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A Review of Methods for Controlling and Monitoring Microbial Corrosion in Power Plant Cooling Sections

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1. ABSTRACT

Biological fouling and microbial corrosion can significantly affect industrial cooling systems' efficiency. This study suggests that low concentrations of chlorine in seawater can be effective in inhibiting biological fouling and consequent corrosion. It highlights that chlorine interacts with (seawater components) and claims that maintaining a residual chlorine concentration below 3 micromoles at condenser outlets is highly effective. A concise review of antifouling methods includes alternatives to chlorination and a monitoring strategy that can enhance treatments. Additionally, the review encompasses various approaches for anti-fouling methods and monitoring to improve treatments. Through electrochemical monitoring and optimized treatments, operators can uphold device performance and oversee the production of halogen-containing by-products in industrial cooling facilities.

Keywords: Microbial Corrosion, Chlorination, Copper Alloys, Biofilm Monitoring.

2. INTRODUCTION

Macrofouling in cooling channels and the formation of biofilms on heat exchangers are two main problems that severely affect the performance of cooling systems. The efficiency and reliability of a power plant are significantly dependent on the integrity and cleanliness of its condensers. More than 5% of power plant efficiency may be lost due to biofilms. In the worst-case scenario, if marine organisms such as mussels, barnacles, algae, etc., block the condenser tubes of power generation units that use seawater as a coolant, they will be inevitably forced to halt operations [1]. Biofilm is the first layer that forms as biological fouling on the surfaces of structures in contact with natural waters. If its growth is not properly controlled, microbial corrosion (MIC) may occur. This type of corrosion affects many metallic materials used in power plants, such as stainless steel and copper alloys used in heat exchangers. Copper alloys are no exception, as biofilms can protect microorganisms against the toxic effects of copper dissolution. Heat exchangers made of titanium are not damaged by microbial corrosion, but the reduction in heat transfer due to biological fouling can become a serious problem instead. Studies have shown that the corrosion rate, especially after passing the initial growth stage of the biofilm, is not directly related to some factors such as the thickness of the biofilm, its roughness, or the number of microorganisms present in it. Cleaning methods should be applied in large power plants and smaller industrial cooling circuits that face the problem of biological fouling. These methods mainly include screening and physical cleaning techniques, as well as using chemical substances[1]. Mechanical cleaning of equipment and water filtration (through rotating filters and specialized mussel filters) are very common methods used. These methods include continuous cleaning of condenser tubes (using hard balls or brushes, trash racks, manual cleaning and filters with various mesh sizes).

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Physical methods can be regularly employed for anti-fouling treatments in cooling systems with appropriate design, which mainly includes the following items/factors:

- Maintaining high enough velocities to prevent the attachment of organisms (velocity >2 m/s)
- Temperature: Raising the temperature of the cooling water to 40 ^oC for a few hours.

Many power plants have a continuous cleaning system based on the rotation of sponge rubber balls inside the condenser tubes. These balls have a density similar to water and a diameter slightly larger than the internal diameter of the condenser tubes. This treatment method is often used synergistically with chemical methods and is very effective in preventing microbial fouling. This method is one of the recommended techniques as the Best Available Technology (BAT) for cooling water circuits.

3. Chlorination and its Alternatives

Chlorination is the most common biocide used for chemical anti-fouling treatments ~~in~~ of industrial waters. Often, plant operators mistakenly use the term of "chlorination" to refer to ~~the~~ dosing or production of oxidizing species other than chlorine (or hypochlorite), such as chlorine dioxide, which is an alternative product. Also, in the case of seawater, where the concentration of bromide is naturally high up to 0.87 mM, the oxidizing power of chlorine rapidly transfers to bromide, and the equilibrium of reaction (1) quickly shifts to the right, thus, the process of "chlorination" changes to "bromination."

$HClO + Br^{-} \leftrightarrow HBrO + Cl^{-}$

The by-products formed from the reaction of chlorine with the ammonia group are shown in the reactions. The stoichiometric ratios of reactions 1 to 6 depend on temperature, reaction time, pH, and the initial ratio of reactants [2]

$NH_3 + HClO \leftrightarrow NH_2Cl + H_2O$
$NH_2Cl + HClO \leftrightarrow NHCl_2 + H_2O$
$NHCl_2 + HClO \leftrightarrow NCl_3 + H_2O$
$2NH_3 + 3Cl_2 \leftrightarrow N_2 + 6HCl$
$NH_3 + 4Cl_2 + 3H_2O \leftrightarrow NO_3^- + 8Cl^- + 9H$

Ultimately, chlorine (like other strong oxidants) reacts with a wide variety of other compounds, both organic and inorganic (such as reducing agents like hydrogen sulfide, ferrous ions, manganous ions, and nitrite ions). Due to stringent regulations, chlorination has become a vital and challenging process to manage and is often overlooked or replaced with alternative products offered by the industrial market. However, to date, none of these alternatives have been able to simultaneously meet industrial needs and environmental safety standards for widespread and actual use. Chlorine dioxide (ClO_2) is an exception; in fact, it is a suitable industrial alternative to chlorine. Currently, several anti-fouling applications in power plants are being implemented using ClO_2 in both open and closed circuits, especially in locations where chlorination is prohibited. Chlorine dioxide reacts with the amino acids in the membranes of bacteria, viruses, and protozoa at lower concentrations (up to ten times less) than chlorine, deactivating biological cells.

4. Monitoring

To estimate fouling in condenser tubes, the calculation of heat exchange based on the specifications of the condenser, especially the back pressure, is commonly used. High back pressure in the condenser indicates the presence of a thick biofilm layer. In recent years, novel methods for monitoring the initial growth stage of biofilm have been developed and extensively tested [3]. In particular, electrochemical sensors have been very sensitive to the initial growth stage of biofilm, and a specific system called Biox has been implemented to monitor the operation of oxidants (chlorination and alternative treatments) in cooling circuits. A comprehensive monitoring method for preventing both biological fouling and microbiologically influenced corrosion includes the use of various types of electrochemical probes (Fig. 1c) in a bypass of the water cooling condensers. Two types of very important tubular electrochemical probes have been recognized [4]: the first, is the Biox probe (Fig. 1d), which is sensitive to the early stages of biofilm growth and the presence of oxidants in water. The second sensor (Fig. 1e) consists of five tubular samples from condenser tubes designed for online measurement of Linear Polarization Resistance (LPR). Electrochemical sensors have the characteristic that they do not require frequent maintenance or special expertise, or the use of chemical reagents. Physicochemical parameters are usually monitored by probes that are installed in line with electrochemical sensors (Fig. 1b), depending on the application. The flow rate (which can be adjusted by means of a bypass line to be as close as possible to the actual flow rate of the condenser tubes) and ~~the~~ water temperature are always monitored. In more sensitive cases, turbidity, ORP potential, corrosion potential (for specific materials), and chemical species are also measured. In addition, some samples that have been cut from working condenser tubes are added for periodic visual observations, determination of weight loss, and other offline measurements. These samples usually complete the hydraulic test line, as shown in the actual example in Fig. 1c. Finally, if regulations require, monitoring of the residual oxidant concentration at the outlet (through electrochemical and/or colorimetric systems) is also performed. In advanced and integrated systems like the one reported in Fig. 1b, the electrochemical sensors can communicate with electronic devices and computers either through direct connection or radio frequency signals. There is specialized software that provides the process of updating and continuous monitoring of the parameters under surveillance and data collection. Modern commercial systems can be remotely controlled and may monitor treatments performed in several factories simultaneously and in real time through a central workstation.

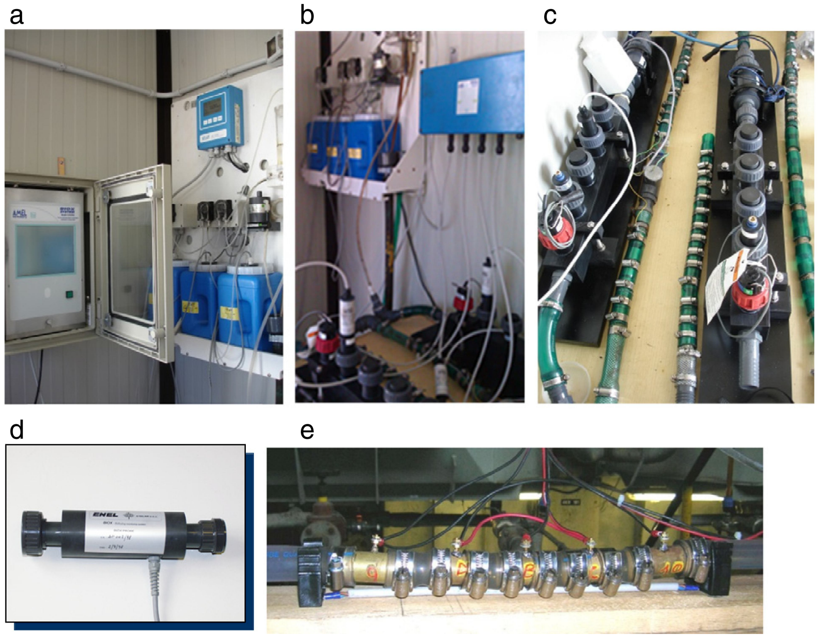

Fig. 1. Views of the equipment (a and b) and the monitoring probes (c) introduced in a hydraulic passage of a power plant's cooling water circuit, including condenser tube samples (d) Biox probe image, and (e) LPR corrosion probe [5].

5. CONCLUSION

To avoid the drops in heat exchange phomena and also corrosion problems caused by microorganisms in power plant condensers, especially when dealing with copper alloys, we must use solutions that are specific to each location and chemical treatments optimized with the use of antimicrobial substances. Considering new regulations that limit the amount of chlorine released into natural aquatic environments, the reported examples show that optimized chlorination tailored to each location can be one of the best available technologies, even though chlorine rapidly and intensely decomposes. For copper alloys used in marine facilities, a chlorination method that is performed with a residual oxidant concentration of less than 3 µM at the condenser outlet and with a flow rate of 1.8 m/s can provide the best protection. This method not only prevents the reduction of equipment efficiency but also, with precise online electrochemical monitoring, prevents the potential negative effects of by-products.

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