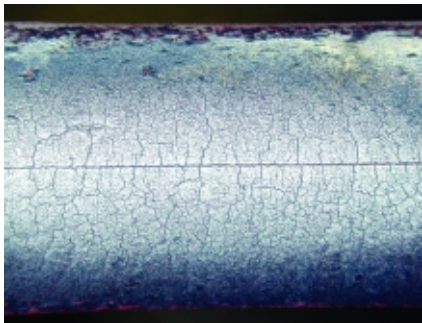


The impact of water cleaning on boiler tube life

Water cleaning of boiler walls has proven effective at removing PRB coal ash from them. But the procedure has a big downside: repeated doses of thermal stress that can cause boiler tubes to crack and leak. A new, real-time hardware/software tool can help cleaning system operators maximize the effectiveness of the process while minimizing the cumulative negative impact of cyclic stress.

By Gary M. Gilmartin and Joel H. Booher, Diamond Power International Inc.

Cleaning your boiler's heat transfer surfaces regularly is a must if it burns Powder River Basin (PRB) coal or any other low-rank solid fuel. Ash deposits on the fireside can rapidly turn the inside of



1. Cycling damage. All furnace tubes are damaged to some extent by the effects of thermal cycling each time they are cleaned by water lances. Shown is the typical "alligator hide" cracking on the fireside surface of a tube. *Courtesy: Diamond Power International Inc.*



2. TIME advisory screen with transient icons. The predictive and historical tube life information produced by the system can help operators adjust the cleaning system to optimize the effectiveness of the process and minimize thermal fatigue cracking. *Courtesy: Diamond Power International Inc.*

your boiler into a mini Carlsbad Caverns, complete with giant stalactites. Though you won't have to pay to see your boiler's innards, you will nonetheless be taken on an expensive tour of reduced boiler performance, steam temperature control problems, and emissions excursions.

To keep your boiler clean, you may have configured your water lances or other cleaning devices to operate on a routine schedule and perhaps even added some additional lances and cleaning ports to get at hard-to-reach areas. Usually, cleaning increases a boiler's efficiency. But not always. For some reason, in the past year there has been a significant increase in the number of furnace wall tube leaks that are tough to explain. It could be that you're cleaning more and enjoying it less because the water lances are cyclically stressing your boiler's tubes.

Understanding cyclic stress

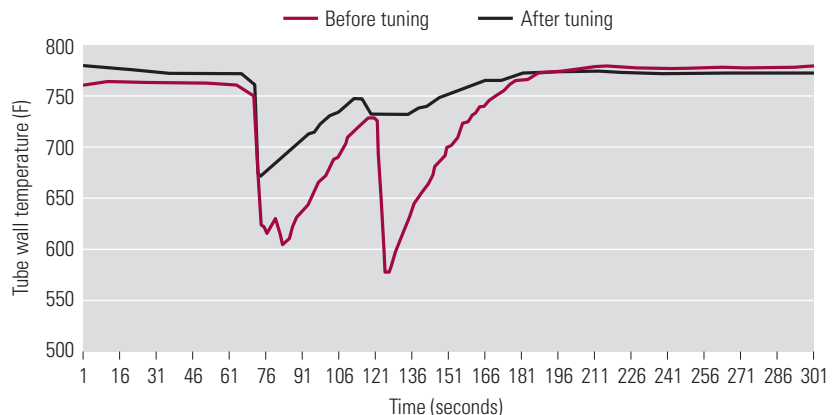
To understand and measure the effects of cyclic stress, start by considering basic tube geometry. There are two constant stresses on

the surfaces of the flat tube panels of the typical boiler. One is hoop stress, which is caused by internal pressures on the tube. The other is tensile stress, which is produced by the gravitational force of the hanging tube wall. When water is applied to a tube wall to clean it, the metal cools and contracts. When the metal heats up again later, it expands. Locally, each cooling/heating cycle increases tensile stress for several seconds, followed by a peak in compressive stress of similar duration. Together, these stresses can turn your furnace tube into what looks like a relief map of the Mississippi Delta (Figure 1).

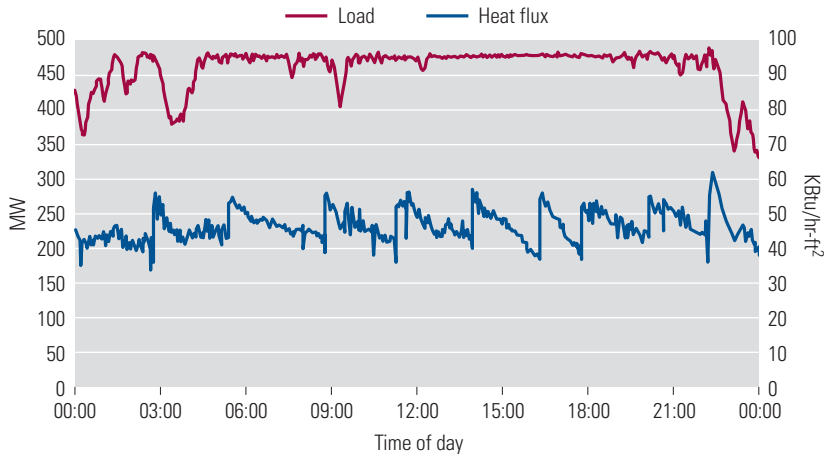
Most theories that attempt to explain the relationship between thermal cycle fatigue and stress assume that each cycle produces the same amount of stress. If that were true, simply counting the number of thermal cycles and multiplying that number by the average stress they produce would be a good way to predict the cumulative stress consequences of thermal cycling.

In the case of water cleaning of utility boilers, however, the assumption that stress is uni-

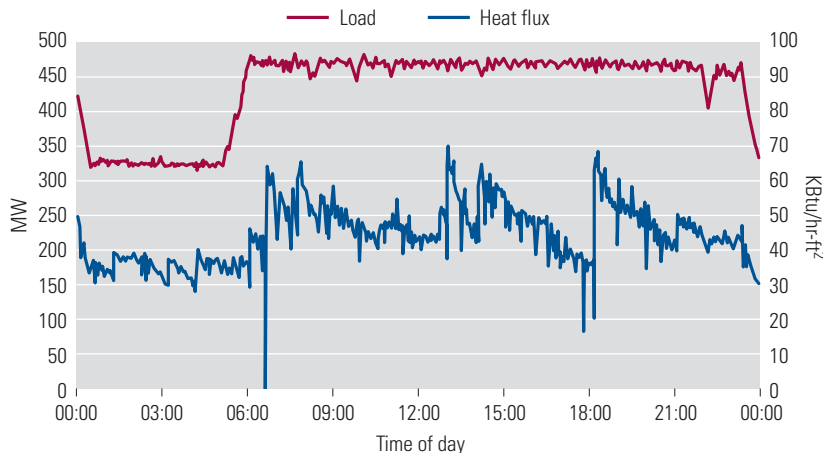
3. Transients detected. The TIME system can be used to thermally tune a cleaning system to reduce thermal impact fatigue, thereby significantly increasing predicted tube life. *Source: Diamond Power International Inc.*



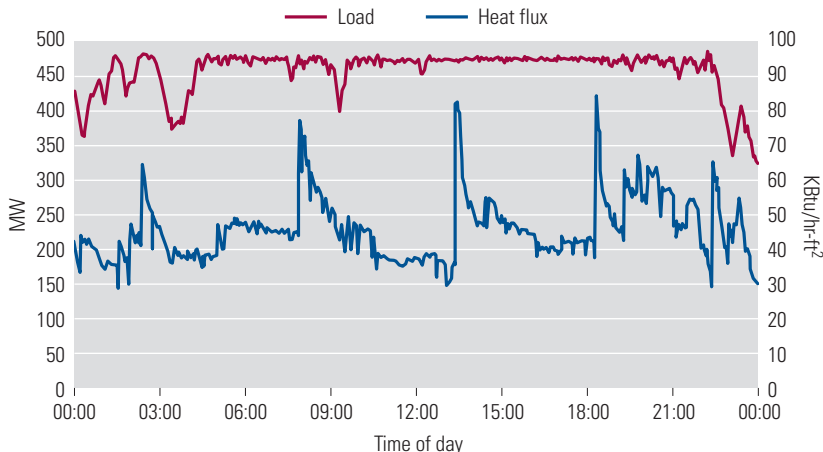
4. Zone 27. At this location, the final JPV needed to be lowered to 250 ft/min in order to get effective cleaning. Note the “sawtooth” pattern on heat flux between the cleaning events, which restore higher heat flux, followed by ash accumulation that degrades heat flux. The maximum thermal impact for this evaluation period was an acceptable 59.4F. *Source: Diamond Power International Inc.*



5. Zone 44 initial results. The initial flow and jet progression settings for Zone 44 provided good cleaning but an unacceptable thermal impact of 283.5F. Note the cleaning event shortly after 6:00 a.m., which immediately drove heat flux to zero. This reversal of heat flow on the sensor is indicative of the severe thermal shock that occurred with the initial settings of the cleaning device at this location. *Source: Diamond Power International Inc.*



6. Zone 44 follow-up. Two days later at the same location shown in Figure 5, water flow was reduced by 30 gpm while maintaining good cleaning. JPV had to be increased to 500 ft/min to lower thermal impact and decrease thermal impact. The resulting maximum impact was 99.5F. *Source: Diamond Power International Inc.*



form is invalid. The magnitude of cycling stress can vary greatly with the amount of water applied, the water’s jet progression velocity (JPV), the tube’s residence time in the water, and the amount of slag on the tube. The effects of these factors are as uncertain as the possible causes of accelerated tube damage. They include overcleaning and excursions in tube metal temperature (either per the boiler design pressure or due to nondesign factors such as tube ID depositing). Overcleaning can result from overlapping cleaning patterns, from overspraying onto adjacent cleaning areas, or from faulty water-cleaning equipment. Tube metal temperatures are affected by the heat transfer characteristics of the local tube area. The only quantity known before a cleaning event is the tube’s geometry.

