Microbiological and Corrosion Control in Cooling Water Systems

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Editor

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1. MICROBIOLOGICAL DEPOSITS AND CONTROL. Microbiological organisms are composed of three classes: algae, bacteria, and fungus. Large biological organisms such as clams, snails, mussels, or similar species are referred to as macrobiological organisms. The presence of any biological growth can be detrimental to cooling tower operations. Problems include fouling, corrosion, and loss of efficiency. These problems can lead to downtime, higher operating cost, and even premature replacement of equipment. Additionally, some bacteria are pathogenic and can pose a risk to human life.

1.1 ALGAE. The term “algae” refers to algal, microbiological, tiny, stringy blue and blue-green plants, which are usually found growing in masses on top of and on sides of cooling towers. Algae grow only in sunlit areas. They will slough off and become part of the suspended matter in the circulating water, a situation which may cause fouling and plugging of water sprays. Algae also provide a breeding place, and are a nutrient, for bacteria.

1.2 BACTERIA. The term “bacteria” refers to a large group of one-celled microorganisms. Bacteria can grow in either the absence or presence of sunlight. There are several ways to classify bacteria, including “aerobic,” meaning those living in the presence of oxygen, and “anaerobic,” meaning those living in the absence of oxygen. In a cooling water system, one can categorize bacteria as either “planktonic” or “sessile,” which are terms that describe whether the bacteria are, respectively, either free floating or found growing on surfaces (stickers). Categories of bacteria are described below. Table 1 shows types of bacteria and their growth conditions.

Bacteria Type	**Technical Names and Examples**	**Conditions for Growth**		**Problems Created**
		Temperature	**pH**	
Aerobic-capsulated	• Aerobacter aerogenes Flavobacterium • Proteus vulgaris • Pseudomonas aeruginosa • Serratia • Alcaligenes	20-40 °C (68-104 °F)	4-8 (7.4 optimum)	Severe bacterial slimes are formed; these are gelatinous deposits
Aerobic-spore forming	• Bacillus myocoides • Bacillus subtilis	20-40 °C (68-104 °F)	5-8	Bacterial slimes; spores produced are difficult to destroy
Aerobic-sulfur	• Thiobacillus thiooxidans	20-40 °C (68-104 °F)	0.6-6	Sulfur or sulfides are oxidized to sulfuric acid
Anaerobic-sulfate reducing	• Desulfovibrio desulfuricans • Clostridium	20-40 °C (68-104 °F)	4-8	Grows under deposits causing corrosion; converts sulfates to hydrogen sulfide (rotten egg smell)
Iron depositing	• Crenothrix • Leptothrix • Gallionella	20-40 °C (68-104 °F)	7.4-9.5	Converts soluble iron salts to iron oxide; can form voluminous deposits

Table 1
Bacterial Types and Problems Created

1.2.1 PLANKTONIC BACTERIA. Planktonic bacteria are suspended in the water, sometimes referred to as “free floaters” or “swimmers,” and are aerobic bacteria that thrive in an oxygenated environment. They are not harmful to the cooling system since they do not cause deposits or corrosion, but they can provide nutrients for other microorganisms; in addition, some planktonic bacteria such as Legionella Pneumophila are pathogenic and can present a significant human health risk.

1.2.2 SESSILE BACTERIA. Sessile bacteria are stickers, or non-swimming bacteria, and can cause deposits and corrosion. Sessile bacteria types include slime-formers and anaerobic (corrosive) bacteria. Slime-formers can grow and form gelatinous deposits on almost any surface in contact with the cooling water. These deposits can grow so large that they restrict water flow and interfere with heat transfer; they also may promote under-deposit corrosion. Feeling the sides of the cooling tower basin just below the water level is one way to detect the presence of slime-formers. Usually if there are slime formers in the system, you can feel deposits. Anaerobic bacteria thrive in oxygen-deprived environments and often establish colonies beneath slime deposits or under other types of deposits. One type of anaerobe is sulfate-reducing bacteria (SRB), which produce hydrogen sulfide, a chemical that is very corrosive to metals. This type of corrosion attack is very localized and can result in pipe and tube failures. The presence of SRB should be suspected in a water system if the underside of a slime layer is black or if you detect the odor of rotten eggs. Any type of microbiological corrosion is referred to as microbiologically influenced corrosion (MIC). Bacteria cause most of the MIC found in cooling water systems. Use surface microbiological measurements to monitor sessile bacteria.

1.3 FUNGI. The term “fungi” refers to classes of organisms made up of molds and yeasts, some of which attack and cause wood decay in cooling towers. The control of fungi requires special preservative treatment of wood. Fungi also produce deposits in cooling water equipment.

1.4 MICROBIOLOGICAL CONTROL. The term “microbiological control” refers to techniques used to minimize the presence of microbiological organisms in cooling water. Chemical biocide treatment is the method used on many installations for microbiological control in cooling water. Biocides that are used to control microbiological growth fall into one of two broad categories: oxidizing and non-oxidizing microbiocides. A cost-effective approach for control involves the regular use of oxidizers as a primary biocide, augmented by selective use of non-oxidizing biocides. Important factors for the effectiveness of any biocide include using a proper dosage and allowing adequate contact time with the microbiological organisms. All microbiocides are toxic and must be handled safely and with caution; use the MSDS for safety instructions.

