Western Regional Boiler Association

MACT Solution Synergies:

How Improving Combustion Can Reduce MACT APC Footprint, Investment and Operating Cost

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BACKGROUND

Project Goal: Begin with the End in Mind

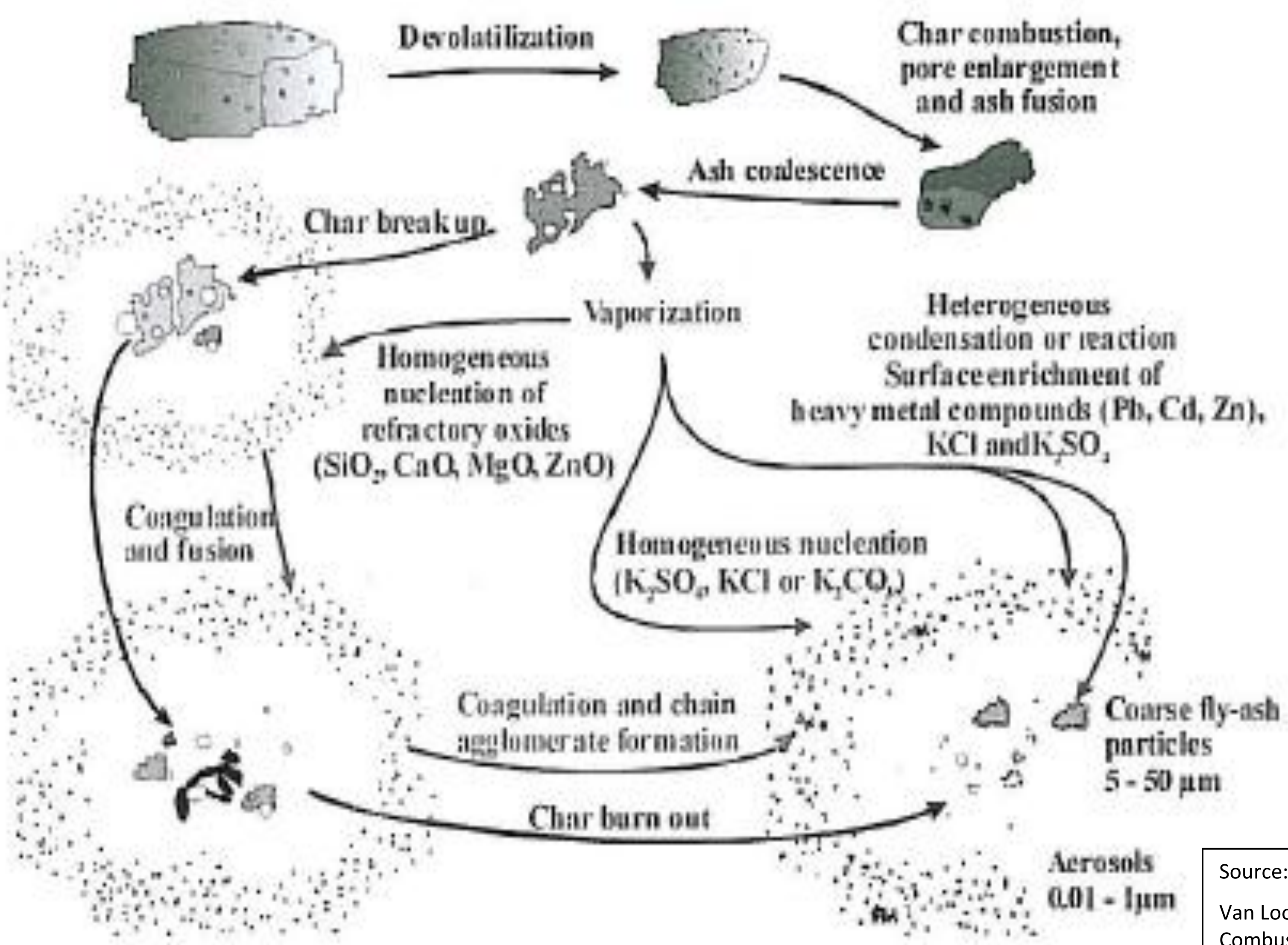
Boiler MACT Facts: Emission Limits, Existing Units, Solid Fuels

Source: Federal Register, Vol. 78, No. 21, Dated January 31, 2013; Part V, EPA 40 CFR Part 63
Data provided is for information purposes only. The rule shall be the governing authority.

Subcategory	PM (Input) [lb/MMBtu]	PM (Output) [lb/MMBtu]	TSM (Input) [lb/MMBtu]	TSM (Output) [lb/MMBtu]	HCl (Input) [lb/MMBtu]	HCl (Output) [lb/MMBtu]	Hg (Input) [lb/MMBtu]	Hg (Output) [lb/MMBtu]	CO (Input) 3 Run Avg. [ppm@3%O2, dry]	CO CEMS (Input) 30 Day Avg. [a] [ppm@3%O2, dry]	CO (Output) 3 Run Avg. [lb/MMBtu]
Coal Stoker	0.040	0.042	5.30E-05	5.60E-05	0.022	0.025	5.70E-06	6.40E-06	160	340	0.14
Pulverized Coal	0.040	0.042	5.30E-05	5.60E-05	0.022	0.025	5.70E-06	6.40E-06	130	320	0.11
Coal Fluid Bed	0.040	0.042	5.30E-05	5.60E-05	0.022	0.025	5.70E-06	6.40E-06	130	230	0.12
Coal Fluid Bed w/FB Heat X	0.040	0.042	5.30E-05	5.60E-05	0.022	0.025	5.70E-06	6.40E-06	140	150	0.13
Biomass Wet Stoker/ Sloped Grate/ Other	0.037	0.043	2.40E-04	2.80E-04	0.022	0.025	5.70E-06	6.40E-06	1,500	720	1.40
Biomass Kiln-Dried Stoker/ Sloped Grate/ Other	0.320	0.370	4.00E-03	4.60E-03	0.022	0.025	5.70E-06	6.40E-06	460	ND	0.42
Biomass Fluid Bed	0.110	0.140	1.20E-03	1.50E-03	0.022	0.025	5.70E-06	6.40E-06	470	310	0.46
Biomass Suspension Burner	0.051	0.052	6.50E-03	6.60E-03	0.022	0.025	5.70E-06	6.40E-06	2,400	2,000 [b]	1.90
Biomass Dutch Oven/ Pile Burner	0.280	0.390	2.00E-03	2.80E-03	0.022	0.025	5.70E-06	6.40E-06	770	520 [b]	0.84
Biomass Fuel Cell	0.020	0.055	5.80E-03	1.60E-02	0.022	0.025	5.70E-06	6.40E-06	1,100	ND	2.40
Biomass Hybrid Susp Grate	0.440	0.550	4.50E-04	5.70E-04	0.022	0.025	5.70E-06	6.40E-06	2,800	900	2.80

- (Input) = Heat input basis
- (Output) = Steam output basis
- (a) = 30 day rolling average, except as noted
- (b) = 10 day rolling average

Biomass Combustion – Ash formation



Source:

