

REINHOLD ENVIRONMENTAL®



2023 Reinhold/PCUG Round Table Presentation

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Impulse Cleaner Benefits with High Fouling Fuels

Vince Barreto
Power Plus Cleaning Systems
President/Owner

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Storm Technologies, Inc.
Chief Engineer

Slagging vs Fouling

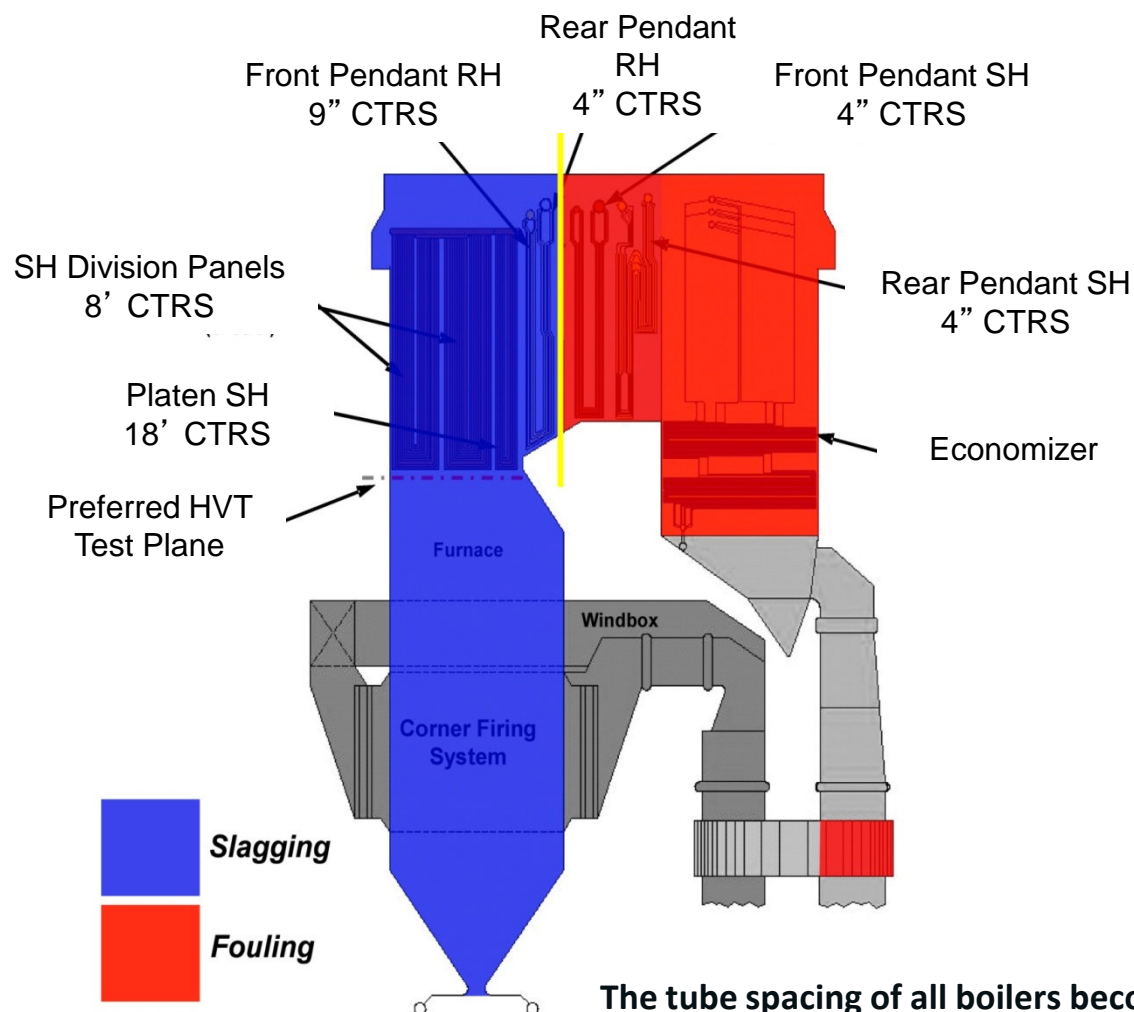


Slagging

Accumulation of molten or 'tacky' deposits on heat exchange surfaces in portions of the boiler exposed to radiant heat.

Fouling

Accumulation of deposits normally by desublimation and sintering on heat exchanger surface in the convection passes of the boiler at temperatures below the fusion temperature of any of the ash constituents.



The tube spacing of all boilers become progressively more restrictive as the heat transfer process changes from "radiant" in the furnace to "convective" heat transfer in the back pass.

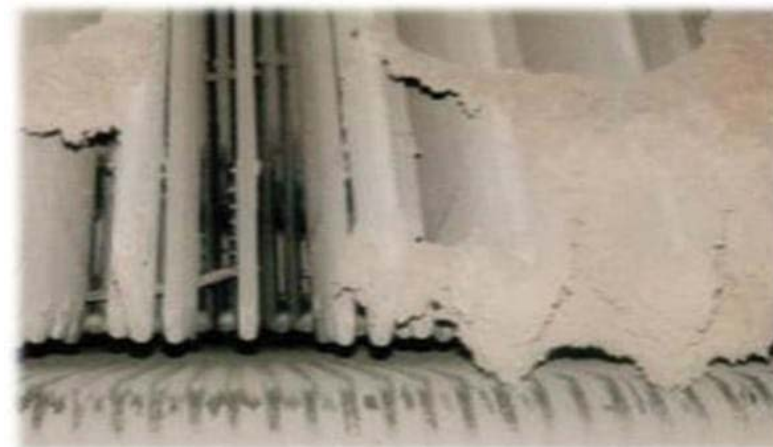
*From ASME Coal Fouling and Slagging Parameters (1974)



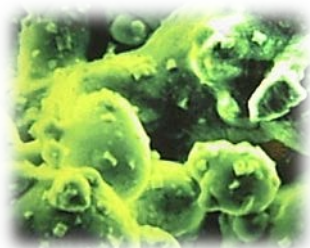
Parameters that Impact Slagging and Fouling



- Fuel Properties
 - Sodium, Potassium, Calcium, Iron
 - Inconsistency
- Low furnace excess oxygen
 - Air In Leakage
 - Air and Fuel Balance
 - Inaccurate Airflow Measurement
- Extreme stratifications of the FEGT flue gas lanes
- High primary airflows
- Burner damage and deficient mechanical condition/tolerances
- Poor coal pulverizer performance



Iron, Fe_2O_3
Calcium, CaO
Sodium, Na_2O



Melting temperatures of coal ash eutectics	
FeO - FeS	1724 F
FeO - Al_2O_3 - SiO_2	1963 F
CaO - FeO	1967 F
Na_2O - Al_2O_3 - $6SiO_2$	2012 F
Na_2SO_4 - $CaSO_4$	1675 F



Fouling Factor / Index



- $R_f = B/A * Na_2O$
- $R_{f'} = B/A * \% \text{ Water Soluble } Na_2O$
 - S = weight percentage of sulfur on a dry basis
 - B/A = Base/Acid Ratio

Fouling Type	R_f	$R_{f'}$
Low	< 0.2	< 0.1
Medium	0.2 – 0.5	0.1 – 0.25
High	0.5 – 1.0	0.25 – 0.7
Severe	> 1.0	>0.7

- * R_f is known to give incorrect results for lignitic type ash
- * $R_{f'}$ used for western type coal

ASTM Test D-1857 (Ash Fusion Temperatures)



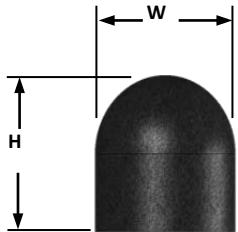
Test should be done in both oxidizing and reducing environments. Fusion temperatures in a reducing environment are normally lower than an oxidizing environment. Iron content of ash increases the difference between oxidizing and reducing atmosphere fusion temperatures.