1.4.1 OXIDIZING BIOCIDES. “Oxidizing biocides” is a term describing microbiocides that oxidize or irreversibly “burn up” the bio-organisms. Oxidizing biocides also destroy nutrients that the microorganisms require for growth. Avoid addition of excess amounts (over-feeding) of oxidizing biocides because they are corrosive to metal and wood in the cooling system and have the potential to destroy some scale and corrosion inhibitors. The various oxidizing biocides are described below. Table 2 provides guidelines for selecting oxidizing microbiocides.

Microbiocide	**Bacteria Types**				**Fungi**	**Algae**	**Comments**
	Slime Forming		**Iron Depositing**	**Corrosive**			
	Spore Formers	**Non-spore Formers**					
Chlorine	P	E	E	N	P	F	Danerous to handle; corrosive to metal; available as dry, gas, or liquid; less effective higher pH (>7.5)
Bromine	F	E	E	N	P	F	Can be produces from bromides; very effective at pH 6.0-10.0; very effective with ammonia; less volatile than chlorine
Ozone	E	E	E	F	G	P	Very volatile; can attack wood, PVC, copper, and gasket
Chlorine dioxide	G	E	E	N	P	F	Must be produced onsite; very volatile; not sensitive to pH; does not react with ammonia and many organics
Peroxide	G	G	G	F	P	F	Does not add TDS; degrades to water

E = Excellent G = Good F = Fair P = Poor N = Not effective

Table 2

Guidelines for Oxidizing Microbiocide Effectiveness

1.4.1.1 CHLORINE AND CHLORINE RELEASE AGENTS. Chlorine (Cl_2) compounds are the most effective industrial oxidizing biocides and the most widely used. Chlorine is available as a chlorine gas, dry calcium hypochlorite (HTH), liquid sodium hypochlorite (bleach), plus several other dry products that release chlorine. When chlorine is introduced into water, it hydrolyzes to form hypochlorite ion (OCl-) and hypochlorous acid (HOCl); it is the latter chemical that is the stronger oxidizing biocide. The presence of hypochlorous acid is greater, proportionate to hypochlorite ion, at low pH levels. At a pH of 5.0, hypochlorous acid exists almost exclusively. At a pH of 7.5, there are approximately equal amounts of hypochlorous acid and hypochlorite ion. Figure 1 shows this relationship. Chlorine is effective, but to a lesser degree, as a biocide at a pH of 7.5 or greater because the hypochlorite ion has about one-tenth the biocidal efficacy of hypochlorous acid. A pH range of 6.5 to 7.5 is considered optimal for chlorine or chlorine-based microbiological control programs. Above pH 7.5, relatively higher levels of chlorine are required to be effective. Military installations seldom use gaseous chlorine for treating cooling towers because of safety concerns, difficulty with controlling the feed of the gas, and increasing concern for the environmental effects of escaping residual chlorine gas. The most commonly used chlorine-based products are bleach and HTH.

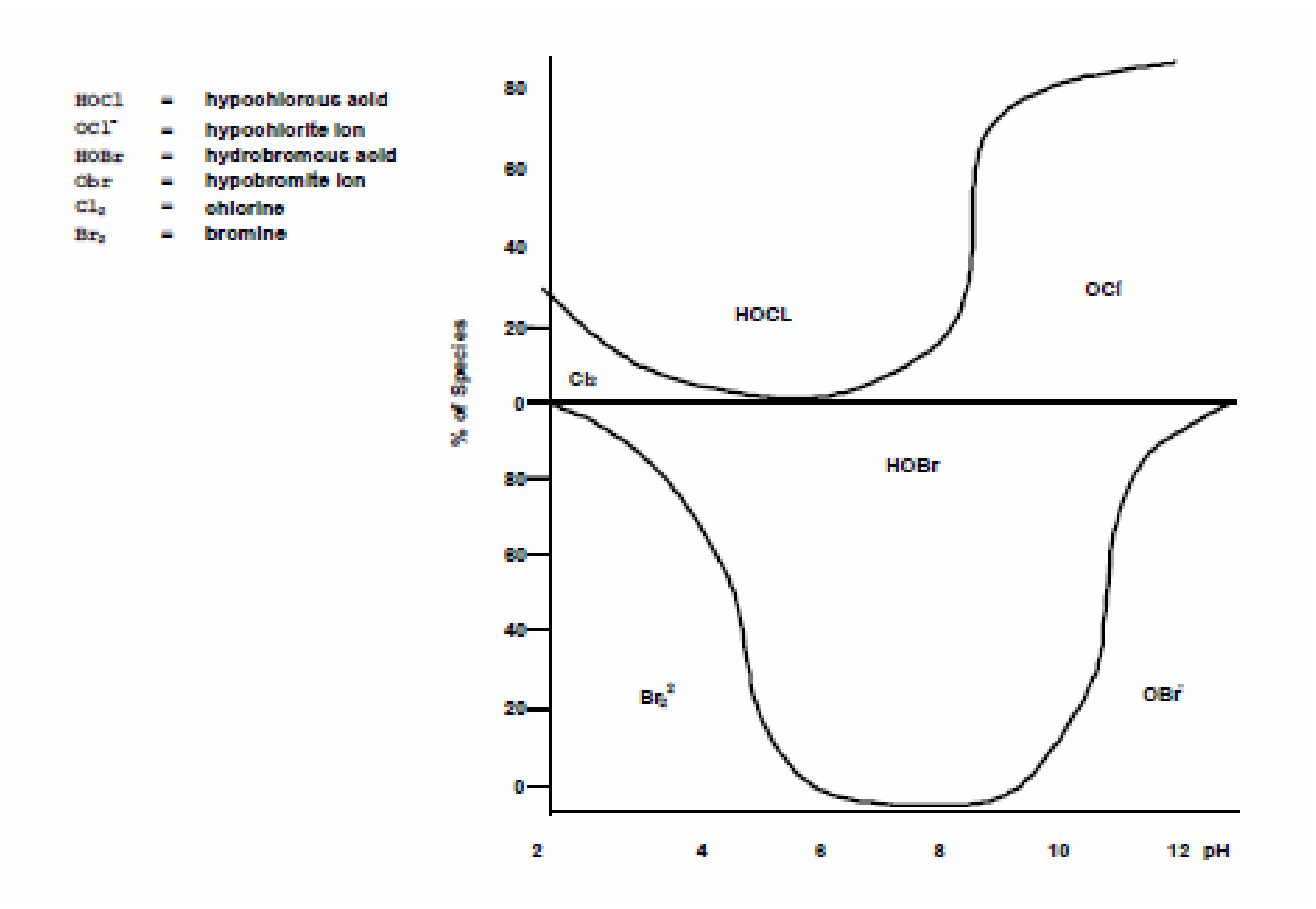

Figure 1

Halogen Species vs. pH in Water

Release Agents	Comments
Sodium hypochlorite 12%	Concentrated liquid bleach
Calcium hypochlorite (HTH)	Dry product; releases chlorine
Chlorine gas	Gaseous chlorine
Chloroisocyanurates	Dry organic chlorine compound; releases chlorine and cyanuric acid

Table 3

Chlorine Release Agents

1.4.1.2 BROMINE RELEASE AGENTS. Bromine (Br_2) compounds are very similar to chlorine compounds. Although more expensive than chlorine compounds, their main advantage is that bromine is more effective at higher pH ranges (7.5 or greater) than chlorine. Bromine has a lower vapor pressure than chlorine and is 6 times as soluble in water, making it less subject to vaporization loss from a cooling tower. When bromine is introduced to water, it hydrolyzes to form hypobromite ion (OBr-) and hypobromous acid (HOBr); Figure 1 shows this relationship. A pH range of 7.5 to 10.0 is considered optimal for the use of bromine. Bromine release agents include dry chemicals called hydantoins and bromine salts, such as sodium bromide. When a salt solution is mixed with an oxidizing agent, such as bleach, and a reaction occurs, bromine is produced. In water, bromine degrades more rapidly than chlorine. Recent developments in bromine chemistry have resulted in the production of a bromine solution (liquid). Table 4 shows examples of some bromine release agents. The most popular sources of bromine are the dry bromine release products.

Release Agent	Comments
Bromo-chloro-dimethyl hydantoin	Dry product – releases bromine
Bromo-chloro-methyl-ethyl hydantoin	Dry product – releases bromine
Isocyanuric acid plus sodium bromide	Dry product – releases bromine
Chlorine plus sodium bromide	Produces bromine liquid
Peroxide plus sodium bromide	Produces bromine liquid
Ozone plus sodium bromide	Produces bromine liquid
Stabilized bromine	Hydrobromite liquid

Table 4

Bromine Release Agents

1.4.1.3 OZONE. Ozone (O_3) is a gas produced by passing dry air either through a strong electric field or near an ultraviolet light. If ozone is dissolved in water, the resulting solution can be added to cooling water. Ozone is a very strong oxidizing biocide that, if properly applied, can provide effective control of microorganisms in cooling tower systems; however, because of safety and operational problems associated with its manufacture and use, and the resulting high capital and operating costs, it is neither the most economical method nor the preferred method for microbiological control in cooling towers under normal operations. Ozone can increase metal corrosion and does not prevent scale.

1.4.1.4 CHLORINE DIOXIDE. Chlorine dioxide (ClO_2) is a gas generated by mixing several chemicals. The chlorine dioxide gas produced in this manner is subsequently dissolved in water, with the water containing the chlorine dioxide then added to the cooling water. Chlorine dioxide must be produced in close proximity to the point of use. It is not recommended for use on some installations due to the complexity of its production and safety concerns associated with its production and handling.

1.4.1.5 HYDROGEN PEROXIDE. Hydrogen peroxide (H_2O_2) is a liquid that is usually used at a concentration of 30% in water. Hydrogen peroxide is considered one of the most environmentally friendly oxidizing biocides because it degrades to water; however, concentrated hydrogen peroxide will react in a violent manner when it comes into contact with organic chemicals and materials.

1.4.2 NON-OXIDIZING BIOCIDES. Non-oxidizing biocides are microbiocides that act as "poisons;" they disrupt the metabolic or reproductive processes of micro- and macro-organisms and are therefore toxic. Non-oxidizing biocides are organic compounds that are very toxic to organisms, including human beings and animals. They are usually liquids, but some are available as dry products (e.g., pellets, solids). A major consideration for their use is their persistence with respect to the discharge limitations for water (effluent) containing these toxic substances. Also, when choosing and applying a non-oxidizing biocide, you must consider the cooling tower system's operating parameters, such as pH and retention time. The applied dosages of microbiocides should never exceed EPA maximum limits, which are always printed on the container labels. The labels will also identify the active microbiocide ingredient, the percentage of each chemical that is present in the formulation, and the EPA registration number. Control programs often combine both oxidizing and non-oxidizing biocides. The most important aspect of bio-fouling control is to match the non-oxidizing biocide to the problem organism. Table 5 provides guidelines for non-oxidizing biocide effectiveness.

