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PREVENTION OF CORROSION, EROSION & ABRASION IN COOLING TOWERS

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Corrosion in Cooling Towers

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Cooling towers are structures designed to remove waste heat from a process stream by means of heat transfer to a moving medium –water. The design principle is based upon evaporative cooling. The heat raises the temperature of a small amount of contact water which evaporates and thereby cools the remaining water. The waste heat is passed into the atmosphere via warm humid air. There are many designs for cooling towers and they come in many capacities. Regardless of design or method of operation, they all can be attacked by a specific type of corrosion with an unusual and perhaps unexpected origin.

Corrosion in water cooling towers is a result of two entirely different, yet related factors. One is scaling or deposits of minerals onto surfaces. The chemical environment under these scale deposits is different from the surrounding areas. These deposits are often cathodic to steel, thereby making the surrounding steel anodic. Corrosion generally is an anodic process, unless mitigating factors dictate otherwise. The other comes from a biological source. It has long been known that some microbes, including certain bacteria species and certain fungi, can cause corrosion of metals and concrete. This process has a special name. It is called Microbiologically Influenced Corrosion (MIC). Further exacerbating the situation are wet/dry cycles and constant temperature fluctuations common to cooling tower operations.

When the amount of dissolved minerals in the recirculating cooling water reach a critical threshold, these minerals will precipitate out of solution and accumulate on surfaces in the cooling water system. In order to control the buildup of these mineral deposits, draw-off, or blow down, is frequently employed.

Makeup water that is low in dissolved minerals tends to be corrosive to metals. Makeup water that is high in dissolved minerals tends to cause scaling. Scaling is the deposits of precipitated minerals, which includes lime scaling. The rate of mineral precipitation is temperature dependent as well as being dependent upon the mineral concentration in the recirculating cooling water. A delicate balance must be maintained in order to minimize scaling and corrosion potential.

Under certain conditions, a biofilm of bacteria, fungi and algae can establish itself and rapidly grow on the wet surfaces of the cooling tower. These biofilms reduce heat transfer efficiency and can lead to severe corrosion of both metallic substrates and concrete. The bacteria excrete a gelatinous substance called extracellular material (ECM). This ECM provides an anchor for the mutualistic microbial community, controls the rate of diffusion of gasses such as oxygen and carbon dioxide, controls the pH and traps inorganic as well as organic nutrients. Concentration cells will be established under these films causing the formation of anodes and cathodes. Further, these biofilms help to stabilize these areas of opposite polarity. This promotes cell corrosion.

In the anaerobic conditions under these biofilms, certain acid producing bacteria thrive. Bacteria such as *Acidithiobacillus thiooxidans* secrete inorganic acids. *Ac. thiooxidans* secretes sulfuric acid as a metabolic waste product. *Ac. thiooxidans* consumes H_2S (hydrogen sulfide) either as the gas or as elemental sulfur (S) and polythionates (sulfur containing organic compounds) and metabolically produces sulfuric acid as a waste product. The sulfuric acid is secreted directly onto the substrate to which the microbial community is adhered resulting in corrosion that can be both severe and rapid. In addition to the inorganic acids, many bacteria and fungi secrete a class of acids called Short Chain Fatty Acids (SCFA). These are organic acids such as acetic, formic, propionic and butyric among others. Pitting corrosion that has resulted in pinholes penetrating through steel substrates has been recorded in as little as 14-

months on a 1/8th-inch thick carbon steel plate. Concrete degradation of as much as 6-inches in as little as 4-years has been reported in the literature and in case studies.

In cooling systems, corrosion causes three (3) significant problems. The first and most obvious is equipment failure. This results in higher operating costs and plant downtime. Secondly, there is a corresponding loss of efficiency of heat transfer because of heat exchanger fouling caused by the accumulation of corrosion products. Lastly, there may be a loss of structural integrity on concrete walls and basins. Metal can experience direct corrosion such as by sulfuric acid, the corrosion can be uniform, pitting, selective leaching (such as dezincification of Cu/Zn alloys like brass) or galvanic. Galvanic corrosion can occur in surprising ways. If two dissimilar metals are connected by a conductive medium, such as water, the anode and cathode can be separated by several feet and galvanic current flow will occur causing corrosion at the anode.

