Control of Copper Transport During Boiler Start-up Using High Flow, High Efficiency Condensate Filtration

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Abstract:
Copper deposits on turbine blades, resulting in a significant loss of power generation capacity, is a fairly common occurrence especially in plants using high drum pressures (2600 PSI and higher), copper alloy condensers, and LP and HP feed water heaters with copper alloy tubes. The primary source of the copper deposition on turbines is the copper oxide that forms during the lay-up on metal surfaces where oxygen and water are in prolonged contact with the metal. This copper oxide along with other metals, notably iron and silica, are dislodged and transported during plant startup. These solids settle out or circulate in the system and turn into dissolved contaminants under appropriate conditions of temperature, pressure and alkalinity. Solid contaminants, therefore, serve as a primary source reservoir in the formation of dissolved contaminants, making their control beneficial for the reduction of dissolved metals and the resulting problem of copper plating. Besides copper, significant amounts of Iron are also present, causing under deposit corrosion of tubes, and Silica deposits on the IP and LP sections of the turbine and on boiler tubes.

Startup is the most appropriate time to capture the solid contaminant since temperatures are low and most of the particles are in suspension due to thermal expansion, vibration, and fluid drag associated with startup. Utilities that monitor copper levels in the boiler feedwater and steam report copper levels during start-up that are as much as 1,000 times higher than the levels seen during normal operation. To date, utilities have employed several methods to reduce solid particulate transport. Improved lay-up practices are helping minimize oxidation of metallic surfaces and better operational procedures on start up help to reduce particulate in the feed water and condensate. Examples of these practices are feed water heater shell side blow down and wide open boiler blow-down during the first few hours of startup.

Additional work at the Ottumwa plant has shown that the installation of an in line condensate filtration system will substantially reduce the transport of solid particulate and consequently reduce the amount of dissolved metal found in the boiler. Mitigating the transformation of particulate metal to dissolved metal, particularly copper, has the beneficial affect of reducing boiler tube deposits and copper deposition on turbine blades. Boiler tube deposits contribute to under deposit corrosion and ultimately forced outages due to tube failure. Copper deposits reduce turbine efficiency and increase required corrective maintenance during outages. Both of the above have a negative impact on plant revenue. The implementation of Pall Ultipleat High Flow filters, specifically designed for application in the condensate system, will provide an effective and economical control of copper, iron, silica, and all other solids for drum and turbine protection.

Description of the problem:
Alliant Energy’s Ottumwa Generating Station, a single unit 725 MW, low sulfur pulverized coal plant is located ten miles northwest of Ottumwa, Iowa. The plant, constructed in 1981, has a 2900 psig maximum, 1005 °F Alstom Power drum boiler with a maximum steam flow of 4,850,000 pounds per hour. The boiler is a tangentially fired, controlled circulation type unit. The condenser, low-pressure and high-pressure heater tubes are copper/nickel, except one high-pressure heater,
which is stainless steel. The plant employs a partial flow (5000 GPM) condensate polisher (mixed bed IX resin). In the recent past Ottumwa had experienced losses in turbine efficiency resulting in reduced power generation capacity, attributed to the deposition of copper onto turbine blades.

Such occurrences of copper deposits in the high pressure section of steam turbines, resulting in a significant loss of power generation capacity, is fairly common. Plants with any combination of the following conditions, higher drum pressures (2600 PSI and higher), LP and HP feed water heaters with copper alloy tubes, histories of high metal transport, excessive hydrazine feed, and problems with drum internals have reported copper plating problems.

The source of copper deposition on turbines is the copper oxide that forms during lay-up on copper-alloy surfaces where oxygen and water are in prolonged contact with the metal. The majority of the contaminant (~ 90%) is in the form of particulates, primarily in the 3-15 µm size. These solids settle out in quiescent zones, plate out on high heat surfaces, and circulate in the system, turning into dissolved contaminants under appropriate conditions of temperature, pressure and alkalinity. Solid contaminants serve as a reservoir for the creation of dissolved contaminants, making their control imperative in order to reduce dissolved metals, which are the contributors to the problem of copper plating. Besides copper, iron and silica are also present as solid contaminants within the condensate water system. Iron typically causes under deposit corrosion of boiler tubes, silica deposits onto the IP and LP sections of the turbine, and both will deposit on boiler tubes reducing plant efficiency.

There are several mechanisms by which copper is carried into the steam. In a properly operating boiler, mechanical transport of water droplets is typically less than 0.2 percent of the steam flow. Chemical carryover of copper oxide (copper oxide dissolved into steam) is 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. Another potential path through which copper can bypass the boiler and go into the superheater is through attemperation sprays. Some plants use attemperation sprays extensively during both start-up and routine online operation.

