

Boiler Fouling, On-line Cleaning Solution Using Impulse Cleaning

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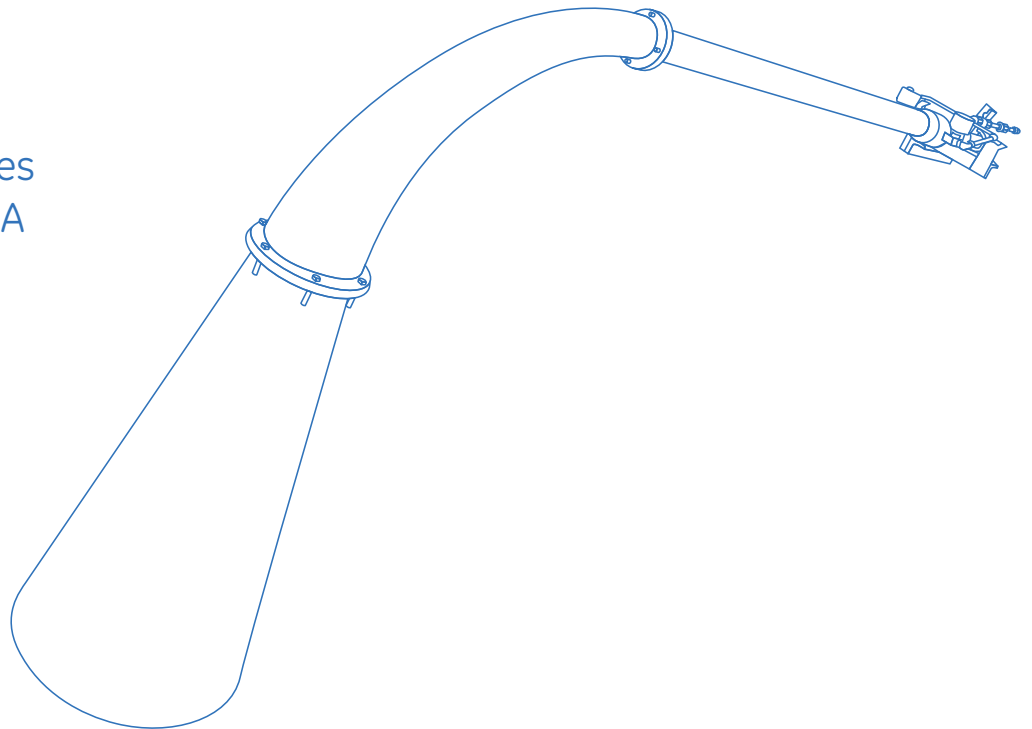


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Introduction

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 what is commonly referred to as slagging and fouling of downstream heat transfer surfaces due to the bi-products of the combustion process. As heat transfer surfaces are layered with or blocked by ash deposits, efficiency of heat transfer drops dramatically. If left to continue to foul, the mass loading of the deposits, the redirected flow patterns, and/or the excessive cleaning using current technology can lead to expensive operation and maintenance expenditures for plants.

Looking at a sample 270 MW coal-fired power boiler, improvement of online cleaning that results in 0.5% efficiency can yield significant direct payback. This payback could equate to a maximum of 5,400 tons reduction of coal consumption or the equivalent of 14,500 MWhr of electricity, 11,500 tons reduction in CO₂ emissions, and up to 50-ton reduction in SO₂ emissions. Significant payback is also seen in terms of reduced maintenance and cleaning costs during outages, and fewer forced outages throughout the year.

Impulse cleaning technology, a derivative of acoustic cleaning, 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 benefited significantly from the implementation of impulse cleaning systems to either augment or replace existing soot blower cleaning systems.

Background

Acoustic cleaning technology in one form or another has been utilized in plants for over 3 decades to aid in cleaning of heat transfer surfaces in boilers, filters in baghouses, plates in electrostatic precipitators, air preheater modules, catalyst in selective catalytic reduction reactors, fans, silos, hoppers, and various other pieces of equipment. Acoustic cleaning systems typically utilize compressed air to rapidly vibrate thick titanium diaphragm plates to create sound waves or pressure waves. The resulting sound waves are amplified and directed into the equipment to be cleaned. The transverse sound waves push and pull at the deposits, breaking them apart, and allowing gas flow or gravity to carry the deposits away from the surfaces. Typically, a dry, friable, ash-deposit is the most receptive to this type of cleaning power. There have been numerous papers written and presented over the years regarding the benefits of acoustic cleaning technology over other types of cleaning systems such as rappers, soot blowers, shakers, reverse-air systems, vibrators, and air cannons.

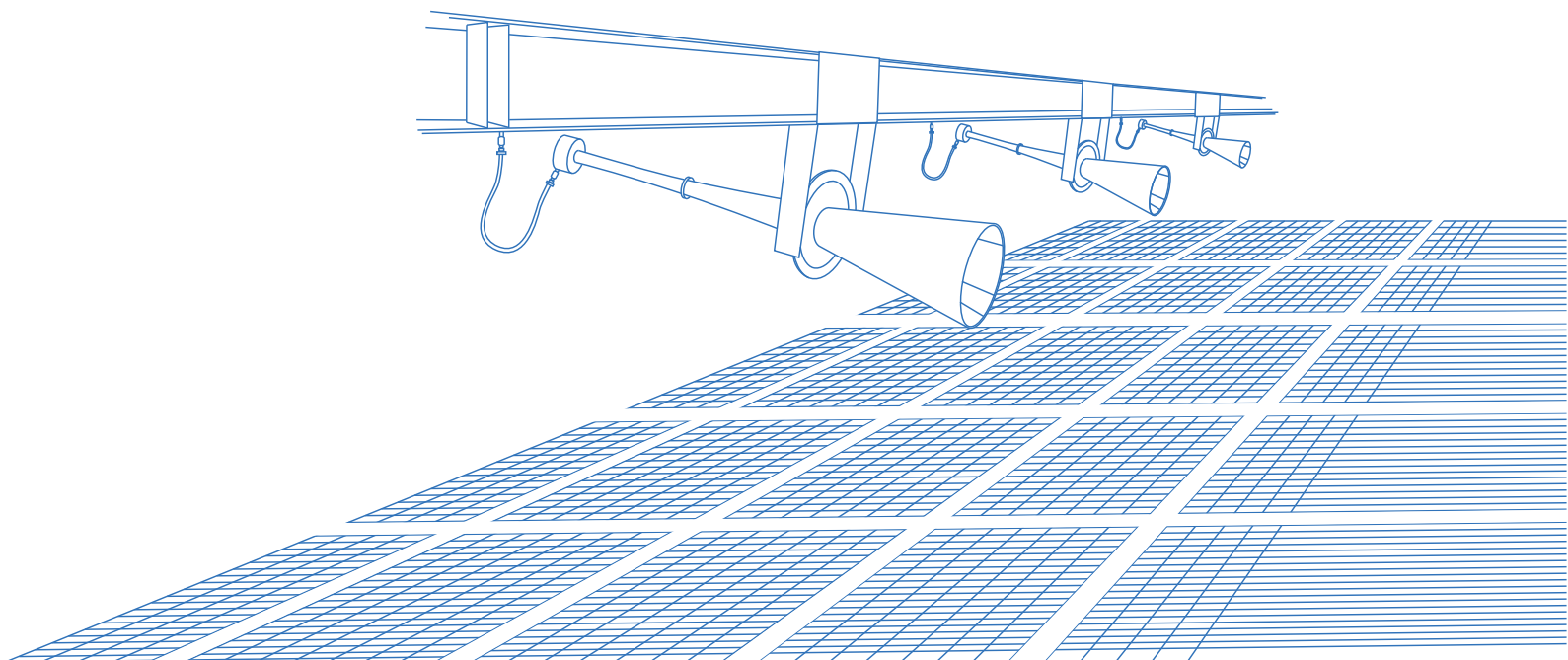
Impulse cleaning technology, the main subject of this paper, utilizes intense pressure waves of magnitudes more intense than acoustic cleaners can emit, to provide significantly more

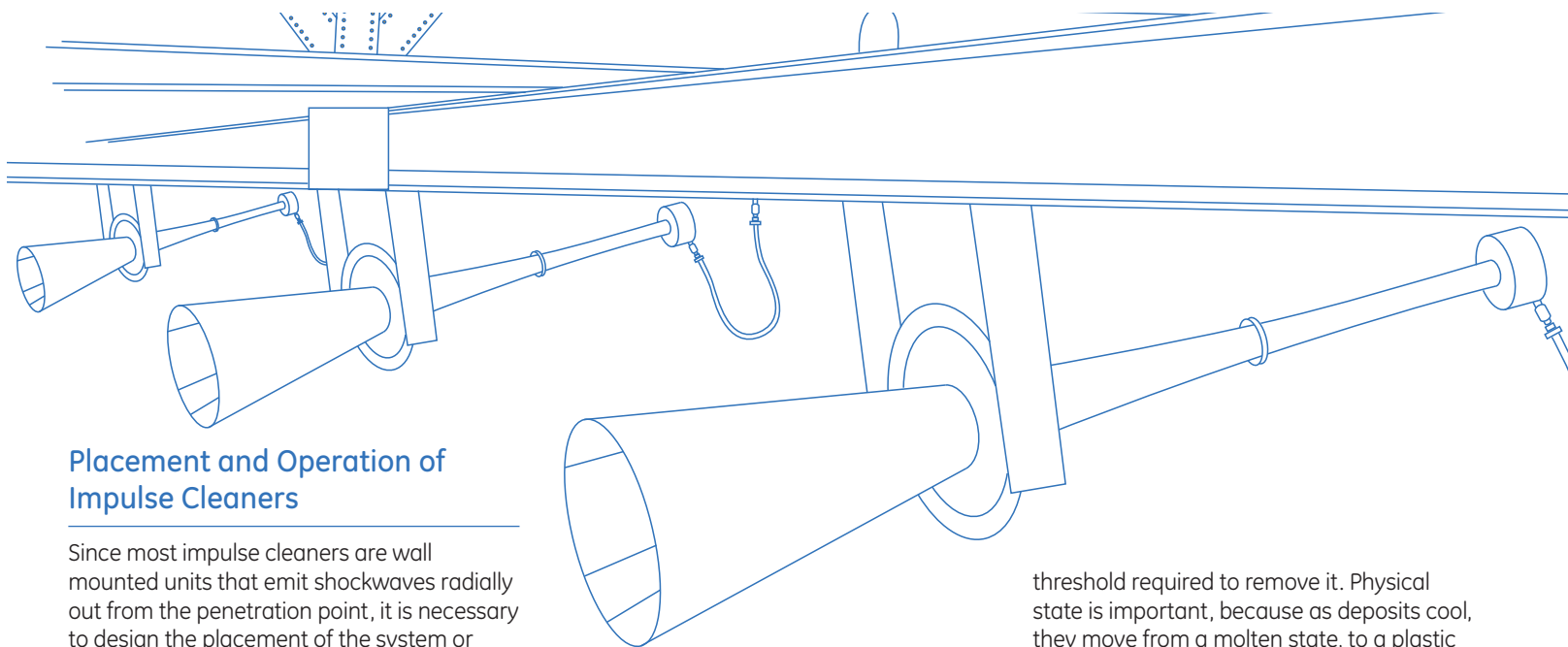
complete and far reaching cleaning of heat transfer surfaces and the ability to address more sticky deposits typically outside the range of acoustic cleaning capabilities. The method utilized to create these impulse pressure waves vary greatly, including just flexing a diaphragm plate with air as described for acoustic cleaners. 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. The basis for this rapid combustion technology has 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. 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. 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.

A significant benefit of acoustic or 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 benefit of this is that on average the boiler maintains more cleanliness and therefore operates more efficiently. Soot blowers typically clean 2-3 times a day and between those cleanings, the tubes become fouled again leading heat transfer efficiencies to continue to degrade until the next soot blower cycle. Impulse cleaners typically operate multiple times per hour throughout the day and therefore maintain higher heat transfer efficiencies.

Impulse cleaners have been applied by plants in boilers to reduce their reliance on soot blowers and slow down the associated tube erosion, augment the cleaning of deposits to gain back efficiency loss, and to completely replace existing soot blowers that are not performing to plant expectations. Impulse cleaners are generally not utilized for cleaning of filter bags in baghouses, or catalyst in SCR reactors, however there are other applications where friable deposits clinging to heavy metal structures can be removed with impulse waves.





Placement and Operation of Impulse Cleaners

Since most impulse cleaners are wall mounted units that emit shockwaves radially out 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 travel away from the

penetration point of the cleaner. A unique benefit of cleaning with impulse waves versus soot blowers is that the impulse waves will actually clean 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). Based on what is known about cleaning with pressure waves, once the wave pressure decreases beyond a threshold, dependent on type of deposit, it is no longer effective at removing those deposits. Similar to how the further away the deposit is from a soot blower jet, the less effective that jet of air/steam is for cleaning. Therefore, the initial shock strength is a variable that can affect the effective cleaning distance of each cleaner. Placement of the cleaners 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 traveling. 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 for coal-fired boilers throughout the entire convection passes, up to temperatures as high as 1650 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 a typical impulse cleaner can cost \$2,000.00 USD to \$4,000.00 in yearly operation costs. Most 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 emergence of sites interested in replacing entire (traditional) cleaning systems with impulse cleaning due to the operational and financial benefits.

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 led to excess buildup on the heat transfer surfaces, which could not be effectively 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 of the impulse cleaning system was approximately \$15,000.00 USD per year.

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) improvement was seen in temperature on the water side of the economizer.

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 customer was to keep the reheat bank more clean 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 to the time between outages.

Conclusion

In the last five years there have been many advances in impulse cleaning systems and they have become more accepted by utility and industrial boiler operators. Placement and operation of the systems is crucial to their performance. When applied correctly, impulse cleaning systems represent a rapid change in boiler cleaning technology and have provided proven benefits that include more effective non-erosive heat transfer surface cleaning, lower operation and maintenance cost, and lower installation costs.

Works Cited

Glaser, A. J. (2007). *Performance and Environmental Impact Assessment of Pulse Detonation Based Engine Systems*. Cincinnati, OH: University of Cincinnati.