the **Conduit**

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In this Issue

Forgotten Water: Stator Cooling Water

By David G. Daniels
Principal Scientist

Even utilities that are very diligent about treating and monitoring their boiler water, demineralized water makeup, and cooling water may know little about treating one of the most critical water systems in the plant: stator cooling water.

Stator cooling water is contained in a closed loop system that cools the copper stator bars in water-cooled generators. The holes though which the water flows are narrow. Unimpeded flow through all stator bar openings is critical to operation of the generator. Overheating of stator bars can result in reduced generating capacity or even catastrophic failure of the generator.

Stator cooling systems contain only deionized water. The cooling loop removes heat from the stator coolers and conveys it away through heat exchangers. The water is continuously passed through a mixed bed polisher that removes any soluble ionic contaminants that enter the water. The stator ion exchange resins often also act as a filter for particulates in the water, though some systems have a separate filter. The ion exchange resin will eventually become exhausted, but in many systems, it is common for the pressure differential across the resin bed (created by accumulated particulates) to require that the resins be replaced before the ion exchange capacity is reached.

Copper contamination

The stator cooling water system's heat transfer surfaces are typically copper, though some are stainless steel. The chemistry of copper in oxidizing and reducing conditions has been the subject of a great deal of recent research. One area of intense focus has been copper corrosion in feedwater systems and corrosion product transport into the boiler and on to the HP turbine. Some of the general metallurgical principles learned in studying copper in feedwater systems can also be applied to stator cooling systems. As with copper in feedwater systems, we know that dissolved oxygen and pH play a major role in determining the corrosion product formation rate and transportation rate through the stator cooling system.

It is important to remember that the major cause of problems in stator cooling systems has not been corrosion per se but, rather, deposit accumulation in critical areas. These deposits are copper oxides released from one area of the stator coolers and deposited in another. The amount of dissolved oxygen in the system, and particularly variations in that oxygen concentration, determines when copper oxides are released.

Copper forms cuprous oxide (Cu_2O) under reducing (low-oxygen) conditions and cupric oxide (CuO) when dissolved oxygen is high. Either of these oxides can be stable and create a passive oxide layer on the channels in the stator bars. A slightly alkaline pH increases the stability of the oxide layer.

Study your options

The recommended treatment regimes for stator cooling water can be categorized by their levels of dissolved oxygen and pH. Of the four options illustrated in Figure 1, three are generally recommended by treatment experts. Each of the recommended options can be found in operating power plants, and each has pros and cons that must be balanced against the particular needs of a plant and its equipment operating history.

Low-O_2, neutral pH option. A thin layer of passive cuprous oxide forms in a low–dissolved oxygen and neutral pH regime. This treatment option is found in about 50% of the stator water cooling systems in the power industry. The water is fully

Low dissolved oxygen (<10ppb) and neutral pH	High dissolved oxygen (>2,000 ppb) and neutral pH
Low dissolved oxygen (<10 ppb) and alkaline pH (8-9)	High dissolved oxygen (>2,000 ppb) and alkaline pH (8-9) (not recommended due to clip corrosion problems)

Figure 1. Three real options. Only three of the four possible stator cooling water treatment options are viable. Source: M&M Engineering

(Continued on page 2)

oxygenated when the system is first filled. As the water circulates, it reacts with the copper in the system, the oxygen is consumed, and the dissolved oxygen gradually approaches zero. The dissolved oxygen is likely to remain at <10 ppb as long as no water is added to the system. Neither oxygen scavengers nor reducing agents are commonly added to stator cooling systems. The trick in this treatment regime is keeping dissolved oxygen out.

The effect of transient oxygen spikes is most profound on low–dissolved oxygen and neutral pH systems. The corrosion or oxidation rate of copper in a system containing 400 ppb of dissolved oxygen is more than five times its rate at low levels of oxygen under neutral conditions.

Every time makeup water is added to the stator system, it receives a little shot of dissolved oxygen. If, due to leaks in the stator cooling water system, makeup rates are significant, the stator cooling water can swing back and forth between low- and high-oxygen conditions. These transient conditions release oxides into the system.

Air ingress can also cause significant increases in the system's dissolved oxygen. Putting a nitrogen cap on the stator cooling water head tank can minimize air in-leakage.

Carbon dioxide can enter the system via the makeup water or along with the air. As carbon dioxide is absorbed into the water, it drops the pH to acidic levels, increasing the corrosion rate of copper. Carbon dioxide can form bicarbonate and carbonate in the water and exhaust the mixed bed polisher. If the polisher is not changed when it is exhausted, the released carbonate can form insoluble copper carbonate in the stator.