Stagnant and low flow conditions promote attachment of the microbes to the substrates. It has recently been shown that fungi also play a vital role in helping establish these microbial communities. The fungi spread by means of a root like network consisting of many individual 'branches, called hyphae. The hyphae can form dense mats that further enable the bacterial colonies to grow. Further, these hyphae provide internal channels for the bacteria to use as "highways" for translocation. These channels also move nutrients from point to point, thus further enabling microbial growth. This is followed by colonization and formation of discrete deposits. These deposits start as biofilms and frequently build to bulkier deposits called biomounds. The composition of these deposits and the chemical environment beneath them is significantly different from and far more corrosive than the surrounding water environment. It might surprise the reader to learn that the MIC microbes and fungi involved in cooling tower corrosion are the principal microbes involved in corrosion in domestic sewage collection and treatment systems.

In order to protect the integrity of water cooling towers, they need to be protected with a high quality coating with a proven track record in combating MIC. Since the corrosion mechanisms are the same as encountered in domestic/municipal sewage systems, the protective coatings used in those environments with success would be expected to perform equally well in cooling tower applications.

Surface preparation

Whether the substrate is metallic or concrete, it must be prepared properly prior to the application of a protective coating.

Metallic substrates are somewhat easier to prepare than concrete surfaces, however there are stringent controls that should be instituted. Since the environment is essentially a continuously wet one, steel surfaces should be cleaned to a NACE (National Association of Corrosion Engineers) 5 or 10 (Near white metal to white metal blast). It should have a profile of 3 to 5 mils for a high build coating. In addition, the surfaces should be checked for soluble salts, specifically chlorides, fluorides, nitrates and sulfates. Their presence should be limited to 50-μ-grams/square meter. If their presence is in excess of this limit, use a suitable chemical treatment to remove the salts. Consult the coating manufacturer for a recommendation.

Concrete can be a more problematic substrate to coat. Concrete is best thought of as a brittle sponge. Like sponges, concrete will absorb whatever liquids with which it comes into contact. Many times, if not most of the time, these absorbed compounds are deleterious to the performance of the coating and thus must be removed. High pressure water blasting or ultrahigh pressure water jetting have proven to be an efficient means of accomplishing both a profile on the concrete and removing contaminated concrete. It is recommended that the pH of the concrete surface be tested after surface preparation has been completed. The surface pH should be between 9 and 13. Virgin concrete has a pH between 12.5 and 13 depending upon the mix design and raw materials used in its design. If the pH is lowered, that means that the concrete has been exposed to acid. Each pH unit represents a change in acid strength of 10 times. Thus, a pH of 4 is ten times as strong an acid as the same acid at pH 5. In our case, if the pH drops from 12.5 to 9.0, that represents a 35-fold increase in the acidity. Once the pH of concrete falls below 9, the soundness of the concrete becomes suspect. Unsound concrete can lead to premature coating failures. Once the desired pH range has been attained, the concrete should receive a profile in accordance with ICRI (International Concrete Repair Institute) 4 to 6 visual standards.

If too much concrete was removed during the surface preparation phase, the concrete may need rehabilitation before applying a coating. There are high strength, rapid setting cementitious repair materials available that allow the coating work to proceed in as little as 6-hours.

<u>Coating Selection</u>

The coating selection is perhaps the most critical element in the process. The average reader has no easy means of determining which coating of hundreds that are available is the best one to use. Some useful guidelines make that choice easier. The role of the physical properties of coatings is often misunderstood and frankly overly hyped by some coating manufacturers. For example, some manufacturers of coatings emphasize that their coating has a higher compressive strength than their competitors do. Compressive strength is an essentially useless piece of information when it comes to determining whether a coating has the properties required to perform as required, as coatings generally will not be placed in compression during their service life. If one examines the stresses to which a coating will be exposed, one can readily determine that properties such as flexural strength, flexural modulus of elasticity, tensile strength, elongation, bond strength to the substrate, coefficient of thermal expansion and permeability are the important physical factors.

