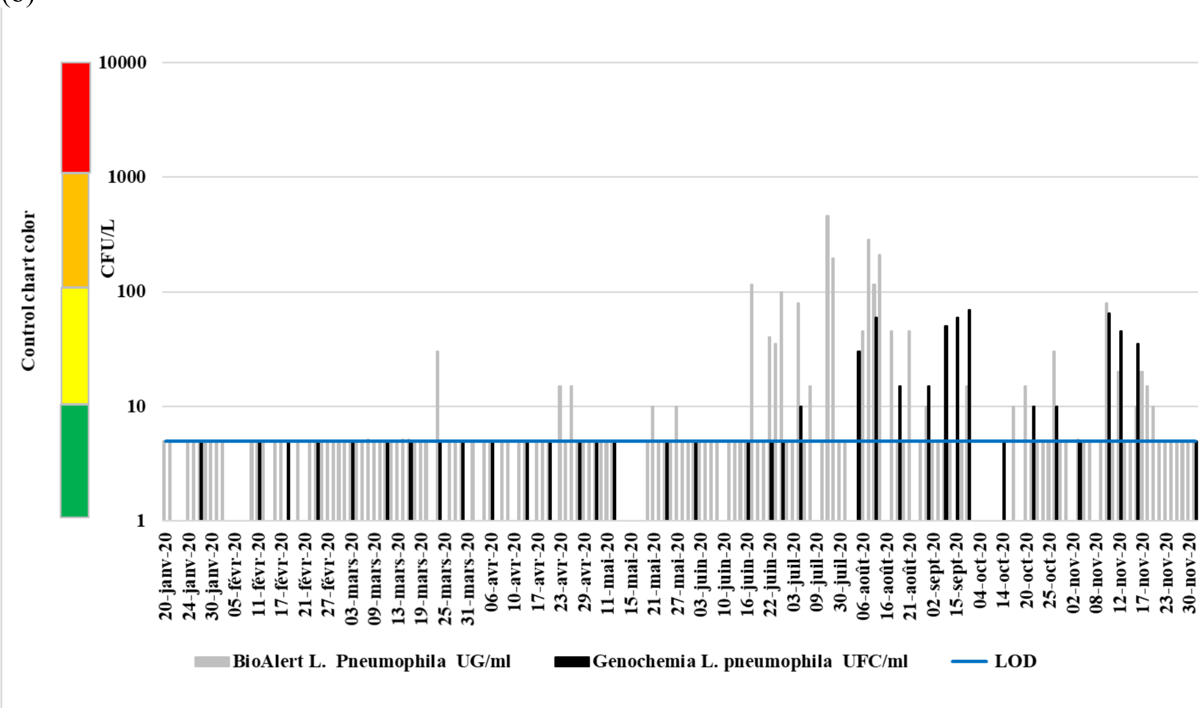
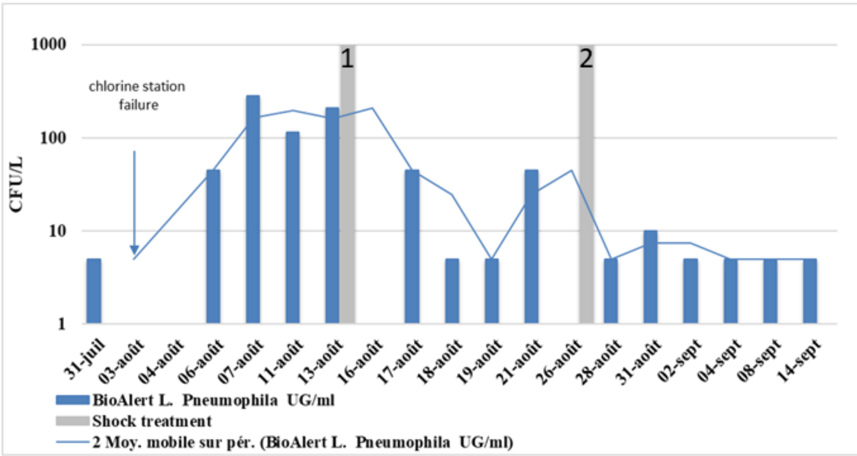



**Figure 4. Top: (a) Plate culture and qPCR results for cooling tower A and B at Laterrière water casting plant, Bottom: (b) Chronological evolution of the BioAlert Lp15™ *Lp* vs plate culture results at Grande-Baie casting water-cooling system.**