To prevent dissolved oxygen contamination resulting from additions of makeup water, some utilities have turned to oxygen removal systems. Some power plants use a series of three gas transfer membranes to remove dissolved oxygen from any makeup water added to its stator cooling system. The system, which uses only nitrogen purge gas to sweep out the oxygen that permeates the membrane, is capable of reducing the dissolved oxygen of the makeup water to about 3 ppb.

Low-O_2, higher pH option. Increasing the pH of the stator water to 8–9 significantly reduces the corrosive response during oxygen transitions (Figure 2). The most direct method for increasing pH is to add controlled amounts of sodium hydroxide to the water. Initially, the sodium will be exchanged with hydrogen on the cation resin of the mixed bed polisher, neutralizing the caustic. If caustic continues to be added, eventually, sodium leakage from the resins will allow the water to maintain an alkaline pH.

Another treatment method is to add a sodium exchange polisher on a side stream and control the amount of water that passes through the sodium exchanger to achieve the desired pH. Some plants have even replaced the mixed bed polisher with all strong base anion resins. However, this polisher will no longer remove soluble copper. Raising the pH also makes it easier to measure the pH of water in the system.

During shutdown, and particularly during a major turbine outage, stator water can become oxygenated. In a number of cases, deterioration of the stator cooling system occurred shortly after the unit came back on-line from an extended outage.

High-O_2, neutral pH option. The other treatment alternative is to

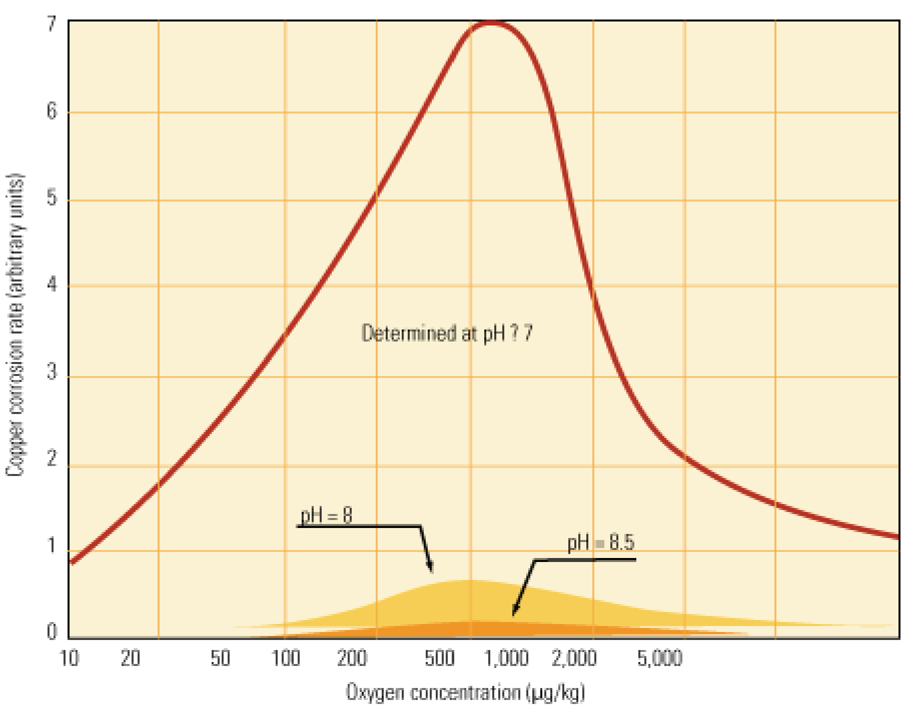


Figure 2. Oxygen therapy. The effect of pH on copper corrosion rates is significant as oxygen levels increase. Source: Journal of Power Plant Chemistry

maintain a high–dissolved oxygen level in the cooling water at all times. It is estimated that 40% of water-based stator cooling systems operate with high–dissolved oxygen and neutral water chemistry. In this treatment regime, CuO is formed on the copper. It will tightly adhere to the surface and create a passive layer on the metal. This layer tends to be thicker than the Cu_2O formed under low-oxygen conditions.

Because the dissolved oxygen will be depleted by its reaction with copper, at least initially, it may be necessary to add air to the system to maintain sufficient dissolved oxygen in the system.

This chemical treatment is impervious to additions of dissolved oxygen in the feedwater when it is operating continuously under high (>2 ppm) levels of dissolved oxygen. However, it may still be susceptible to low-pH corrosion from carbon dioxide and carbonates if these are not removed by the mixed bed polisher.

