Minimizing Unplanned Outages and Boiler Fouling Utilizing On-Line Impulse Cleaning

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INTRODUCTION

Due to ever increasing efforts towards maximizing availability and efficiency of utility and industrial coal-fired boiler equipment and minimizing emission rates, there have been recent surges in research and development in the areas of alternative fuels, chemical additives, active monitoring, combustion tuning, and online cleaning.

Burning of solid hydrocarbon fuels results in slagging and fouling of downstream heat transfer surfaces due to the by-products of the combustion process. As ash deposits on heat transfer surfaces and/or flue gas paths become blocked by ash deposits, efficiency of heat transfer drops dramatically. If this deposition is left to expand and grow, the mass loading of the deposits, the redirected flow patterns, and/or the excessive cleaning using current technology can lead to unplanned and expensive outages for maintenance, as well as an overall reduction in boiler efficiency.

Using a 270 MW coal-fired power boiler as an example, improvement of online cleaning that results in 0.5% efficiency improvement could yield significant benefits. This improvement could equate to a maximum of 5,400 tons reduction of coal consumption or the equivalent of 14,500 MW/hr of electricity, 11,500 tons reduction in CO2 emissions, and up to a 50-ton reduction in SO2 emissions. Additional valuable benefits could also be achieved through reduced maintenance and cleaning costs during outages, and a reduction in forced outages throughout the year.

Impulse cleaning technology has recently shown potential for dramatic improvements in online cleaning of fouled surfaces when compared to existing cleaning systems being used. This paper will present a brief background and description of impulse cleaning technology, explanation of placement and operation, and highlight case studies from a sampling of plants that have significantly benefited from the implementation of Impulse Cleaning systems to either augment or replace existing soot blower cleaning.

BACKGROUND

Though configuration of boilers can vary widely, one of the fundamental problems they all encounter is buildup on heat exchanger surfaces of the by-products released during combustion. Boilers rely on transmission of thermal energy from direct firing of fuel and when combustion materials are deposited on the surface of the heat transfer surface, the conductivity or heat transfer of the system is reduced.

The deposits on heat transfer surfaces are a result of the combustion process. The deposition can lead to degradation of performance, including increased pressure drop across critical heat exchangers, reduced combustion efficiency, and damage to mechanical components due to falling deposits or excessive wear from inefficient sootblowing. All of these issues can eventually lead to planned or unplanned outages, which could be extremely costly to the plant from lost production, purchased power and maintenance and repair costs.

The ability to maintain effective heat transfer without damaging internal components is a major objective of boiler and heat exchanger operators.

With the advent of more rigorous environmental emissions monitoring, especially throughout the power industry, many plants have or are making a switch to “compliance” fuels. These are fuels which allow operation of the boiler in compliance with regulations related to sulfur dioxide and sometimes particulate.

Powder River Basin (PRB) coal is one such fuel that has a lower sulfur content compared to many eastern coals. PRB also has a lower price per equivalent heating value and better availability making it an attractive fuel source for plants. PRB coal has a lower heating value per ton of coal, and ash slagging characteristics due to elements such as sodium and calcium, which can lead to plugging and buildup problems in plants that were not specifically designed to handle this fuel. As a result, the ability to effectively burn PRB coal may rest with the ability to effectively maintain clean heat transfer surfaces.

Additionally, certain chemical additives such as lime, trona, soda ash and SBS that alter the chemistry of the gas stream are being utilized to improve environmental performance and comply with new environmental standards. Some of these additives may increase the cohesiveness of the ash deposits and create additional challenges related to pluggage or fouling of the heat transfer surfaces.

Build up is never consistent in its distribution within a boiler. As a result, variations in the heat transfer flux rates can occur throughout the boiler. When the thermal energy transfer rate is variable, it becomes more difficult to control steam pressure at the variety of heat transfer surfaces in a boiler. It is essential to minimize the variability in heat transfer rate to optimize boiler operation.

Every boiler uses some form of cleaning technology to remove deposits. The technology may be steam soot blowers, compressed air soot blowers, water lances, water cannons, acoustic horns, fuel additives, or a combination of two or more of the aforementioned technologies. The purpose of the cleaning technology is to maintain adequate heat transfer through removal of surface build up to maintain heat transfer.