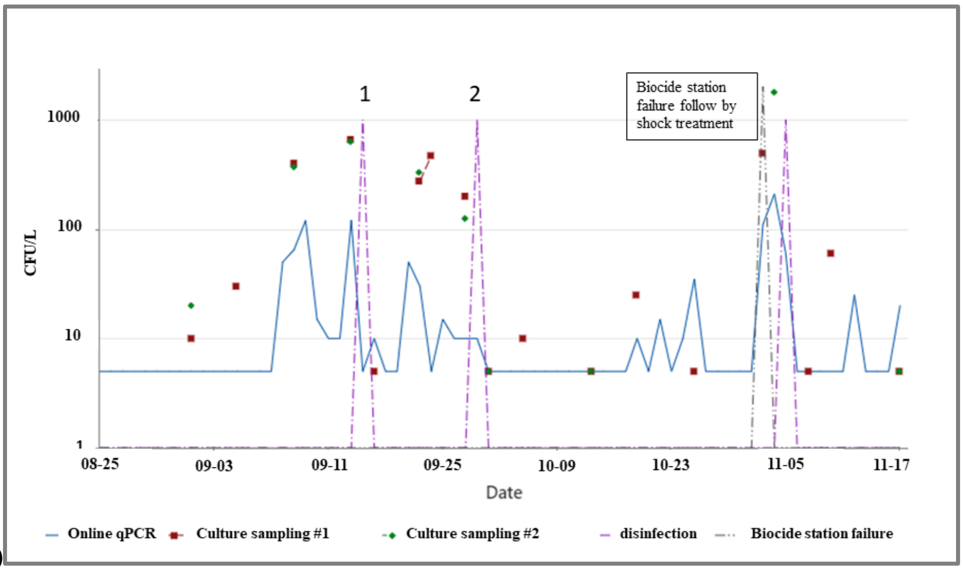
## 5.2 Biocide Station Failure and Shock Treatment Impact

Figure 5 shows the effects of discontinuing biocide injection (pump failure), as well as the impact of shock treatments on *Legionella* level at Grande-Baie and Alma water casting system. To get the detection at Grande-Baie below the threshold, two disinfections were required (Figure 5a). The root cause of higher *Lp* level was a malfunction of the biocide pump. In Figure 5b the data from Alma casting water system, includes plate culture from two different sampling point (cooling tower intake and outlet), with on-line qPCR monitoring sampling at the inlet cooling tower as well. The trend shows equivalence between the sampling points and the two detection methods.

With regard to the impact of shock treatment (September 11$^{th}$), a second treatment was carried out to reduce the detection of *Legionella* (September 25$^{th}$) because the level of *Lp* was still high following the first shock treatment. This was monitored using online qPCR. Another event happened on November 5$^{th}$, as shown in Figure 5b. The operational crew noticed that the biocide injection was not functioning during the weekend due to a breakdown, and on-line qPCR results was extremely high. The same day, there was a sampling taken for plate culture. They immediately applied a disinfection treatment as a curative action. After the disinfection treatment was completed, the plate culture result was obtained seven days after the sampling, demonstrating to the public health that the remedial activity had been effective enough to lower and control *Lp* detection. The pattern shown in the online qPCR findings was also observed in the three plate cultures obtained subsequent to the occurrence




(a)




(b)

**Figure 5. Top: (a) *Legionella* count variations in process water treated at the Grande-Baie smelter due to the failure of the chlorine pump, corrective actions, and shock treatment, Bottom: (b) *Legionella* count variations in process water treated at the Alma smelter, Biocide station failure and disinfection efficiency.**

In Figure 6, five shock treatments were applied to the cooling water system between May and August. This illustrates how it can also influence the measurement of conductivity in the water system.

