Material Matters

High-temperature ceramic coating protects boiler tubes from slag deposition and corrosion

Boiler water wall tubes in this combustor were recently coated with a green, high-temperature ceramic coating. Temporary scaffolding is used to spray-apply the coating as well as service the boiler. Photo courtesy of Antonio Liberatore, FMP.

In the power generation industry, one of the leading causes of forced maintenance outages of coal-, petroleum coke-, refuse-, and biomass-fired power plants is boiler tube failure caused by fireside corrosion and erosion. Although several techniques can be used to mitigate boiler tube corrosion, such as nickel and chromium weld overlays, metallized coatings, fuel additives, and design modifications to the boiler, several power plants have opted to use an inorganic, high-temperature ceramic coating to protect boiler tubes from the corrosive environment found inside the boiler.

Tubes are found throughout a power plant boiler—in the furnace (where combustion takes place, also known as the combustor), the superheater (where steam is heated for use in the turbine), and the economizer (where waste heat is recovered), says Dick Arens, retired superintendent of the Wyandotte Municipal Services power plant (Wyandotte, Michigan). Boiler tubes are typically ~2-in (51-mm) in diameter and constructed of carbon steel (CS) or steel alloys, depending on their location in the boiler. In the superheater, boiler tubes are typically a thicker, higher-quality tube made of an alloy with more chromium and molybdenum, whereas tubes in the combustor (called water walls) and the economizer are typically fabricated of CS. Fireside corrosion of boiler tubes occurs for many reasons and may be influenced by the

Information on corrosion control and prevention


Before being coated, superheater boiler tubes in the Rosebud Operating Services' power plant in Billings experienced severe slag build-up (left) that was removed by sandblasting. After coating the superheater boiler tubes, slag buckles and breaks off (right). Photos courtesy of Dan Gray, Rosebud Operating Services.

design of the boiler; the type of burners used in the boiler; the type of fuel burned; the atmospheric temperature inside the boiler, which can range from 1,000 up to 2,500 °F (538 up to 1,371 °C); the by-products of combustion in the atmosphere; and the build-up of coal ash agglomeration (also known as slag) on the tubes.

The use of low nitrogen oxide (NO_x) burner technologies to reduce NO_x emissions creates an oxygen-starved reducing environment in the boiler that prevents oxidation and the formation of a protective iron oxide layer on the boiler tube surface, which makes the tubes susceptible to pitting corrosion, says NACE International member Antonio Liberatore, general manager for Furnace Mineral Products, Inc. (FMP) (Stouffville, Ontario, Canada), a manufacturer of ceramic coatings for boiler fireside components. The higher temperatures utilized by the low NO_x burners also create more hydrogen sulfide (H_2S), which results in higher corrosion rates, adds Dan Gray, director of operations for Rosebud Operating Services, Inc. (Billings, Montana), a small, independent electrical utility company that operates a coal-fired power plant in Colstrip, Montana and a petroleum coke-fired power plant in Billings, Montana. Gray notes that the Colstrip plant combustor has a reducing atmosphere with a significant amount of sodium and potassium, which causes corrosion of the water walls. At the Billings plant, boiler tube corrosion was a concern in the superheater, where tube corrosion was found under slag.

The problem with slag is two-fold. Elements in the slag react with the elements in the underlying steel tubes and corrode the metal. In addition to causing boiler tube corrosion, slag also acts as an insulator when it builds up on boiler tubes and reduces the heat transfer efficiency of the boiler, requiring power plants to burn more fuel to produce the same amount of steam. Slag must be periodically removed from the boiler tubes, which requires the plant to be shut down and may involve abrasive blasting the tubes to clean them. Outages can be very expensive when the cost of repairs and lost revenues are considered. Arens comments that a single boiler outage can cost $500,000.

The type of fuel burned as well as fuel additives to reduce NO_x emissions can intensify the build-up of slag on the boiler tubes as well as affect its corrosivity. Biomass fuel contains more phosphorus, sodium, and magnesium—elements that cause the slag to be sticky, comments

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Coated superheater tubes are shaken to remove slag. Underneath the slag, the green ceramic coating is visible. Photo courtesy of Dan Gray, Rosebud Operating Services.

Arens. The by-products of burning municipal solid waste for fuel are chlorides, bromides, and fluorides, Arens adds, which attack chromium and CS. "A normal 40-year lifetime of a boiler tube can be reduced to as little as four years when burning trash if you don't take precautions," he says.

Any boiler that burns petroleum coke would be susceptible to pitting corrosion of tubes under slag due to reactions with sodium by-products, notes Gray. Additionally, depending on the petroleum coke being burned, alkali oxides that corrode the tubes can be formed inside the boiler. Raising the temperature above 1,250 °F (677 °C) is one option to help lower the corrosion rates, Gray says, because the higher heat decomposes most of the alkalis and some other chemicals in the fuel stream.

To mitigate corrosion of boiler tubes, as well as deter slag build-up and protect the tubes against erosion, both Arens and Gray used a high-temperature inorganic ceramic coating technology developed by FMP to coat fireside boiler tubes. The spray-applied barrier coating, green in color, comprises a blend of silicon dioxide (SiO_2)-based ceramic particles and chemical compounds in a water-based binder. According to Liberatore, the additives' various particle sizes create a tightly packed matrix that reduces the coating's porosity and improves its density. Typically, during maintenance outages, the coating is applied in situ to surface-prepared (NACE No. 1/SSPC-SP 5[1]) boiler tubes at room temperatures, where it mechanically bonds to the steel tubes, although it can be shop-applied to new tubes. The coating is applied in multiple 1-mil (25-μm) layers, with total coating thickness typically ranging from 6 to 12 mils (152 to 304 μm), depending on the boiler's operating conditions and service environment. Once the boiler is fired and ambient temperatures reach 1,000 °F, the coating cures and chemically bonds to the tubes to create a dense, hard, glass-like surface. The resulting impervious, nonreactive barrier film is resistant to combustion by-products, such as chlorides, and prevents these corrosive elements from coming into contact with the metal substrate. Additionally, the slick surface of the coating prevents slag from anchoring to the tubes.

Arens, who used the ceramic coating in the municipal waste-fired boiler at the Wyandotte power plant, comments that sealing the boiler tube surfaces with the coating prevented the build-up of slag and inhibited pitting corrosion in the reducing atmosphere in the bottom of the furnace. "During an outage, the sight of the green coating on the water walls told us that there was no boiler-side corrosion or erosion of the tubes in that area, and we could concentrate our repair efforts on areas where there was evidence of missing coating. Normally, the coating should be monitored for thickness and touched up every four to five years, but we did not do so because it lasted longer than we expected," Arens says.

Gray applied the ceramic coating to boiler tubes in the combustor at the Colstrip plant and in the superheater in the Billings plant. He observes that slag adheres to the coating rather than the boiler tubes, making it simpler to remove. "Slag will stick to the tubes; there is nothing you can do to stop it. But it comes off a lot easier than before," Gray says. Previously, slag was removed by chipping and abrasive blasting. Now the slag is removed by shaking the tubes. "Before we started using the ceramic coating, we spent $300,000 per year trying to reduce the agglomeration and subsequent corrosion," Gray remarks. "If we hadn't gotten to the point of protecting these tubes, we would have eventually seen a substantial amount of damage and would be looking at $1 million to replace them," he says.

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Reference

1 NACE No. 1/SSPC-SP 5, "White Metal Blast Cleaning" (Houston, TX: NACE International). MP