Microbiocide	**Bacteria Types**				**Fungi**	**Algae**	**Comments**
	Slime Forming		**Iron Depositing**	**Corrosive**			
	Spore Formers	**Non-spore Formers**					
Quaternary ammonium salts	E	E	E	G	P	G	Effective pH 6.5-9.2; foaming potential; reacts with anionics
Organo tin plus quaternaries	E	E	E	G	P	G	Effective pH 6.5-9.2; foaming potential; reacts with anionics tin compounds often restricted
Dibromo-nitrilo-propionamide	E	E	E	G	N	P	Effect pH 6.5-7.5; degrades quickly; uses glycol solvent
Methylene bis thiocynate	E	E	G	E	P	P	Effective pH <7.5; deactivated with high pH
Isothiazolone	E	E	G	G	G	G	Effective pH 4.5-9.3; dangerous to humans
Dodecylguanidine	E	E	G	G	G	G	Effective pH 6.5-9.5
Glutaraldehyde	E	E	G	E	G	G	Effective pH 6-10
Terbutylazine	N	N	N	N	N	E	Very effective algaecide; blocks photosynthesis
Carbarnates	E	E	G	G	G	F	Effective pH 7-9; corrodes copper

E = Excellent G = Good F = Fair P = Poor N = Not effective

Table 5

Guidelines for Non-Oxidizing Microbiocide Selection

1.5 ALGAE CONTROL. Algae can be controlled by two techniques: chemical methods and physical methods. Since algae require sunlight to survive and grow, covering the upper hot water decks of cooling towers with plywood can often control algae deposits. Chemical methods consist of using oxidizing and non-oxidizing biocides, which can control algae to various degrees (see Tables 2 and 5). The effectiveness of oxidizers is considered only fair while that of several non-oxidizers is in the range of very good to excellent. One of the more effective biocides for algae is terbutylazine, a triazine product (see Table 5).

1.6 BACTERIAL CONTROL. Accepted industry practice for bacterial control is the use of oxidizing and non-oxidizing biocides that are specific for the type of bacteria. The most cost-effective microbiocide programs for medium and large cooling towers use an oxidizer as a primary biocide and one or more non-oxidizers selectively as a secondary biocide (see Tables 2 and 5). Smaller cooling systems often use one or more non-oxidizing biocides, although dry oxidizing biocides are also used commonly. The most overlooked aspect of bacterial control is maintaining a system kept clean of deposits and SS (i.e., dirt, silt, sand, corrosion products) through the use of filters and periodic wash-down procedures. Clean systems reduce the demand for chemical and microbiological control. Table 6 shows accepted industry guidelines for a bacterial control program with the use of a test kit.

Bacterium Type	Colony-Forming Units/ml
Total aerobic bacteria	$< 10^4$
Sulfate-reducing bacteria	Undetectable
Surface microbiological	$< 10^5$ - Undetectable

Table 6

Guidelines for Bacterial Control in Cooling Towers

1.6.1 Bacterial Control with Oxidizing Biocides. Bacterial control with oxidizing biocides can be accomplished by either continuous feed or slug feed of the oxidant. A continuous-feed process typically maintains 0.1 to 0.3 ppm of free halogen in the return water to the cooling tower. A typical slug-feed process adds treatment chemicals periodically to give 0.5 to 1.0 ppm of free halogen in the return water to the cooling tower for a period of 2 to 4 hours, 3 times per week. Halogen refers to the group of elements including chlorine and bromine. “Free” halogen refers to the measured residual of halogen available for disinfection. Stabilized Halogen technology is generally controlled on a total halogen residual. For continous feed, control at 0.5 to 1 ppm total, and for slug feed control at 2.4 ppm for a period 2-4 hours, 3 times per week.

1.6.2 Bacterial Control with Non-Oxidizing Biocides. Bacterial control with non-oxidizing biocides uses one or more biocides as shown in Table 5. Usually different non-oxidizers are added on an alternating schedule; they are slug-fed every other week for optimum effectiveness. Each time you use a non-oxidizing biocide, it is important to maintain an adequate dosage for 24 hours to enable sufficient contact time for maximum effectiveness.

1.7 Legionnaires’ Disease. Legionnaires’ Disease (Legionellosis) is a respiratory disease (atypical pneumonia) that is caused by infection of susceptible individuals who have inhaled a fine water mist containing the bacterium known as Legionella Pneumophila. Water in a cooling tower can become infected with the bacterium if an inadequate microbiological control situation occurs. The presence and density of Legionella Pneumophila bacteria cannot be detected by standard microbiological testing methodologies. Instead, cooling water samples must be sent to a laboratory that has been certified to conduct the required tests. If the presence of the bacteria in cooling water is established, proper disinfection steps are required. A procedure known as the Wisconsin Protocol, developed by the Wisconsin State Health Department, has proven effective. This protocol requires the addition of high dosages of chlorine (10 ppm free residual) at a pH of less than 7.5 for 24 hours, flushing the system, then repeating. Additional testing for Legionella is required to determine the effectiveness of the procedure. Maintaining a clean, microbiologically free cooling water system and using effective water treatment is preferable to dealing with remedial efforts. The Cooling Technology Institute (CTI) and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) have published position papers on the prevention of Legionella; these can be downloaded from their respective websites: www.cti.org/ and www.ashrae.org/.

1.8 Macrobiological Control. The term “macrobiological control” refers to control of larger biological organisms such as mussels, clams, and snails. They can exist in cooling systems that use seawater or river water as makeup. The first line of defense is using mechanical prevention with strainers and filters on the intake water to prevent infiltration into the cooling water system. Control methods within the cooling system include thermal shock and chemical treatment with oxidizing and non-oxidizing biocides.

2. CORROSION IN COOLING SYSTEMS. The term “corrosion” (in a cooling water system) is defined as the electrochemical deterioration of a metal that is in contact with cooling water. Corrosion occurs when an electric current flows from one part of the metal (anode) through the water (electrolyte) to another part of the metal (cathode). Corrosion takes place at the anode only. The cathode is the driving force of the corrosion action. Forms of corrosion associated with industrial water systems are illustrated in Figure 2.

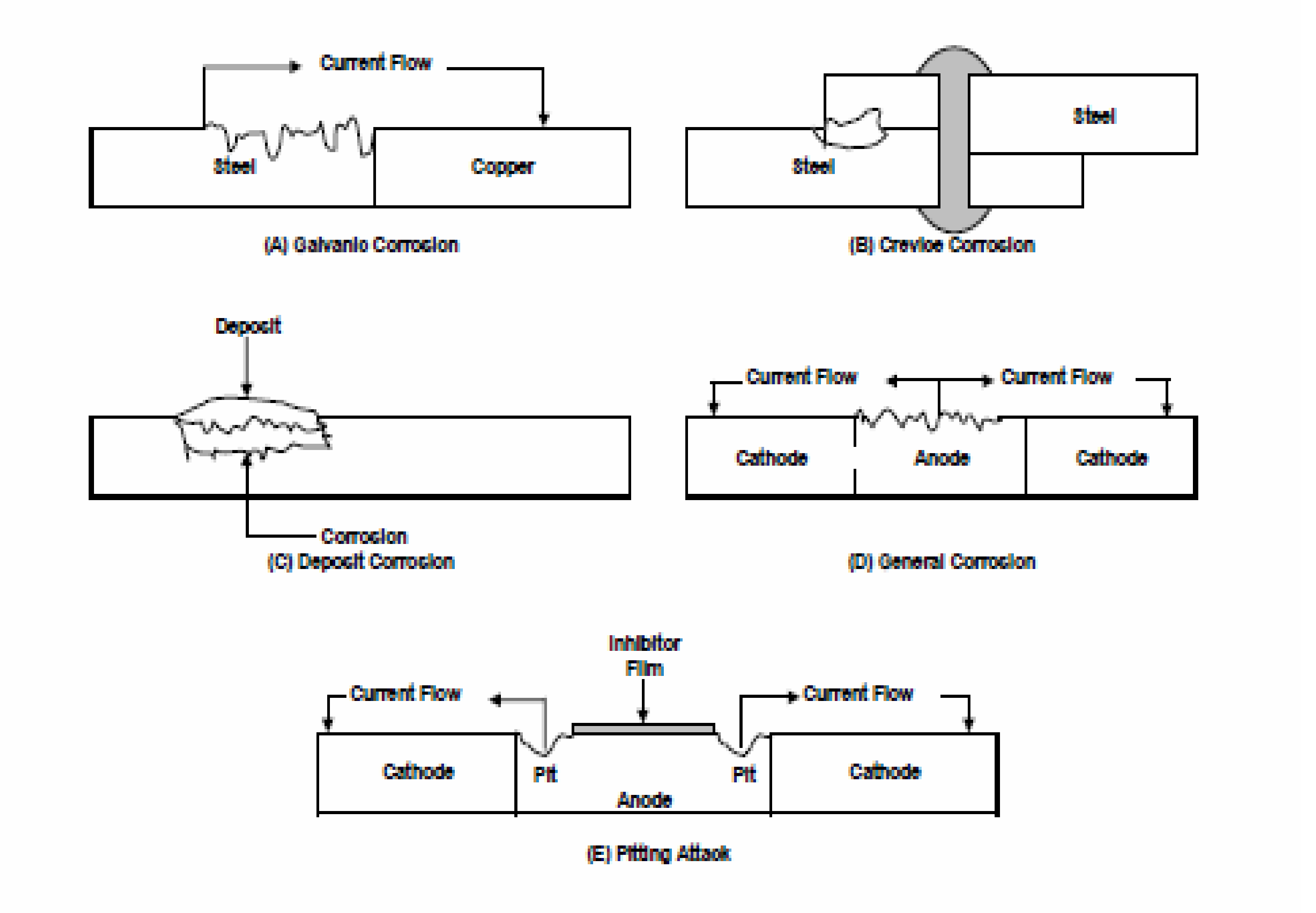

Figure 2

Forms of Corrosion

2.1 GALVANIC CORROSION. See Figure 2(A). This term refers to corrosion that occurs when two different metals are coupled together. The metal with the least resistance becomes the anode and will corrode due to the electrochemical reaction produced. One of the most common instances of galvanic corrosion occurring in cooling water systems results when mild steel and copper alloy metals are brought into contact with one another (e.g., copper tubing attached to a mild steel tube sheet or brass valves connected to mild steel or galvanized piping). As a result of the electrochemical reaction, the copper is dissolved in the water and corrosion of copper alloy results. The copper can also plate out (stick) on mild steel surfaces, setting up additional galvanic cells. Another example is the electrochemical reaction that occurs when mild steel and zinc (galvanizing) are coupled together at temperatures normally found in cooling tower systems. The zinc becomes the anode and is corroded. Figure 3 shows the galvanic series. Any coupling of a metal that is higher in the galvanic series with a metal or alloy that is lower in the galvanic series results in electrochemical reaction in which the “higher” metal functions as the anode or active metal.

Active End
Magnesium
Magnesium alloys
Zinc
Galvanized steel
Aluminum 1100
Aluminum 6053
Alclad
Cadmium
Aluminum 2024 (4.5 Cu 1.5 Mg 0.6 Mn)
Mild Steel
Wrought iron
Cast iron
13% Chromium stainless steel Type 410 (active)
18-8 Stainless steel Type 304 (active)
18-12-3 Stainless steel Type 316 (active)
Lead-tin solders
Lead
Tin
Muntz metal
Manganese bronze
Naval brass
Nickel (active)
76 Ni – 16 Cr – 7 Fe alloy (active)
60 Ni – 30 Mo – 6 Fe – 1 Mn
Yellow brass
Admiralty brass
Aluminum brass
Red brass
Copper
Silicon brass
70-30 Cupro nickel
G-Bronze
M-Bronze
Silver solder
Nickel (passive)
76 Ni – 15 Cr – 7 Fe alloy (passive)
67 Ni – 33 Cu alloy (Monel)
13% Chromium stainless steel Type 410 (passive)
Titanium
18-8 Stainless steel Type 304 (passive)
18-12-3 Stainless steel Type 316 (passive)
Silver
Graphite
Gold
Platinum
Noble or Passive End

Figure 3
Galvanic Series of Common Metals and Alloys Found in Cooling Water Systems

2.2 GENERAL CORROSION. See Figure 2(D). The term “general corrosion” refers to uniform corrosion of metal surfaces. A single piece of metal will have cathodic and anodic areas due to differences in impurities and stresses. These areas will change periodically, causing the metal to corrode over the entire surface at a more or less uniform rate.

