Non-Chemical Disinfection & Dechlorination to Protect RO and Demineralizer Treated Boiler Make-up Water

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ABSTRACT

Chlorine and biocides have traditionally been used to mitigate biofouling and manage microbial induced corrosion, and are commonly injected into the feed lines of the water treatment process at power plants to reduce the microbial load. However, when the water treatment process consists of reverse osmosis (RO) trains, it is important to make sure the membranes are protected from oxidation by chlorine. Therefore, dechlorination is undertaken to remove free chlorine compounds from the feedwater in order for the RO trains and other chlorine-sensitive equipment to operate properly.

In this paper, a technology is evaluated which uses broad-spectrum ultraviolet (UV) lamps for the reduction of chlorine and disinfection. Through photodecomposition by UV light, the system decomposes the free chlorine oxidant. Additionally, the technology provides disinfection to reduce the membrane biofouling potential.

The core of the discussed UV system is its water disinfection chamber made of high-quality quartz surrounded by an air block instead of traditional stainless steel. This configuration uses fiber optic principles to trap the UV light photons and recycle their light energy. The photons repeatedly bounce through the quartz surface back into the chamber, effectively lengthening their paths and their opportunities to inactivate microbes.

The efficacy of the technology, coupled with its specific operating principles and ease of use, allows for a unique non-chemical approach to dechlorinating and disinfecting boiler make-up water.

INTRODUCTION

Chlorine and biocides have traditionally been used to mitigate biofouling and manage microbial induced corrosion (MIC). As an oxidizer in aqueous solutions, free chlorine generating solutions such as sodium hypochlorite are commonly injected into the feed lines of the water treatment process at power plants to reduce the microbial load. However, chlorine is a strong oxidant that can easily damage the reverse osmosis (RO) membranes typically used in power applications.

It is important to make sure the membrane elements in the RO system are protected from oxidation by chlorine. Therefore, dechlorination is undertaken to remove free chlorine compounds from the feedwater in order for the RO technology and other chlorine-sensitive equipment to operate properly.

Chemical neutralization, through the injection of a sodium bisulfite (SBS) or sodium metabisulfite (SMBS) solution into the feedwater, is a common dechlorination practice in power applications. The difficulty of SBS/SMBS neutralization is that it is a chemically based approach that can foul membranes, acts as a food source for microbes, and has additional handling, storage, and operational requirements [1].

A 3 160 MW coal-fired power station faced frequent membrane and micron-filter maintenance and replacement as a result of bio- and solids-fouling. Over a three-month period (4 March – 30 May 2014) the facility evaluated a technology as a dechlorination treatment alternative that would enable them to replace the use of SMBS, reduce or eliminate the usage of chlorination, and achieve a non-chemical dechlorination process [2].

The evaluated technology uses proprietary broad-spectrum ultraviolet (UV) lamps for the reduction of chlorine and disinfection. Through photodecomposition by UV light, the technology decomposes the free chlorine oxidant in process water to protect RO membranes. Additionally, the technology provides disinfection to reduce the membrane biofouling potential.

ULTRAVIOLET TECHNOLOGY

The UV technology is a physical process for disinfection that exposes bacteria, viruses, and protozoa to germicidal wavelengths of UV light, measured as nanometers (nm), to render them incapable of reproducing or further infecting a water system. Through UV oxidation, UV light can also destroy chemical contaminants [3].

Medium-pressure (MP) UV lamps provide polychromatic UV light (200–415 nm), while low-pressure (LP) lamps provide monochromatic light (254 nm). The polychromatic nature of MP lamp technology enables the production of a high-density broad-spectrum UV light. Medium-pressure UV light inactivates a broad spectrum of bacteria, viruses, and organisms [4]. Additionally, the light emitted by MP lamps is within the absorption spectrum of free chlorine (200–360 nm), making it the ideal UV treatment for dechlorination applications [5] as can be seen in Figure 1.

Atlantium Technologies developed a proprietary MP lamp, which effectively "recycles" a required UV dose throughout the reaction chamber using a patented internal reflection technology similar to fiber optic science. The core of the Hydro-Optic™ (HOD) UV system is its water disinfection chamber made of high-quality quartz surrounded by an air block instead of traditional stainless steel. This configuration uses fiber optic principles to trap the UV light photons and recycle their light energy. The photons repeatedly bounce through the quartz surface back into the chamber, effectively lengthening their paths and their opportunities to inactivate microbes (Figure 2).