Research has shown that startup is the most appropriate time to capture the solid contaminants since temperatures are low and most of the particles are in suspension. Release and transport of the particulate is due to thermal expansion, vibration, and fluid drag associated with the startup. The amount of Copper and other metals, notably Iron and Silica, transported in the condensate system of a power plant during start-up largely depends on the utility's lay-up and start-up practices. It may take days before copper levels return to acceptable limits. At these high levels, the amount of copper transported into the boiler and superheater can be significant.

Utilities that monitor copper levels in the boiler feedwater and steam report copper levels during start-up that are as much as 1,000 times higher than levels seen during normal operation. Analysis at a 260 MW coal fired plant has indicated that the peak in total solids transport, documented to be 5 lbs/hr, occurs within the first 2 hours of the startup, with 95 percent of the transport occurring within four hours.
The consequences of copper / iron transport:
The solubility of copper and copper-based corrosion products in the steam decreases as the superheated steam passes through the high-pressure turbine blades. Copper then precipitates out on the high-pressure turbine as pure copper metal. These copper deposits affect the efficiency of the turbine by creating a rough surface that alters and reduces aerodynamic efficiency across the blades, and reduces the flow capacity or open area of the turbine. The net result of these changes is to reduce the MW output power and overall plant efficiency. As MW output decreases due to copper deposition, the plant must increase its heat rate (fuel consumption) to maintain a consistent energy output at a lower efficiency. The ultimate result is a loss of plant revenue as costs rise per MW generated.

Once the copper plating occurs on the turbine, it is typically removed either by mechanical or chemical cleaning. Mechanical cleaning requires complete turbine disassembly, rotor removal, grit blasting of the parts with deposits, and re-assembly. It can take up to six weeks and cost in excess of $350,000 for a 400 MW steam turbine. Chemical cleaning, done with a foam cleaning agent, does not require turbine disassembly and is relatively inexpensive but has the potential of contaminating the intermediate pressure and low pressure turbines, heaters, and the condenser, all of which are highly undesirable. Typically, the boiler is chemically cleaned every few years and the copper removed. In contrast superheaters, which typically continue to accumulate copper over the life of the unit, are very difficult to clean and, hence are not cleaned as often. Although both methods can be effective in cleaning contaminated systems, neither method addresses the action of minimizing or eliminating the deposition process in the first place.

The EPRI (Electric Power Research Institute) boiler startup guideline stipulates hold points for Copper, Iron and Silica of 2 ppb, 10 ppb and 10 ppb, respectively, before full power is reached. The guidelines also require total corrosion product concentrations to be below 50 ppb before power can be ramped up to 50%. Therefore, attaining the chemistry guidelines is usually the determining factor for startup duration in plants that adhere to EPRI or similar criteria. Since a typical 150 MW plant costs over $100,000 per day of outage, the faster the chemistry guidelines are achieved the better it is for the plant. Failure to control metals transport during startup prolongs the chemistry holds resulting in delayed plant startups.

The presence of particulate material in the condensate water, especially iron, also fouls and loads expensive demineralizer resin beds. Originally designed and installed to control dissolved contaminants, the mechanical fouling results in shortened service life, excessive regeneration, high chemical costs, additional labor requirements, and the leakage of resins fragments downstream.

Elevated levels of solids in the condensate water influence the cycles of concentration in the drum, resulting in increased frequency of boiler blowdown and, lost thermal energy, increased water requirements, and lower plant revenue.

The Solution:
Numerous in-plant studies have shown that the majority of the metals transport occurs during the initial hours of startup. Operational changes such as feed water heater shell side blow-down and wide open boiler blow-down at start-up help reduce particulate transport. The addition of an inline flow filtration of the condensate has been studied and proven to make a significant difference in metals transport above what the operational practices achieved. The use of inexpensive disposable cartridges, although a straightforward solution for the removal of the copper and other particulate
contaminant during the startup, was considered impractical in the past because of the high flow rates involved (~ 4000 GPM for a typical 700 MW plant during startup) and expected high dirt load.

Pall’s Ultipleat High Flow (UHF) technology offers the unique combination of inline flow filtration, ranging from 1 to 20 µm ($\beta_x > 5000$, 99.98% removal efficiency), tapered pore medium and the high flux capability of the patented pleat configuration. The unique crescent shaped pleat design, see Figure 1, allows a uniform flow distribution across the filter and optimization of envelope size. Packing an optimum amount of filter media into a small element volume gives high flux filtration in a smaller footprint and lower cost. The crescent pleat design is significantly more rigid than the standard radial pleat design, resulting in stable flow channels, lower pressure drop and higher integrity of the filter element. These design features enables the Pall UHF filter elements endure the high stresses associated with start up conditions and prevent the possibility of failure during this critical time.