Van Loo, The Handbook of Biomass Combustion & Co-firing

Combustion Products: Gases and Gas Pollutants

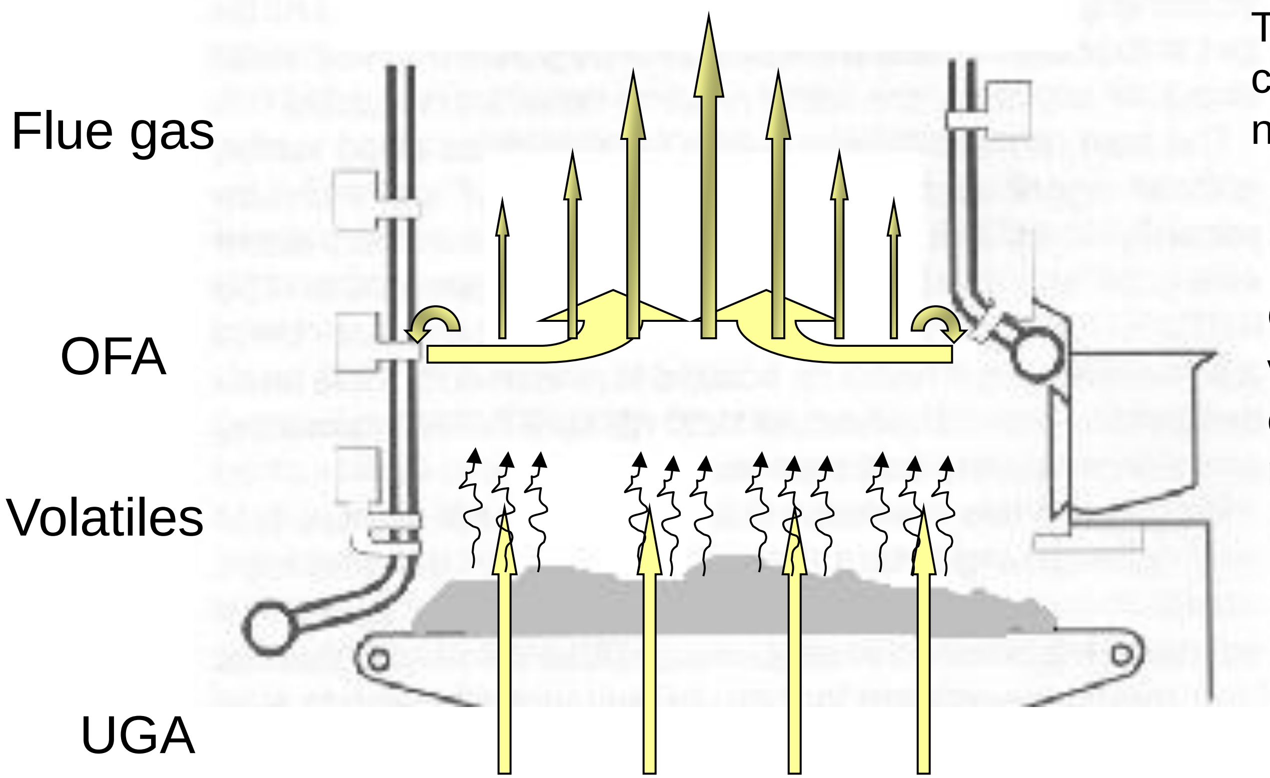
- Combustion products of standard fossil fuels and biomass in commercial and industrial boilers produce the following main gases:
  - carbon dioxide (CO_2)
  - nitrogen (N_2)
  - oxygen (O_2)
  - water (H_2O)
  - carbon monoxide (CO)
  - nitrogen oxides (NO and NO_2 called NOx, N_2O)
  - sulfur oxides (SOx: SO_2, SO_3)
  - volatile organic compounds (VOC) and hydrocarbons (HC)
- CO, NOx (NO+NO_2), N_2O, SOx (SO_2, SO_3) and VOC's and HC's are considered pollutants
- The primary greenhouse gases in the Earth's atmosphere are water vapor, CO_2, methane, nitrous oxide and ozone.

In-Furnace Emission Control Techniques

- Reducing CO/NOx emission formation in-furnace requires the proper burner/boiler design and a delicate balance of operating conditions
  - ➔ Grate/Burner:
    - Design for Low NOx Modifications
    - Optimize operation to control emissions
  - ➔ Combustion Tempering:
    - Water/Steam Injection
    - Near burner zone water wall cleaning
  - ➔ Flue Gas Recirculation
  - ➔ Air staging: Overfire Air
  - ➔ Fuel staging: Reburning
  - ➔ Oxygen use: Oxy Fuel

STACKED AIR SYSTEM

Conventional Overfire Air System



The result is a central column with no lateral motion

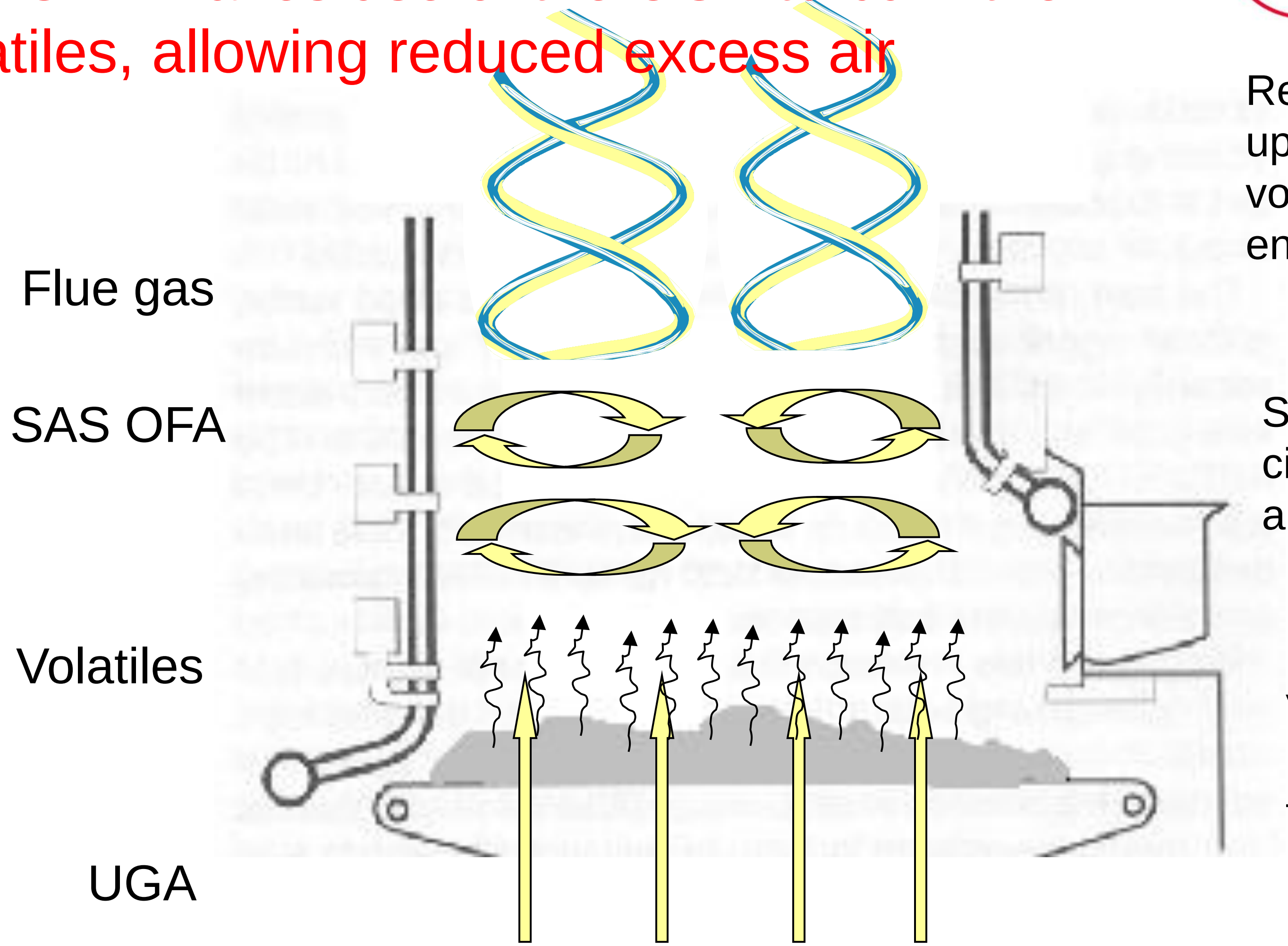
OFA pushes air & volatiles to the centre, but does not mix them well

Volatiles and UGA parallel flow, little mixing as they rise

With such an air system, neither the UGA or OFA is effectively utilized, necessitating more excess air