In a water cooling tower, the most common forces exerted on the coating are flexural and thermal. Bending moments on the cooling tower are translated to flexural stresses on the interior coating. Therefore, a high flexural strength, but a relatively low flexural MOE, are desirable characteristics. These bending moments will also result in tensile stresses on the side opposite the point of imposition. To resist these stresses, the coating should have a high tensile strength and at least a moderate amount of elongation. If the coating's coefficient of thermal expansion (cte) is too large, disbondment will occur. Disbonded coatings will crack, thereby destroying their corrosion protection in those cracked areas. Thus, bond strength to the substrate is also highly critical. Coatings function primarily as "barriers" to penetration of corrosive media. If the coating has a high permeability, corrodents can penetrate more easily and attack the coating and the bond line at the coating/substrate interface. In order to prevent this, a low permeability is required. The following properties have been found to provide a coating that can be expected to last for decades with minimal maintenance.

Property	Typical 7-day value
Flexural strength	7000-psi
Flexural MOE	<10^5-psi
Tensile strength	>2000-psi
Bond strength – steel	>1200-psi
Bond to concrete	concrete failure
Slant shear bond to concrete	>600-psi
CTE	<$25 \times 10^{-6}/F^0$
Permeability	<10^{-9} g/m·s·Pa
Elongation	>10%

Equally important to coating performance is the chemical resistance of the coating itself to the expected chemical exposure and biological environment. In water cooling towers, as in sewer applications, another attribute is also important. The coating must not provide a support platform for either bacteria or fungi.

Decades of successful applications in the wastewater collection and treatment industry has shown that a quality ultrahigh solids bisphenol A epoxy coating will provide more than 25-years of protection against MIC, if it has the required physical and chemical resistance properties. Although generally not required, biocides can be blended into these coatings to provide extra protection against microbiologically influenced corrosion.

High quality linings based upon bisphenol A epoxies are available in several different formulations that possess the above attributes. For example, the same resin/hardener system can be used to formulate a spray applied thin film sealer, a trowel applied 125-mil liner or a 150-mil high build spray applied lining, as well as other systems. Recently 100% solids aromatic urethane linings with properties similar to the bisphenol A epoxies are being used where crack bridging and elongation are the primary concerns of the user, rather than microbiologically influenced corrosion.

Summary

The corrosion found in water cooling towers can be attributed to the relative alkalinity and dissolved solids in the water, deposition of scale and MIC. Microbiologically influenced corrosion, sometimes called biogenic corrosion, is the cumulative result of bacterial and fungal activity. Certain bacteria, chief among them *Acidithiobacillus thiooxidans*, form mutualistic communities with several fungi species which appear as a biofilm or in later stages as thicker and more massive biomounds. Corrosion in water cooling towers reduces heat transfer efficiency, reduces equipment availability, causes expensive downtime and outages, and in severe cases can threaten the structural integrity of the equipment.

Experience in an environment with the same corrosion issues and causative microbes, i.e., municipal sewage, has proven the long term viability of properly formulated bis A epoxy linings in providing the required corrosion protection. Without such protection, the projected service life of the water cooling tower may be unachievable.

Appendix

Compressive Strength - The capacity of a material or structure to withstand axially directed pushing forces. It provides data (or a plot) of force vs deformation for the conditions of the test method.

Modulus of Elasticity - The ratio of the stress applied to a body to the strain that results in the body in response to it. The modulus of elasticity of a material is a measure of its stiffness and for most materials remains constant over a range of stress.

Tensile Strength - The resistance of a material to a force tending to tear it apart, measured as the maximum tension the material can withstand without tearing.

Elongation - Measure of the ductility of a material as determined by a tension test, it is the increase in the gauge-length of a test specimen after fracture divided by its original gauge-length. Higher elongation mean higher ductility

Bond Strength - The degree to which each atom joined to another in a chemical bond contributes to the valency of this other atom.

Coefficient of Thermal Expansion - The size of an object changes with a change in temperature. Specifically, it measures the fractional change in size per degree change in temperature at a constant pressure.

Permeability - a measure of the ability of a material (such as rocks) to transmit fluids