FAILURE ANALYSIS

Microbiologically Influenced Corrosion in a Copper Tube Chiller

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The increased use of recycled water has led to the need for an effective water treatment program to prevent microbiologically influenced corrosion (MIC). This article describes an investigation of copper tubes in a chiller that failed from MIC because of a poor water treatment program.

Over the years, numerous industries have reported microbiologically influenced corrosion (MIC) problems. The cooling industry is particularly susceptible to MIC because of the increased use of nontraditional water sources. The easiest and most cost-effective way to prevent the development of MIC is to address the issue during the design and installation phases. Therefore, proper operating procedures such as effective water treatment must be instituted. Once MIC has developed in a system and has caused multiple failures, great difficulties arise in mitigating the damages inherent with MIC.

Microscopic organisms and their byproducts can influence the electrochemical corrosion of metals. Generally, a protective slime, or biofilm, will develop on surfaces. If the biofilm coverage is discontinuous, organic decomposition within the biofilm creates favorable conditions for corrosion initiation. If the flow rate in the pipe is slow, the biofilm will thicken. The biofilm traps nutrients and provides an ideal microenvironment for the bacteria, causing the development of colonies that ensnare ions and create localized chemical and physical gradients at the metal surfaces. As the biofilm increases in thickness, oxygen permeability to the interior decreases. This creates an ideal environment for anaerobic bacteria. The remaining aerobic bacteria consume any oxygen that does penetrate the biofilm. A small electrochemical cell is formed, which can lead to general or pitting corrosion under the biofilm.

The area under the biofilm, which contains the lowest oxygen concentration, will become the anode in the reaction. The area outside the deposit is the cathode. Thus, the electrochemical reaction is self-sustaining.

Background

A copper tube chiller experienced a leak after six years in service. For the past four years, recycled gray water has been used for the cooling tower makeup. Gray water is classified as recycled sewage water generated from dishwashers, clothes laundry, and bath water. The critical parameters, which were used in the water treatment program, were provided: copper inhibitor TTA (Tolytriazole) between 1 and 2 ppm, bacteria control by free chlorine between 0.2 and 0.5 ppm, and corrosion inhibitor orthophosphate between 10 and 20 ppm. The treated cooling tower water flowed through the copper tubes while the shell contained a refrigerant. The tubes were rifled on the interior and exterior surfaces.

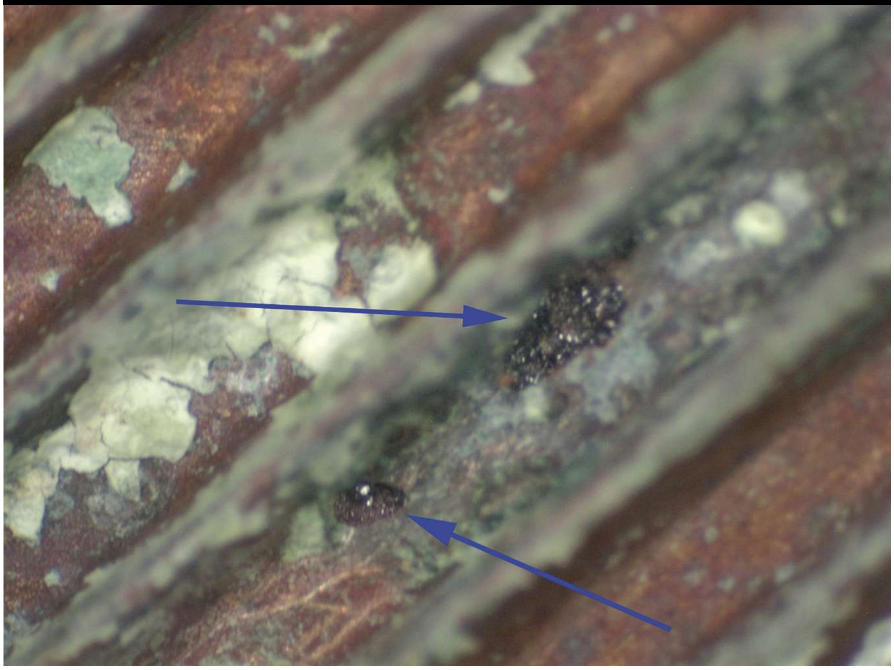
Findings

Green-colored deposits and scaling were readily apparent throughout the waterside (inside) of the tube. Beneath the deposits, areas of localized corrosion were apparent (Figure 1). Metallographic mounts, prepared at the corrosion sites, revealed a perforation at one location and severe corrosion of an internal rifle at another location (Figures 2 and 3).

Three samples of the tubeside deposits were analyzed by energy dispersive x-ray spectroscopy (EDS) for elemental composition: the loosely adhered green-colored scale, the tightly adhered deposits above the pitting, and the corrosion products inside of a pit. The green-colored scale and the deposits contained significant concentrations of calcium and phosphorus in addition to other elements typically present in water scale. The corrosion products inside the pit contained significant concentrations of chloride.

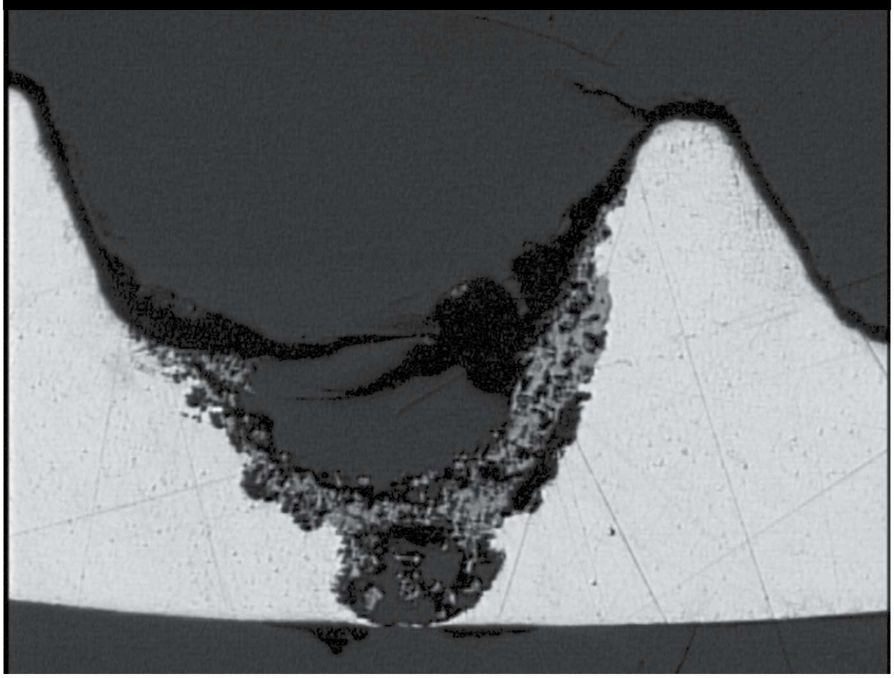
A cursory analysis of the treated cooling tower water and the gray makeup water was performed. These water samples were analyzed for pH, conductivity, and anion components. Additionally, the cooling tower water was analyzed for the copper inhibitor, TTA (Table 1). Because of a large time span between sample acquisition and analysis, biological testing would not have been meaningful.