CBAM Stacked Air System

The OFA makes use of the UGA to burn the volatiles, allowing reduced excess air

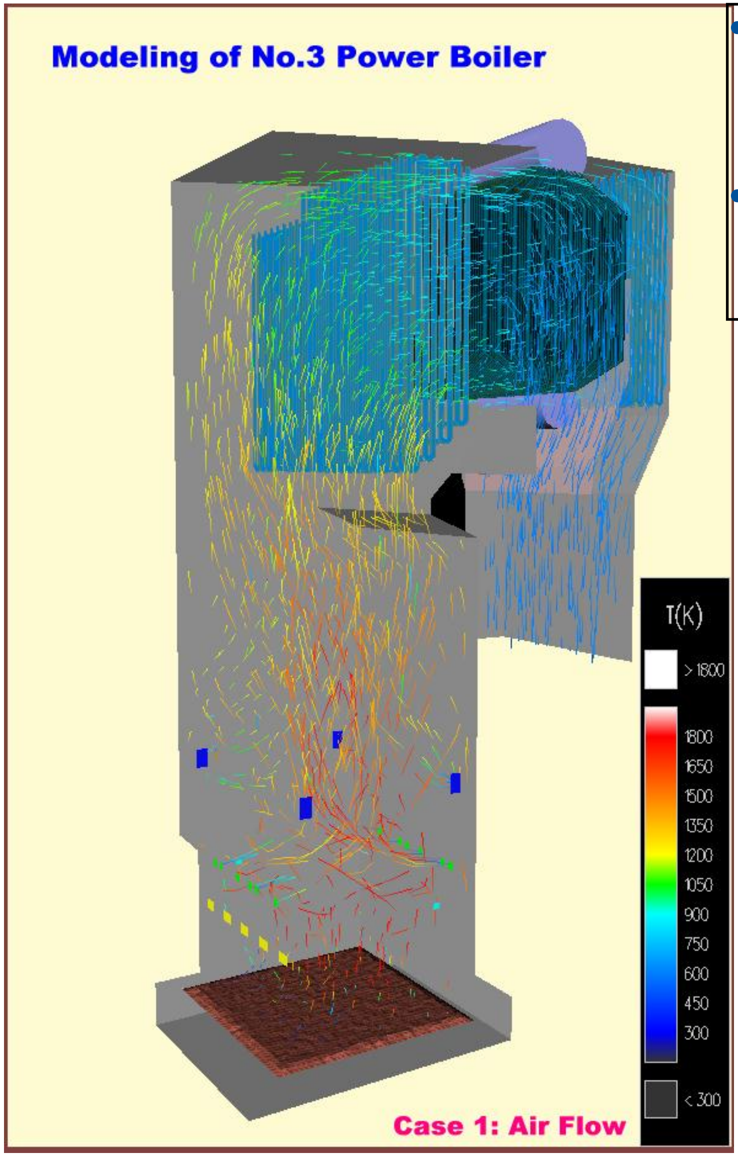


Resulting in two upwardly spiraling vortices, utilizing entire furnace area

SAS entrains and circulates rising air and volatiles

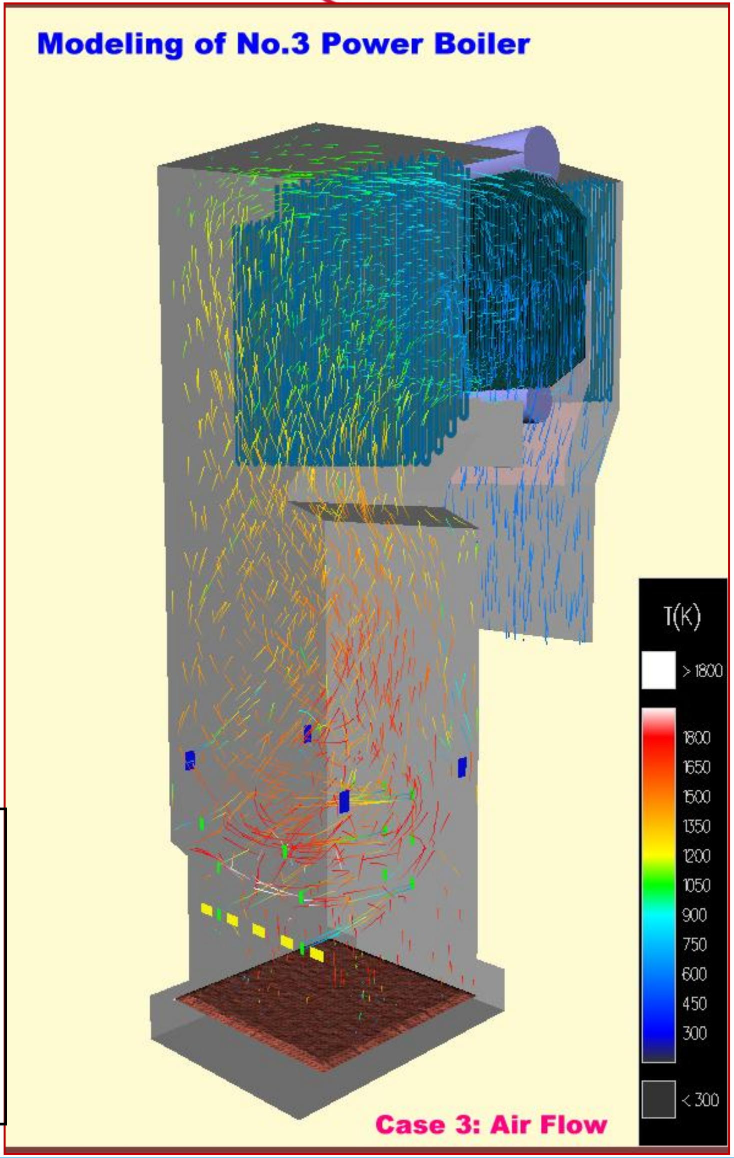
Volatiles and UGA parallel flow, little mixing

Case Study – Interlaced vs SAS

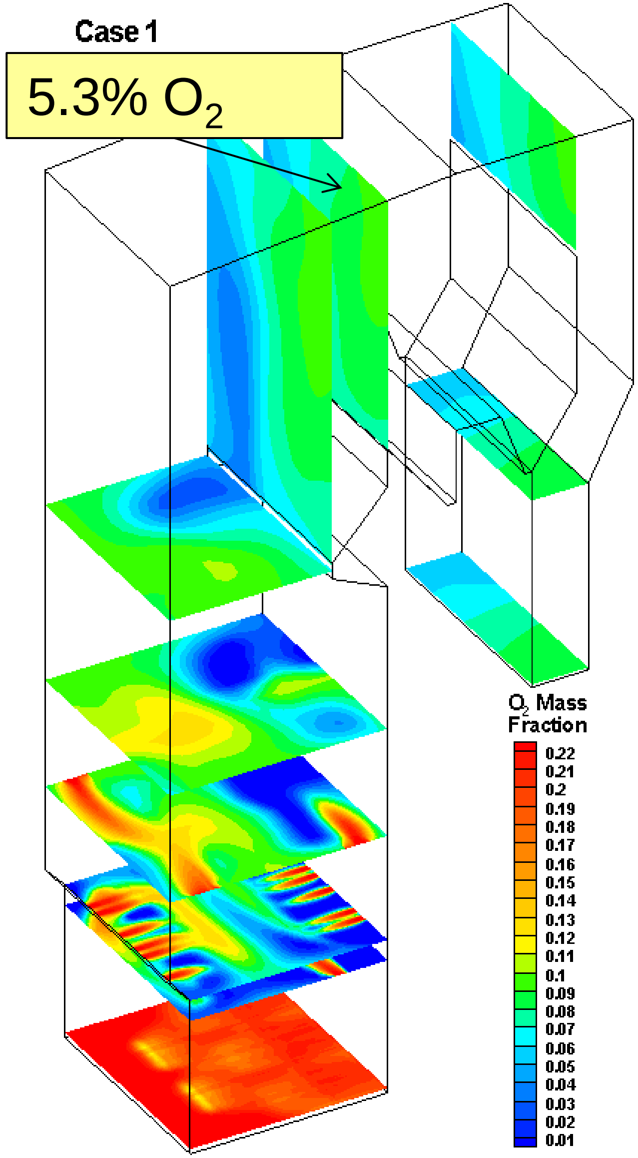


- Air goes straight up central chimney
- Rapidly carried up and out of the combustion zone

