Issue 152
June 2025
Division of Technical Resources
Office of Research Facilities
National Institutes of Health
Technical News BULLETIN

Corrosion in Closed Loop Water Systems Part 2 – Evaluation and Prevention

Introduction

Practical strategies for evaluating, preventing, and controlling corrosion in closed-loop water systems (CLWSs) are vital for ensuring consistent system performance, minimizing unplanned downtime, and extending the life of critical infrastructure. Key evaluation criteria such as corrosion rates, metal ion concentrations, and water chemistry parameters are essential for assessing system health. Part 2 of this article series explores proven monitoring techniques and industry best practices in chemical treatment and maintenance to support long-term reliability, protect equipment, and sustain efficient operation.

Evaluation Criteria

Evaluating corrosion in CLWSs requires focusing on corrosion monitoring methods, water chemistry parameters, corrosion inhibitor concentrations, microbial growth assessment, and system design and maintenance. Key performance indicators (KPIs) include: corrosion rate, which measures metal loss over time, typically via corrosion coupons or other electrochemical methods; water chemistry parameters, including pH, temperature, conductivity, dissolved oxygen (DO), metal ions, chloride/nitrate/sulfate ions, turbidity, and inhibitors (e.g., nitrites, molybdates, inhibited glycol or triazoles); and microbial assessment of various bacteria such as heterotrophic bacteria, sulfate-reducing bacteria, iron-related bacteria, and nitrifying and denitrifying bacteria.

Corrosion Rate:

Quantitative analysis of corrosion rates provides insight into system health. Methods of monitoring corrosion rates in a CLWS include:

- Corrosion coupons: Exposed to system water for a set period, then cleaned and weighed to determine metal loss.
- Linear polarization resistance: Measures real-time corrosion rates electrochemically.
- Electrochemical impedance spectroscopy: Assesses detailed corrosion behavior and inhibitor effectiveness.

Water Chemistry Parameters:

Regular water analysis is essential for identifying corrosion risks.

- pH levels: Depending on metallurgy, pH should be maintained within a thermodynamically and empirically established range. For carbon steel, the pH should be within 9.0–10.5 to minimize metal attack.
- Mechanical cross-connect: Intrusion of untreated makeup water or steam/chilled water leaks can introduce external contaminants, oxygen, and particulates that can potentially increase corrosion. These can be identified by comparing related water chemistry parameters with those of potential intrusion sources.
- Dissolved oxygen: Implement de-aeration and scavengers to reduce DO.
- Chlorides, nitrates, and sulfates: Elevated levels of chlorides and sulfates contribute to pitting and crevice corrosion. Nitrates can act as a dangerous inhibitor because a very localized corrosion attack can be initiated when the environment allows a passivation-activation transition.
- Conductivity: High conductivity without inhibitors increases the risk of localized corrosion.
- Iron and copper concentrations: A higher concentration of iron and copper than is present in makeup water indicates active corrosion of system components.
- High turbidity or cloudiness: Can be an indicator of a high-corrosion situation, as makeup water has minimum dirt or silt.
- Nitrite concentration: Indicates the presence of corrosion inhibitors for a CLWS with iron piping.
- Orthophosphate/molybdate concentration: Low levels or absence of orthophosphate or molybdate in glycol-added preheat hot water suggest dormancy, stagnation, leaks, or microbial issues requiring repair, cleaning, or chemical replenishment.
- Triazoles: The presence of triazoles, commonly used in closed-loop chilled water systems, in the heating hot water (HHW) system indicates potential unintended intrusion of chilled water into the HHW system.

Microbial Assessment:

Microbial-induced corrosion (MIC) is a major concern in preheat hot water and chilled water systems. A corroded surface site provides an ideal environment for MIC to initiate or accelerate.

- Bacterial culture tests: Identify specific types of bacteria. Dip slides or Petrifilm can detect heterotrophic bacteria, while biological activity reaction tests detect sulfate-reducing and iron-oxidizing bacteria, among others.
- ATP-based methods measure microbial activity. Microscopy techniques, staining assays, and biochemical assays can visualize and quantify biofilm.
- MIC indicators: The presence of iron sulfide deposits and acidic byproducts suggest microbial activity.