FIGURE 1



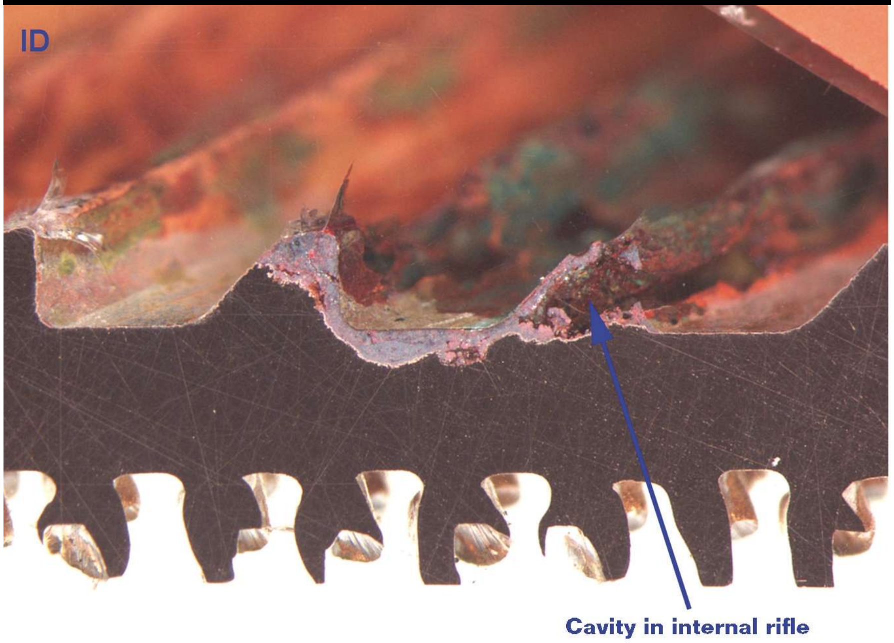
Pitting beneath internal diameter (ID) deposits, 30X original magnification.

FIGURE 2



Tube perforation, 63X original magnification.

FIGURE 3



ID corrosion of internal fin, 25X original magnification.

TABLE 1

Analysis of water samples (ppm)

Analysis	Treated Cooling Tower Water	Gray Makeup Water
pH	6.7	6.9
Conductivity	3,840 Ω^{-1}	1,230 Ω^{-1}
TTA	1.2	—
Chloride	622	192
Nitrate	242	57
Phosphate	30	8
Sulfate	530	27

Discussion

The copper tubes contained numerous sites of localized corrosion (pitting). The pits were covered by tightly adhered deposits, which were rich in phosphorus. It has been reported that phosphorus-rich deposits might indicate bacterial activity, as bacteria use phosphorous chemistry in their energy processes.[1]

The water analysis revealed significant differences between conductivity, chloride, and sulfate between the gray makeup water sample and the treated cooling tower water sample. The cooling tower water contained significantly higher concentrations of chloride and sulfate, as well as having a higher conductivity. These characteristics contributed to the copper tube corrosion.

A preliminary review of the water analysis history revealed that the treated cooling tower water contained significant amounts of chloride. In addition, the free chlorine level exceeded 0.5 ppm on numerous occasions. It has been suggested that a range of 0.1 to 0.3 ppm of free chlorine should be used in water treatment programs.[2]

Chlorine, added to prevent bacteria growth, combines with copper azole inhibitors to make them ineffective. Furthermore, chlorine is ineffective in penetrating biofilms, thus making it ineffective in controlling bacteria within a biofilm. The bacteria growth can be increased by certain corrosion inhibitors. One such inhibitor, orthophosphate, can stimulate the growth of bacteria by acting as a nutrient.[3] Consequently, the bacteria, protected from chlorine by the biofilm, probably benefited from the presence of orthophosphate.

Conclusions

The poor water treatment program created conditions conducive to MIC. In select locations, the growth of bacteria most likely caused the corrosion of the copper tubes until a perforation occurred.

The use of gray water has to be carefully monitored. The poor water quality supplied to the copper tubes produced bacteria that contributed to the tube failure. If a properly executed water treatment program had been implemented, the corrosion may have been avoided.

Acknowledgment

The author would like to thank Corrosion Testing Laboratories, Inc., Newark, Delaware, where the work described in this article was undertaken.

References

1 R.E. Tatnall, D.H. Pope, "Identification of MIC," A Practical Manual on Microbiologically Influenced Corrosion (1993), p. 67.

2 C. Frayne, Cooling Water Treatment Principles and Practice (1999), p. 185.

3 G.B. Hatch, "Inhibition of Cooling Water," Corrosion Inhibitors (1973), p 135.

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