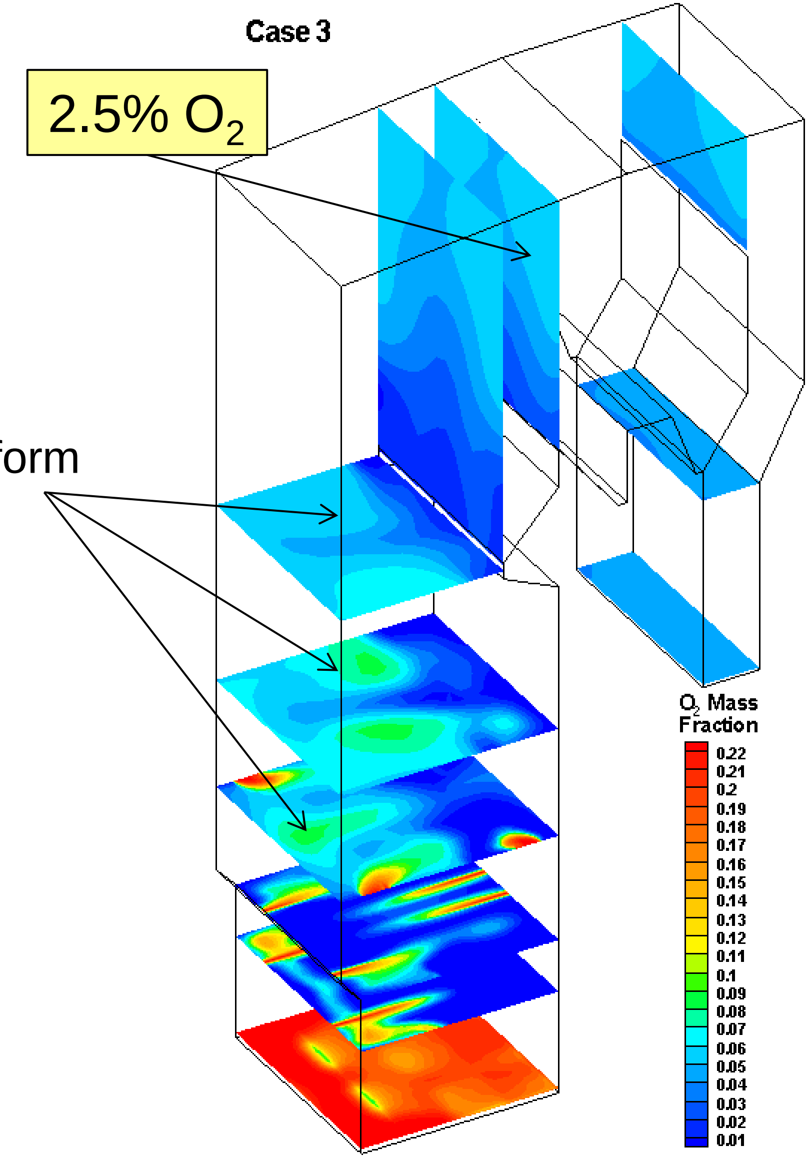
- Air swirls around, utilizing all of furnace volume
- Longer residence time in the furnace



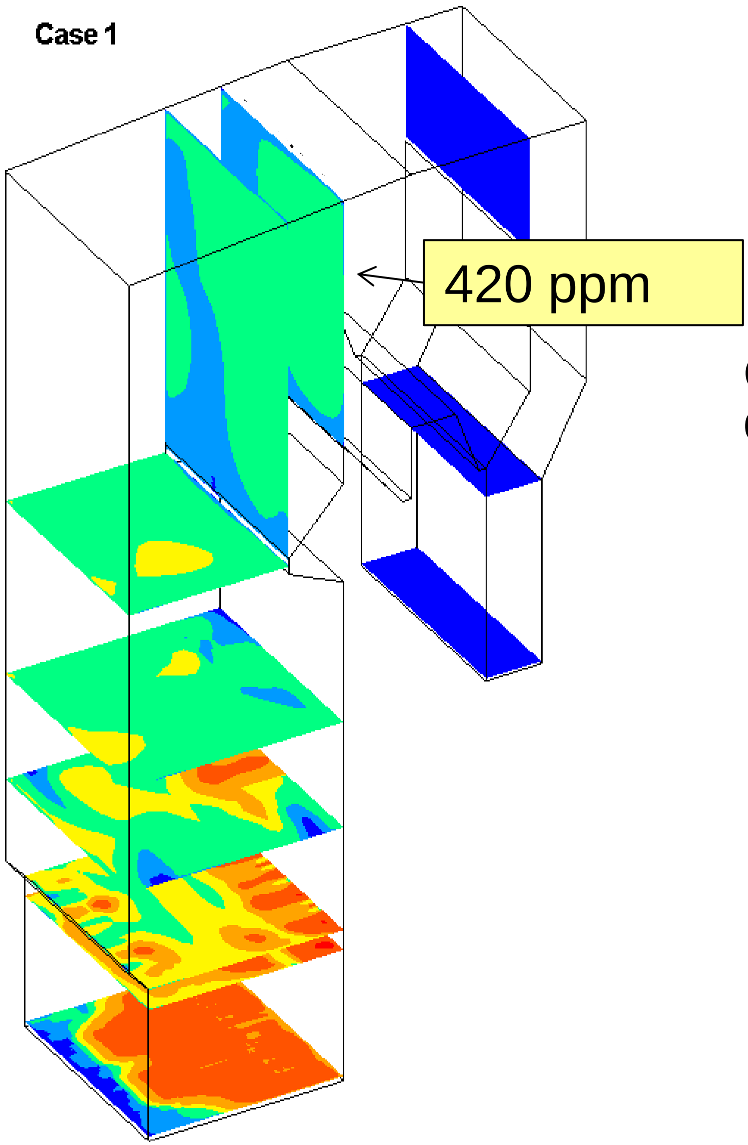
SAS Reduces Excess O2



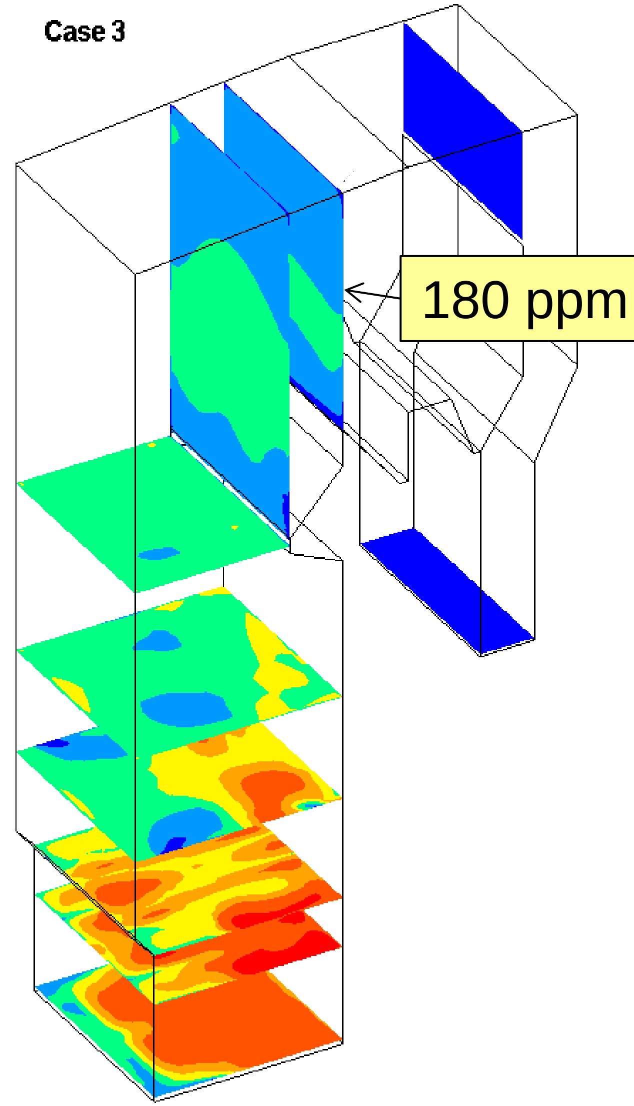
- O2 is lower at each level, also more uniform