Maintaining a correct UV dose with any UV system is dependent on three parameters: UV intensity, water UV transmittance (UVT), and water flowrate. These parameters are dynamic and fluctuate, thus requiring continuous measurement. The HOD UV system uses a proprietary total internal reflection (TIR) based design that when coupled with the comprehensive monitoring of critical parameters in real time, allows the system to determine the actual UV power produced by each of the UV lamps and achieve and maintain the specified UV dose (Figure 3).

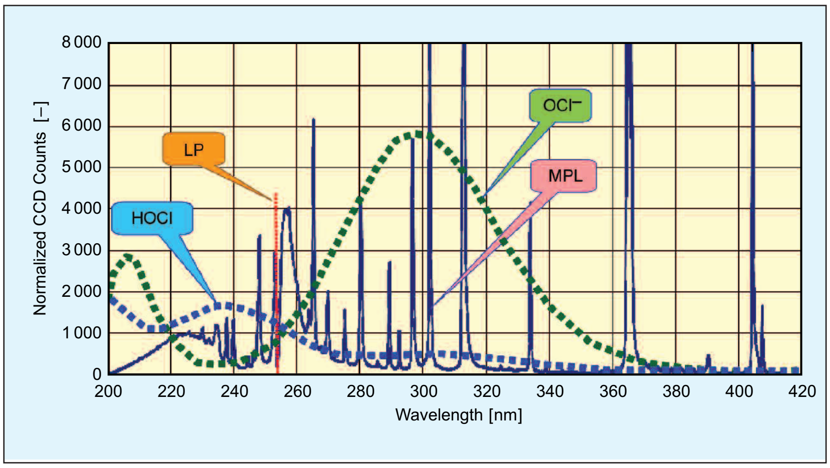

Figure 1:
The spectral match of LP lamps and MP lamps to the free chlorine absorption spectrum.
CCD charge coupled device
Note: The "single-line" spectral emission of LP lamps (vertical red line) and the broad spectral emission of MP lamps (dark blue curve) are overlaid on the absorption spectrum of the two free chlorine compounds.

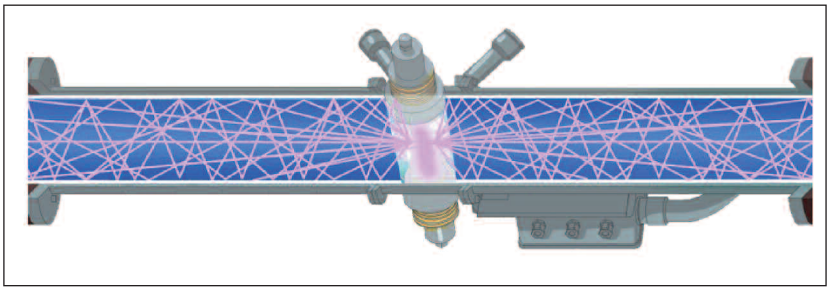

Figure 2:
Medium-pressure UV lamp and chamber.

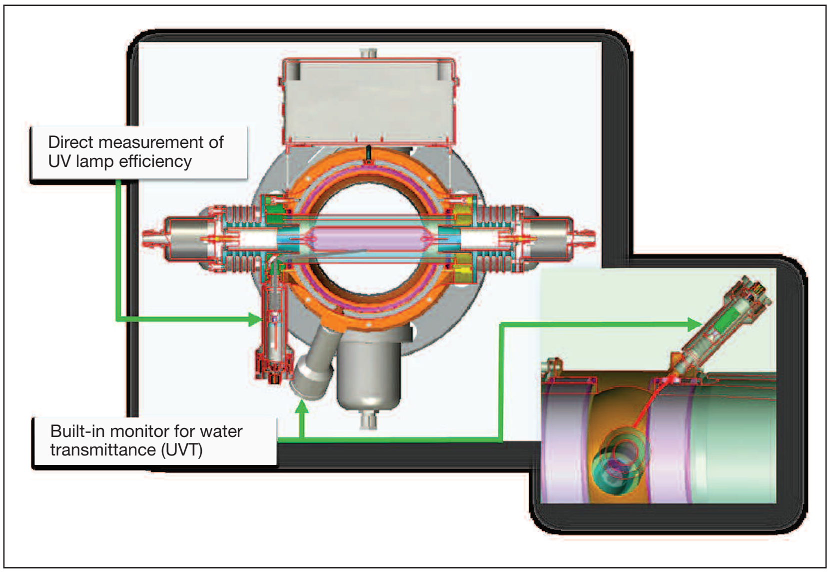

Figure 3:
Sensor configuration.

Research has shown the UV dose required for effective dechlorination by oxidizing free chlorine is significantly higher than UV dose rates commonly used in potable and wastewater disinfection treatment applications [4]. A UV dose rate of 100–200 $mJ \cdot cm^{-2}$ provides disinfection of deleterious microbes, including MIC, while also reducing and stabilizing the chlorine demand. A UV dose rate of 1 000 $mJ \cdot cm^{-2}$ replaces the use of SBS/SMBS and achieves a non-chemical dechlorination process to improve RO feedwater [6]. The disinfection and dechlorination applications can be provided through a single system or the applications can be separated with the use of a unique system for each.

Proprietary software enables the reactor to self-adjust and manage a "safety zone" so the HOD UV system continuously provides the minimum dose or registers and reports off-spec status when any of the critical parameters affecting UV dose fluctuate outside of the "safety zone."

EVALUATION STUDY

Plant Bowen receives its source water from the Etowah River. Following clarification and multimedia filtration, water passes through a two-stage micron filter process before entering the RO system. The two-stage micron filter process is composed of two trains, each containing a 3-micron filter followed by a 1-micron filter. The RO system consists of two 114 $m^3 \cdot h^{-1}$ (250 gpm) trains (Train A, Train B) containing 72 membranes (DOW FILMTEC™ BWXFR-400/34i) per train. The RO system is arranged in a double pass configuration with 48 membranes in the first pass, followed by 24 membranes in the second pass.

Three units of the RZ300-13 HOD UV system were provided by Atlantium Technologies for the full-scale demonstration study to achieve dechlorination of feedwater with a free chlorine concentration of 0.5 $mg \cdot L^{-1}$. The three units were installed in series flow to accommodate a flowrate up to 154 $m^3 \cdot h^{-1}$ (680 gpm) with 95 % UVT. The units were installed in the treated raw water line on existing stainless steel piping just before the 10-micron filters and the RO train (Figure 4).

Operational parameters as well as dechlorination and bacteria removal efficiencies of the HOD UV system were evaluated. To evaluate the effectiveness of the HOD UV system at removing chlorine, free and total chlorine levels were monitored at four sampling points. Oxidation reduction potential (ORP) values of the RO feedwater were continuously monitored as well.

Operational parameters continuously monitored included:

- the water flow in the pipe in $m^3 \cdot h^{-1}$ (gpm) through a signal received from a flow meter;
- the actual UV output ($mJ \cdot cm^{-2}$) of each lamp as measured by a UV efficiency sensor, one per lamp;
- the UVT in % of the water as measured by an embedded UVT sensor (two per unit);
- the delivered UV dose ($mJ \cdot cm^{-2}$) as calculated by the controller based on the water flowrate, the actual output of each lamp, and the UVT of the water;
- the water temperature in °C (°F) as measured by a temperature thermocouple.

Several operational modes were tested and included 100 % power (three units), 90 % power (three units), and 90 % power (two units with no power to the third). The results discussed below refer to 100 % power in all three units.

Figure 4:
System installed at a 3 160 MW coal-fired power station for evaluation.

RESULTS

Processing of RO boiler feedwater with average inlet values of 0.3 $mg \cdot L^{-1}$ total chlorine and 0.2 $mg \cdot L^{-1}$ free chlorine through the units yielded an effluent with an average total chlorine of 0.05 $mg \cdot L^{-1}$ and non-detectable free chlorine (< 0.02 $mg \cdot L^{-1}$). The technology was extremely effective at decomposing total and free chlorine in water; the overall total and free chlorine were reduced by 83.1 % and 90.3 %, respectively.