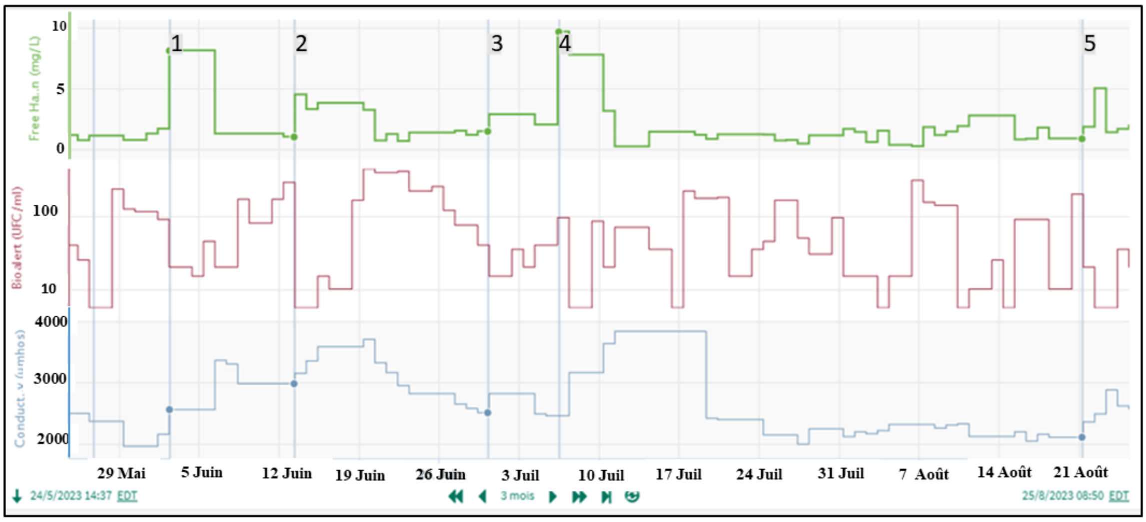



**Figure 6. qPCR *Legionella pneumophila* count variations in process water treated at the Grande-Baie smelter: disinfection efficiency and impact on conductivity.**

### 5.3 Introduction of New Chemical Strategy

The impact of adding a new chemical (biodetergent) at the Grande-Baie and Laterrière locations is demonstrated in the following example, as shown in Figures 7abc. Prior to increasing the dosage of the new chemical, keys indicators used to assess efficiency were on-line qPCR *Legionella* detection, free chlorine levels and plate culture. It was discovered that the *Lp* detection rate was directly related to the chemical dosage. Rather than administering a shock treatment or raising the biodetergent dosage, the operating team could wait for balance and stabilization or just make faster and smaller adjustments when free chlorine was getting lower. Without significant chemical interference, they were able to maintain *Lp* detection within the lower limits. It is now possible to adjust the chemical dose based on the system's reaction rather than strictly following a fixed schedule.

The Laterrière water casting plant's introduction of a new chemical into the water system serves as another illustration concerning Figure 7c. *Lp* detection for both techniques significantly decreased as a result of the nearly instantaneous effect. The chemical addition had to be discontinued since the increase of the dosage was since simultaneously dispersing the oil in the water, decreasing the efficiency of the oil removal unit, and jeopardizing the environmental compliance with effluent. Even after ceasing the injection, the impact persisted, as evidenced by the low results on plate culture, although detection increased with qPCR. It was only a matter of time before detection on plate culture occurred later as shown. Additionally, it is highly suggested that a single sampling point is not representative of a complex water system when variations in *Lp* levels are observed across two or more sampling locations.


**Figure 7. Top: (a) Effect of adding new chemical at Grande-Baie smelter, Middle: (b) Impact of adding new chemical (b) at Grande-Baie smelter, Bottom: (c) at Laterrière smelter.**

## 5.4 System or Equipment Failure

Figure 8 shows the potential side effects of an equipment failure indirectly unrelated to *Lp*. The root cause analysis of the increased *Legionella* detection from the online qPCR monitoring pointed to a pump failure at the polymer injection station. Due to the thicker biofilm produced by the lack of polymer injection and the hydraulic design, *Legionella* could thrive in this matrix. To reduce the qPCR detection, two shock treatments were needed.