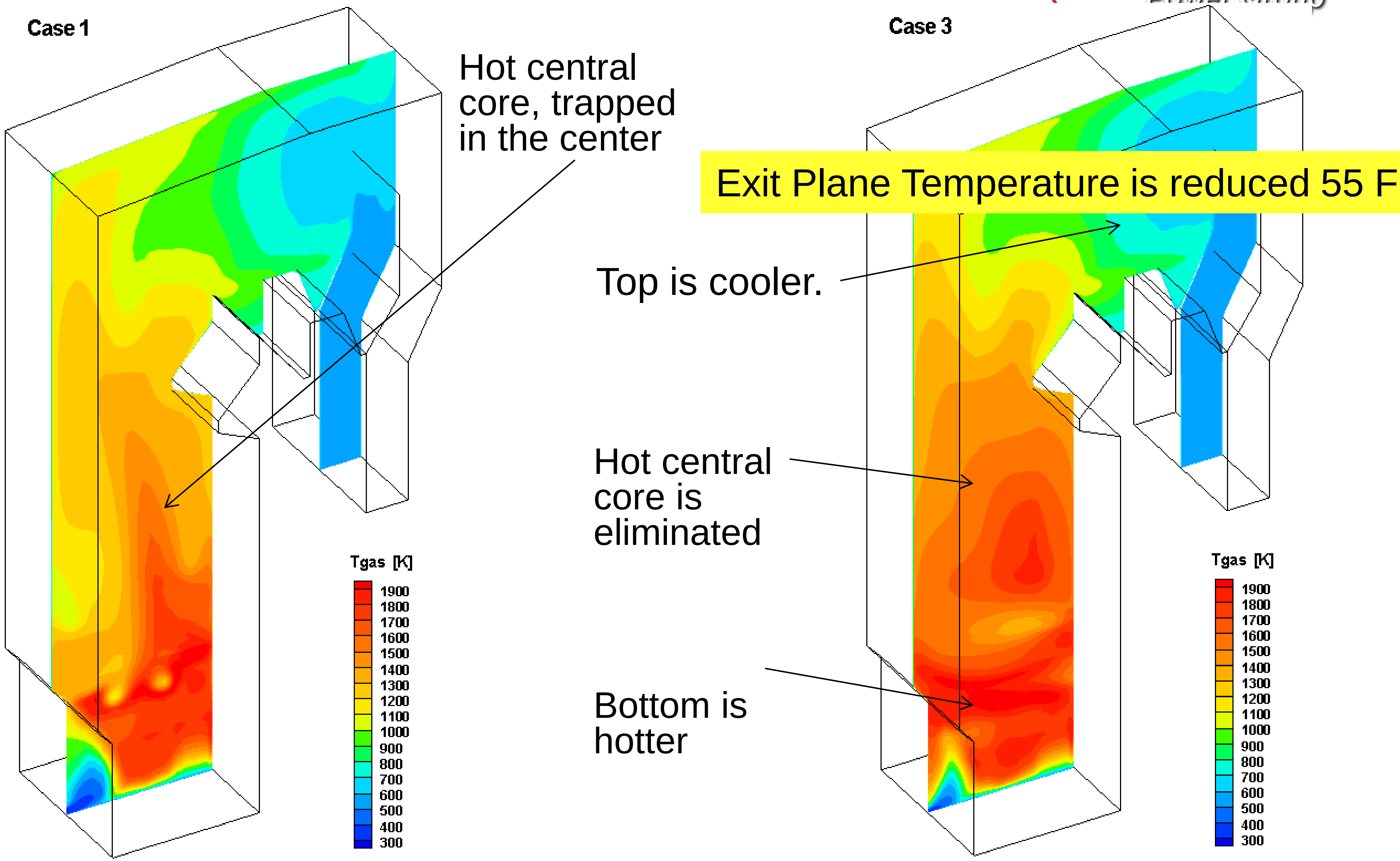
CO Reduction



CO reduced by half despite O_2 reduction



Reduction in Boiler Exit Gas Temperature



Hot central core, trapped in the center

Exit Plane Temperature is reduced 55 F

Top is cooler.

