Computers and chemicals fight slag

Slagging of the walls and fouling of the superheat and reheat sections of furnaces firing PRB coal necessitates more-frequent outages for cleaning and even unit derates in severe cases. A control technique that combines virtual-reality simulations and a chemical reagent has proved effective at inhibiting slag formation in small to large-size utility boilers.

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Due to the lower heating value, higher inherent moisture, and different burning characteristics of Powder River Basin (PRB) coal, the lower waterwalls of boilers firing the low-grade fuel are prone to slagging. The result is often increased furnace exit gas temperatures as well as fouling in the boiler's convection and platen sections. As the deposits grow, they can begin to restrict gas passes and perhaps even form "ratholes" that can increase local gas velocities five to seven times over design specs. The inevitable results are increased fan vibration, tube surface erosion, shorter runs between cleanings, and capacity derates.

PRB and other Western coals frequently contain ash compounds with low melting points. The compounds can travel through the furnace in a molten state and freeze or harden after contacting cooler tube surfaces, producing tenacious slag deposits. As the deposits grow, they can cause the following problems:

- Loss of heat-transfer ability, indicated by falling superheater steam temperatures and increasing stack temperatures.
- Increased fuel usage to maintain steam temperatures.
- Restricted flue gas flows, which lead to higher draft losses and gas velocities, tube erosion, and eventual tube failure.
- Formation of large clinkers that fall and damage boiler furnace floor tubes.

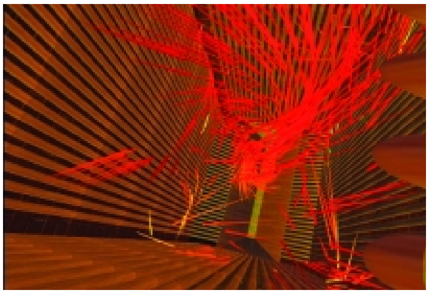
Fuels are sometimes switched to nonslagging varieties, but often at a cost penalty. Alternatively, many plants have settled on fuel mixtures—such as 85% PRB coal and 15% Eastern coal—as a tradeoff that minimizes SO_2 and makes for acceptable maintenance schedules. It's not unusual for a unit burning PRB coal to be shut down prematurely for furnace cleaning. With blends of particularly poor coals, a unit may be able to run for only a week before diminished thermal efficiency dictates a shutdown.

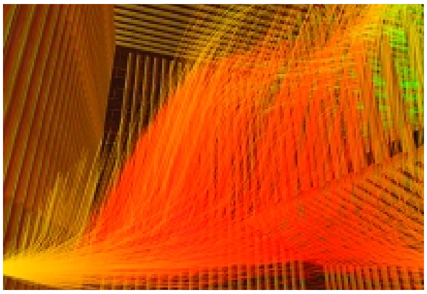
Targeting the problem

TIFI, which stands for targeted in-furnace injection, is a chemical slag-control technique based on technology originally developed by Fuel Tech Inc. (Batavia, Ill.) for selective noncatalytic reduction (SNCR) of nitrogen oxides in the 1980s. In 2000, after TIFI proved successful at controlling slag in PRB-fueled boilers, the company adapted the technique to the needs of the utility boiler market.

The main advantage of chemical slag control is its ability to target problem areas in the furnace rather than the fuel itself. Typically, a magnesium-hydroxide slurry is diluted with water, atomized with air, and then injected into critical gas path areas.

TIFI technology uses computational fluid dynamics (CFD) modeling and a supercomputer to create an electronic "replica" of a furnace, including its physical dimensions and design characteristics such as fuel heat rates and chemistry, air flows, and boiler geometry (Figure 1).





1. Virtual reality simulations. These simulations enhance understanding of the slag-formation and removal processes. "Flying arrows" used to depict temperatures and velocities of the moving gases in various parts of the boiler (left) show the upper furnace looking down toward the bottom of the boiler. A virtual reality visualization of "streamers" (droplet trajectories) ends when evaporation is complete and the chemical is released and activated (right). *Courtesy: Fuel Tech Inc.*

After the computing engine calculates temperature profiles and gas velocity gradients for the entire furnace, it next calculates how to get the prescribed chemical reagent into the furnace. The entire gas path, from the radiant section through the superheaters and reheaters, is targeted for chemical application by adjusting the number of injectors, placement, design, and performance settings. The results are injection overlays and dosage maps that ensure complete chemical coverage of targeted zones. The targeted area can be as small as a dedicated problem heat exchanger or as broad as the furnace's waterwalls, convection sections, and platen areas combined.

How the technology works

The chemical reagent is a special slurry whose reactivity and stability are high because of its huge ratio of surface area to unit weight (about 530,000 ft^2/ft^3). The reagent's high reactivity enables reductions in treatment dosages, and its high stability eliminates many of the handling and feeding problems associated with unstabilized compounds. The chemical reagent arrives at the customer site in the form of a slurry in which particles 5 to 8 microns across are suspended.

Only small amounts of the chemical are required for good performance because the chemical modifies the crystal structure of the slag as it forms. It also reduces the crystal strength of slag that has already adhered to tube surfaces, making it easy for sootblowing to remove deposits. Chemical feed rates are much lower than stoichiometric requirements, and ash fusion temperatures are unaffected. Physical chemistry reactions involving crystal morphology do the actual work of controlling slag formation and fouling.

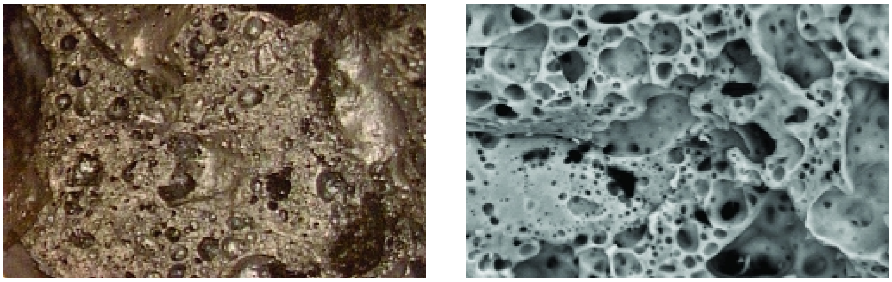
Key to the effectiveness of the TIFI process is its use of chemical droplets of various sizes. Different-sized droplets containing particles of the reagent travel to different depths in the furnace and convection section. When the slurry water evaporates, there is a brief period of travel as the reagent's 5-micron particles are heated up to about 617F. At this point, they explode into smaller particles ranging from 0.03 to 0.30 microns across. In the form of the smaller particles, the reagent has a vastly greater surface area, enabling it to attract more molten and sticking ash particles and chemically condition them so they cannot form strong bonds with tube surfaces.

Putting TIFI to the test

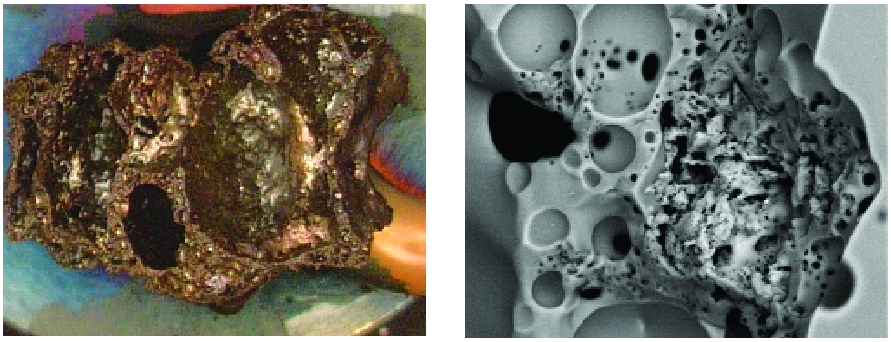
TIFI's recent field experience has been at three different facilities burning different mixes of bituminous and subbituminous western coal. At all three, application of the process has reduced the severity of fouling and increased unit run times. The first plant, a tangentially fired unit rated at more than 400 MW and burning western coal, had to switch fuel when the mine sourcing its current variety was closed. The alternatives were moving to a more-expensive fuel to avoid heavy fouling or going with a lower-cost fuel whose likely downside would be fouling issues.

After weighing the two options, plant management elected to test TIFI technology on its current fuel mix to assess whether the technology merited further consideration. If TIFI could control fouling on the old fuel mix, perhaps it could be used on the higher-fouling but cheaper coal to avoid incurring serious fouling problems.

The plant designed the most difficult test possible for TIFI technology. It was a 60-day trial during which an "average" blend of four available coals would be burned. This blend was certain to cause measurable fouling and slagging during regular operation. As a final "worse case scenario" demonstration, the last four days of the trial would be on a burn consisting of 100% of only the most problematic coal. In the past, when forced to burn this unblended problem coal, the unit had always become irreversibly fouled in just a matter of hours.



2. Untreated slag. Shown on the left, at 5.5X magnification, is untreated slag removed from the furnace exit after the baseline test. This sample is dense, hard, and relatively heavy for its volume and is typical of the slag formed by Western coals. At right is the same sample magnified 1,000 times by a scanning electron microscope; it appears to be perforated by pores with a diameter of 0.1 micron. *Courtesy: Fuel Tech Inc.*



3. Slag after TIFI. Slag removed from the same part of the boiler (on the left, at 5.5X) after switching to TIFI for eight hours looks quite different. Although it has the same chemical composition as slag untreated by the TIFI reagent, it is much lighter, softer, and easy to crumble. At 1,000X, the treated sample surface (right) is seen as having more small particles that break up the slag's orderly structure. Smooth and dense areas can still be seen, but the pores are generally larger and add to the lightness and friability of the treated slag. *Courtesy: Fuel Tech Inc.*

Test procedures

To establish a baseline for comparison, plant engineers and Fuel Tech technicians conducted a 60-day "pre-trial trial" burn on the current fuel mix and monitored the process closely by compiling operating data and written reports of visual inspections. During this baseline run, which started with a clean furnace, there was a steady but tolerable accumulation of slag on the furnace's superheat and reheat tubes. However, regular—and then accelerated—sootblowing proved only marginally effective at removing slag deposits, as the superheater pressure differential increased from 1.4 to 1.7 inches of water.

In the written reports, the deposits on the reheat, finishing vertical superheat, division pendants, and primary superheat sections of the furnace were described as "like taffy." Cleaning only served to spread the slag around the tubes. By the end of the baseline run, operators had no choice but to derate the unit by 30 MW to avoid serious buildups on the division panels. Some of these buildups (Figure 2) were small, but others were the size of a small car; if they broke off they would seriously damage floor tubes.

Following the pre-trial run, and prior to the start of the real trial, the unit was mechanically cleaned to restore it to the same conditions that had existed at the start of the baseline test. The coal yard was instructed to provide one of two "normal" blends of coal, and the unit was then fired and ramped up to full load.

This time, however, with application of the TIFI process and reagent, operators observed that all the superheat and reheat tubes that had fouled during the baseline run remained clean with normal sootblowing. This was an encouraging sign, so 30 days into the trial the frequency of sootblowing was reduced by 50%. Whatever sintered ash deposited upon the tubes proved easily removable by sootblowing on this relaxed schedule.

The acid test

In keeping with the test protocol, four days before scheduled completion of the TIFI trial run, the coal yard began to send up 100% of the plant's most troublesome coal. In the past, when forced to burn this coal unblended with higher-fusion-point coals, plant operators observed markedly higher ash deposition rates on the furnace's superheat and reheat tubes within several hours. These deposits could not be completely removed, even with accelerated soot blowing.

As expected, as soon as the poor-quality coal hit the burners, a huge increase in the rate of deposition of slag on tube surfaces was observed. The difference this time—thanks to TIFI—was that the deposits (Figure 3) remained sintered rather than fused, so they were easily and completely removed by sootblowing. There was no measurable increase in secondary superheat gas-side pressure differential, and the unit did not have to be derated as a result of burning its most problematic fuel. ■

This article is based on a paper presented by the author at the American Coal Council's June 2003 PRB Coal Use Seminar.