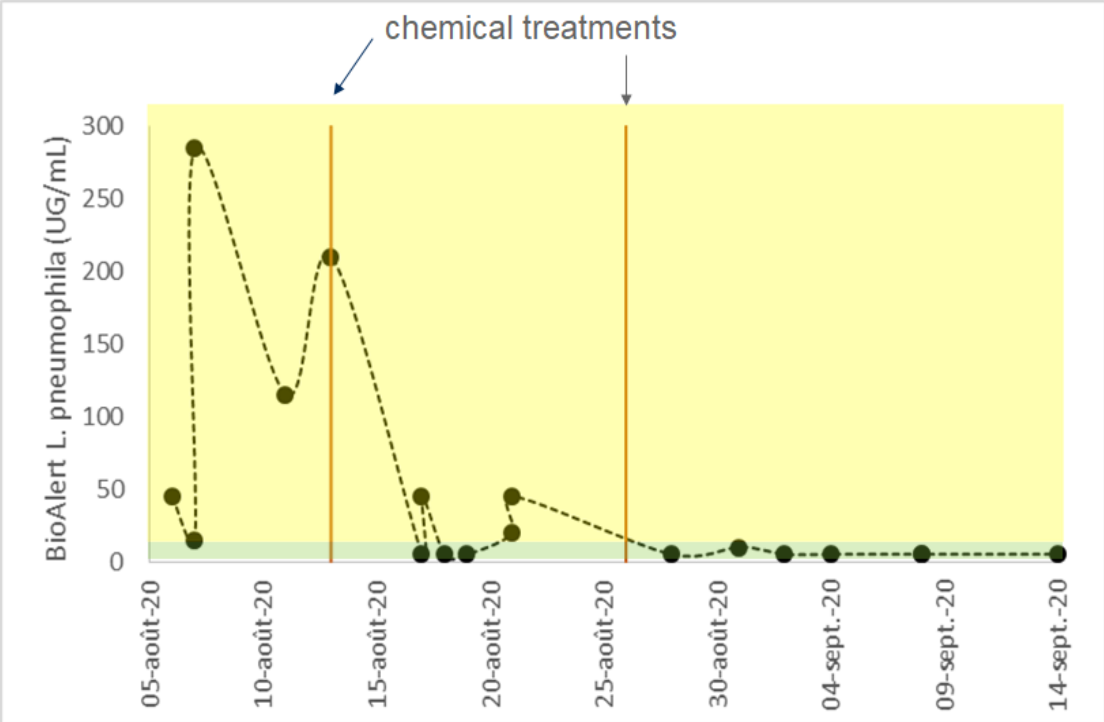



**Figure 8. *Legionella* count variations in process water treated at the Grande-Baie smelter: Polymer pump failure detection.**

## 6. Discussion

Result of *Legionella* readings from the plate culture are only available seven to days after sampling. If corrective actions are required, such as shock treatment, disinfection or shutting down a cooling tower for mechanical cleaning, the water chemistry will suddenly change. This can lead to issues with producing and adjusting casting recipes. Importantly, by the time the results are available, it may already be too late. The *Lp* concentration may have changed and corrective actions taken by the operations team may be ineffective in reducing the risk of exposure. Depending on the system's half-time cycle, these changes can last from days to weeks, resulting in fluctuations in quenching power. Since culture plates are lagging indicators, they may not be the most effective tool for fine-tuning the water management program. The question of detecting the underlying cause is not addressed

If the main objective is to quickly detect unexpected *Lp* levels changes in a cooling water system, qPCR-based techniques are the best option because result can be obtained within hours [18]. Even though water samples are collected at various points in each of the three locations where the system is installed, the patterns between qPCR and culture follow the same trend. Based on the results, the *Lp* testing method used for on-line qPCR monitoring was accurate and allowed for better control of the risks related to *Lp* levels. It demonstrates its ability to identify an increasing trend in *Legionella* counts, enabling quick planning and execution of corrective measures. With a shortened response time to 4 hours, the units allow for multiple daily measurements to map the system.

This on-line monitoring method provides results that are more sensitive than plate culture alone. It also allows operators to have better control over the process without unnecessarily disturbing the water matrix chemistry. This improves operational practices and deepens the understanding of processes in the water casting plant. If a shock treatment is needed, on-line qPCR monitoring can identify the effects step by step. Often, more than one shock treatment is required when high level of *Lp* is detected. The near real-time analysis provided by this monitoring is helpful in identifying the operational tasks that initially resulted in the *Lp* detection and in facilitating prompt adjustments to operations. It also highlights the challenges of maintaining multiple cooling tower in the same water system. Finally, it provides a significant incentive to avoid non-compliance by reducing the risk of *Lp* exposure from complex water systems

By recognizing drift in the system, it also helps optimize activities such as equipment start-up practices around the process water system, and better achieve and prioritize maintenance failure and operations. It enhances overall water management and chemical strategies by enabling a better understanding of the factors that influence *Legionella* proliferation in the system. The bacterial matrix responds more quickly to changes in the system than other parameters do, and online monitoring makes it possible for operators to better manage the water system. Even in case where it is not possible to change the design, corrections can be made and different innovative ways can be experimented with. It is possible to measure performance faster and assess the risk associated with *Legionella* detection.  On-line monitoring puts new lenses on system management optimization. The following statement can be taken to mean: "*You can only control what you can measure*".

When trying to connect chemistry issues with pattern in daily laboratory tests on grab samples, it can be challenging for managers, technical teams or supervisors in cast production to pinpoint shifts in the water system. This task becomes even more difficult if they are unfamiliar with the process. Vigilance has been increased by using a dashboard for the water casting system. This tool has allowed for adjustments and follow-up of the impact at the DC enabling tracking changes in chemistry and potentially establishing a connection with water quenching power. Instead of just observing various trends, operators can quickly evaluate stability of water chemistry and make necessary corrections (Figure 9).

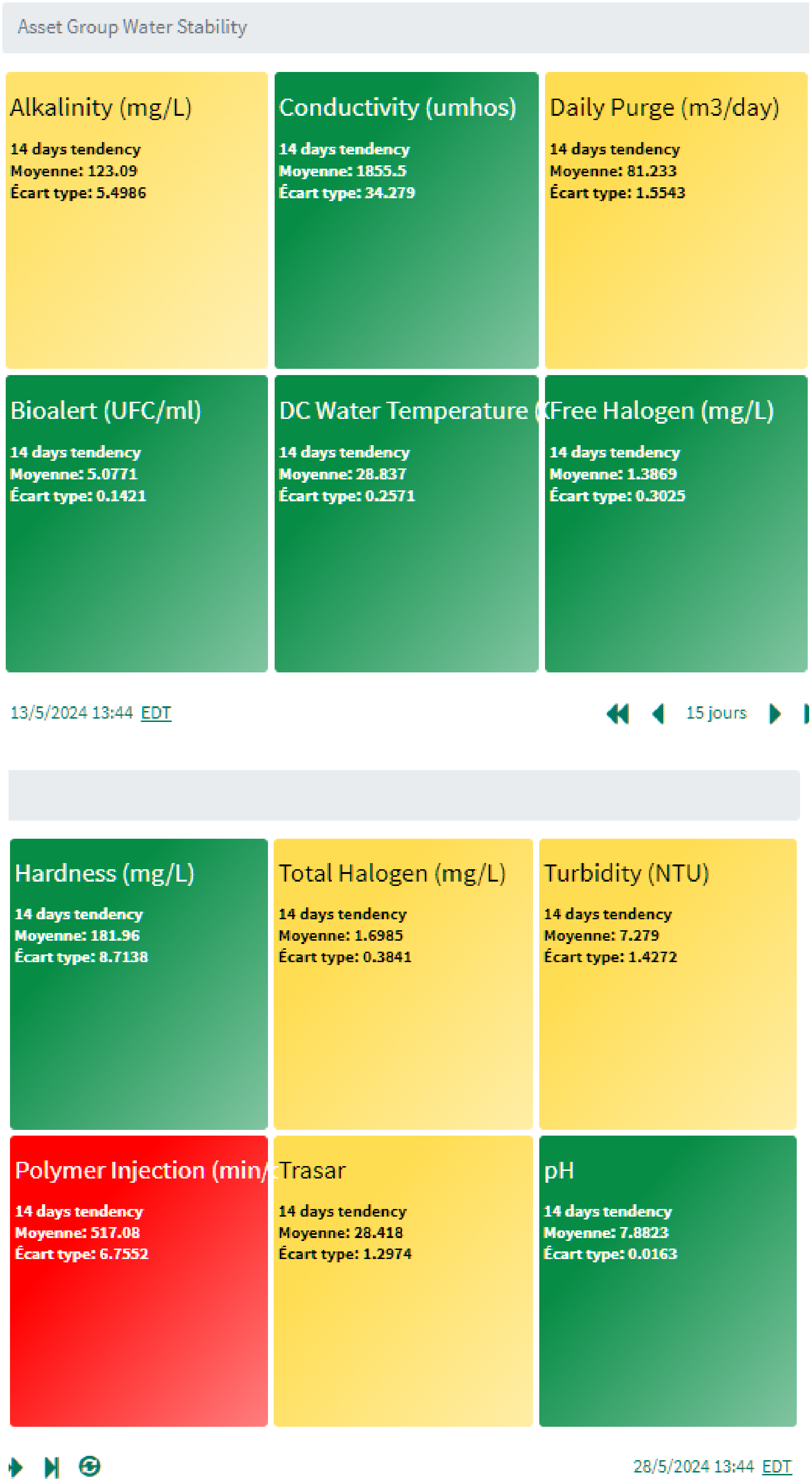



**Figure 9. Dashboard at the Grande-Baie smelter: Process water chemistry analysis. A full dashboard screen was split in 2 for readability.**

## 7. Conclusions

Proactive water management is essential, but what does it involve? Sustainable performance of a water-cooling system includes three aspects: operation, chemistry, and equipment. These components are all interconnected, as shown in Figure 10.