Factors such as high operating cost, high maintenance cost, ineffectiveness at creating clean surfaces and maintaining heat transfer rates, and negative impact on mechanical component life are all problems that may affect the various cleaning technologies. Soot blower and water lance cleaning devices are often only partially successful in removing deposits, they also require considerable maintenance, and reduce boiler efficiency when in use. Acoustic horns are low maintenance, but have a limited cleaning pattern and are best suited for a dry, friable, ash deposit, and are not as effective on sticky or tenacious ash deposits.

All of these technologies can potentially benefit from chemically modifying the crystalline structure of the deposit and altering the ash fusion temperature. Additives such as magnesium hydroxide have been successfully utilized to increase deposit friability thus allowing increased efficiency in removing deposits.

IMPULSE CLEANING TECHNOLOGY

Impulse cleaning technology, the main subject of this paper, utilizes intense pressure waves, orders of magnitude more intense than acoustic cleaners can emit, to provide significantly more complete and far reaching cleaning of heat transfer surfaces and have the ability to address more sticky deposits typically outside the range of acoustic cleaning capabilities. Impulse cleaning or detonation cleaning is not in reference to the use of dynamite or detonation cord, both of which occur offline and have significant risk and liability associated with it. Detonation cleaning for boilers was derived from the research conducted in an effort to develop a new propulsion system known as a pulse detonation engine (PDE). A PDE offers the potential for highly efficient propulsion.

In most cases, the impulse or shock waves are created through the rapid combustion, or detonation, of a charge of fuel/oxidizer in such a manner to direct the resulting impulse wave into the heat transfer surface to be cleaned. This basis for this rapid combustion technology has its roots deep within the aerospace research and development field where high-throughput, pressure-rise combustion has the potential to radically change the design of future propulsion systems.

The process of creating a detonation consists of injecting a mixture of fuel and oxidizer into a chamber, igniting this mixture, transitioning the resulting combustion wave to a detonation wave, and then purging with air to prepare for the next cycle. (Fig.1)

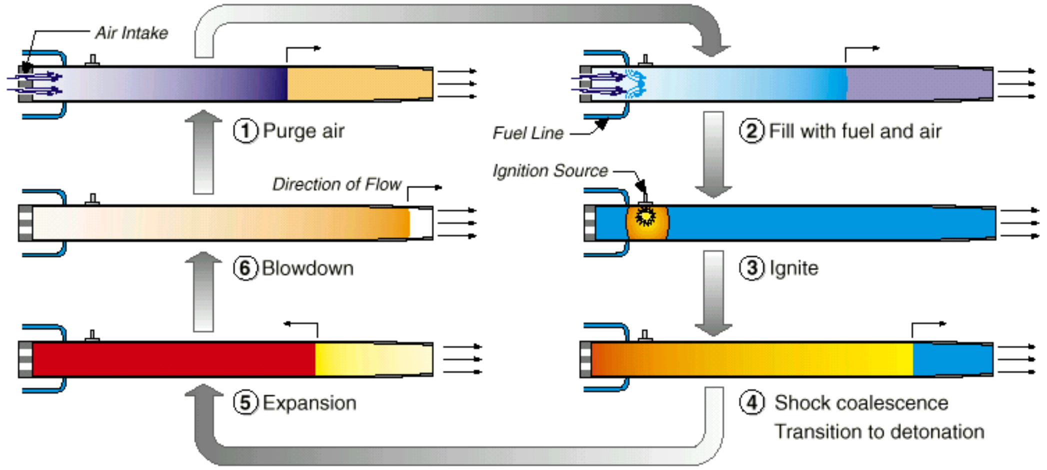
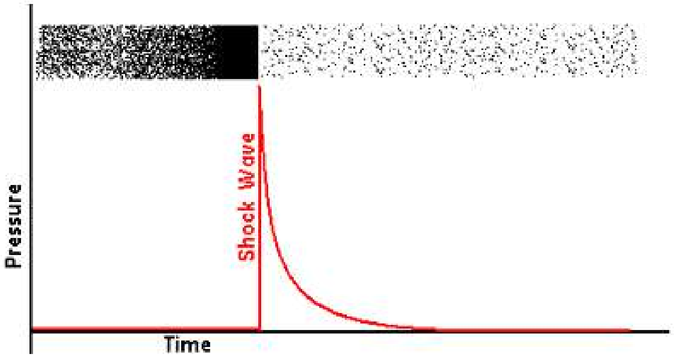


Figure 1

The detonation wave travels at supersonic speeds within the combustion chamber and quickly decays to a sonic blast wave once it leaves the chamber and propagates in open space (or within a large structure, such as a boiler). The blast wave, also known as a pressure wave, a pressure pulse or simply an impulse has the energy required to remove sintered and unsintered ash in the back pass of boilers.

HOW IT WORKS

A shock wave, or impulse wave, is an intense single pressure pulse characterized as having an immediate pressure rise followed by a sharp pressure-decay. (Fig.2)



Pulse Detonation Shock Wave

Figure 2

This pressure wave is utilized in impulse cleaning systems to physically break apart agglomerations and facilitate them to move on through the process, without damaging the heat transfer and surrounding structure.

Detonation waves are high strength, high velocity combustion waves which are similar to normal shock waves. They travel at a supersonic velocity and consequently involve extremely high pressure differentials.

A normal deflagration wave, on the other hand, propagates at a subsonic velocity, does not involve shock compression and hence pressure differentials involved are negligible.

This diagram (Fig.3) shows a longitudinal wave, with its main features of rarefactions and compressions:

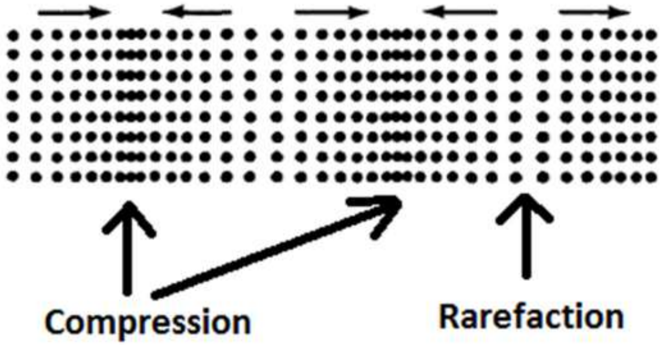


Figure 3

Essentially a longitudinal wave is made up of compressed parts and loose parts. A compression is the area of the wave that is pushed together - this is the wave's crest (or peak). A rarefaction is the area of a wave that is spread out - this is the wave's trough. You can also think of a rarefaction in terms of density: The rarefaction is the part of the wave that has the lowest density.

Wave strength and velocity are also important variables for ash/fouling deposit removal applications. The direct impact of shock waves on heat transfer surfaces and its pressure force and thermal impact are basically the major cause of destruction and subsequent removal of the deposits.

In addition to the shearing potential, the wave reverberations established will be more effective in breaking up and removing ash deposits over large areas. Besides the wave reverberation in the deposits, the wave also reverberates in the convective path upon which ash is deposited, and, thus removes the deposits on both sides of tube. This is likely a joint and simultaneous action of several factors associated with or generated by the shock wave that contribute each in its own way to the final effects.

The following graphic (Fig.4) is utilized to help illustrate how rarefactions and compressions in a shockwave effectively work to excite and dislodge ash particles.

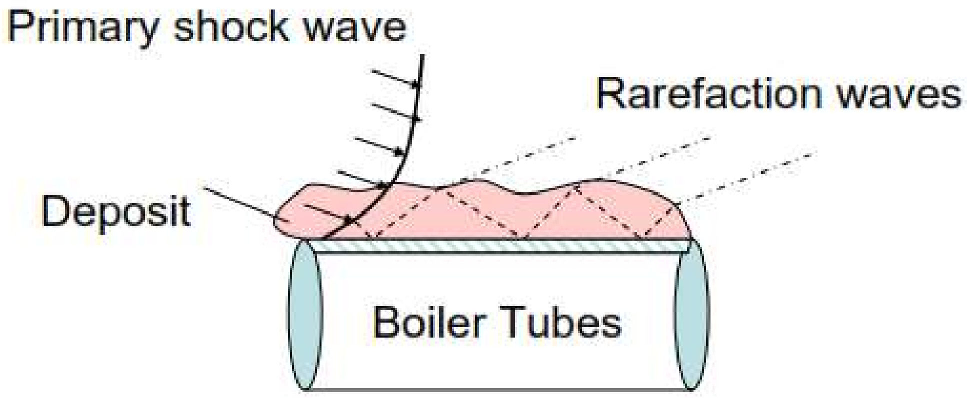


Figure 4

A simplified picture of the impulse cleaning technology can be summarized as follows:

- Shock wave impinges the heat transfer surface directly and its pressure force promotes removal of the ash
- The direct impact of exhaust gases from the impulse cleaner.
- Deposit cracking and loosening due to stress developed by a sharp increase/decrease in pressure.
- Produces multiple reverberations in cavities of the deposits.