The HOD UV system yielded a post-UV-treatment total chlorine ranging between non-detectable and 0.11 $mg \cdot L^{-1}$ and non-detectable free chlorine (< 0.05 $mg \cdot L^{-1}$) when processing boiler make-up water with average inlet values of 0.3 $mg \cdot L^{-1}$ total chlorine and 0.2 mg · L^{-1} free chlorine. These values indicate that the HOD UV system effectively removed chlorine. The post-UV-treatment ORP values fluctuated between 277 mV and 368 mV with an average value of 316 mV. The pre-RO-train ORP values varied between 197 mV and 444 mV with an average value of 326 mV, which was acceptable for plant operations.

At equipment start-up, the SMBS feed was reduced from 19 L per day (5 gpd) on 4 March 2014 to 0 L per day (0 gpd) on 20 March 2014. After reducing the SMBS feed rate to zero (or near zero), the water was strictly dechlorinated and the results were comparable, or better in certain instances, than with chemical dechlorination.

The HOD UV system was also effective at controlling bacteria growth. The post-UV-treatment heterotrophic plate counts were comparable with those in pre-UV-treatment chlorinated waters. Average heterotrophic plate counts of 3.2 and 3.8 CFU · mL^{-1} were found in pre- and post-UV waters, respectively. Pre-UV water contained an average total chlorine value of 0.26 mg · L^{-1}, while post-UV water contained an average value of < 0.05 mg · L^{-1}.

At the conclusion of the evaluation period, results showed the HOD UV system to consistently meet or exceed treatment objectives. The technology effectively removed free and total chlorine from boiler feedwater to undetectable levels from inlet free and total chlorine levels above 1 mg · L^{-1}. Bacteria levels were also reduced to low acceptable levels [2].

The HOD UV system has been operational at the 3 160 MW coal-fired power station since June 2014. Over the past three years the use of SMBS has been reduced and the frequency of micron-filter replacement has also been minimized. The performance of the micron filtration system has also been enhanced with the use of the HOD UV technology. In 2015 the 4 pre-RO micron filters were changed 6 times, which could be reduced to 4 times in 2016, and 2 times in 2017. The reduction in cleaning frequency has resulted in a net savings of 160 000 USD. Since the installation of the HOD UV system, the chemical feed rate has decreased by 75 %; while the facility was originally feeding SMSB at a 4 mg · L^{-1} rate in 2014, the 2017 feed rate was 1 mg · L^{-1}. The monthly chemical usage could be reduced from 167.3 L per month in 2013 to 28.8 L per month in 2017. The facility has realized an annual cost savings of 5 000 USD with the reduction in chemical usage. These operational efficiencies have resulted in a net savings of 175 000 USD, providing a two-year return on investment. Moreover, there has been no reduction in performance of the RO membranes with the use of the HOD UV technology. As a result, Plant Bowen has been able to maintain the integrity of the feedwater for the boiler and steam cycle, ensuring production and quality levels necessary for the facility to operate efficiently.

Presently, the HOD UV technology is in full-scale operation at seven hydroelectric power facilities and eight fossil fuel plants in North America, providing non-chemical disinfection, dechlorination, or a combination of disinfection and dechlorination.

CONCLUSION

The HOD UV system decomposes the free chlorine oxidant in process water to protect RO membranes. Additionally, the technology provides disinfection to reduce the membrane biofouling potential by eliminating anaerobic and aerobic bacterial growth.

Power plant applications looking to replace the use of SBS/SMBS and achieve a non-chemical dechlorination process may benefit from the HOD UV system. While UV is a viable treatment option, all UV systems are not alike. System-specific operating principles and associated UV dose rates regulate how a particular system will perform in a full-scale installation. The HOD UV system discussed in this paper is unique in its ability to consistently monitor water quality and UV intensity and to adjust the UV dose rate accordingly to meet application specific needs.

The HOD UV system allows for a dechlorination treatment approach with the potential to eliminate the handling, storage, and operational requirements of chemical disinfection solutions. The efficacy of the technology, coupled with its specific operating principles and ease of use, allows for a unique non-chemical approach to dechlorinating and disinfecting boiler and steam cycle water.

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