2.3 CONCENTRATION Cell Corrosion. When two pieces of the same metal are in a solution capable of acting as an electrolyte, and the electrolyte contains different substances or the same substance in different amounts, such as a salt or a mixture of salts, or oxygen, an electrical potential difference will develop between them.

2.3.1 CREVICE CORROSION. See Figure 2(B). The term “crevice corrosion” refers to corrosion that occurs in a slight separation between two pieces of metal, such as at the contact point of two mild or stainless steel plates that have been bolted together. Water flow is restricted in a crevice and, as a result, oxygen is consumed faster than it can be replenished. The metal in the crevice functions as an anode and corrodes. This is a form of concentration cell corrosion, also called “differential oxygen cell” corrosion. Stainless steel is particularly susceptible to this type of corrosion, which results in localized or pitting attack.

2.3.2 UNDER-DEPOSIT CORROSION. See Figure 2(C). The term “under-deposit corrosion” refers to corrosion occurring under any type of deposit. The underside of a deposit that has been caused by fouling, bacterial slime, or debris acts in much the same way as the inside of a crevice. The metal under the deposit becomes anodic and corrodes. This process is considered another form of concentration cell corrosion because oxygen cannot easily get under the deposit. All metals are susceptible to this type of corrosion, which results in localized or pitting attack.

2.3.2.1 MICROBIOLOGICALLY INFLUENCED CORROSION (MIC). See Figure 2(E). This term refers to metal corrosion associated with microbiological organisms whose presence contributes to the creation of, or maintenance of, a corrosive environment. MIC can be either eliminated or prevented to a large degree by the proper use of biocides.

2.4 CORROSION RATE. The term “corrosion rate” refers to the rate at which the corrosion action proceeds. The rate is measured in units of mils per year (mpy). A mil is 0.0254 millimeter (one-thousandth of an inch). The rate measurement is performed using corrosion coupons that have been exposed to cooling water for a short period of time (i.e., 30 to 90 days). The weight of the coupon is measured before and after exposure to the water. The thickness of the metal lost due to corrosion over the testing period is then calculated using a measurement of the weight loss. This weight loss is extrapolated to give a rate for 1 year and a calculation of the thickness loss is then performed and the value is reported. Alternatively, this measurement can be taken using specialized instruments that rapidly measure corrosion rates. Table 7 shows the corrosion rates for corrosion coupons of different metals.

Metal	Mpy	Comment
Mild steel piping	< 1	Excellent
	> 1 to 3	Good
	> 3 to 5	Fair
	> 5 to 10	Poor
	> 10	Unacceptable
Mild steel Hx tubing	< 0.2	Excellent
	> 0.2 to 0.5	Good
	> 0.5 to 1.0	Fair
	> 1.0 to 1.5	Poor
	> 1.5	Unacceptable
Copper and copper alloys	< 0.1	Excellent
	> 0.1 to 0.2	Good
	> 0.2 to 0.3	Fair
	> 0.3 to 0.5	Poor
	> 0.5	Unacceptable
Galvanized steel	< 2	Excellent
	> 2 to 4	Good
	> 4 to 8	Fair
	> 8 to 10	Poor
	> 10	Unacceptable
Stainless steel	< 0.1	Acceptable
	> 0.1	Unacceptable

NOTE: Determine pitting on coupons by visual observation; any pitting is unacceptable.

Table 7

Assessing Corrosion Rates in Cooling Water Systems: 90-Day Corrosion Coupon Test

2.5 CORROSION CONTROL METHODS. In cooling water systems, two basic techniques are used to provide corrosion protection to the metals that the water contacts: use of chemical corrosion inhibitors, and raising the pH of the cooling water. Figure 4 illustrates the effect of pH on the corrosion rate of mild steel. Most military cooling water systems contain components fabricated primarily of copper alloy and mild steel. Galvanized steel is present in galvanized cooling towers and stainless steel may be present in piping. As the cooling water pH is increased (ideally to within the range of 8.0 to 9.5), copper and mild steel corrosion rates will decrease as shown in Figure 4, although very high pH levels are corrosive to copper. The increase in pH alone cannot always protect metals adequately, especially since cooling water is highly aerated (oxygen saturated). Chemical corrosion inhibitors are used to provide protection from corrosion of the metal components of cooling water systems. Table 8 shows criteria for the selection of corrosion inhibitors. The principal strategy for a cooling system corrosion protection program is to ensure protection of the metal in the heat exchanger (metal that is the thinnest metal in the system). The secondary goal is to provide protection from corrosion of the mild steel piping. When galvanized steel cooling towers are part of the cooling system, specialized corrosion inhibitors are the best control method. Galvanized steel is corroded at pH levels above 9.0 and below 6.0.

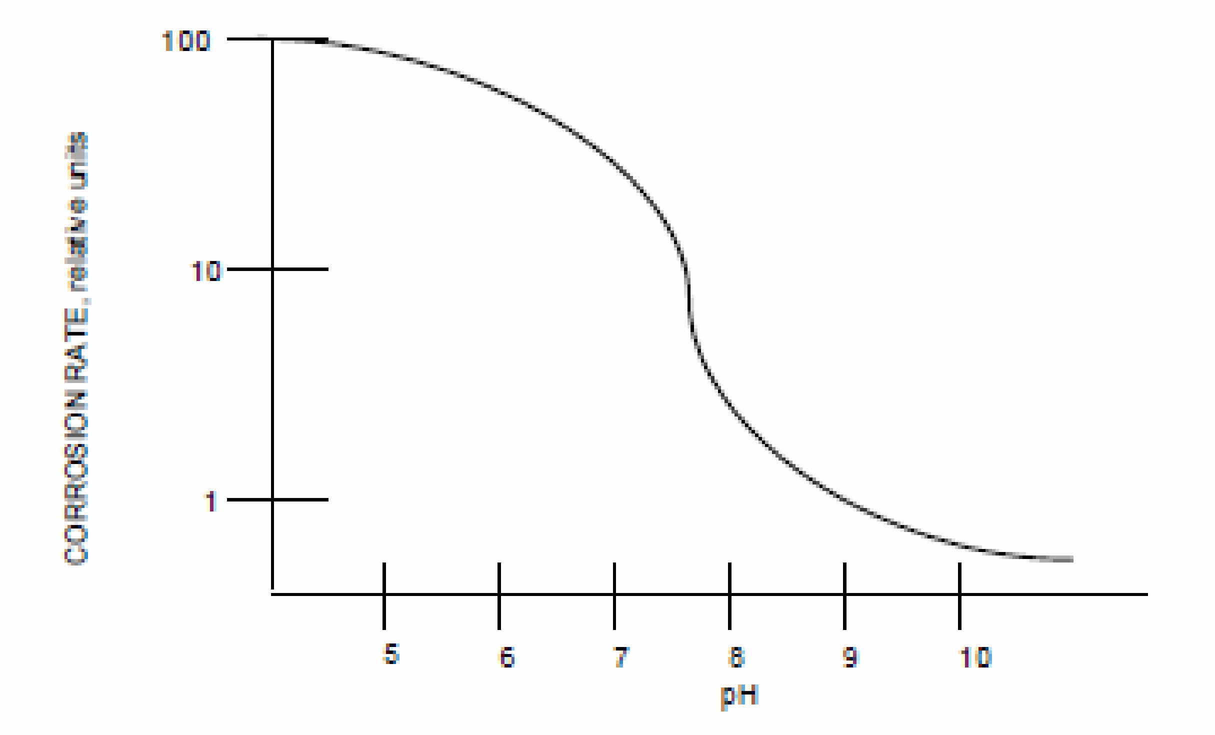

Figure 4

Effect of pH on Corrosion Rate of Unprotected Mild Steel in Water

Corrosion Inhibitor	Metal			pH Range (ideal)
	Steel	Copper	Aluminum	
Cathodic Inhibitor				
Polyphosphate[1]	Excellent	Attacks	Attacks	6.5-8.5
Zinc salts[2]	Excellent	None	None	6.5-8.5
Polysilicate[3]	Excellent	Excellent	Excellent	7.5-10.0
Molybdate	Good	Fair	Fair	7.5-10.0
Anodic Inhibitor				
Orthophosphate[1]	Good	Attacks	Attacks	6.5-8.5
Orthosilicate[3]	Good	Good	Good	7.5-10.0
Copper Corrosion Inhibitor				
Azoles	Fair	Excellent	Fair	6.0-10.0

NOTES:

1. May require polymeric calcium phosphate dispersant.
2. Rarely used alone. Requires zinc solubilizer above pH 7.8.
3. DO not use if natural silica is 150 ppm or greater.

Table 8

Criteria for Corrosion Inhibitor Selection

2.5.1 EFFECTIVE CORROSION CONTROL. Effective corrosion control requires maintaining appropriate pH levels, plus adding maintenance dosages of chemical corrosion inhibitors. Chemical corrosion inhibitors form a protective film or barrier on the cooling system metal surfaces that have been cleaned prior to adding an initial high dosage of inhibitor. The initial high dosage of inhibitor passivates (protects) the metal. The appropriate dosage of corrosion inhibitor must be maintained continuously in the cooling water to ensure continuing protection. Table 9 shows examples of various passivation and maintenance dosage levels of corrosion inhibitors. Corrosion inhibitors are divided into three classes: cathodic, anodic, and general filmers. Corrosion inhibitors form a protective film on either the anode, the cathode, or over the entire metal surface. The types of corrosion inhibitors are described below

Corrosion Inhibitor	Dosage (ppm)		Film-Formation Time (Days)
	Initial	Maintenance	
Cathodic Inhibitor			
Polyphosphate[1]	40-60 as PO_4	10-20 as PO_4	5-6
Zinc salts[2]	10-20 as Zn	3-5 as Zn	5-6
Polysilicate[3]	40-60 as SiO_2	10-20 as SiO_2	10-12
Molybdate	40-60 as Mo	5-20 as Mo	10-12
Anodic Inhibitor			
Orthophosphate[1]	40-60 as PO_4	15-20 as PO_4	5-6
Orthosilicate[3]	40-60 as SiO_2	10-15 as SiO_4	10-12
Copper Corrosion Inhibitor			
Tolyltriazole	10-20 as TTA	1-2 as TTA	5-6

NOTES: General: Maintenance dosage shifts to lower part of range as pH rises.

1. May require polymeric calcium phosphate dispersant.
2. Rarely used alone. Requires zinc solubilizer above pH 7.8.
3. DO not use if natural silica is 150 ppm or greater.

Table 9

Guidelines for Passivation Film Formation and Subsequent Maintenance

2.5.1.1 ANODIC INHIBITORS. Anodic inhibitors form a protective film coating on the anodic metal (where the metal is lost) and thus directly control corrosion by preventing the reaction that results in corrosion. Any unprotected areas will corrode at a much faster rate than the protected areas, a factor that could result in pitting or localized attack of the unprotected areas. Examples of anodic inhibitors include orthophosphate, nitrite, and orthosilicates. Under certain conditions, molybdate can function as an anodic inhibitor.

2.5.1.2 CATHODIC INHIBITORS. Cathodic inhibitors form a protective film coating of the cathodic metal (where metal is not lost) and thus indirectly prevent corrosion by interfering with the current flow required for the electrochemical reaction to proceed between the cathodic and anodic metals. The corrosion reaction rate is governed by the size and type of the cathode relative to the anode. Even when cathodic areas are not completely covered by the protective film, corrosion will occur, but usually more slowly and uniformly than when using anodic inhibitors alone. The occurrence of localized corrosion or pitting attack is greatly reduced. Examples of cathodic inhibitors include zinc salts, polyphosphates, and polysilicates. Under most conditions, molybdate will function as a cathodic inhibitor.

2.5.1.3 GENERAL INHIBITORS. General inhibitors produce a protective film on the surfaces of all metals. These corrosion inhibitors are organic compounds, such as certain phosphonates, amines, and other nitrogen chemicals. They may be used in cooling water systems.

2.5.1.4 CORROSION INHIBITORS FOR SPECIFIC METALS. Some corrosion inhibitors provide corrosion control for specific metals. The protection of copper and copper alloys requires the use of azoles, such as tolyltriazole (TTA), benzotriazole (BZT), and butylbenzo-thiazole, which can be added to the system separately from, or as part of a blend of, other treatment chemicals.

2.5.1.5 GALVANIC OR CREVICE CORROSION. Control of galvanic or crevice corrosion is achieved primarily by engineering and mechanical design. These types of corrosion can also be partially controlled by physical and chemical considerations. A dielectric coupling (insulator), used to separate two different metallurgies, can help to prevent galvanic corrosion. From a chemical perspective, adjusting pH and using proper corrosion inhibitors will reduce corrosion.

2.5.1.6 MIC. MIC is best prevented by stopping conditions that foster biological growth and by using an effective microbiological control program. A MIC prevention program includes adequate control (prevention) of deposits and fouling, avoidance of low-flow and dead-leg conditions, and implementation of a consistently effective microbiological program.

2.5.1.7 DEPOSIT CORROSION. Control of deposit corrosion requires maintaining deposit-free metal surfaces. This applies to any form of deposit, such as scale, biomass, corrosion products, or foulants. The occurrence of most types of deposits is prevented by dispersants, scale inhibitors, or biocides, along with the maintenance of adequate flow velocities. Routine, adequate cleaning of filters and tower sumps will help reduce deposits.