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A Review on the Role of Microorganisms and Its Control in Industrial Cooling Water System

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Abstract:
Water plays a significant role in many industrial processes may it be the manufacturing process for semiconductors or the creation of steam for electricity generation or even the production of drugs in the pharmaceuticals industry. The water in an open recirculating cooling system is continuously infested with a variety of nuisance microorganisms introduced for the most part in wind-blown dust. Essentially all of these microorganisms are indigenous to soil; they include bacteria, algae, fungi and protozoa in addition to a few multicellular bacterial predators. This infestation in the cooling water system is majorly controlled by introduction of oxidizing biocide such as chlorine while sodium hypochlorite, bromine, chlorine dioxide and ozone are gaining popularity owing to their benefits. Underfeed of the biocide will result in microbiological growth whereas overfeed of the biocide can lead to elevated chemical utilization and cost and also potential damage to the system metallurgy (corrosion) or the cooling tower (wood delignification). Laboratory screening procedures are coupled with maintaining a residual level of the biocide to ensure the maximum "kill" rate. This method has typically resulted in a periodic underfeed, leading to organism growth, or overfeed, adding unneeded expense and potential component damage, but typically all microbiological control programs are designed to eliminate 99% or more of the organisms in the water, as well as prevent any future growth from occurring. Oxidation Reduction Potential (ORP) can be implemented to rectify the underfeed and the overfeed problems. This ORP value is a direct reading of the activity of the oxidizing as well as reducing agents in the water. Measurement of ORP offers major improvements over treatment programs using residual control of an oxidizing microbiocide, resulting in improved life for heat exchangers and cooling towers, minimal usage of treatment chemicals for chlorinating and dechlorinating, and increased efficiency of plant processes that utilize the cooling water for heat exchange purposes. This review work will provide an insight to the vital destruction being created by the microorganisms in the industrial cooling water system. Also the mode of action of the biocides and importance of ORP measurements are discussed briefly.

Keywords: *cooling systems, corrosion, fouling, biocide, Oxidation-reduction potential.*

1. Introduction

Water, the workhorse of the industry, removes unwanted residual heat from process stream. It is an effective heat transfer medium. This transfer plays a vital role in the efficiency of the plant. This efficiency of the heat exchanger is affected by several factors especially microbial growth. Also, natural pollution by phosphates, nitrates, iron, manganese, sulfides is being noticed in some water supplies. Waterside problems develop in cooling water systems depending on the quality of the fresh water supply. These problems include: scaling, corrosion, dirt and dust accumulation and biological growth.

The combination of these problems lead to unscheduled downtime, reduced capacity, excessive water usage, elevated operation and maintenance costs and also includes expensive parts replacement and sometimes acid cleaning needs to be performed which diminishes the life of the cooling system.

2. Some Important Properties in Cooling Water Chemistry

Water is extensively used to perform heat exchange process owing to several of its attributes like: abundance, ready availability, and ability to carry large amounts of heat per unit volume, ability to withstand expansion or compression and being non-decomposable. The various physical and chemical properties of water influence the performance of the cooling water system. They are as follows:

2.1. Conductivity

It is the measure of the ability of water to conduct electricity. In cooling water, it indicates the amount of dissolved minerals in the water. Conductivity is measured in µS/cm (microSiemens/cm) and ranges from a few for distilled water to over 30,000 µS/cm for sea water.

2.2. pH

It gives an indication of the relative acidity or basicity of water. The pH scale runs from 0 to 14, with 0 representing maximum acidity and 14 representing maximum basicity.

2.3. Alkalinity

There are two forms of alkalinity in cooling water. These are carbonate ions (CO3 –2) and bicarbonate ions (HCO3 –). If the pH is greater than 8.3 then water is in carbonate form which leads to scale formation. If the pH is lesser than 8.3 then water is in bicarbonate form and hence there is no scale formation. The alkalinity acts as a buffer to charges acidity or basicity.

2.4. Hardness

This refers to the amount of calcium and magnesium ions present in the water. The hardness in natural waters can vary from a few parts per million (ppm) to over 800 ppm. Lesser the hardness the water is good to be used.

3. Microbial Problems

There are two major sources for the entry of microorganisms; one is from the makeup water and the other from ambient air. Open recirculating cooling water system provides favourable medium for proliferation of microorganisms. There are two classes of microorganisms namely planktonic or sessile. The former is dispersed into the cooling water whereas the latter attaches to the surface. The biofilm happens due to sessile microorganisms which are responsible for deposition and corrosion problems.

3.1. Alage

The most commonly observed biofouling problem is caused by Algae. They contain colored pigments mainly chlorophyll. They appear green, red or brown and occur in damp places where there is direct or diffused sunlight. Under these circumstances the algae develops into large slime layers which causes blockages. Algae growth will result in oxygen production, which can accelerate the corrosion reaction. Some forms of algae are responsible for the accelerated deterioration of nitrite-based corrosion inhibitors. Other types are known to cause silica fouling. Dead algae will collect in the water, increasing the suspended solids, which can cause fouling, providing food that will enhance bacterial growth, as well as absorbing microbiocides, which can minimize the effectiveness of microbiological control.