- Reflection of the waves also facilitates the removal of ash.

- No moving parts to fail or replace.

A significant benefit of impulse cleaning systems over soot blowers is that they can be operated very aggressively in terms of their cleaning frequency per day without causing the tube erosion caused by soot blowers. The great advantage of a proactive cleaning cycle is that it provides a more consistent heat transfer profile and removes the ash deposits before they have an opportunity to harden or sinter into place.

Soot blowers typically only clean 2-3 times a day, allowing the tubes to become more heavily fouled between those cleanings. The heat transfer efficiencies continue to degrade until the next soot blower cycle. In many cases, the deposits tend to sinter and harden, thus reducing effectiveness of subsequent sootblowing cycles. Impulse cleaners typically operate multiple times per hour throughout the day and therefore maintain higher heat transfer efficiencies.

An additional advantage of impulse cleaning systems over soot blowers is the ability of the pressure wave to encompass the tube surface, transition around to back side, reconnect, and continue travelling throughout the depth of the tube bank, providing non-line-of-sight cleaning and deeper penetration throughout the tube bundle. (Fig.5)

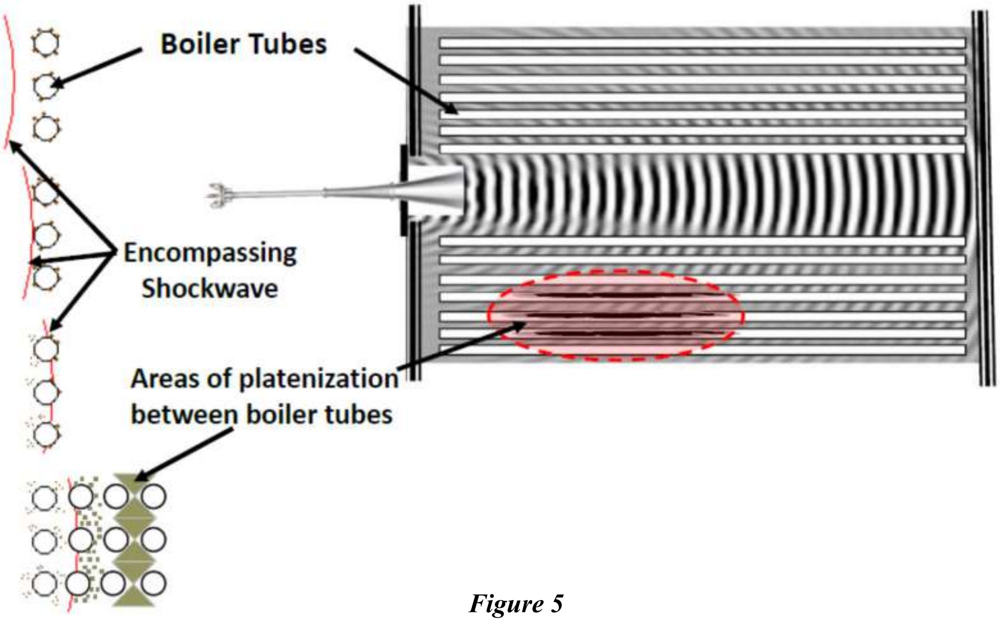


Figure 5

Impulse cleaners have been applied in many boilers to reduce their reliance on soot blowers and slow down the associated tube erosion, reducing subsequent tube leaks and the unplanned outages to repair them. They are also used to augment the cleaning of deposits and gain back efficiency loss, or to completely replace existing soot blowers that are not performing to plant expectations.

PLACEMENT AND OPERATION OF IMPULSE CLEANERS

Since most impulse cleaners are wall mounted units that emit shockwaves outward radially from the penetration point, it is necessary to design the placement of the system or systems and operate them in such a manner to fully cover the area to be cleaned. This section will describe the basic operation of impulse cleaners and how this impacts cleaning sequence and range of the cleaning impulse wave.