If there is a hydrogen leak into the stator cooling water system, the hydrogen can replace the dissolved oxygen and create low–dissolved oxygen transients in the system, causing oxides to be released.

High-O_2, high-pH option. Operating with high dissolved oxygen and an elevated pH is not recommended because it increases the likelihood of clip corrosion.

Monitoring stator water

Monitoring the health of stator water systems is more about looking at a variety of related temperatures and pressures than collecting grab samples and running them for pH or dissolved oxygen. Water temperature is one example: An increase in stator cooling water temperature puts the cooling water system at higher risk for plugging.

Monitoring the makeup water usage in a stator cooling system is also important. If the system is operating under a low–dissolved oxygen regime, an increase in makeup water may signal a potential problem from oxide accumulations. Monitoring gas flow rates from the stator cooling water head tank is one way to detect hydrogen leaks that can deplete dissolved oxygen in the water, if you are using the high-oxygen regime.

Conductivity of the water and pressure drop across the polisher are critical monitoring parameters and should be monitored continuously with carefully selected setpoints. The frequency with which the filter needs to be changed, due to particulate plugging, is an indication of corrosive conditions in the system. The resins themselves can be tested to determine the amount and nature of the copper that is being transported through the system.

Generators should also be equipped with flow and pressure differential metering of the cooling water system across the generator. These parameters can also provide an indication of fouling if they are monitored regularly and trended.

On-line monitoring for dissolved oxygen is recommended if the plant will be operating under a low-oxygen regime. Grab sampling is not usually recommended for these systems due to the amount of water required to flush out sample lines before one can be sure of getting an accurate sample. This water is then replaced with oxygenated water, thus changing the analysis.

—David G. Daniels

(david_daniels@mmengineering.com) is a principal of M&M Engineering and a contributing editor to POWER.

Deaerator Vessel Assessment Guideline

By Catherine Noble
Senior Engineer

On January 1, 2011, the Deaerator Vessel Assessment Guideline (Report 1021199) will be made available for purchase and download by the Electric Power Research Institute (EPRI). M&M Engineering Associates, Inc. conducted the primary research and documentation for this manual. The report will allow plant engineers, plant chemists, and operators/owners to identify the risk in their DA systems and provides sound engineering evaluation practices for running vessels with damage, repairing them if necessary or replacing them with vessels with greater integrity.

The goal of this project was to revise and update the EPRI *Deaerator Vessel Assessment Guideline* (DVAG) to reflect current industry technology and approaches. This updated guideline incorporates technical input from the NACE *Standard Practice Document SP0590-2007,* but is focused on utility applications. This document provides a comprehensive guideline of today's "best practices", including information and guidance on the following:

- Design and materials of construction.
- Advanced understanding of damage: description and explanation of damage mechanisms including examples of failure.
- Operational conditions that promote failure.
- Inspection and evaluation.
- Repair options.
- Technical criteria for mitigation of damage including

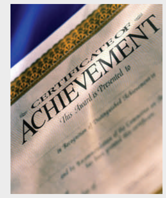
recommendations of repair-run-or replacement. This includes reference to current fitness-for-service best practices such as ASME FFS-001 and API 579.

To find more information regarding the manual, visit www.epri.com.

Interim Amine Guideline

By David G. Daniels
Principal Scientist

Amines such as cyclohexylamine and morpholine were used in many industrial and fossil power plant steam cycles for years to raise the pH of the feedwater, steam, and condensate. The nuclear industry uses amines to minimize iron corrosion in moisture separators by raising the pH of the first condensate. Recently the nuclear power industry pioneered the development of what has been termed "advanced amines to replace morpholine. These include ethanolamine, methoxypropylamine, and dimethylamine. Essentially all nuclear power plants in the US now use one or more of these advanced amines in their steam cycle.
While nuclear power has been embracing amines, large fossil plants have shied away from using them due to the elevated cation conductivity that is produced as these organic compounds breakdown in the steam cycle. These are primarily carbon dioxide, acetate, and formate. The affects of acetate and formate on the steam turbine are not fully understood and turbine OEM's have been reluctant to move away from the cation conductivity limits that have little room for even ppb levels of acetate and formate. However, corrosion in air cooled condensers and flow accelerated corrosion (FAC) concerns, particularly on the shell-side of feedwater heaters has caused some fossil plants to reconsider using amines.
In November, M&M Engineering completed sponsored research of the use of amines for pH control in fossil power plant. The research project surveyed, arranged sampling and analysis, and interpreted amine stability and amine breakdown products at three power plants. This work determined the stability of two amines, ethanolamine and methoxypropylamine in actual generating plants. It provided some excellent insight into the effectiveness of these amines in actual steam cycles and the concentration of the breakdown products that can be expected. Proprietary third party software was used to calculate the pH at temperature (pHT) at various points throughout the steam cycle. This helps to predict the effectiveness of these amines at various points to minimize iron corrosion.



David Daniels awarded the 2010 Paul Cohen Award

On October 25, 2010, David Daniels was presented the 2010 Paul Cohen Award at the 71st Annual International Water Conference ® in San Antonio, TX. The award is presented "In Memory of Paul Cohen, as Testimony to His Invaluable Contributions to the Power Generation Industry and to the International Water Conference ®." This award was presented to Mr. Daniels in recognition of the "Most Precise and Innovative Presentation in the field of Power Systems Water Technology." (IWC 09-31: "A Review of Hydrogen Damage and Phosphate Gouging Corrosion Mechanisms."-70th Annual International Water Conference ®).

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Failures in Steam/Power Generation

Staying Out of Trouble!!!

M&M Engineering Associates, Inc. will be hosting a Two-Day Conference that will focus on the issues most common in steam generation systems

March 9-10, 2011

Radisson Hotel & Suites Austin/Town Lake
111 East Cesar Chavez at Congress Avenue
Austin, Texas 78701

Conference Registration

$300.00 per day or $500.00 for both days
(Continental Breakfast & Lunch provided)
Registration will close on March 1, 2010
Enrollment cap of 20 people
Please call Candice at (512) 407-8598 to register or for additional information.

Accommodations

Rooms may be reserved by calling (800) 333-3333. Please be sure to mention the M&M Engineering conference to receive a special rate for attendees.

Confrence Schedule

March 9th

Failure modes that occur in:

8:30-10:00 AM	Water Treatment Systems–David Daniels, Principal Scientist
10:30-12:00 PM	Water Kissed Furnace Tubing–Jon McFarlen, Consulting Engineer
1:00-2:30 PM	Steam Kissed Furnace Tubing–Ron Munson, Corporate Engineer
3:00-4:30 PM	High Energy Piping–Ron Munson, Corporate Engineer

March 10th

8:30-9:15 AM	Turbines–Mark Tanner, Senior Principal Engineer
9:30-10:15 AM	Turbines–Charlie Rutan, Senior Principal Engineer
10:30-12:00 PM	Condensers–David Daniels, Principal Scientist
1:00-2:30 PM	Feedwater Heaters–Andi Cragen, Mechanical Engineer
3:00-4:30 PM	Miscellaneous (Dearators, etc…)–Catherine Noble, Senior Engineer

Seminars and Workshops

Ron Lansing and Max Moskal attended the TAPPI Pulping, Engineering, Environmental, Recycling and Sustainability conference held October 17-20, 2010, in Norfolk, Virginia. Mr. Moskal presented a paper entitled *Paper Machine Dryer and Felt Roll Corrosion*, which described the corrosion damage mechanism resulting from increased carryover of bleach plant oxidants when achieving high paper brightness targets.

Ron Munson and Catherine Noble attended the EPRI-BRIG (Boiler Reliability Interest Group) conference in Houston, Texas on December 7th, 2010. They presented a summary of EPRI's updated deaerator guideline.

John Molloy attended the ASME Gas Turbine Users Symposium October 4-7, 2010, in Houston, Texas.

Upcoming Events

Catherine Noble will be attending the CORROSION 2011 Conference hosted by NACE (National Association of Corrosion Engineers) to be held March 15-16, 2011 in Houston, Texas. She will be presenting 2 papers on the 16th—*Glossary of Boiler Tube Microstructures and Its Use to Verify Oxide Thickness Temperature Estimations* and *Damage Mechanisms in Creep Strength Enhanced Ferritic (CSEF) Steels (T91 and T23).*

Ron Lansing will be giving a presentation entitled *Burning Up the Refinery: Metallurgical Examination After a Fire* at the 2011 API (American Petroleum Institute) Inspection Summit and Expo January 24-29, 2011 in Galveston, Texas.

Best Wishes for a Happy New Year from all of us at M&M Engineering Associates, Inc.

***the* Conduit** is distributed free of charge by M&M Engineering Associates, Inc.. We welcome your comments, questions, and suggestions, and we encourage you to submit articles for publication.

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