Given so many unknowns, the only way to accurately assess the impact of a cleaning is to measure the magnitude and other characteristics of the roughly 1-minute temperature transient it produces. These measurements can then be summed up over time to provide insight into the cumulative effect of multiple water cleanings.

Calculation of the cyclic stress produced by a cleaning event can be done manually. According to EPRI report CS-4914, the impact of thermal fatigue on the life of a boiler tube can be expressed as its crack growth rate (CGR). CGR can be calculated using this equation: $CGR \propto \Delta T^3$. Here, ΔT is the difference between the temperature at the start of a transient and the minimum temperature produced during the transient by the application of cleaning water. The standard place to measure this temperature is 0.050 inch under the surface of the boiler tube.

To track CGR, relate the measured temperature to the temperature at the correct depth inside the tube using the correct proportionality constant. For example, to calculate how deeply a crack has penetrated a through wall, use the following formula: through wall crack (%) = initial depth (%) + ΣN (crack growth for cycle N)/100.

It’s about TIME

The magnitude of the impact of cyclic stress on boiler tubes also can be calculated automatically using a new hardware/software tool called the Thermal Impact Module (TIME). If deployed at each cleaning location, TIME can provide real-time monitoring and assessment of each water-cleaning cycle. One of its benefits is letting operators know where cleaning should not be done to avoid damaging tubes.

Here’s how TIME works. When its software detects a transient, the sensor at that location captures the tube metal temperature. The system then calculates the stress

impact of the transient from quantities such as the size and duration of the transient and the characteristics of the tube.

When the impact has been determined, a signal is immediately sent to the cleaning system operator in the form of a blinking icon on the module's interface screen. Each transient is characterized as either a low-, medium-, or high-impact event. Locations at which the impact is higher than a setpoint are immediately identified—via an alarm—so that adjustments to the cleaning system can be made to maximize tubing life.

TIME uses a color-coded system to differentiate transients. A blinking blue symbol represents a detected thermal transient, a blinking green symbol means that a cleaning event has produced a transient of expected size, and a blinking red symbol tells the operator that there has been a transient large enough to produce a crack growth rate greater than eight times nominal. Figure 2 (page 49) shows a typical TIME advisory screen.

For additional information about a particular cleaning area, the operator can click on the area's icon to retrieve data such as the size of the metal temperature transient, the cumulative thermal fatigue impact in that zone, or the number of thermal cycles it has endured. In addition to this real-time infor-

mation, the TIME system provides a report with summary information on the cumulative thermal impact, number of thermal cycles, and predicted crack growth rates for a zone or within a user-defined period. This information is available both graphically and in the form of Excel spreadsheets.

TIME for action

One of the first installations of TIME was evaluated this past spring on a 350-MW, wall-fired boiler burning PRB coal in which furnace wall cracks had become a real concern. The first step in putting the system in service was to tune the boiler's water-cleaning system to its vendor's recommended settings, despite the fact that the system was almost certainly causing unacceptable cyclic stress. Figure 3 (page 49) compares the transients detected in a particular cleaning zone using the initial and post-tuning settings.

As the figure shows, changing the settings between the two cleaning events produced a decrease in pressure, an increase in JPV, and an increase in step size. These changes caused the thermal impact to improve from a corrected 135F to 72F, or almost an eight-fold improvement in predicted tube life.

Another new TIME system was started up this May on a 450-MW, tangential-fired unit

burning PRB coal. This time, the objectives of tuning the system were to determine the effect of JPV on cleaning effectiveness and the thermal impact of a typical HydroJet cleaning system. Different furnace tube zones and selected specific heat flux sensors were used to trend heat flux and boiler load over a 24-hour period. Shown in Figures 4 to 6 (page 50) are the results of a study to determine the corresponding maximum thermal impact at each sensor location based on an initial JPV of 300 ft/min at a selected flow rate.

The results of both field tests indicate that negative thermal impacts can both be effectively monitored and used as a measure of cleaning effectiveness. But a more impressive result is the significant reduction in thermal impact on the furnace tubes. To put the results into perspective, a reduction of thermal impact of 283.5F to 99.5F is about a two-thirds reduction. Because CGR is proportional to thermal impact to the third power, this two-thirds reduction translates into a reduction in crack growth by a factor of more than 20. Here's an even more succinct way of explaining the benefits of automated cleaning monitoring to reduce cyclic thermal stress: Would you rather have your boiler tubes last 50 years or 20? ■