Corrosion Inhibitors

The most effective corrosion inhibitors for a CLWS are molybdate and nitrite, either separately or in combination. These inhibitors protect metal surfaces by forming an oxide layer (preventing the corrosive agent from reaching the metal) or by reacting with corrosive elements in the system. Molybdate provides excellent protection in various water conditions but requires DO, while nitrite promotes oxide formation on steel but can oxidize to nitrate if air ingress occurs and feeds certain microbes. A molybdate-nitrite combination offers synergistic protection, with nitrite aiding oxide film formation. Maintaining alkaline pH is essential for this combination, though excessive pH (>12) can cause caustic

embrittlement. Nitrite-molybdate-azole blends inhibit corrosion in steel, copper, aluminum, and mixed-metallurgy systems.

While inhibitors can help control corrosion, effective oxygen control remains essential for comprehensive corrosion prevention, as DO in makeup water can cause flash rusting on carbon steel. Oxygen control can be achieved by using oxygen scavengers. System materials are also a consideration; although stainless steel can tolerate a high concentration of DO, smaller components like brass valves may experience accelerated corrosion. Finally, proper pressurization and limited flushing are key to preventing air ingress. Effective corrosion control requires a combination of oxygen exclusion, controlled flushing, and microbial management.

Piping Visual Inspection and Monitoring

Routine inspections help detect early corrosion indicators.

- Internal pipe and heat exchanger inspections help detect scale, deposits, and rust.
- Corrosion coupon, instantaneous corrater, and electrical resistance probe monitoring assess metal loss.
- Ultrasonic thickness testing measures pipe wall degradation over time.

A comprehensive monitoring approach ensures early detection of corrosion risks, optimizes water treatment strategies, and enhances the longevity of closed-loop systems.

Evaluation with City Water Markers

Comparing water quality parameters between a closed-loop system and city water may indicate intrusion of unwanted sources of makeup water, inadequate treatment, or depletion of corrosion inhibitors over time, any of which may then require repair, corrective chemical dosing, and ongoing monitoring. Routine analysis of pH, conductivity, alkalinity, hardness, DO, and inhibitor levels helps assess water stability and treatment effectiveness. Steam leaks into hot water systems can be identified by comparing their pH values with that of city or makeup water. Neutralizing amine-treated steam will have a higher pH than city water. Untreated steam will have a lower pH than city water. Comparing metal ion concentrations (e.g., iron, copper, zinc) between closed-loop and city water can identify contamination sources or treatment deficiencies. Monitoring chloride, sulfate, and total dissolved solids helps detect corrosive elements introduced from city water or progressive corrosion activities. Additionally, testing for biofilm formation and MIC is crucial to prevent microbiological fouling and under-deposit corrosion.

Prevention and Mitigation Strategies

Effective strategies to prevent or mitigate corrosion in a CLWS include:

- Chemical treatment: Use oxygen scavengers (e.g., sodium sulfite, erythorbate, and diethylhydroxylamine) and corrosion inhibitors (e.g., nitrite, molybdate, phosphate, and triazoles). For new piping or equipment tie-ins, regular flushing and passivation are recommended.
- Electropolishing and passivation: Stainless steel is widely used in cleanroom applications for its durability and corrosion resistance. However, to prevent and mitigate corrosion—especially in welded systems and piping—surface treatments such as electropolishing and passivation are essential. These processes, as specified in the *Design Requirements Manual* Section 13.8.21 and Exhibit 6.3, Sections A–C (see also ASTM A967 and ASTM A380), enhance the protective oxide layer and improve surface finishes, reducing the risk of contamination and corrosion. Electropolishing can also be applied to other compatible pipe materials to further enhance corrosion resistance.
- System design optimization: Minimize dead legs, maintain proper flow rates, and avoid dissimilar metal contact by using dielectric unions or insulating fittings at joints to prevent galvanic corrosion.
- Filtration and backwash practices: Remove particulates to reduce the risk of under-deposit corrosion.
- Cathodic protection: Apply sacrificial anodes or impressed current systems where appropriate.
- Regular monitoring and maintenance: Conduct periodic water testing, system flushing, and condition assessments to detect and address early signs of corrosion. Regular monitoring for specific bacteria, like sulfate-reducing bacteria and iron-related bacteria, is essential to detect and prevent MIC.

Conclusion

Regular corrosion evaluation in closed loop heating and cooling systems is essential for maintaining efficiency and extending system lifespans. Routine monitoring and preventive strategies help protect system components and ensure long-term performance. Monitoring water chemistry, physical inspections, and corrosion rate assessments offer vital information on system conditions. By adopting proactive mitigation measures, it is possible to reduce the risk of early failure and expensive repairs.

Additional Reading

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