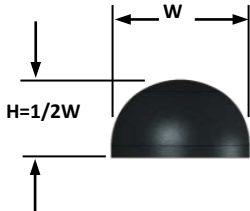
Conical Ash Sample
Before Heating



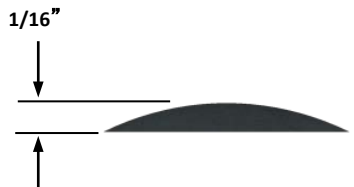
Initial Deformation Temperature (IT)
Temperature at which the first rounding of the Apex of the cone occurs



Softening Temperature (ST)
Temperature at which the cone has fused to a spherical lump in which the height is equal to the width at the base



Hemispherical Temperature (HT)
Temperature at which the cone has fused down to a hemispherical lump at which point the height is one half the width of the base

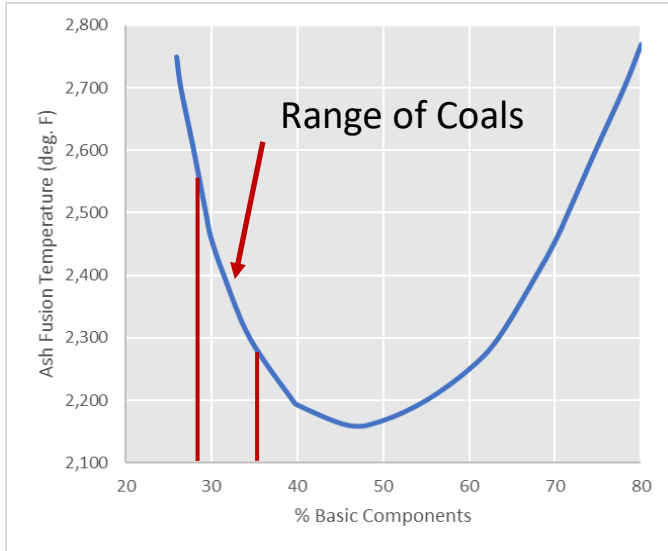


Fluid Temperature (FT)
Temperature at which the fused mass has spread out into a nearly flat layer with a maximum height of 1/16"

Not an exact test, but a useful guide



Bituminous Ash Slagging Index



- Bituminous Ash = $FE_2O_3 > CaO + MgO$
 - Slagging index – $R_s = B/A * S$
 - S = weight percentage of sulfur on a dry basis
 - B/A = Base/Acid Ratio
- $R_s < 0.6 = low$
 $0.6 < R_s < 2.0 = medium$
 $2.0 < R_s < 2.6 = high$
 $2.6 < R_s = severe$

Mineral Analysis of Ash	March 2022 Composite	April 2022 Composite	Feb 2022 Composite	March 2022 Composite	Feb 2022 Composite	March 2022 Composite	Jan-22	Feb-22	Mar-22	Apr-22	May-22
	Iron Senergy	Iron Senergy	ACNR	ACNR	ACNR	ACNR	ACNR				
	Cumberland	Cumberland	Ohio Co	Ohio Co	Marshall Co.	Marshall Co.	Marion County				
% Aluminum Oxide (Al ₂ O ₃)	23.14	23.30	16.95	18.88	19.34	19.94	19.71	19.24	21.96	21.86	21.31
% Silica Dioxide (SiO ₂)	44.84	42.54	46.10	43.94	43.63	42.23	48.45	47.76	45.35	45.46	44.23
% Titanium Dioxide (TiO ₂)	1.07	1.05	0.85	0.90	0.85	0.88	0.88	0.96	1.02	1.03	0.97
% Iron Oxide (Fe ₂ O ₃)	20.46	22.12	28.43	28.68	28.43	27.90	17.22	18.52	17.64	17.88	17.98
% Calcium Oxide (CaO)	3.71	3.52	2.91	2.49	2.91	3.39	5.98	5.47	5.12	5.21	5.55
% Sodium Oxide (Na ₂ O)	0.58	0.55	0.30	0.52	0.34	0.38	1.01	0.99	0.88	1.06	1.12
% Magnesium Oxide (MgO)	0.78	0.78	0.51	0.48	0.51	0.55	0.98	0.93	0.81	0.81	0.87
% Potassium Oxide (K ₂ O)	1.47	1.42	1.57	1.61	1.62	1.63	1.63	1.52	1.40	1.40	1.33
% Phosphorous Pentoxide (P ₂ O ₅)	0.24	0.28	0.12	0.04	0.05	0.08	0.50	0.49	0.12	0.11	0.11
% Sulfur Trioxide (SO ₃)	3.21	3.64	2.37	2.34	2.21	2.63	3.63	3.23	5.31	5.03	6.21
T ₂₅₀ (deg. F)	2,421	2,379	2,281	2,279	2,280	2,275	2,420	2,424	2,453	2,441	2,428
Acid Value	69.05	66.89	63.90	63.72	63.82	63.05	69.04	67.96	68.33	68.35	66.51
Base Value	27.00	28.39	33.72	33.78	33.81	33.85	26.82	27.43	25.85	26.36	26.85
Base/Acid Ratio	0.39	0.42	0.53	0.53	0.53	0.54	0.39	0.40	0.38	0.39	0.40
Slagging Index (B&W)	0.98	1.35	2.55	2.52	2.46	2.44	1.03	0.99	0.98	1.01	1.19
% Basic Components	28.11	29.80	34.54	34.65	34.63	34.93	27.98	28.76	27.45	27.83	28.76



Lignitic Ash Slagging Index



- Slagging Index:
$$R_S^* = \frac{(Max\ HT) + 4(Min\ IT)}{5}$$

- Index indicates the temperature range where plastic slag is likely to exist

- Max HT = higher of the reducing or oxidizing hemispherical temperature*

- Min IT = lower of the reducing or oxidizing initial deformation temperature*

$2450 < R_S^* = \text{Low}$
 $2250 < R_S^* < 2450 = \text{Medium}$
 $2100 < R_S^* < 2250 = \text{High}$
 $R_S^* < 2100 = \text{Severe}$

Ash Fusion Temperatures										
<u>Reducing (F)</u>	Antelope	Alpha West	Black Thunder East	Black Thunder North	Black Thunder West	Buckskin	Coal Creek	Cordero	Caballo	Narm
Initial	2,160	2,160	2,132	2,141	2,150	2,221	2,109	2,145	2,135	2,150
Softening (H=W)	2,180	2,171	2,162	2,163	2,181	2,238	2,127	2,165	2,145	2,165
Hemispherical (H=1/2W)	2,190	2,179	2,175	2,171	2,195	2,243	2,137	2,175	2,155	2,175
Fluid	2,220	2,191	2,211	2,204	2,228	2,263	2,171	2,205	2,200	2,205
<u>Oxidizing (F)</u>	Antelope	Alpha West	Black Thunder East	Black Thunder North	Black Thunder West	Buckskin	Coal Creek	Cordero	Caballo	Narm
Initial	2,220	2,196	2,218	2,214	2,234	2,268	2,176	2,205	2,180	2,190
Softening (H=W)	2,235	2,204	2,230	2,233	2,247	2,286	2,189	2,220	2,185	2,200
Hemispherical (H=1/2W)	2,250	2,212	2,240	2,244	2,260	2,302	2,203	2,230	2,195	2,210
Fluid	2,280	2,223	2,312	2,312	2,329	2,348	2,278	2,260	2,230	2,255
Slagging Index (R_S^*)	2,178	2,170	2,154	2,162	2,172	2,237	2,128	2,162	2,147	2,162

High Slagging Index for Each of These Coals!!

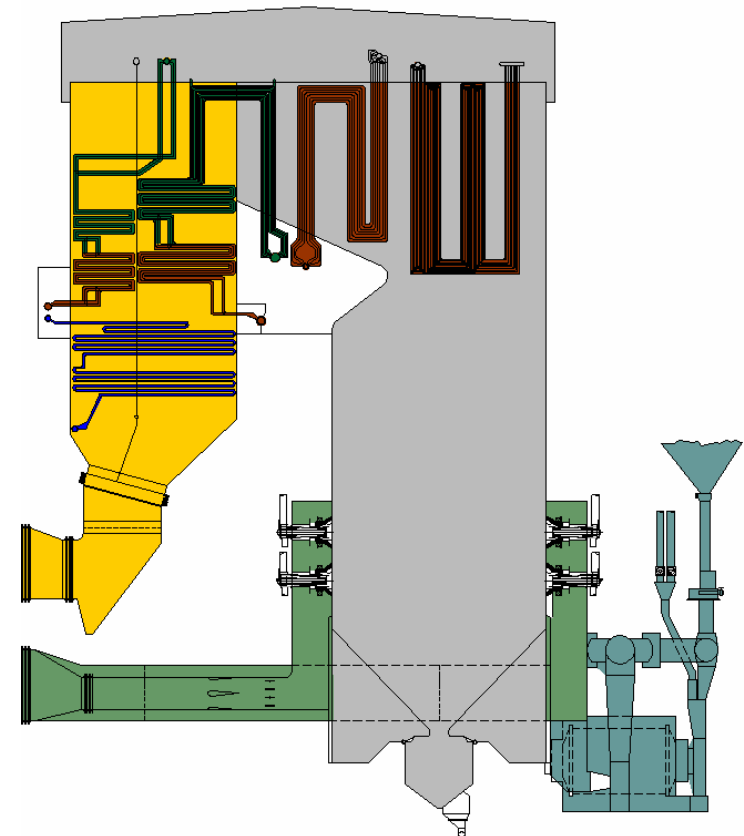


Results of Fouling



- Increased Boiler Exit Temperatures
- Reduced Boiler Efficiency
- Higher Firing Rate
- Derates
- SCR Catalyst Temperature Limits

For every 35°F change in corrected gas outlet temperature there is an approximately 1% impact on boiler efficiency





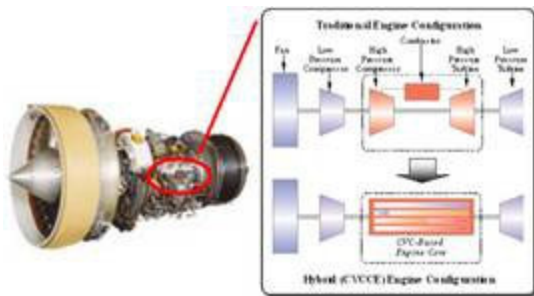
IMPULSE[®] Cleaning Technology Overview

Background of the Technology



In 2004 GE Energy began the initiative to integrate GE Aviation's pulse detonation propulsion technology with GE's PowerWave acoustic cleaning product line to create a much more powerful and effective on-line boiler cleaning technology. The system detonates a mixture of fuel and air in a highly engineered combustion tube to produce a rapid series of powerful supersonic shock waves.

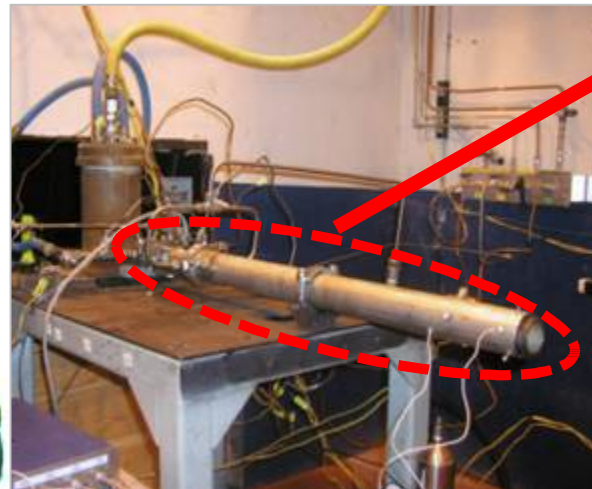
The system was introduced to the market by GE in 2006 as the PowerWave+



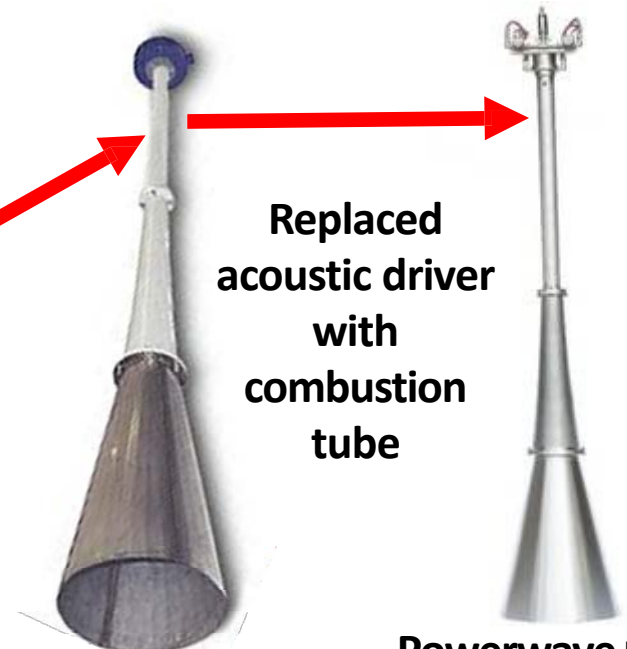
Pulse detonation engine with a series of combustion tubes



2" Combustion Tube Bench Test



Powerwave 75 hz Acoustic Horn



Replaced acoustic driver with combustion tube

Powerwave+ Pulse Detonation Cleaner



Experience



The IMPULSE cleaner was introduced to the market in 2006.

We have successful experience on the following applications:

- Coal Fired Boilers
- Pet Coke Fired Boilers
- Waste to Energy Boilers
- Wood Fired Boilers
- Industrial Heat Recovery (Reformers, Oxidizers, Recuperators, Calciners, etc.)
- Heat Recovery Steam Generators(HRSGs)



How It Works

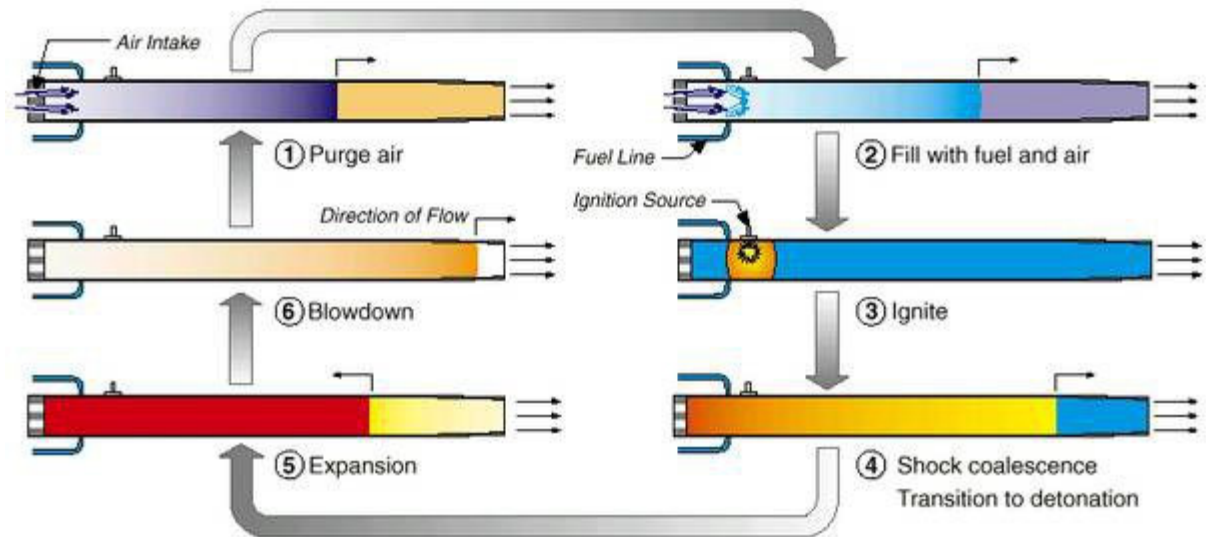


Formation of an impulse or shockwave

1. Cyclic combustion event creates supersonic impulses
2. Injection of fuel and air into an integral mixing chamber followed by ignition and combustion
3. Shockwave is result of the acceleration of a flame to supersonic speeds over short distance and time



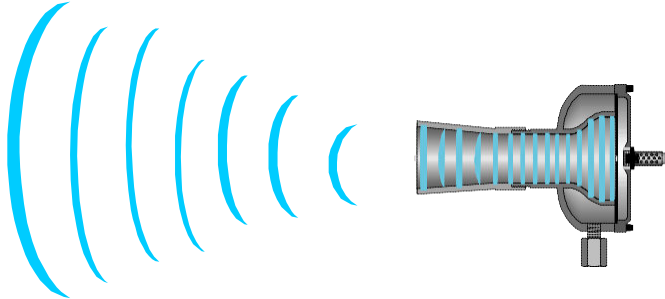
Combustion Chamber Mixing Head



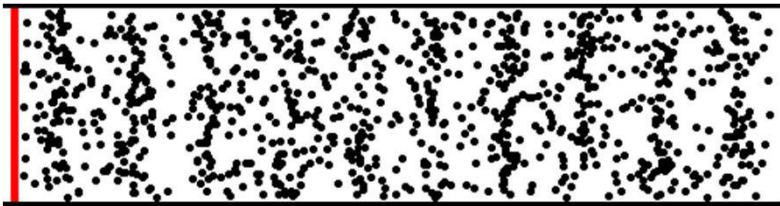
How It Works



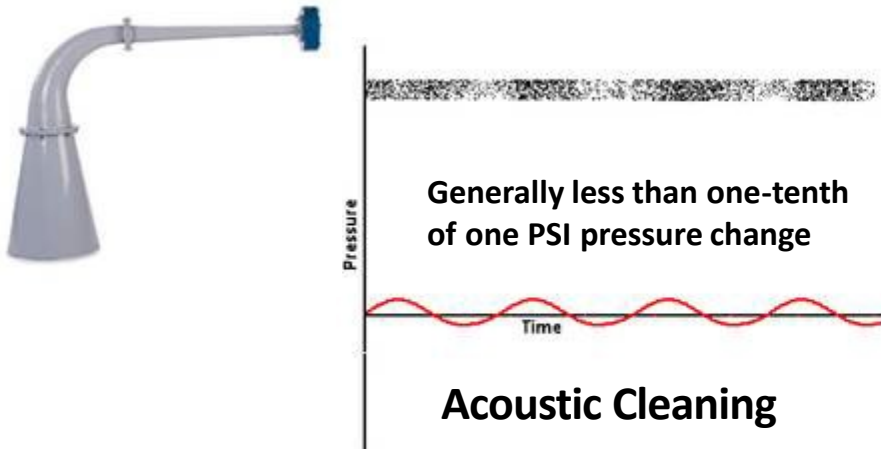
Cleaning with Sound



Acoustic cleaners utilize sound waves to create particle displacement in order to resonate and dislodge particulate deposits.



Particle displacement



vs

Pulse Detonation

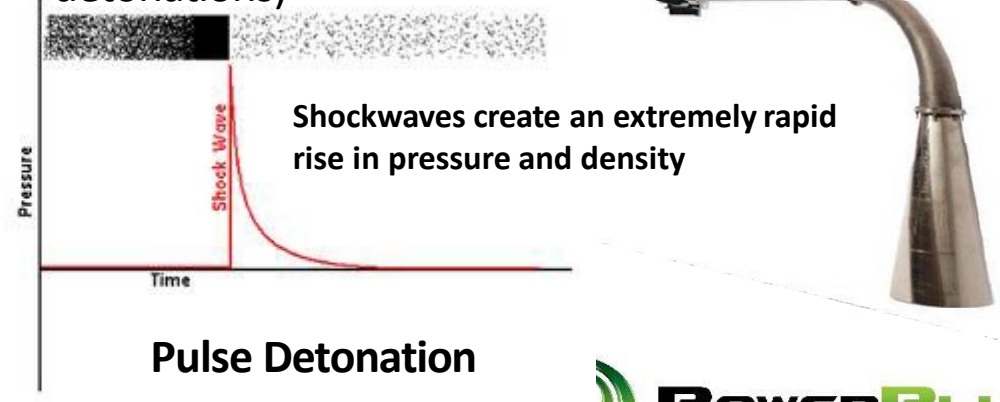
A shock wave is characterized by a sharp increase in pressure and temperature across a boundary.

They are orders of magnitude more intense than sound waves

The resulting shockwaves provide a large amount of cleaning energy

The instantaneous rise and drop in pressure excites the deposits

A typical cleaning cycle would consist of 2 detonations per second, for 10 seconds (20 detonations)



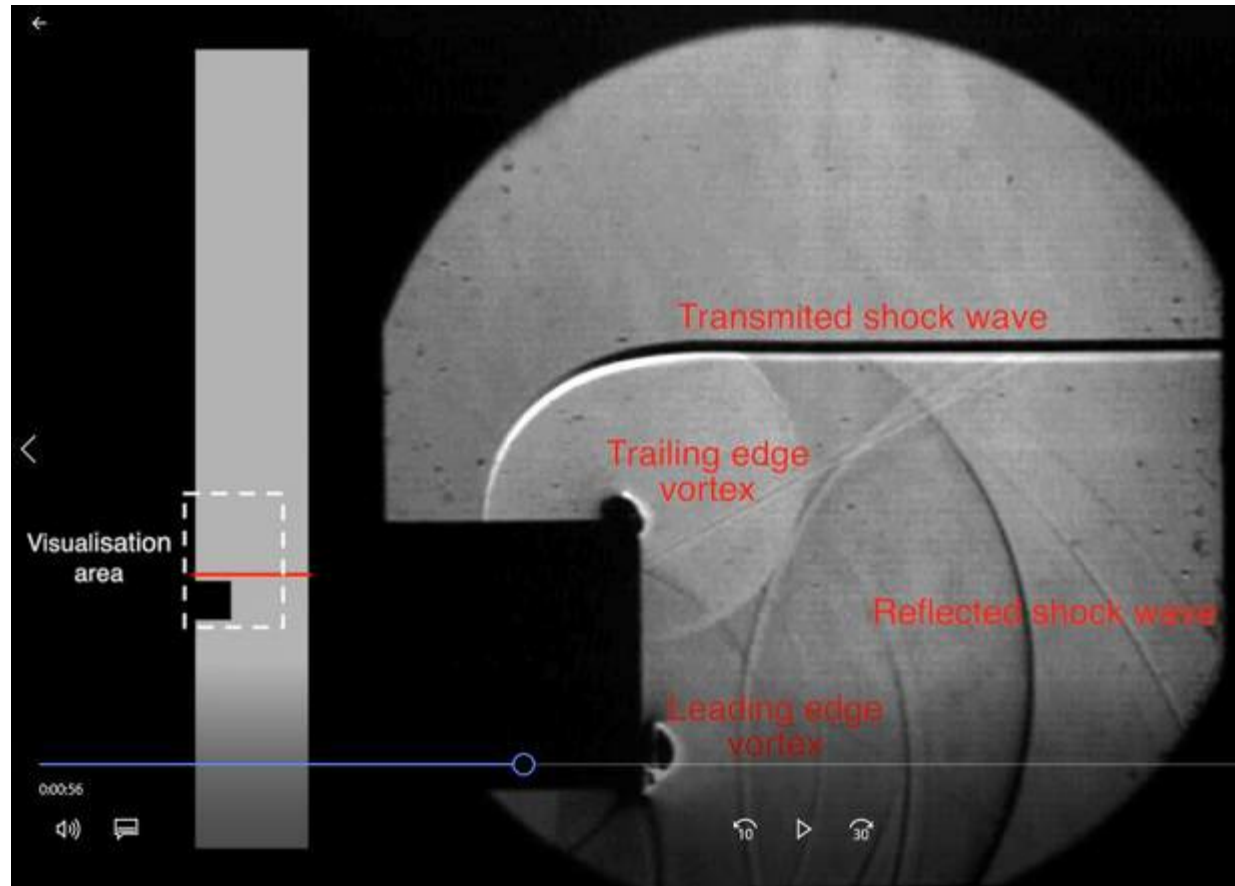
How It Works



Cleaning energy consists of compression and rarefaction waves with omni-directional vectors.

When a detonation occurs in the combustion tube, a shockwave is generated, characterized by a sharp rise in pressure and a tremendous amount of reversing airflow with it.

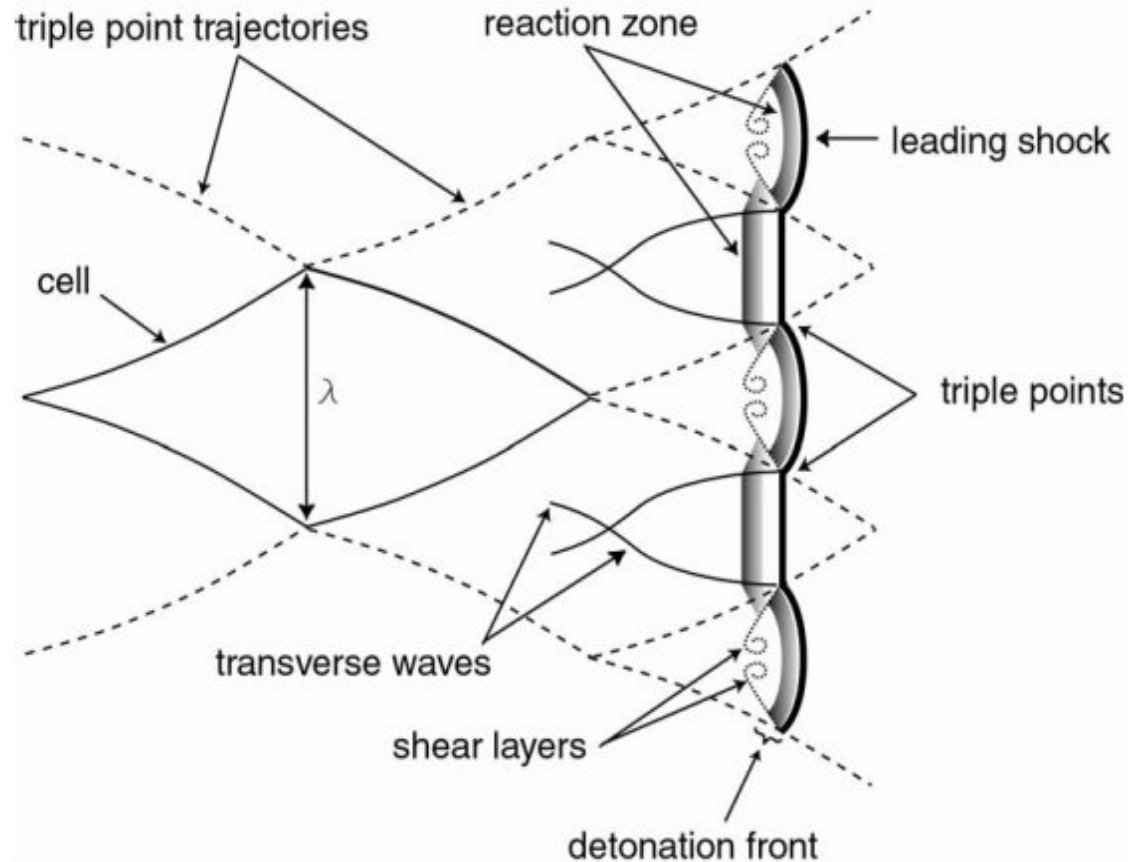
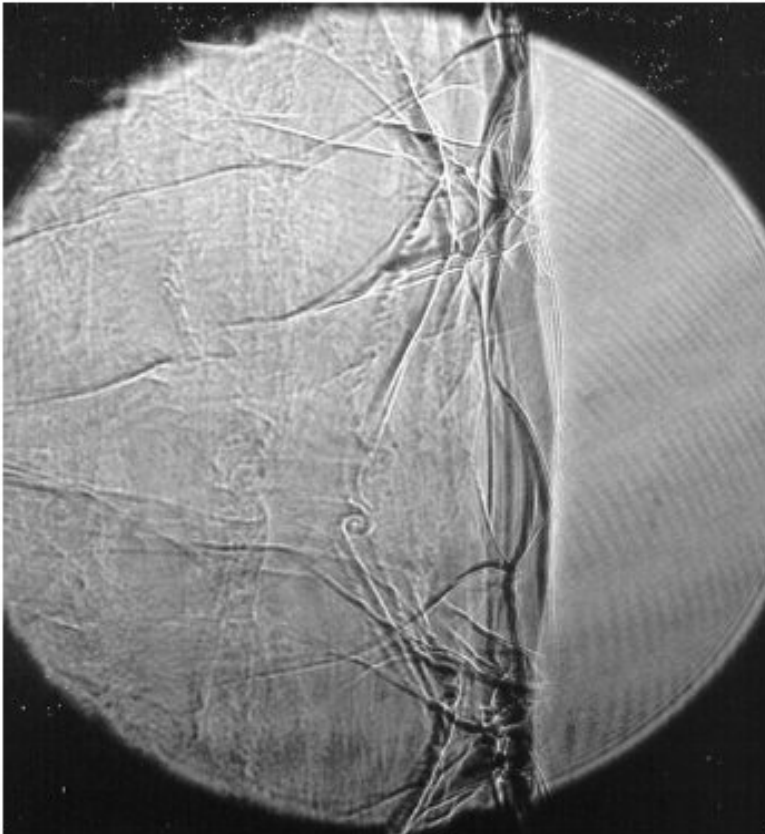
The IMPULSE Cleaner creates high velocities combined with a high-density front, and ultra- low pressures behind the shock, create an infinite amount of multi-directional high/low pressure vectors that serve as extremely effective cleaning energy.





Cleaning Wave Structure

Cleaning energy consists of compression and rarefaction waves with omni-directional vectors.



Benefits of the IMPULSE Cleaning System



- Provides effective cleaning without erosion or damage to the heat transfer surfaces.
- The shockwaves are encompassing and penetrate deeper into the tube bundle than the traditional sootblower “line of sight” cleaning.
- Orders of magnitude more powerful and effective than traditional acoustic cleaning systems.
- No costly repair, maintenance or operational costs.
- Does not scavenge steam/Reduces steam use (cost of steam).
- The IMPULSE cleaner can improve heat transfer efficiency, reduce operational and maintenance costs, and minimize or eliminate costly unplanned outages.
- Minimal intrusion into and out of boiler, has minimal installation footprint and minimal installation costs.





IMPULSE Cleaning System Specifications



Specifications - System Consists of:



Electrical	110/220 VAC
Fuel	Ethylene gas (C2H4)
Fuel consumption	Based on operation
Impulse/cycle	20 bursts (typical)
Cycle frequency	Every 30 min. to 1 hour
Oxidizer	Plant Air
Air Consumption	100-120 SCFM @ 70-90 PSI
Material	Stainless steel



Combustion Assembly



Fuel Rack



Control System



POWERPLUS
CLEANING SYSTEMS

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System Specifications



The IMPULSE Cleaner is constructed from 3 separate pieces that are bolted together in the field.

The “A”-section, also referred to as the combustion chamber, is fabricated from stainless steel and is about 48” long and two-inches in diameter.

The “B”-section is a casting that diverges from two-inches out to approximately 6 inches in diameter over an axial length of 30 inches. There are 2 options: a straight or curved version. The curved section has a 90-degree bend in it, which allows for a slim mounting profile.

The “C”-section diverges from 6” out to 10-16” inches over the length and is typically partially located inside the boiler.



Mixing Head





Experience Cleaning Many Different Applications



Coal Fired Boiler



Before



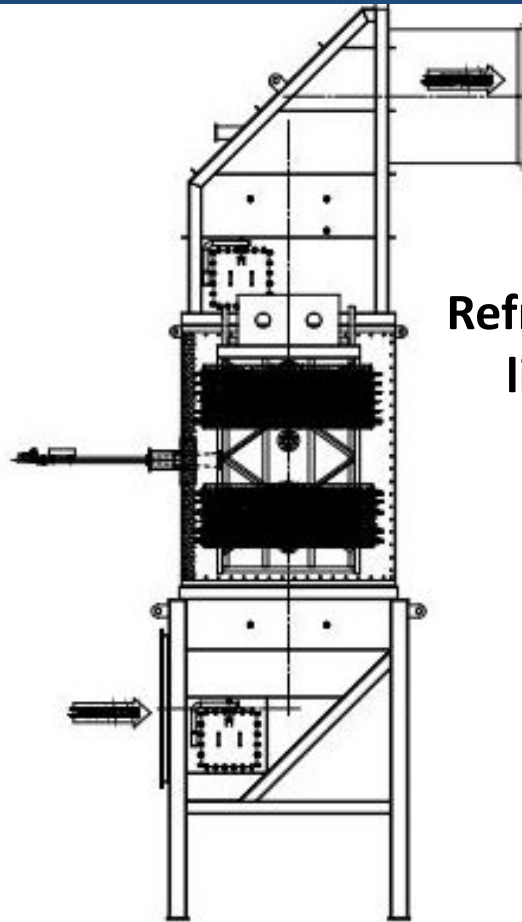
After



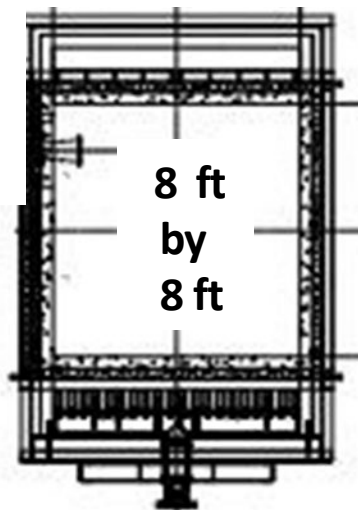
Small Package Boilers



Thermal Reformer



Refractory lined



8 ft
by
8 ft





Case Histories

Documented Results



Pet Coke-Coal Fired CFB Boiler



Note:

Boiler had been cleaned with Det-Cord prior to installing and commissioning the IMPULSE cleaner.



Pet Coke-Coal Fired CFB Boiler



Results

The IMPULSE cleaning systems were installed on the Unit 2 boiler in December of 2020.

On July 26, 2021, the customer reported that the Unit 2 boiler with our IMPULSE cleaning system installed had realized a 2.5% improvement in heat rate.