Hot central core is eliminated

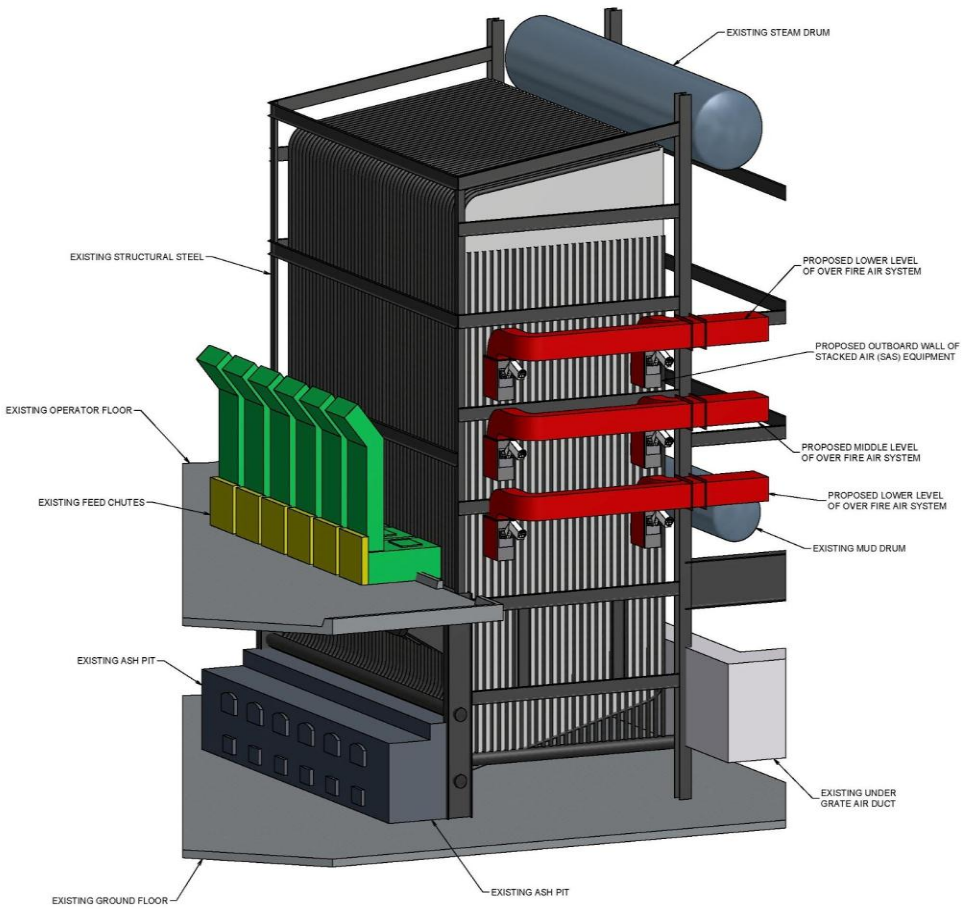
Bottom is hotter

Combustion Modifications Impact on APC Technologies

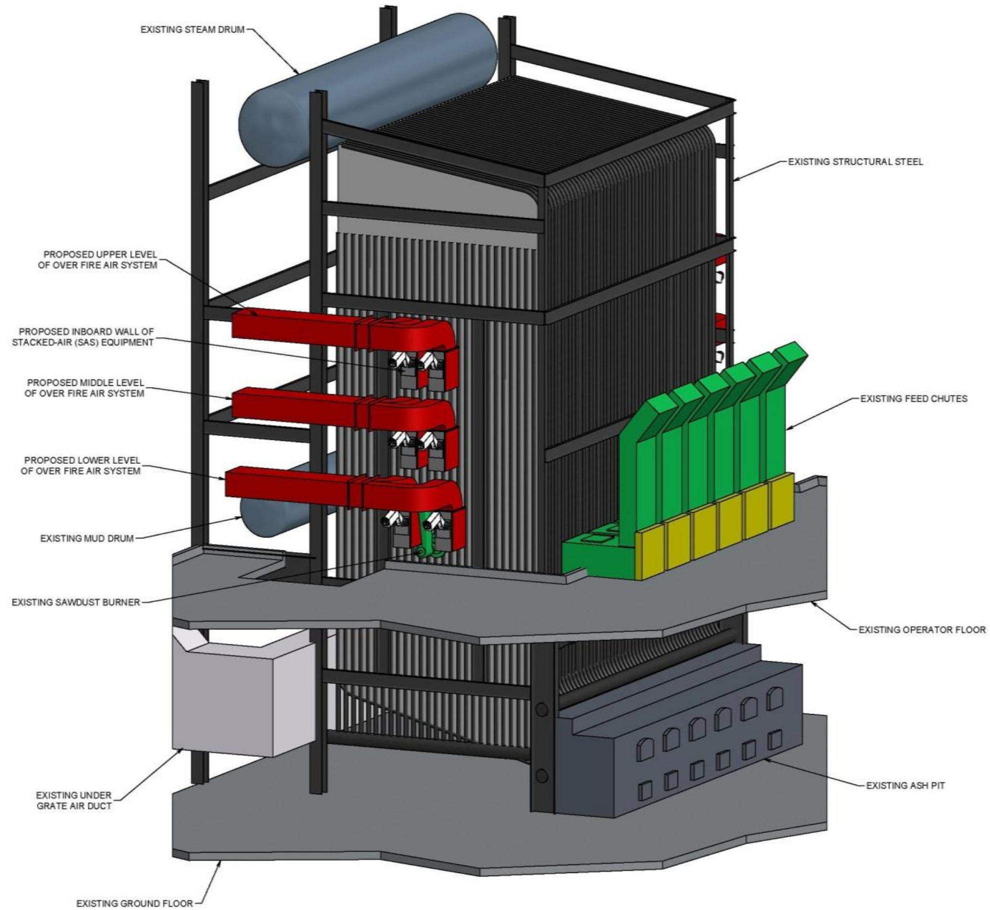
- Reducing unburned gases CO and unburned solids (LOI)
- Reducing Particulate matter carryover
- Reducing combustion air, flue gas flow and excess O_2
- Reducing NOx
- Reducing FEGT (Furnace Exit Gas Temperature) by helping transfer heat to the waterwall)
- Increasing boiler efficiency and improving fuel utilization
- Improving Inlet Conditions to APC Control Equipment

	FEGT and Profiles	Flue Gas Flow	Flue Gas velocity and Profiles	Flue Gas NOx and Profiles	Total Comb. Air	UBC	CO	Fuel Use
Impacts	√	√	√	√	√	√	√	√

Clyde Bergemann Stacked Air System Schematic



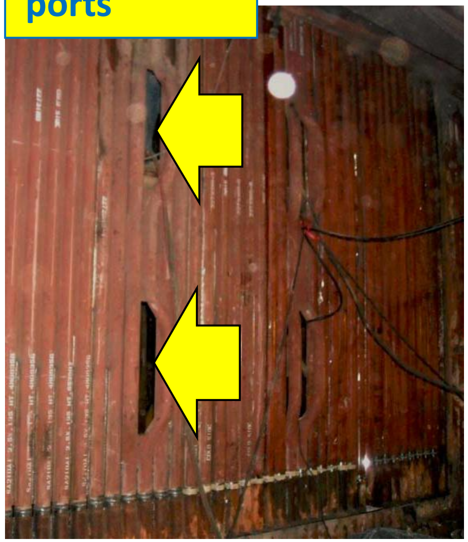
FRONT / RIGHT ISOMETRIC VIEW
OUTBOARD WALL



FRONT / LEFT ISOMETRIC VIEW
INBOARD WALL

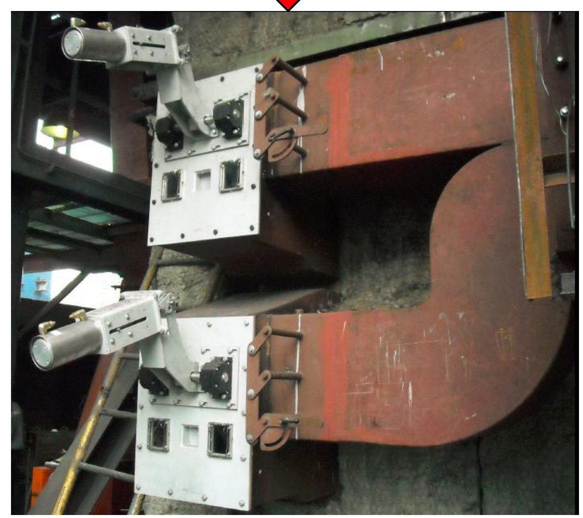
SAS Modifications

Waterwall ports



Port enclosures

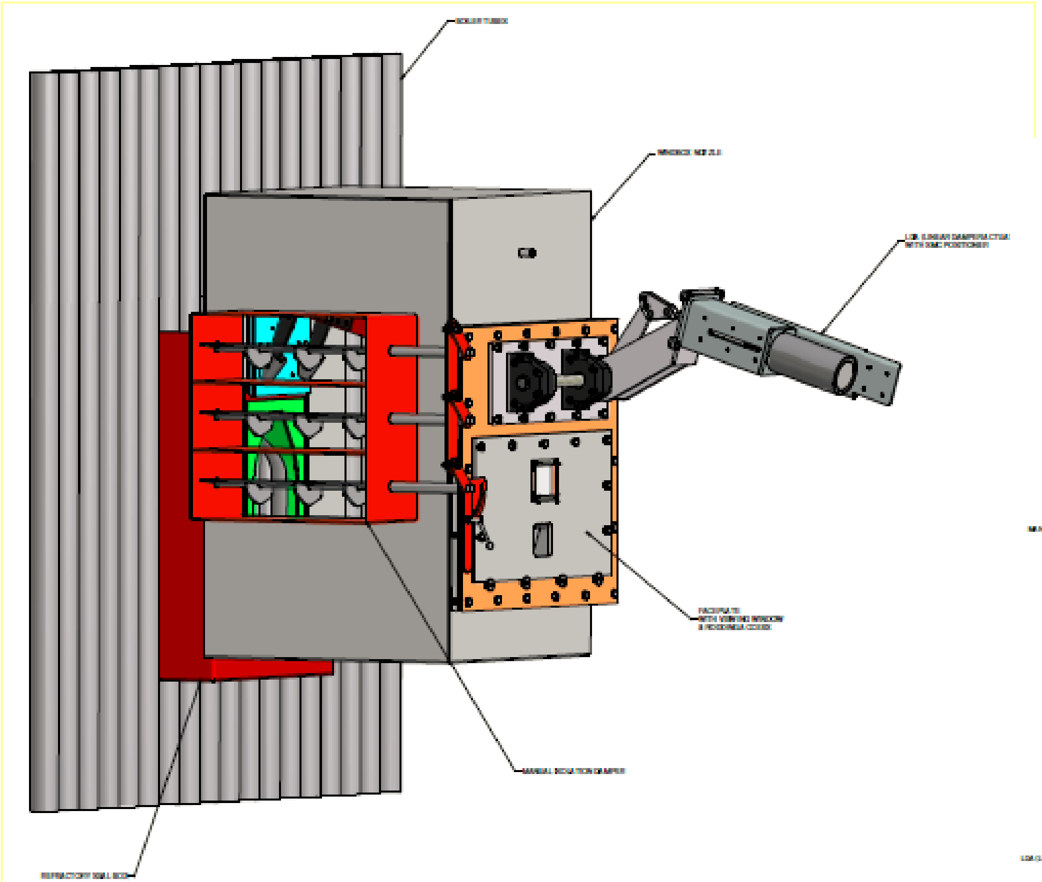
Mass flow dampers

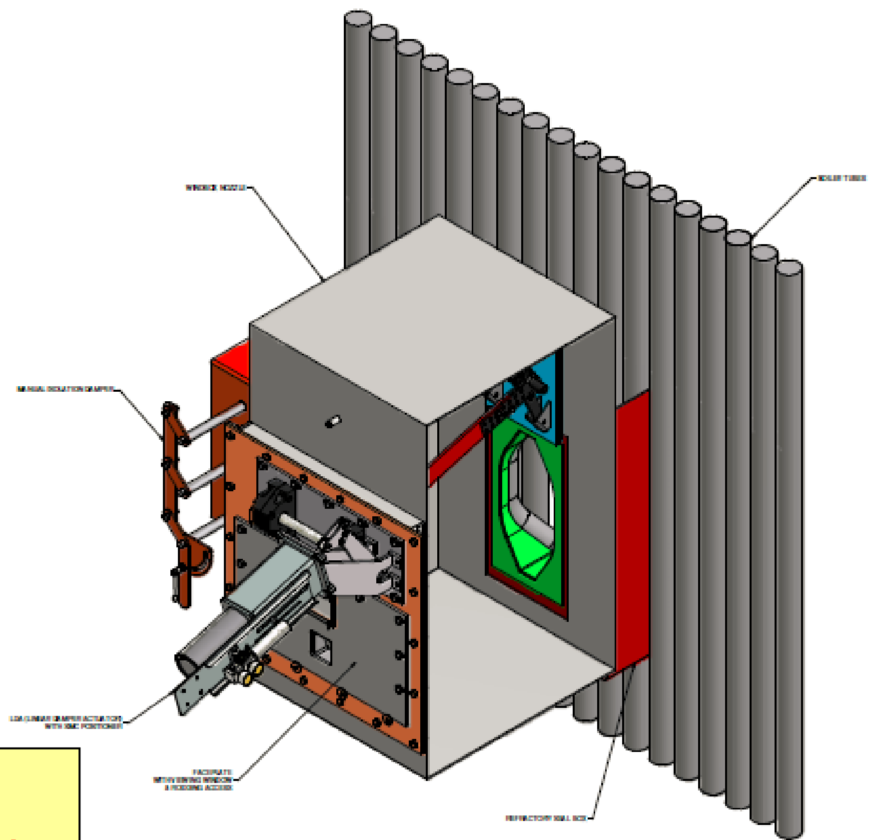


Complete outboard ports with positioners

Complete inboard ports with positioners

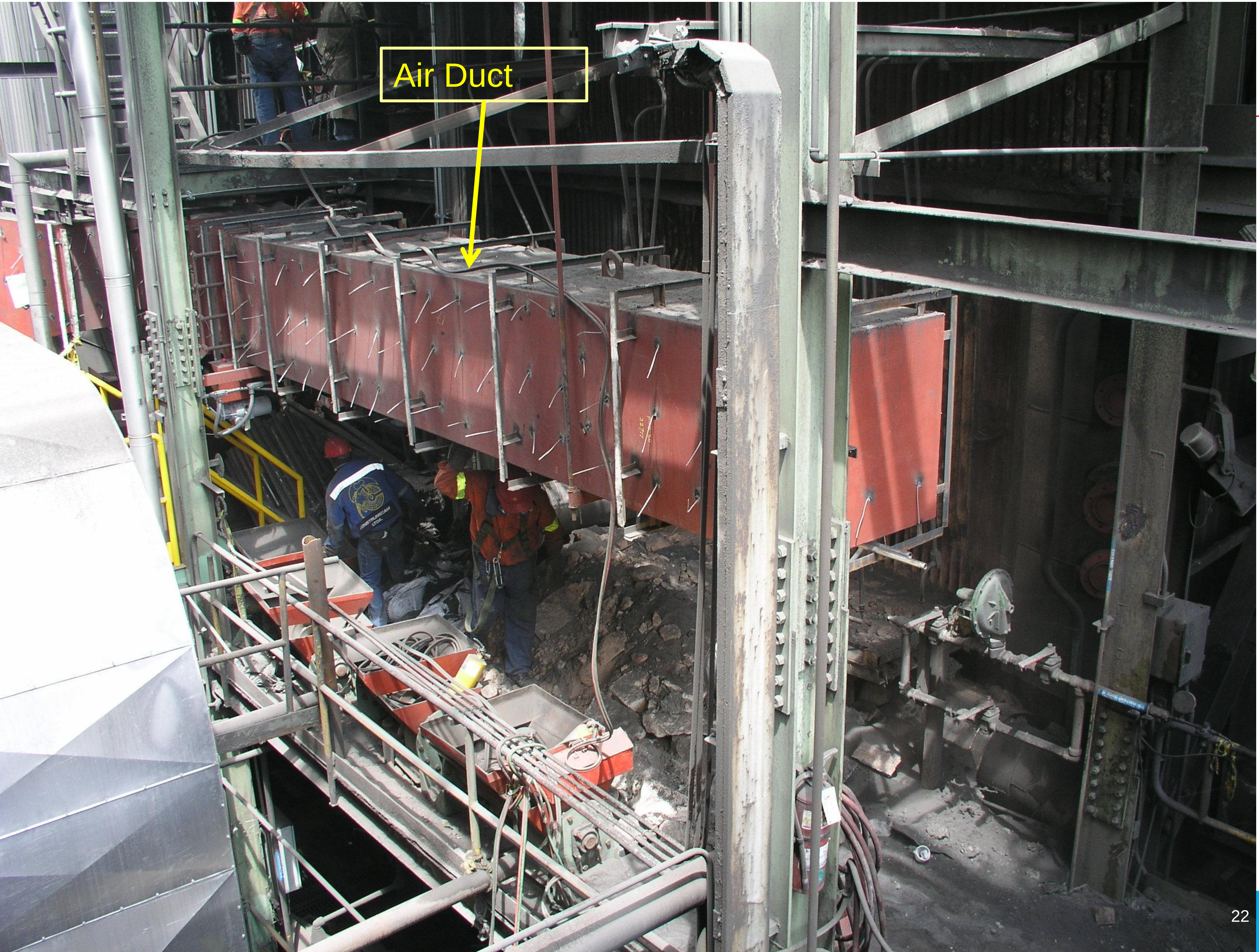
Clyde Bergemann Wind box Nozzle, Positioner and Components





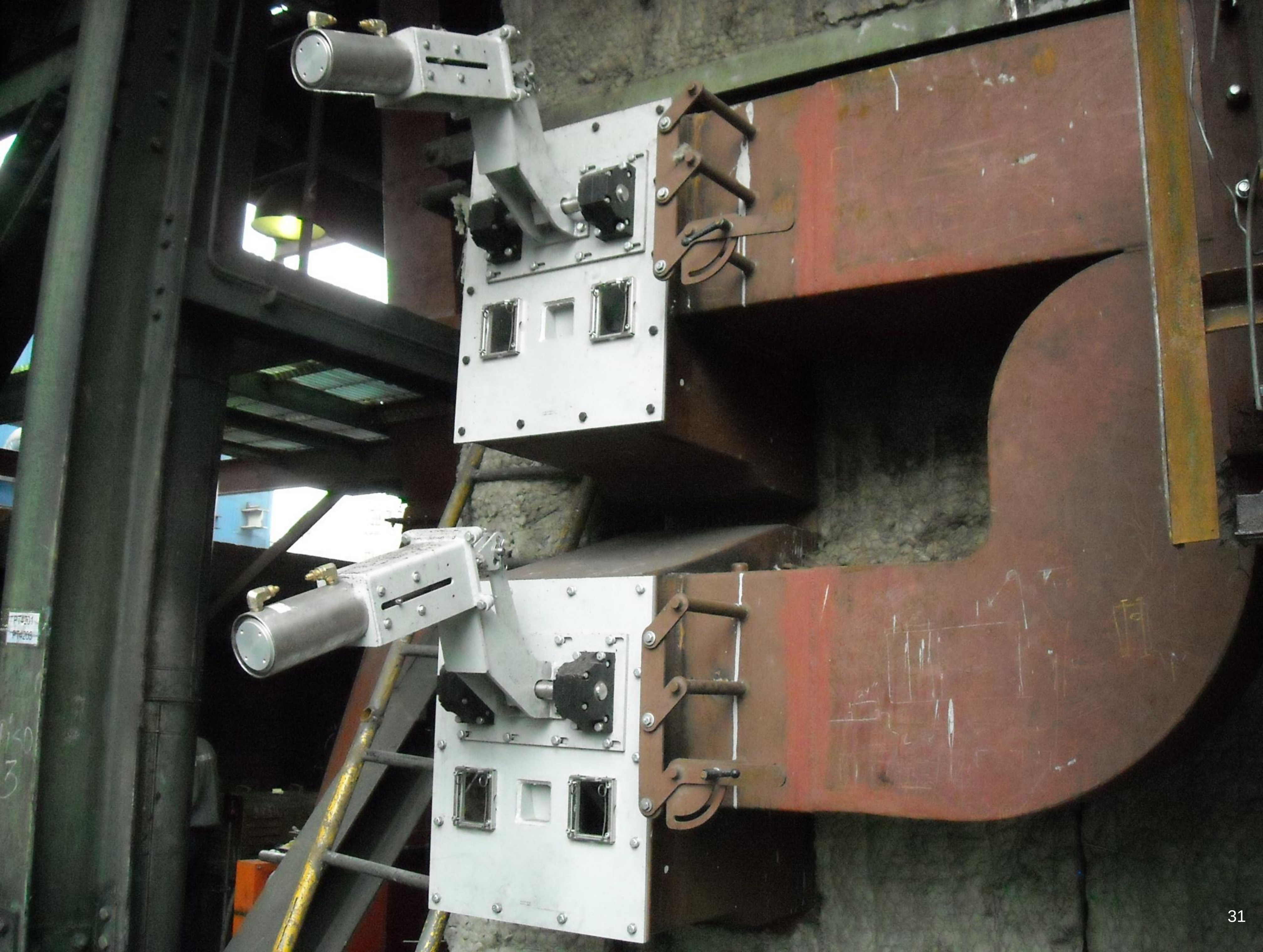
The most important feature of this design is that it provides the ability to independently control jet mass flow and jet velocity