3.2. Bacteria

Bacteria are unicellular, microscopic, plant-like organisms that are similar to algae but lack chlorophyll. They exist in three basic forms: rod-shaped, spherical and spiral. In the cooling towers, bacteria account for more than 50% of fouling. Corrosion related problems are caused by anaerobic bacteria such as sulphate-reducing bacteria (SRB)

3.3. Fungi

Slime is mainly caused by fungi. The packing inside the cooling tower are prone to fungi attack which rots the wood used in tower structures. They also lack chlorophyll. Yeasts and molds are two main classes of fungi. They require moisture and air but not sunlight and survive on nutrients found in water.

4. Metabolisms

A vast variety of enzymes are secreted by bacteria, fungi and algae which are dispersed into the surrounding environment. These enzymes are capable of breaking down the organic and inorganic molecules, thereby providing the microorganisms with food and energy to grow and multiply. Also the microorganisms excrete a large number of organic and inorganic acids and other waste materials which can create local concentration of ions. The normal metabolic functions of microorganisms like respiration (oxygen uptake) can cause problems such as the system deposits, corrosion, loss of heat transfer, pH depressions, depletion of dissolved oxygen and loss of applied inhibitors.

5. Microbiological Damage

5.1. Biofouling

Mixed microflora which includes fungi, algae and filamentous bacteria causes fouling of cooling towers, heat exchanger surfaces, screens/filters and other parts of cooling water. Microbial slimes are masses of microscopic organisms and their waste products. These sticky slime layers effectively in trap foulants present in the bulk water. Other microorganisms and suspended solids can add to the already existing fouling deposit.

5.2. Macrofouling

The attachment of complex organisms like clams and mussels to piping and other surfaces of a cooling system leads to macrofouling. It is most common in once-through cooling systems or water intakes using surface water, like lakes, rivers, or oceans. Filiform organisms accumulate oil and hydrocarbons and these compounds metabolize to form harmful byproducts such as carbondioxide, hydrogen sulphide and hydrochloric acid.

5.3. Biofilm formation

A solid surface exposed to water in an open atmosphere can become contaminated with microorganisms and organic compounds in a relatively short period of time. The development of biofilm is considered to be a multistage process. Adhesion of microorganisms to the absorbed organic molecules (e.g., the humic acid subtances) takes place. Replication of attached cells and production of exo-polymers called as extracellular polysaccharide occurs which causes loses in heat transfer due to its insulating properties.

6. MIC

Corrosion related to the uncontrolled growth of microorganisms has become increasingly more frequent and more severe in all types of process cooling water systems. Microbial corrosion is a specialized form of electrochemical corrosion. Its occurrence is high due to operation at higher pH which renders chlorine less effective. There are three types of MIC namely:

6.1. Aerobic Corrosion

Corrosion of iron & steel forming acid metabolites. (e.g., sulphur oxidising bacteria- Thiobacillus)

6.2. Anaerobic Corrosion

Acidic water produced by some anaerobic bacteria directly attacks the metal sufaces.(e.g., sulphate reducing bacteria-Desulfomonas)

6.3. Pitting Corrosion

Effect of microbes and their biomass on pH, dissolved oxygen, secretion of corrosive waste.

7. Microbiological Control

The most practical and efficient method of controlling microbiological activity in cooling water is by using microbiocides, also commonly called biocides. Microbiocides kill microbiologicals or inhibit their growth and reproductive cycles and some alter the permeability of the microbe cell wall, thus interfering with their vital life processes. Others damage the cell by interfering with the normal flow of nutrients and discharge of waste.

In order to effectively control the growth of micro-organisms in cooling water, chemical and physical water treatment methods shall be adopted.

7.1. Treatment Methods

Chemical biocides are the most common products to control the growth of micro-organisms. Three general classes of chemicals are used in microbial control 1) Oxidizing biocides, 2) Non-oxidizing biocides and 3) Bio-dispersants.

7.2. Oxidizing Biocide

Oxidizing biocides are powerful chemical oxidants, which kill virtually all micro-organisms, including bacteria, algae, fungi and yeasts. Common oxidizers are chlorine, chlorine dioxide, and bromine, ozone, and organo-chlorine slow release compounds. Chlorine is one of the most widely used, cost effective biocides and is available in liquid, gaseous or solid form. Its effectiveness is increased when used with non-oxidizing biocides and biological dispersants. Bromine chloride or chlorine dioxide should be considered for use in circulating water treatment for systems with high ammonia concentrations. Ozone, the green biocide, is now days widely used to bring down microbial growth.

7.3. Non-Oxidizing Biocide

Non-oxidizing biocides are organic compounds, which kill micro-organism by targeting specific element of the cell structure or its metabolic or reproductive process. Non-oxidizing biocides are consumed slowly when compared to the oxidizing types and remain in the system for a longer period of time until they pass out with the blowdown. They often have the added advantage of breaking down into harmless, nontoxic chemicals after accomplishing their bacteria-killing purpose. They are effective where chlorine may not be adequate.