A single 6” diameter by 60” long Pall UHF cartridge can handle up to 500 GPM throughput depending on the application and the desired service life, thus is suitable for high flow systems. The filter housing made of either coated carbon steel with 304 stainless steel tube sheets or all stainless construction can be used in a horizontal or vertical configuration.

Figure 1
Unique Crescent Shaped Pleat Configuration of Ultipleat® High Flow Filter.

Pall UHF filter elements have a unique sealing system and inside-out flow that keeps the contaminants inside the filter cartridge, preventing accidental spillage in the housing during removal. The UHF filter elements are ‘coreless’, without any metal parts, making their disposal through shredding or incineration possible.

Case history at Ottumwa and other plants:
Alliant Energy’s Ottumwa Generating Station had previously experienced losses in power generation capacity, typically 27,000 MWh per year due to the deposition of copper onto the turbine blades and consequently requested the assistance of Pall Corporation in resolving the problem. The Scientific and Laboratory Services (SLS) Department of Pall Corporation conducted a field evaluation of its Ultipleat® High Flow filter elements on a side stream from the condensate circuit during plant startup in 2002. A pilot system and test rig was installed at the plant and was maintained at a flow rate equivalent to 4200 GPM through the 38” filtration assembly that was being considered for the application. The test was conducted for 33 hours. Water samples taken from upstream and downstream of the filter assembly were obtained at various intervals during the test. The water samples were analyzed for iron and copper content using an HP4500 ICP-MS analyzer after acid digestion of the contaminant. The test results showed an average of 88% reduction in copper and 82% reduction in iron as a result of the Pall UHF filter in the test filtration
unit. The final concentrations at the end of the 33 hours, downstream of the filter assembly, were 1.0 ppb copper and 1.7 ppb iron. The results of the pilot testing are presented in Figures 2 and 3.

Based on the side stream test results, Alliant Energy installed a filtration assembly consisting of a 38” diameter filter housing containing 19 filter cartridges at Ottumwa Unit 1, downstream of the condenser and upstream of the boiler feed pump.

The typical startup conditions for Ottumwa Unit 1 are as follows:

- **pH:** 9.5
- **Temperature:** 110 – 120 °F
- **Flow rate:** 3000 – 4800 GPM
- **Chemical treatment:** Hydrazine – 20 ppb, Ammonium hydroxide for pH

Since its installation, the condensate filtration assembly at Ottumwa Unit 1 has undergone 5 startups. For each startup the filter assembly had been in-line for approximately 15 to 20 hours. Ottumwa Unit 1 has consistently achieved the EPRI startup guidelines for Copper, Iron and Silica in 15-20 hours, compared with >35 hours prior to the installation of the filters. This has resulted in reduced chemistry holds, reduced chemical feeds, reduced boiler blow down, faster return to the grid and an increase in revenue generation for the plant.

The pressure drop across the filter assembly just after installation, at full flow, was 15 PSID. The pressure drop after 5 startup cycles was reported to be 25 PSID. The maximum pressure drop limit for filter element replacement is 50 PSID.

Four of the 19 filter elements that were installed initially, and had been in service during the 5 startup cycles, were removed from the filter housing in September, 2003 and analyzed by Pall to determine the amount of iron and copper that has been captured. The analysis was performed by removing sections from each of the 4 filter elements and extracting the metals through acid digestion, followed by determination of the concentrations of iron, copper, and silicon in the extract via Inductively Coupled Plasma (ICP) Atomic Emission (AE) spectroscopy.
The analysis indicated that the total mass of the contaminant removed by the 19 filter elements in the Pall Ultipleat High Flow filter assembly was approximately 40 kg (88 lbs). Iron constituted 80.4% of the contaminant, copper 19.4% and silica 0.2%. A photomicrograph depicting the contaminant flushed from the filter element at 100X magnification is shown in Figure 4.

A cutaway view of the serviced filter element showing the black debris captured on the inside surface (the flow through the filter element is inside to out), is shown in Figure 5.

Combined with improved lay-up practices to minimize oxidation of the metallic surfaces and start-up operational procedures such as feed water heater shell side blow-down, boiler blow-down wide open during the first few hours, the installation of the Pall UHF full flow filtration system in the condensate has proven to make a significant reduction in the metals transport. The cleaner condensate effluent from the filter has helped minimize the resulting problem of copper deposits on turbine blades and under deposit corrosion of boiler tubes due to iron. Pall’s UHF filters provide the required particulate removal efficiency and handle the high flux rates to provide effective and economical control of Copper, Iron and other solids during startups.

References: