Prepare Your Cooling System Before Startup

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Pre-startup actions such as initial water treatment and equipment coatings in cooling tower water systems can increase system life expectancy and efficiency, and reduce corrosion and fouling.

New industrial and commercial cooling tower water systems often experience serious corrosion, fouling, and microbiologically induced (or influenced) corrosion (MIC) within the first year of operation. This corrosion can be prevented with proper pre-startup cleaning and coating of equipment, as well as initial treatment of the first water added to the system.

A cooling tower system consists of three main components: the cooling tower, heat exchangers, and piping that connects the tower and heat-transfer equipment (Figure 1). These components are often made of different materials of construction. The cooling tower may be made of galvanized steel, treated lumber, concrete, or fiberglass with polyvinyl chloride (PVC) fill. Heat exchanger tubes may be constructed of mild steel, stainless steel, copper alloys, or titanium. The piping may be mild steel, copper, galvanized steel, or PVC.

This article discusses some of the problems that can occur prior to and during cooling tower startup, and outlines steps that can be taken before startup to minimize corrosion and fouling. The design and fabrication of cooling tower systems vary from industry to industry, and some industries require specialized pre-startup actions to prevent or minimize premature corrosion. Specific recommendations are provided for petroleum refineries and chemical plants; utility power plants; and heating, ventilation, and air conditioning (HVAC) systems.

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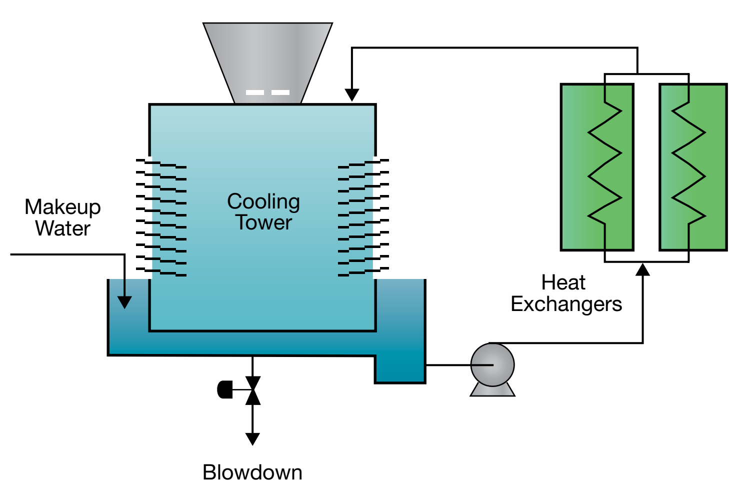
Corrosion before initial startup

The components of a cooling tower system are often delivered to the site before construction of the system begins. The cooling tower, the heat exchangers, and the piping may be on-site for weeks or even months prior to setup and installation. This equipment may be protected from the weather, moisture, dust, and dirt; or it may be completely unprotected, for example if the owner or contractor does not understand what corrosion can occur or plans to clean it during startup. Unprotected equipment will begin to corrode and/or become contaminated with corrosive and/or pathogenic microbiological organisms (*e.g., Legionella*).



▲ **Figure 1.** A typical cooling tower water system consists of a cooling tower, heat exchangers, and piping.

▲ **Figure 2.** Galvanic corrosion can occur in an HVAC system with a mild-steel tubesheet and copper tubes; this corrosion can be severe (bottom).

▲ **Figure 3.** Significant corrosion can occur in mild-steel piping prior to startup. This 1.5-in. pipe experienced severe corrosion within three months of installation (top); the bottom image shows the pipe after it was cleaned.

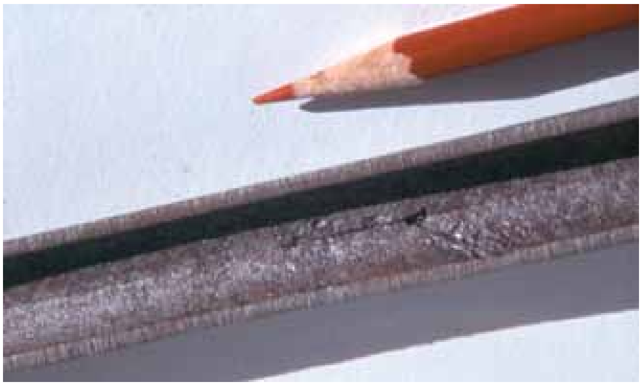
After the complete system is assembled, air pressure testing and hydro testing are performed to check system integrity. Hydro testing is typically performed with untreated water (because it is readily available), which initiates corrosion of mild steel components and piping.

Once the hydro testing is complete, the system may remain filled with untreated water until startup, causing further corrosion as well as the formation of rust deposits. A few days, a few weeks, or a few months may pass before the facility is ready to begin operation — resulting in even more corrosion. The facility may use only a portion of the cooling system's lines and equipment for several additional months before full-scale operation occurs. The water left in the system from hydro testing contains minerals, oxygen and biological organisms that can cause corrosion during this pre-startup period.

Many chillers in HVAC systems have enhanced (internally grooved) copper alloy tubes, often with a mild-steel tubesheet. In the presence of water, these metals act as a battery to cause galvanic corrosion of the mild-steel tubesheet (Figure 2). Severe corrosion will also develop rapidly in mild-steel piping that contains nontreated water prior to system startup (Figure 3).

Incomplete welds in steel piping are very susceptible to crevice corrosion and early leakage due to the reduced wall thickness at the incomplete weld (Figure 4). Corrosion pits in enhanced copper-alloy tubed heat exchangers can cause pitting failures within one year (Figure 5). Stainless steel heat exchangers and piping that are not disinfected can corrode rapidly and start leaking within the first several months of operation due to MIC that was present before startup (Figure 6). Galvanized steel corrosion (*i.e.,* white rust) of cooling towers can occur during the first few months of operation as well.

The following sections provide guidelines for preventing or minimizing pre-startup equipment corrosion and damage.



▲ **Figure 4.** Incomplete welds in mild-steel pipe foster corrosion, and can eventually lead to leaks.

Design strategies

These initial design considerations will minimize or even eliminate corrosion and deposits that can occur during fabrication and construction, as well as during operation, of the cooling water system.

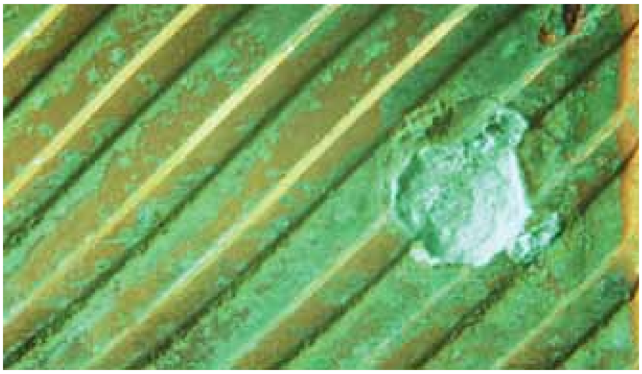
Eliminate all dead legs and dead-end pipe extensions. Stagnant water in dead legs and pipe extensions has the potential to create corrosion, and allows the accumulation of corrosive microorganisms and those that can cause diseases such as legionellosis. These bacteria can contaminate the entire cooling water system after operation begins, and cause severe corrosion of mild steel and stainless steel, which are especially susceptible to MIC.

If mild steel pipe extensions are necessary, they should be connected to the cooling water return line so that treated water can circulate through them during operation. The dead legs should be as short as possible.

Use PVC pipe instead of mild-steel pipe, if possible. Plastic pipe, such as PVC or chlorinated PVC (CPVC), carrying untreated or contaminated cooling water will not corrode, as mild-steel, copper, or stainless steel lines do. PVC pipe requires less, or even no, corrosion inhibitor. PVC pipe is ideal for lines that are 8 in. in diameter or smaller. Mild-steel pipe with an internal epoxy coating offers comparable corrosion resistance.

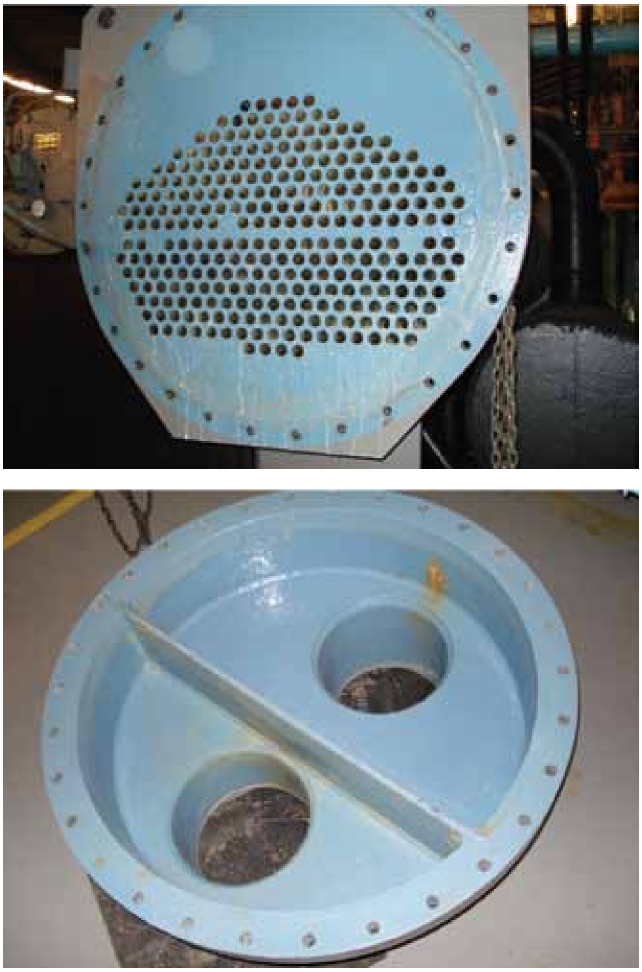
Use seamless pipe if mild steel is necessary. Incomplete welds can be as thin as one-half the normal pipe thickness. These thinner areas are prone to crevice corrosion and early leaks. Therefore, a pipe without any weld seams, or one that is guaranteed to have full welds, is preferable to a pipe with crevices. Once corrosion forms in a crevice due to rust deposits or corrosive microbes, most corrosion inhibitors and microbiocides cannot penetrate the deposits to reach the metal surface and stop the corrosion.

Specify or apply an epoxy coating on the tubesheets and water boxes of heat exchangers. To prevent galvanic corrosion on mild-steel tubesheets and copper tubes, or other mild-steel surfaces, specify that the chiller manufacturer apply an epoxy coating before shipment. Or, the coating can be applied to heat exchanger tubesheets and water boxes after installation but prior to startup (Figure 7). This



▲ **Figure 5.** Enhanced copper-alloy heat exchanger tubes are subject to pitting corrosion (50X magnification).

▲ **Figure 6.** MIC corrosion occurs in untreated stainless steel condenser tubes. The black spots are perforations due to corrosive bacteria.



▲ **Figure 7.** An epoxy coating on mild-steel tubesheets (top) and water boxes (bottom) prevents the buildup of iron rust deposits that could break off and plug tubes, and eliminates galvanic corrosion.

is particularly useful in HVAC chillers with copper tubes and mild-steel tubesheets that are prone to severe corrosion over short periods of time. Epoxy coatings are also useful for protecting metals that are widely separated in a galvanic series of metals (Table 1), such as titanium tubes with an active stainless steel tubesheet.

The epoxy coatings reduce the cooling water corrosion inhibitor requirements and the amount of iron rust deposits that could plug tubes. Epoxy coatings can be installed after corrosion is seen, but this requires excellent surface preparation.

Specify or apply epoxy coatings to water-wetted surfaces of galvanized steel cooling towers. Epoxy coatings prevent galvanized steel corrosion in new cooling towers. If corrosion occurs in an existing cooling tower, an epoxy coating can be applied after a thorough cleaning to prevent further damage.

Table 1. Avoid galvanic corrosion by selecting materials that are near each other in a galvanic series.

Corroded End (Anodic, or Least Noble)
Magnesium
Magnesium Alloys
Zinc
Aluminum
Cadmium
Aluminum Alloys
Steel or Iron
Cast Iron
304 Stainless Steel (Active)
316 Stainless Steel (Active)
Lead-Tin Solders
Lead
Tin
Nickel (Active)
Inconel (Active)
Brasses
Copper
Bronze Alloys
Copper-Nickel Alloys
Monel
Nickel (Passive)
Inconel (Passive)
304 Stainless Steel (Passive)
316 Stainless Steel (Passive)
Hastelloy C-276
Silver
Titanium
Graphite
Gold
Platinum
Protected End (Cathodic, or Most Noble)

Specify an effective combination of corrosion inhibitors and cleaners. A corrosion inhibitor must be added to all water that passes through a cooling water system. To protect the metal components in the tower, piping, and heat exchangers, it is very important to add an effective rust cleaner and a metal-passivating corrosion inhibitor to the initial batch of water entering the system. These chemicals should also be added to the water used for hydro testing to minimize or eliminate corrosion throughout the pre-startup period. The use of phosphate-based or silicate-based corrosion inhibitors and cleaners is widespread because they pose little risk to site workers and the environment. If considerable corrosion has occurred prior to startup, a chemical cleaning may be needed to remove the deposits.

Wash cooling towers made of pressure-treated wood before circulating any water through them. Pressure-treated lumber used in cooling towers usually contains a copper salt, along with a chromate salt, to prevent decay of the wood. This treatment, known as acid copper chromate (ACC), will leach copper and chromate from the wood into the cooling tower water when water is first circulated through the system. The copper-laden water must not be allowed to contact any mild-steel surfaces, as it can cause significant corrosion. This occurs because copper plates onto mild steel surfaces and creates a galvanic cell, which causes rapid corrosion of mild steel.

This can be prevented by circulating water through the cooling tower to its basin and back to the tower using temporary rubber or plastic lines. This causes the "loose" copper to leach from the wood into the wash water, which then can be disposed of. After the cooling system starts normal operation, a high level (100 ppm) of copper inhibitor should be added to the cooling water to prevent any additional leaching of copper.

Protect all equipment delivered to the site. The heat-transfer equipment, piping, and cooling tower should be protected from contaminants such as moisture, dust, dirt, and microbiological organisms prior to and after delivery to the construction site. These contaminants can create corrosive conditions after installation and may make extensive cleaning and corrosion control necessary after startup.

Pre-startup considerations for petroleum refineries and chemical plants

Many chemical processing plants and refineries have mild-steel tubed heat exchangers, typically with the cooling water flowing through the tubeside (occasionally the water is on the shellside). It is important to clean and passivate these mild-steel tubed heat exchangers during or immediately after hydro testing. If this is not done, cleaning may be needed and/or leaks can occur within a year. Usually a phosphate-based corrosion inhibitor and a cleaner can be used to clean and passivate the mild-steel tubes. Even during the idle period prior to startup, mild-steel heat exchangers should be filled with water that contains a high level (100 ppm) of phosphate, which is an excellent mild-steel corrosion inhibitor. The National Association of Corrosion Engineers (NACE; www.nace.org) offers guidelines on the use of phosphate and other corrosion inhibitors.

Stainless steel exchangers with cooling water on the shellside require a different approach. They should be cleaned with a mildly alkaline cleaner to remove fabrication oils and greases, then rinsed with water containing 30–50 ppm active hydrogen peroxide. This helps disinfect the stainless steel, and ensures that a stainless oxide film is established. Chlorine- and bromine-based disinfectants should be avoided because they produce chloride corrosion on the stainless steel.

Pre-startup of utility power plant cooling systems

Many nuclear and fossil-fuel power plants have mild-steel piping in both their service-water cooling water system and their safety-related cooling water system. During the construction phase, this piping may be in place for months or even years before normal operation begins. As a result, serious corrosion and heavy rust deposits due to both minerals and microbes can form in these mild-steel lines if they contain stagnant, untreated water. The following steps can help to prevent corrosion buildup:

- Clean mild-steel lines after construction to remove rust buildup.
- Treat the initial water with corrosion inhibitors to prevent corrosion even during hydro testing.
- Disinfect pipes to prevent MIC.

Piping in safety-related cooling water systems often holds stagnant water for months at a time, as they often only operate when the plant is shut down due to an emergency or routine maintenance outage. Iron rust nodules (called tubercles) can form on pipes and restrict cooling water flow. Therefore, early addition and maintenance of corrosion inhibitors are crucial in safety-related water systems.

Preparing HVAC cooling towers for startup

The most common design for air conditioning cooling water systems consists of a cooling tower and a chiller connected with large-diameter mild-steel piping. The design considerations discussed previously apply to this type of system.

A more-modern design does not employ a central air conditioning chiller. Instead, it uses heat pumps in individual offices, condos, or apartments. These are connected by many thousands of feet of mild-steel pipe 2–10 in. in diameter (and often thinner than the larger pipe used in central air conditioning) that is prone to early corrosion. Requirements for these systems include:

- Dead legs and capped pipe extensions should be connected to the cooling tower return to eliminate stagnant areas and assure treated water is continually circulated.
- High levels of a mild-steel corrosion inhibitor should be added to the hydro test water, and high concentrations maintained until normal startup.
- A copper corrosion inhibitor should be used to prevent copper corrosion in the coils of the heat pumps.

Closing thoughts

Protection of water-contacted equipment and piping in cooling tower systems should begin in the design stage in order to most effectively minimize corrosion and deposits. By following the guidelines outlined here before starting up the system, you can reduce system maintenance requirements by increasing the time between cleanings and repairs, reduce labor and initial water-treatment costs, and extend the life of the equipment. CEP

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Additional Reading

"Cooling Water Systems — Passivation of Cooling Systems," *WaterChem Solutions,* published by Puckorius & Associates, Inc. (2001).

Esmacher, M. J., and G. Geiger, "Identifying Corrosion and Its Causes," *Chem. Eng. Progress,* **107** (4), pp. 36–41 (Apr. 2011).

Geiger, G., and M. J. Esmacher, "Inhibiting and Monitoring Corrosion," *Chem. Eng. Progress,* **108** (3), pp. 29–34 (Mar. 2012).

"Microbiologically Influenced Corrosion," *WaterChem Solutions,* published by Puckorius & Associates, Inc. (2001).

Puckorius, P. R., "Cooling Water Treatment vs. Cooling Systems, Parts 1 and 2: Identifying Water Treatment Needs," *Process Cooling,* p. 14 (Jan/Feb 2002).

Puckorius, P. R., "How to Protect Enhanced Copper Tubes," *Process Cooling,* p. 57 (May/June 2001).