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THE Locomotive
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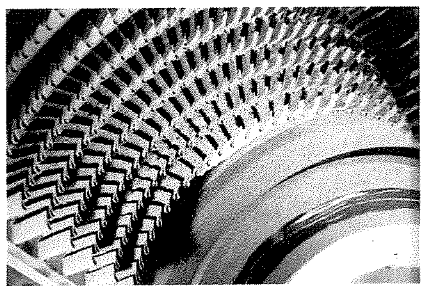
A COPPER-PLATED THIEF: THE PROBLEM OF COPPER DEPOSITS IN TURBINES



By Dave Daniels and John Latcovich

Operators at a coal-fired, 2,600 PSI power plant performed monthly tests to determine the generating capacity of the unit with the steam valves wide open. Every month the test showed fewer megawatts generated. Typical was a 33 MW loss over a five-month period. Upon examination of the turbine, the utility found the culprit: copper deposits on the high-pressure (HP) blades. A chemical cleaning of the high-pressure turbine blades restored all the lost capacity, but monthly tests after the cleaning indicated the deposits were building again. Further chemical or physical cleaning would be required.

To identify the source of the copper, the plant embarked on a rigorous feedwater sampling program. Sample results indicated that the source of some of the copper was the copper-alloy HP feedwater heaters, so the plant replaced the heaters with stainless steel. After the change, feedwater analysis showed copper levels in the feedwater were at or below the EPRI Guidelines. Yet, the monthly tests continued to show deposits were building, robbing the plant of generating capacity. Since that time, the plant has scheduled semi-annual cleanings of the turbine to remove copper deposits. Maintenance costs and lost generation have skyrocketed.

A Growing Problem

Until recently such a scenario was thought to be an isolated problem. But the number of utilities reporting copper deposits on their turbine blades is growing rapidly. When a conference on this topic was held in Salt Lake City in the summer of 1996, the attendance was overwhelming. The problem also was the subject of papers and discussion at the 1996 International Water Conference.

What is causing the deposit accumulation? How does it affect a turbine's ability to generate power? Why are some units affected and not others? What can be done to prevent the problem from occurring? How can the problem be corrected, if it already exists?

The jury is still out on many of these questions. Many utilities with this problem are still trying to separate cause and effect from coincidence. While we cannot provide all the answers, we will discuss some of the conditions common to units with this problem. We will draw some interim conclusions, propose a few steps that can be taken to reduce the risk and provide you some details on copper removal methods.

Who Is At Risk?

Copper deposition on turbines seems to be most prevalent in units that meet one or more of the following criteria:

- Drum boilers operating at or above 2,600 PSI
- Copper alloys in the low-pressure and high-pressure feedwater heaters
- A history of high levels of corrosion product transport during start-up
- Excess hydrazine feed
- Have had problems with drum internals (e.g., cracks in the steam chest)

Let's take these facts in turn and see what conclusions we can reach.

Effect of Operating Pressure This problem seems to be almost exclusively confined to drum units that operate at 2,600 PSI pressure or greater. Why 2,600 PSI? Why not 1,800 PSI or supercritical units?

One reason we do not see copper problems in supercritical units is that the use of mixed metallurgy (copper and iron components) in the feedwater system is confined to drum units. This is particularly true in the United States. Supercritical units tend to have all ferrous metallurgy in the feedwater system, so they avoid this problem. Supercritical units also have condensate polisher systems that can trap corrosion products during start-up.

Why mixed metallurgy units operating at 1,800 PSI and lower do not seem to have this problem is still an open question. It could be a function of temperatures in the feedwater, steam flow through the drum, superheat temperatures or a combination of all these. Or, it could be that all the data isn't in yet.

Copper Alloy Feedwater Heaters The second point seems obvious. But it's important to note that to date we do not see reports of units with copper deposition problems which started with all-ferrous feedwater heaters and a copper-alloy condenser. Testing in two cases has shown that copper-alloy HP heaters are the most likely source of copper corrosion products, particularly during operation. It should be noted, however, that unit operators who replace feedwater heaters with all-ferrous heaters after copper deposition on the turbine starts, do not see relief from the deposition problem. It seems that once the damage is done it cannot be as easily undone by removing this source.

Theoretically, copper has only a few paths that will allow it to eventually find its way to the turbine. Copper corrosion must first take place somewhere in the condenser or the feedwater heaters. This can be the result of the protective copper oxide layer being physically or chemically removed from its parent surface. The corrosion products may stay in solution or may deposit out in another area of the feedwater piping or in the boiler.

Once in the boiler, the copper must be chemically or mechanically carried over into the steam. In a boiler operating at the correct steam drum water level and where all the drum internals are doing their job, the mechanical transport of water droplets should be less than 0.2 percent of the steam flow. These water droplets, in turn should only contain small amounts of copper. Chemical carryover of copper oxide (copper oxide actually dissolved into steam) should be even smaller.

Once the copper leaves the boiler drum, it may precipitate in the superheater tubes before the steam goes to the turbine. Both copper in the steam and copper that was previously precipitated in the superheater may migrate towards the turbine, eventually precipitating out on the HP turbine blades. There is one way that copper can bypass the boiler and go straight into the superheater: through the attemperation sprays. Some units use attemperation sprays extensively during start-up and operation.

Start-Up Practices The amount of copper transport during start-up is a function of a utility's lay-up and start-up practices. These corrosion products typically are copper oxides and ferrous oxides that formed during the shutdown on any surface where oxygen and water were in prolonged contact with metal. During start-up these products find their way into the boiler, superheater and reheater — and onto the turbine. Utilities that monitor copper levels in the feedwater and steam report copper levels during start-up that are up to 1,000 times higher than any levels seen during normal operation.

Depending on lay-up practices and how the unit is started, it may take days before these copper levels return to normal. At these high levels the amount of copper transported into the boiler and superheater can be significant. Typically, the boiler is chemically cleaned every few years and the copper removed. But the same is not true of the superheater, which typically continues to accumulate copper over the life of the unit.

In the long run, start-up and lay-up practices may turn out to be the most critical factors in how much copper deposition a unit experiences.

Excess Hydrazine Feed There is a very strong correlation between excess hydrazine feed and copper transport during operation. For years hydrazine has been the oxygen scavenger of choice in boilers with superheat and reheat sprays. This includes most utility boilers. The hydrazine reacts with dissolved oxygen quickly at temperatures typical of those in the deaerator storage tank. Any hydrazine that does not react with oxygen by the time the water leaves the deaerator will quickly decomposes to ammonia in the HP heaters.

Ammonia at these temperatures can be very corrosive to copper alloys. Utilities that have fed excess hydrazine also have reported excessive corrosion in the HP heaters. Being volatile, the ammonia leaves the steam drum with the steam. Most of the ammonia reaches the condenser, where it's either swept out through the vacuum pumps or steam jet air ejectors, or is condensed on the copper-alloy condenser tubes.

Ammonia that condenses on copper tubes in the condenser causes corrosion of these tubes, particularly at the tube sheet. Some ammonia travels with the extraction steam to the shell side of the copper-alloy feedwater heater. Where ammonia and copper meet, we have the potential for copper corrosion and generation of a copper-ammonia complex. This may occur at any copper-alloy condenser, feedwater heaters or other component. The copper-ammonia complex travels through the feedwater system and into the boiler until it becomes unstable. At this point, the ammonia volatilizes and the copper finds the nearest surface on which to precipitate. This may be a boiler tube, superheater tube or turbine.

Hydrazine decomposition is not the only source of ammonia. Neutralizing amines will all eventually break down into ammonia and carbon dioxide. Overfeed of amines can be just as harmful as the overfeed of hydrazine.

So far, we have listed two different types of copper corrosion products that are created: copper oxides that are created during shutdown and sloughed off the surface during start-up, and ammonia-copper corrosion products that are created by an excess of hydrazine or amine.

Problems in the Steam Drum Many of the utilities that have copper deposition problems also have had problems in the steam drum. In at least two cases this has been related to leaks in the steam chest. In some drums, water entering the drum impinges on the outside of the area above the secondary separators. If there is a crack in this area, feedwater can be pulled in and carried with the steam. These leaks allow water contaminated with copper and iron oxides (particularly during start-up) to have easy access to the superheater. Other drum problems such as level control problems, or broken primary or secondary separators also could be at fault. Any problem that would allow significant amounts of boiler water to enter the superheater could create a copper-deposition problem.

How Do The Deposits Cause Generation Loss?

As the superheated steam passes through the high-pressure turbine blades, the solubility of copper and copper-based corrosion products in the steam decreases. Copper deposits then precipitate out in the high-pressure turbine as pure copper metal. The deposits affect the efficiency of the turbine in two ways: first by creating a rough surface that reduces the aerodynamic efficiency across the blades, and secondly, reducing the flow capacity or open area of the turbine blading. The net result of these changes is to reduce the output power and to increase the heat rate (fuel consumption) of the steam turbine.

Prevention First

If you have one or more of the risk factors, the fact that you do not have a copper problem today doesn't mean that one will not develop. This is one of those problems that develops over time and requires diligent effort to avoid. The most important things you can do to prevent copper turbine deposits is reduce the sources. That means:

- Improving lay-up and start-up procedures to reduce corrosion product transport
- Reducing the amount of ammonia in the steam by reducing the amount of hydrazine residual and neutralizing amines that are added to the feedwater, while still maintaining the desired pH and dissolved oxygen levels
- Minimizing the amount of attemperation or de-superheat spraying during start-up when corrosion product transport is the most severe
- Regularly inspecting drum internals for problems with steam separators or cracks in

the steam chest
- Replacing copper-alloy feedwater heaters with all-ferrous designs, particularly HP heaters

Replacing the heaters was included as the last item for a reason. It is considered a last resort. You may need to do it, but try to get control of corrosion in the feedwater system first. Every material has its strengths and weaknesses. Adding a third material to the feedwater system (many copper-alloy heaters are being replaced with stainless steel) may just increase your headaches.

What If The Problem Already Exists?

If you are seeing significant deposits of copper on the turbine, chances are very good that you have a significant supply of copper in your superheater. At one unit, deposit analysis estimated almost 2,000 pounds of copper in the superheater. In addition to the steps listed above, you will need to remove that copper, either by replacing or chemically cleaning the superheater. Chemical cleaning of a superheater is not trivial. It requires serious planning and creation of temporary piping before you can start the job. Some estimate a lead time of more than one year to get ready for this cleaning. If you think that you will need to clean your superheater, it's best to get preparations started now.

How Do You Remove Copper Deposits From The Turbine?

Mechanical Cleaning One obvious means is by mechanical cleaning. This requires a major outage for complete turbine disassembly, rotor removal, grit blasting of the parts with deposits, and re-assembly. Such efforts can take up to six weeks and cost in excess of $350,000 for a 400 MW steam turbine. Because the deposits may return, accomplishing one or two mechanical cleanings per year does not make this an attractive system.

Chemical Cleaning *A* second solution offered by HydroChem Industrial Services Inc. uses a foam cleaning process that is performed without requiring disassembly of the turbine. While the turbine is on the turning gear and turbine metal temperatures are between 150° and 170° F, ammoniated foam is continually injected through the HP turbine flow path with auxiliary steam via a chemical injection valve installed at a governor/control valve position on the steam chest.

Once the foam enters the unit, the copper oxide deposits dissolve and are removed through the cold reheat line where an antifoam agent is injected to break the foam into a liquid. Upon completion, the turbine is rinsed with auxiliary steam until the turbine is clean and ready for service. Particular care is taken to ensure foam and the resultant dissolved deposits do not contaminate the intermediate pressure and low pressure turbines, heaters, and the condenser.

Steam purity measurements at both the HP inlet and cold reheat lines are monitored until the levels are the same after rinsing. The foam cleaning takes approximately 24-36 hours to complete. Prior to conducting the foam cleaning, HydroChem pre-engineers the injection supply/return lines and turbine interface connections so that the cleaning process can be scheduled to begin in concert with the client's schedule. The piping can remain in place to facilitate subsequent cleanings.