Further commenting that the Unit 2 boiler was burning much less fuel to produce the same output as the Unit 1 boiler, stating that the Unit 2 boiler was \$1.07 per MW cheaper to run than the Unit 1 boiler.

The only difference that they could see between the two boilers is the use of our IMPULSE cleaning system.

Subsequently the facility purchased an additional 14 IMPULSE cleaners in 2022 for their Unit 1 boiler.

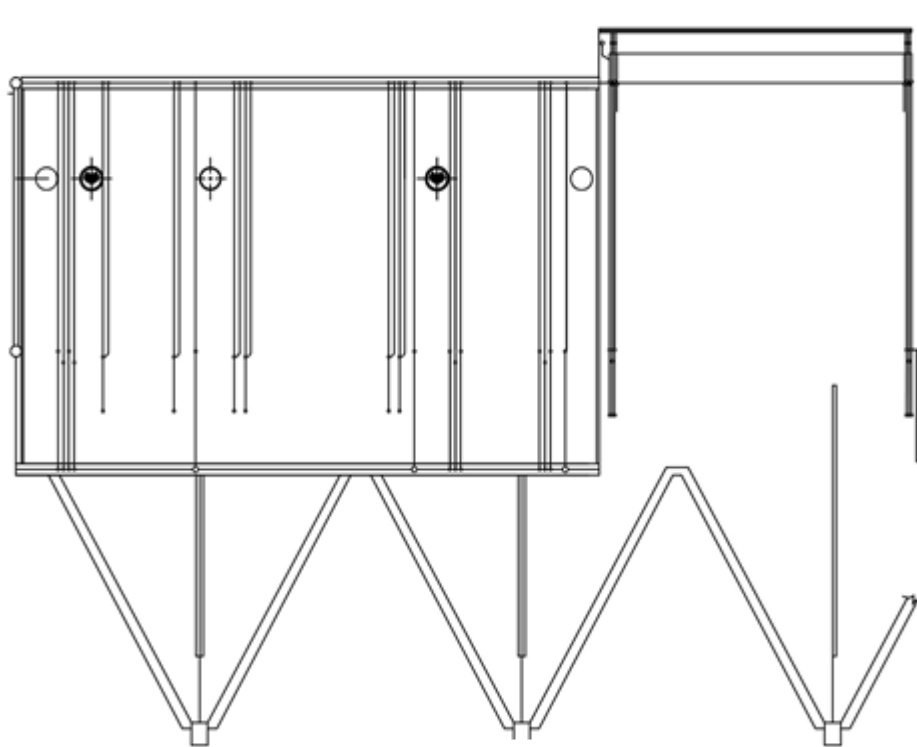


Waste to Energy Boiler

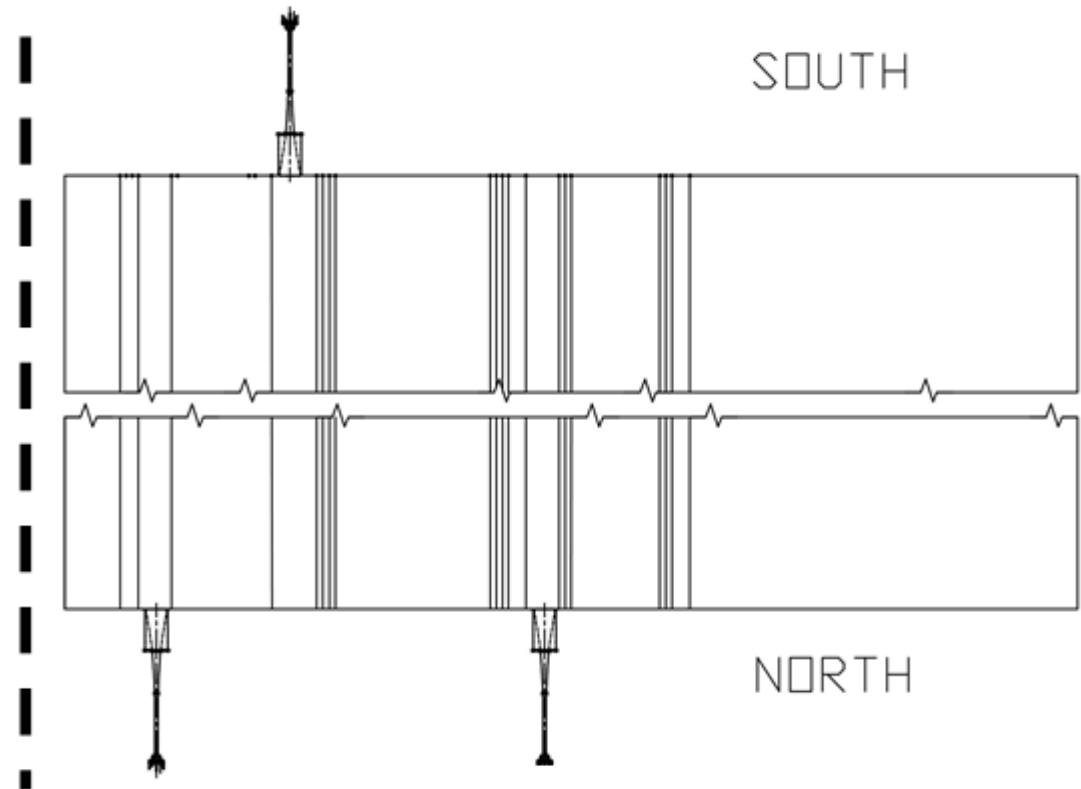


DESCRIPTION OF INSTALLATION

A total of three (3) IMPULSE cleaners installed on a Waste to Energy boiler at a large midwestern facility; two (2) IMPULSE cleaners installed on North side of the boiler, and one (1) IMPULSE cleaner installed on the South side of the boiler. The first cleaner on the North is located in the Secondary Superheat and most problematic area of the boiler, the second cleaner is on the South and is located in the Primary Superheat, the third and last cleaner is on the North side located in the Evap 2 section of the boiler.



Elevation View



Plan View



Waste to Energy Boiler



IMPULSE cleaners Installed on North Side of Boiler

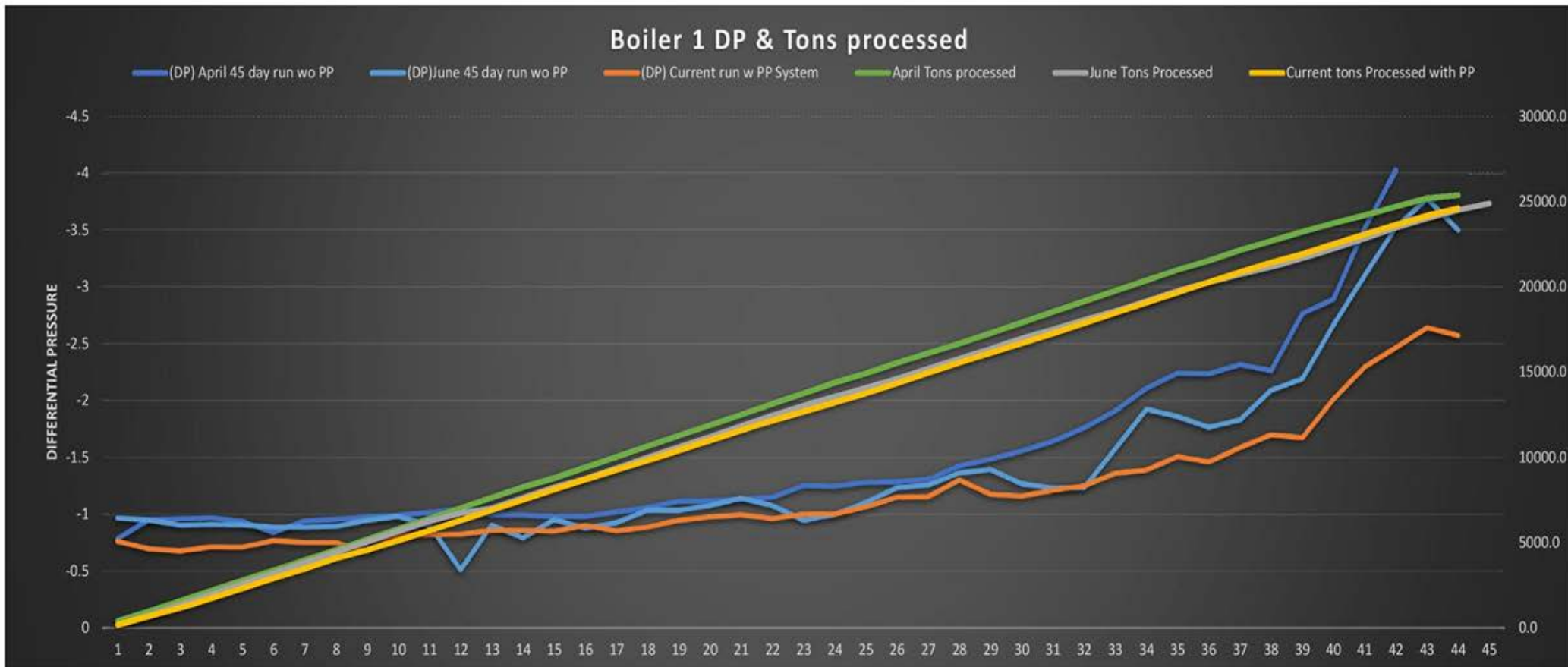


Waste to Energy Boiler



COMPARATIVE RESULTS

Typical differential pressure prior to the installation of the IMPULSE cleaners after only 45 days of operation averaged 3.5 to 4". Differential pressure following the installation of the IMPULSE cleaners after 45 days of operation reduced to 2.5".