However, the non-oxidizing biocides are more costly and normally injected only in small systems, as a supplement to an oxidizing biocide in a large system, or when a particular problem exists in a large system and an alternative to the use of chlorine is required.

7.4. Bio-Dispersants

Bio-dispersants do not kill organisms. They loosen microbial deposits, which upon detachment from a metal surface, are flushed away with the bulk cooling water. They also expose new layers of microbial slime or algae to the attack of oxidizing biocides. In addition to removing bio-deposits, bio-dispersants are also effective in preventing biofilm formation from taking place.

8. ORP and Microbiocide Control

Measurement of total number of microorganisms present in the system apart from identifying its types plays an important role in proper microbial control. Visual techniques alone are never enough to determine whether a problem is occurring, since by the time organisms are visible, the situation has become critical.

Traditional microbiocide control has come from maintaining a residual of the oxidant of choice in order to ensure that any excursions of organic growth are immediately arrested. There are many shortcomings in this residual method. The concentration units used to report residual levels do not furnish sufficient representation of the quantity of organics that will be oxidized. This is because a particular amount of oxidant will always oxidize the same number of microorganisms, regardless of the concentration level. Another shortcoming is that the oxidizing ability of the oxidant is often related to the pH of the water, which cannot be taken into account and therefore if any fluctuations in water pH occur the ability of a measured amount of oxidant to perform its function is hence affected. As a result, control of the addition of an oxidant by residual control will result in endless overfeed and underfeed of the oxidant which will cause two problems to occur. Extreme excesses of chemical costs as well as potential damage to system components and metallurgy is resultant due to an overfeed of oxidant. Similarly, an underfeed of oxidant will cause potentially irreversible damage and loss of efficiency due to microorganism growth.

Here comes the need for using ORP; Oxidation Reduction Potential. ORP is used to perform accurate control of oxidant feed. The ORP value indicates direct reading of the oxidizing and reducing agents' activity in the water as they correspond to oxidation-reduction reactions. Research shows that the ORP of the water influences the microorganism's ability to survive in water. Thus the oxidizing microbiocide effectively destroys certain processes that keep the organism alive by removing electrons from them. Since this transfer of electrons is an oxidation-reduction reaction, ORP gives a direct correlation of the ability of the water to prevent microbiological growth.

ORP measurement uses an inert metal (typically platinum) measuring electrode that detects a millivolt potential due to the transfer of electrons within the process. The levels of oxidizing and reducing agents in the water determines the polarity and strength of the millivolt potential created. The millivolt potential is established on the measuring electrode with respect to a reference electrode, which is similar to that used in pH measurements. The typical reference electrode is the silver/silver chloride (Ag/AgCl) electrode, although a saturated calomel electrode has been occasionally used. Millivolt values are reported with respect to one or the other, depending on which is used, and care must be taken not to interchange the two, as millivolt differentials will exist.

A higher ORP will exist in an oxidizing environment, caused by the presence of an oxidizing microbiocide, whereas in reducing environment a lower ORP prevails. It is important to note that the actual crossover point between water being oxidizing or reducing is dependent upon the reference electrode. This point is typically somewhere between +200 to +250 mV, depending upon whether the Ag/AgCl or the calomel electrode is used and, to a lesser extent, the temperature and oxygen content of the water.

ORP control can be implemented with a feedback loop, with the sensor placed either before or after the heat exchanger. A location after may be preferred to ensure compensation for any drop in oxidant levels within the heat exchanger. Determination of the ORP control setpoint must be done for each individual site, since there will be many variations between sites, including organism type, water chemistry, temperature, and oxidant type. For the most part, control setpoints for oxidizing biocide addition will be within the +550 to +650 mV range.

9. Benefits of ORP

- Provides rapid and single-value assessment of disinfection potential of water in postharvest system.
- Assess the activity of applied disinfectant rather than the applied dose.
- Free floating decay and spoilage bacteria as well as pathogenic bacteria are killed within 30 seconds. At an ORP value of 650 to 700 mV.
- Spoilage yeast and more-sensitive types of spore-forming fungi are also killed at this level.

Pathogen/ Indicator	**Survival in sec/hr at ORP(mV)**		
	<485	550< x <620	>665
E.coli	>300 s	<60 s	<10 s
Salmonella spp	>300 s	>300 s	<20 s
Listeria monocytogenes	>300 s	>300 s	<30 s
Thermotolerant coliform	>48 h	>48 h	< 30 s

Table 1: Results from various lab simulation & commercial hydrocooler.

10. Conclusion

Control of microbiological growth is not an option for the vast majority of cooling water systems. Inadequate control has resulted in shortened component life, loss of efficiency, and wasted chemical costs. Yet microbiological control remains one of the most misunderstood and thus neglected parts of a chemical treatment program for cooling water. Measurement of ORP offers major improvements over treatment programs using residual control of an oxidizing microbiocide, resulting in improved life for heat exchangers and cooling towers, minimal usage of treatment chemicals for chlorinating and dechlorinating, and increased efficiency of plant processes that utilize the cooling water for heat exchange purposes. Hence, by appropriate biocidal application methods, the water usage in excess can be avoided which presents us one way to save water.

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