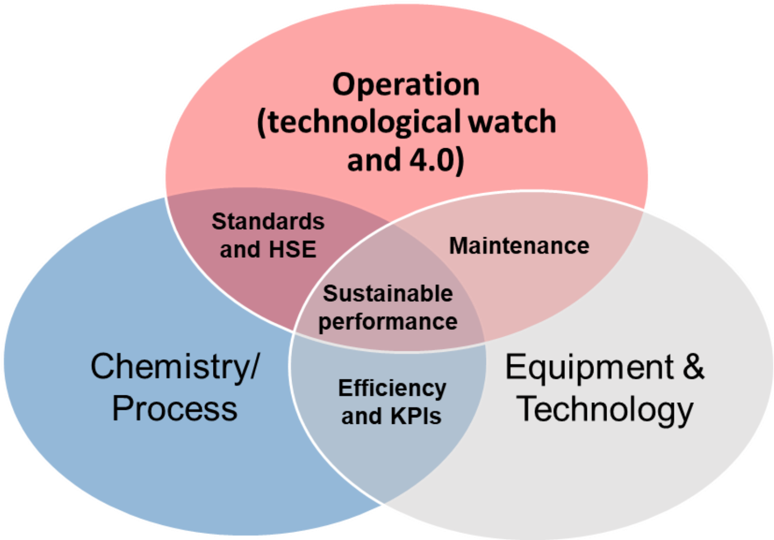



**Figure 10. Sustainable process water system management (Original figure).**

Because the tap water source is not sterile, water management programs are necessary to identify, prevent and control the risk of contracting waterborne diseases from water. *Legionella* monitoring guidelines and policies are constantly evolving. System design also affects the choice of sampling locations, frequency, and monitoring technique. Along with the standard objectives of preventing corrosion, scale, microbiological development, and fouling, an effective water treatment program should additionally address asset maintenance, cooling capacity, and the avoidance of unscheduled shutdowns. These goals will be more successful if they are clearly stated and well-planned. The program will perform better by delivering a consistent quench rate with a predictable impact on production. [10].

One of the major challenges in environmental testing has been the ability to consistently detect *Lp* within the constraints of the traditional plate culture approach for process water. Results from the qPCR approach using BioAlert Lp15$^{TM}$ provide results in less than 4 hours, and it is both sensitive and specific.

From the observations and analysis of three different cooling tower systems, it is evident that none is ideal, and each has its own challenges in terms of controlling the risk of exposure [17]. Research has confirmed the advantages of on-line qPCR monitoring, prompting each site team to develop their unique action plan. They are now sharing their lessons learned and observations. The combination of a culture-based method and an on-line qPCR-based method is now a standard practice for controlling the process water. This allows for corrective actions to be taken more quickly and at the right time, ultimately reducing the chemical upsets needed to maintain a high level of performance in aluminium casting production.

Monthly compliance with single-point sampling may not be sufficient to effectively monitor a complex system that includes cooling towers. While the cooling tower is the primary source for *Legionella* dispersion by aerosol, the actual contamination occurs elsewhere in the system and is released from the biofilm.  Systems at high risk for biofilm development will exhibit varying levels of *Legionella* detections despite the use of culture, qPCR or other detection methods. Implementing closer on-line monitoring allows for a more rapid response to prevent *Legionella* from reaching public health threatening levels. The selection of multiple sampling points is crucial to confirm where the highest levels of *Legionella* detection are in the system to better identify the root cause of detection.

Validating various on-line monitoring systems in complex water systems will presents a significant challenge, but it is an undeniable necessity to improve operations and guarantee a consistent and stable quenching water for aluminium casting production. This will drive the exploration of alternative chemistries and the adoption of innovative equipment that can greatly enhance performance and production compared to traditional water treatment strategies, all while taking into consideration environmental and human health perspectives.

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