Impulse waves from each cleaner are created individually, in that each combustion event results in a single impulse wave. Impulse cleaners therefore operate in cyclic cleaning sequences, creating multiple cleaning waves per cleaning sequence. Typical cleaning sequences consist of 10-20 impulses with delays of 30 minutes to two hours between cleanings, radically different from the typical operation of a soot blower cleaning system. This exemplifies a pro-active cleaning cycle that enables continued removal of deposits resulting in improved average efficiency of the boiler. As mentioned above, this is possible due to the low operation cost of the cleaner and the fact that it does not damage tube surfaces.

Each impulse is the result of the filling of the generating chamber with a mixture of fuel and compressed air and igniting that mixture instantaneously. The combustion event moves at speeds approaching 1800 m/s (roughly five times the speed of sound) as it consumes the fuel/air mixture. This supersonic combustion speed is what creates the strong shock wave coupled to the leading edge of the combustion flame as it consumes the volume gas within the chamber. The generating chamber shape can affect the strength of the resulting shock wave significantly. Once the fuel and air is fully consumed, the shockwave decouples from the combustion process, exits the chamber, and begins expanding spherically as it continues to travels away from the penetration point of the cleaner. As illustrated above, this provides the unique benefit of cleaning the leading edge and trailing edge of all tube-scale structures it passes. This is what allows the impulse wave to penetrate deeply throughout tube bundles and clean in a “non-line-of-site” manner to remove deposits typically left behind by other cleaning systems. This is a very important feature of an impulse wave with regards to boiler cleaning, where deposits buildup in many areas that soot blowers cannot reach.

Although the Mach 5 velocity of the impulse wave quickly decays to the speed of sound once it leaves the combustion chamber, the steep pressure rise associated with the wave decays significantly slower as the impulse wave expands and travels throughout the boiler. This pressure decay is approximated by blast wave decay theory and has been verified via previous research (Glaser, 2007). Therefore, the initial shock strength is a variable that can affect the effective cleaning distance of each cleaner.

Placement of the cleaner is important to the success of installation and it is important to take into account tenacity of deposit, its physical state, and the temperature of the flue gas through which the shock wave is travelling. The more tenacious, or more aggressively attached that the deposit is to the heat transfer surface, the higher the pressure threshold required to remove it. Physical state is important, because as deposits cool, they move from a molten state, to a plastic state, and eventually to a solid state. In a molten state, the deposits absorb acoustic energy without breaking apart. Another important consideration is gas temperature in the area of the boiler through which the impulse waves are traveling. As gas temperature increases, the density of that gas decreases. Pressure waves moving through less dense gas result in smaller pressure rise and therefore less cleaning range. Taking all of these variables into consideration, impulse cleaning technology has been successfully implemented in coal-fired boilers throughout convection passes, with temperatures as high as 1,850 degrees Fahrenheit.

Various fuel and oxidizer combination requirements exist for impulse cleaning systems. Physical sizes of the combustion chambers can vary greatly based on the fuel/oxidizer combination. Operation costs vary based on many factors, but typically each impulse cleaner can cost less than $500.00 USD a month to operate. Many installations have less than a one-year payback.

When impulse cleaners were first introduced to market, they were initially sought after to improve difficult buildup situations in existing boilers where changes in fuel, operating conditions, or degradation of existing cleaning systems had caused serious issues in the efficient operation of convection passes in boilers. Now, industry is seeing the emergence of sites interested in replacing entire (traditional) cleaning systems with impulse cleaning on boiler and other applications like air heaters, turning vanes and spray dryer absorbers due to the operational and financial benefit.

CASE STUDIES

Below are three case studies representing three different utility boilers that were experiencing three different issues, all related to poor heat transfer cleaning. Each study will present the background, cleaning solution, and the performance/financial impact resulting from the implementation of the impulse cleaning system.

Case Study #1

Heavy buildup in the horizontal convection pass (super-heat through economizer tube bundles) of a 220 MW T-fired boiler caused low heat transfer efficiencies and high pressure drops to the extent that the utility had to de-rate towards the end of each run cycle. A special boiler cleaning outage was performed annually so that the utility could operate until the next scheduled outage.

Although this unit had operated with soot blowers since start-up, a recent change in coal type to a higher ash and lower sulfur content coal lead to excess buildup on the heat transfer surfaces, which could not be effectively be cleaned by the soot blowers. In the fin-tubed economizer section, with staggered tube arrangement, ash was piling to significant levels on top of the economizer causing effective loss of entire areas of heat exchanger surface and significant pressure drop. In the low-temp superheater banks, with in-line tube arrangement, the buildup was forming between the vertical gaps in the tubes, also referred to as platenization, resulting in a significant loss of heat transfer surface. Although the gas lanes were kept clear by the soot blowers, the high pressure jets could not break out the vertical walls of ash forming between the tubes.

The entire convection pass of this boiler was retrofit with impulse cleaners to operate in conjunction with soot blowers in order to reduce the fouling issues, and ultimately to allow the customer to operate outage to outage, eliminating that additional annual outage for cleaning.

At the end of the first year of operation, the results were as follows:

- The additional cleaning outage was eliminated and during all inspections the tube banks were significantly cleaner.
- The plant tracked a 33° F (18 °C) improvement in economizer outlet temperature and a corresponding 25° F (14 °C) improvement in air preheater outlet temperature across all operating loads.
- There was significantly less buildup in the air preheaters, resulting in a 30% improvement in pressure drop across the preheaters.
- Operating cost for all six impulse cleaners in the system has been approximately $15,000.00 USD per year.

Case Study #2

Pluggage of the hottest reheat bank just over the bullnose of a 100 MW boiler was causing excessive loading and sagging of the tube bundle support brackets and was the main driving factor for the 1-year run cycle, outage to outage, of this city owned utility. Soot blowers installed above the reheat bank were not effective at removing the shear mass of fouling. The utility installed impulse cleaning systems two weeks prior to their annual outage. This allowed an opportunity to immediately evaluate how effective the impulse waves were at removing existing deposits, and develop a short-term payback analyzing time spent for boiler cleaning versus previous outages. The ultimate goal for this user was to keep the reheat bank cleaner and to increase the boiler run-time between outages, without causing additional structural damage to the tube bundle supports.

After only two weeks of operation, the pluggage was completely eliminated in the reheat section.

Additionally, no manual cleaning of this area was required during the outage. After a full year of operation the plant experienced the following results:

- The boiler maintained temperatures and pressures throughout the run cycle.
- The time between scheduled outages was increased from 12 months to 18 months, effectively eliminating one outage every 3 years.
- Soot blowers were completely removed from this area of the boiler.
- This site is currently evaluating a further increase the time between planned outages.

Case Study #3

The combination of fly-ash and tight spiral-wound fin design in the economizer section of a 70 MW peaking unit resulted in significant packing of ash into the gaps between fins. In the peak months of summer, the boiler would become fan limited and cause the need to de-rate. This site had previously seen benefit from the installation of acoustic cleaners in this area, but was searching for a more effective cleaning system to ultimately be able to operate even more efficiency and generate more electricity. This plant installed two impulse cleaners above the economizer bank. The systems were installed on opposing walls at the same elevation to fully clean the 35' width.

After only a year of installation, the site found the following results:

- On average, the site was able to increase output by 3 MW
- The change in temperature across the economizer was improved by over 70° F (39 °C) on the gas side and a corresponding 18° F (10 °C) improvement across the tubular air preheaters.
- A 25° F (14 °C) degree improvement was seen in temperature on the water side of the economizer.

CONCLUSION

There are continuing and expanding challenges related to rigorous environmental regulation throughout the power industry. These challenges are forcing many plants to switch to "compliance" fuels and/or utilize chemical additives that can alter the chemistry of the gas stream and increase the cohesiveness of the ash deposits, further adding to the existing challenges related to pluggage of the heat transfer surfaces.

Maintaining effective heat transfer without damage or degradation of the internal components that can force costly, unplanned outages, continues to be a priority for most operators.

There have been many advances in impulse cleaning systems and they have become more widely applied by utility and industrial boiler operators over the last ten years.

Impulse cleaning systems have proven to provide a rapid change and improvement in boiler operation, offering substantial benefits, including more effective, non-erosive heat transfer surface cleaning with dramatically lower operational and maintenance costs. Impulse cleaning systems utilized in combination with targeted chemical addition such as magnesium hydroxide which alters ash friability, offers the potential to provide unmatched effectiveness in cleaning and maintaining efficient heat transfer, even with the use of highly challenging fuels.

Similar benefits can be gained on other applications like air heaters, turning vanes and spray dryer absorbers.

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