Waste to Energy Boiler



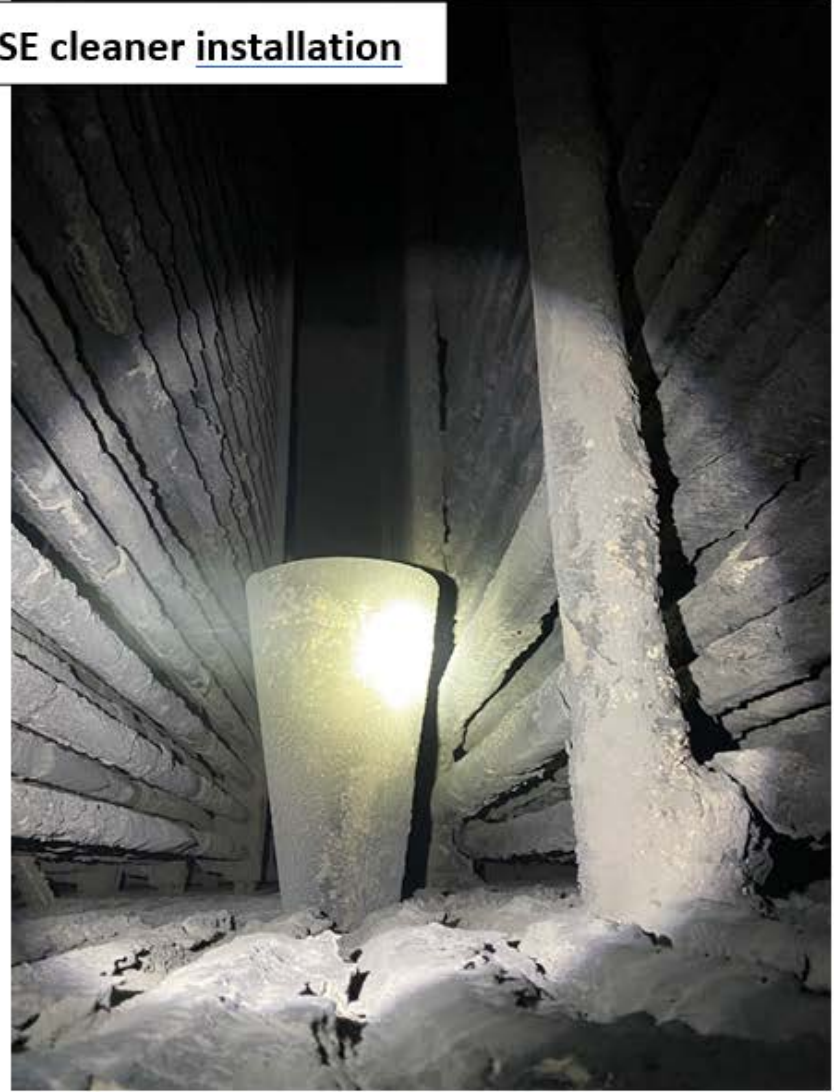
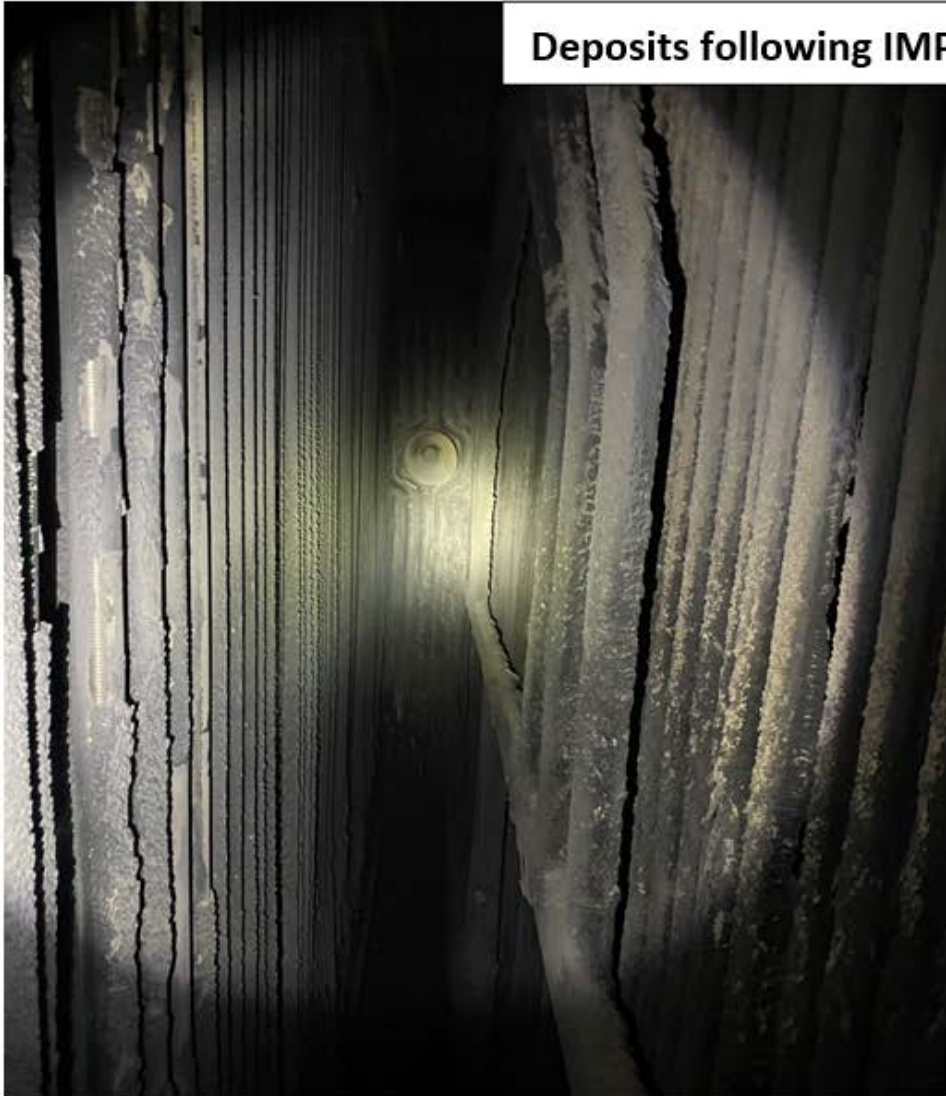
Deposits before IMPULSE cleaner installation



Waste to Energy Boiler



Deposits following IMPULSE cleaner installation



Biomass Poultry Litter Boiler



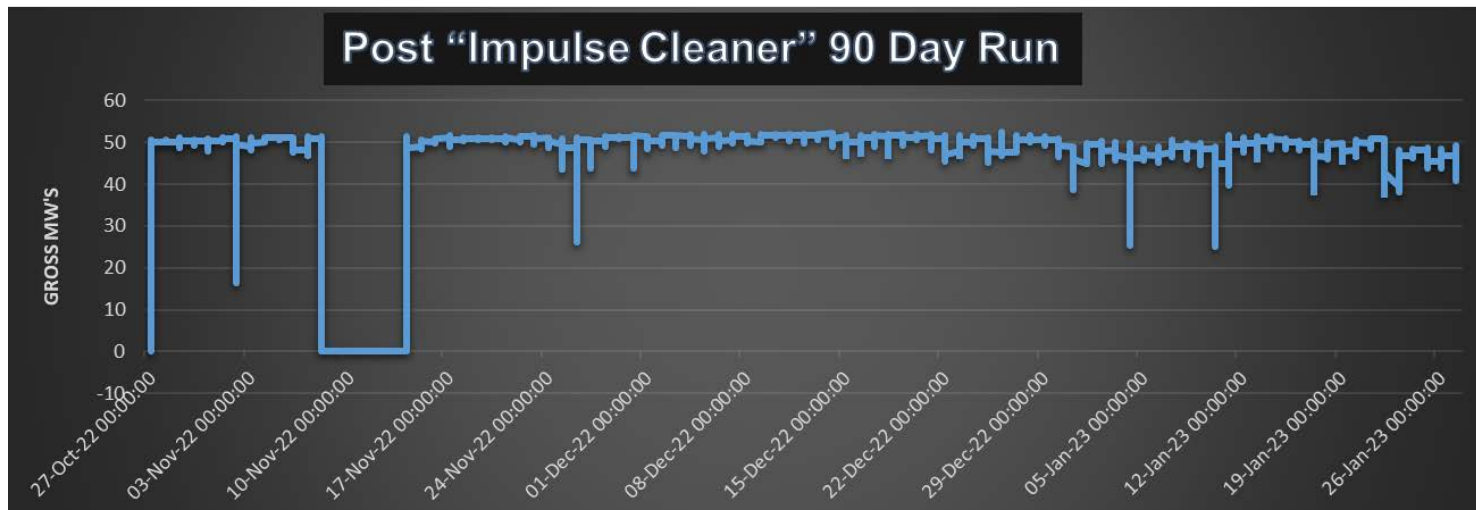
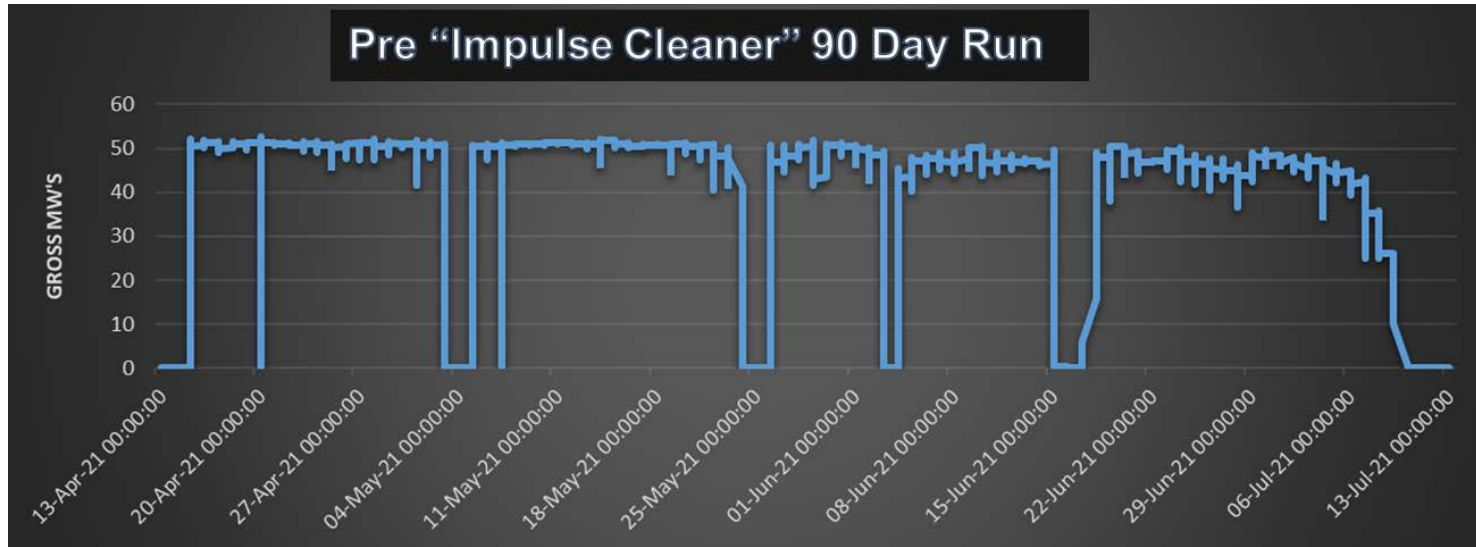
High Fouling fuel



Biomass Boiler



Before Installation: Forced Outages to clean 7 times in 90 days

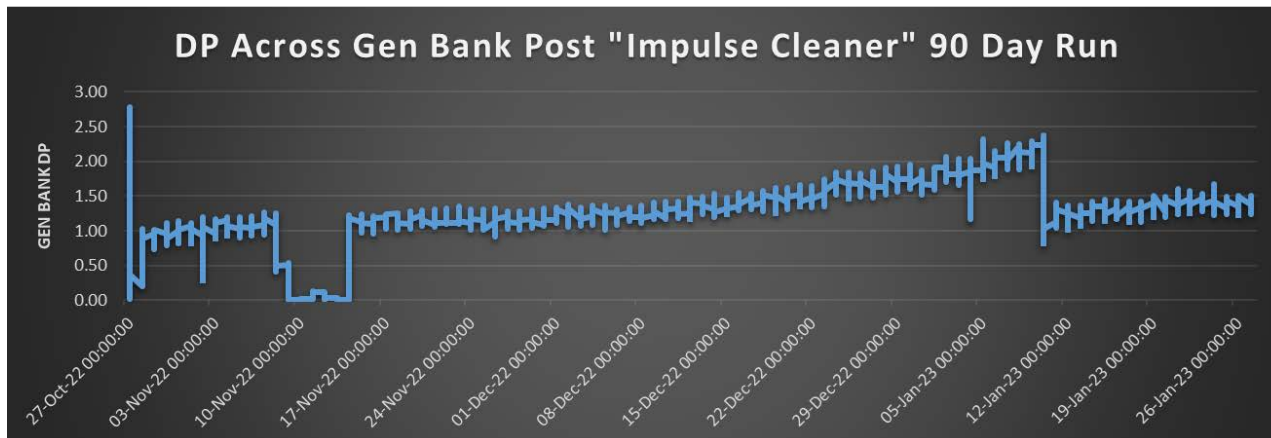
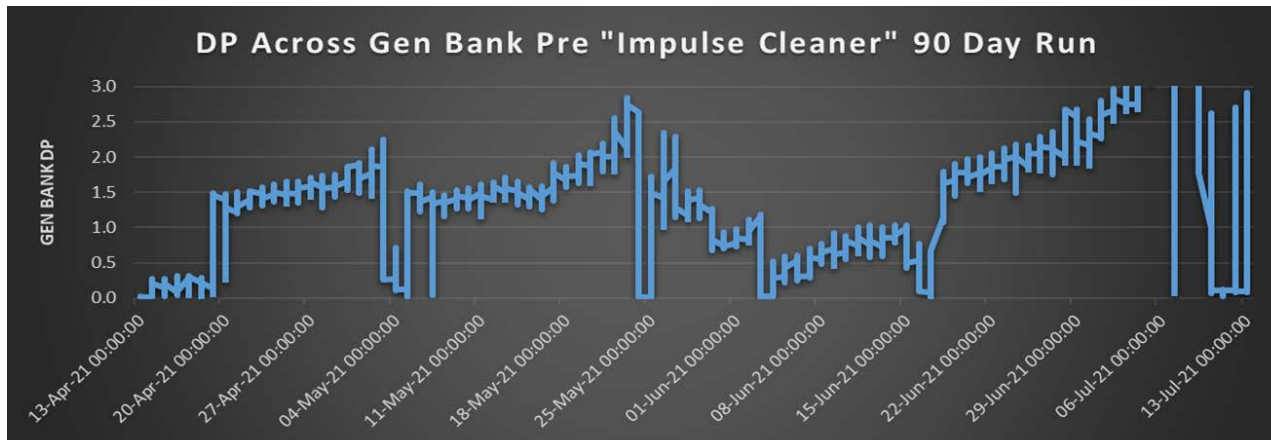


Biomass Boiler



Economizer Gas Outlet Temperature Reduced 20°F

Generating Bank after 90+ days of operation



IMPULSE® Cleaning System Summary



- Intense shockwaves are utilized to proactively dislodge fly ash without damage to equipment
- Can replace, augment, or significantly reduce soot blowing
- Much lower operational and maintenance costs
- Can dramatically increase heat transfer efficiency and minimize unplanned outages
- Minimal installation footprint



Questions



POWERPLUS
CLEANING SYSTEMS