Outboard
Port
Assembly


Air Duct


ERECOS


25
50
SOLDAD



SAS Impact on ESP Design

ESP Inlet Design Parameters

- Boiler type
  - Fuel analysis
  - Fly ash analysis
- Operating conditions
  - Temperature, pressure
  - Heat Rate
- Flue gas volume & constituents
- Particulates
  - Inlet particulate loading
- Outlet emission requirements

Boiler/Fuel Type Impact on ESP

- **Fuel/Fly ash Analysis**
  - → PC, Cyclone, CFB, and Stoker all have different particle sizes
  - → Mechanical collector will impact particle size of particulate
  - → Fuel analysis provides indication of particle size and flue gas environment (amount of SO_3 and moisture present)
- **Fly ash Resistivity is the fundamental basis of ESP sizing**
  - → Ash analysis provides an indication of the resistivity of fly ash
  - → Na_2O, Fe_2O_3 are beneficial to good resistivity
  - → CaO, MgO counter effects of SO_3 - not beneficial
  - → Al_2O_3, SiO_2 are insulators - create excessive resistivity
  - → Resistivity is temperature related. Higher temps (on a cold-side ESP) usually lead to higher resistivity

ESP Operating Conditions and Flue Gas

- **Operating Conditions**
  - Resistivity is temperature related
    - Higher temps (on a cold-side ESP) usually lead to higher resistivity
  - Temperature and pressure are used to correct from actual to standard conditions
- **Flue Gas Volume**
  - Used to size ESP in terms of gas velocity and time of treatment
    - Typical gas velocity for most applications is between 3.5 – 4.5 fps
    - Typical treatment times are 8.0 - 12.0 seconds
  - Lower gas velocity and higher time of treatment are more conservative, yet may be necessary for very low emission levels

Flue Gas and Particulates Design Inputs

- **Gas constituents**
  - ➔ Moisture is a conditioning agent
    - Increased moisture improves (lowers) resistivity slightly
  - ➔ SO_3 is a conditioning agent, related to amount of sulfur in fuel
    - Increased SO_3 improves (lowers) resistivity
- **Inlet particulate loading**
  - ➔ Related to Efficiency calculation
  - ➔ Impacts size of ESP
  - ➔ Affects discharge electrode selection & sizing
  - ➔ Also affects size & type of power supply (transformer rectifier, or T/R)

ESP Outlet Requirements

- **Outlet emission requirements**
  - ➔ Related to efficiency calculation
  - ➔ Impacts size of ESP
    - Desired efficiency
    - Desired gas velocity & time of treatment
  - ➔ Low outlet emission requirements may necessitate
    - Slowing down gas velocity
    - Extending time of treatment (TOT)
  - ➔ Some requirements may be too low to commercially guarantee

Technology CBPG Rigitrodes

– Over 170 new installations with Rigid Electrodes

Developed By CBPG
81 New Recovery installations
Numerous retro-fits
More Rigid Electrode Experience than ALL others combined!

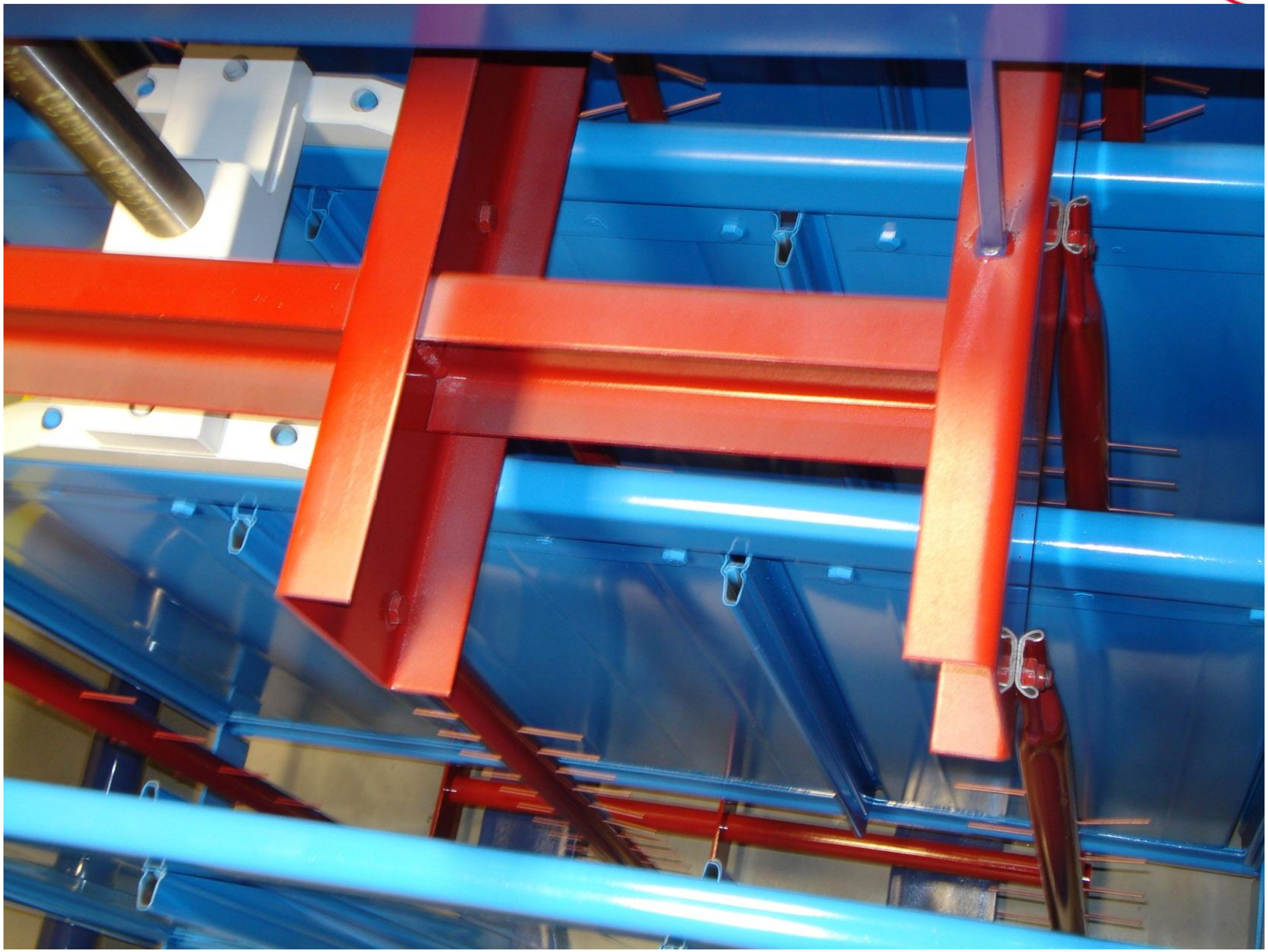
– Stable High Voltage Frame System

Bolted Top & Bottom Frame to form Rigid matrix design
Solid Large Diameter Pipe (one-piece) Design
Bolted / Closed ends prevent build-up
NO Weights required

– Multiple Pin Designs tailored to Application

Power Boiler Design
Salt cake Design

CBPG Collecting Plates and Rigitrodes

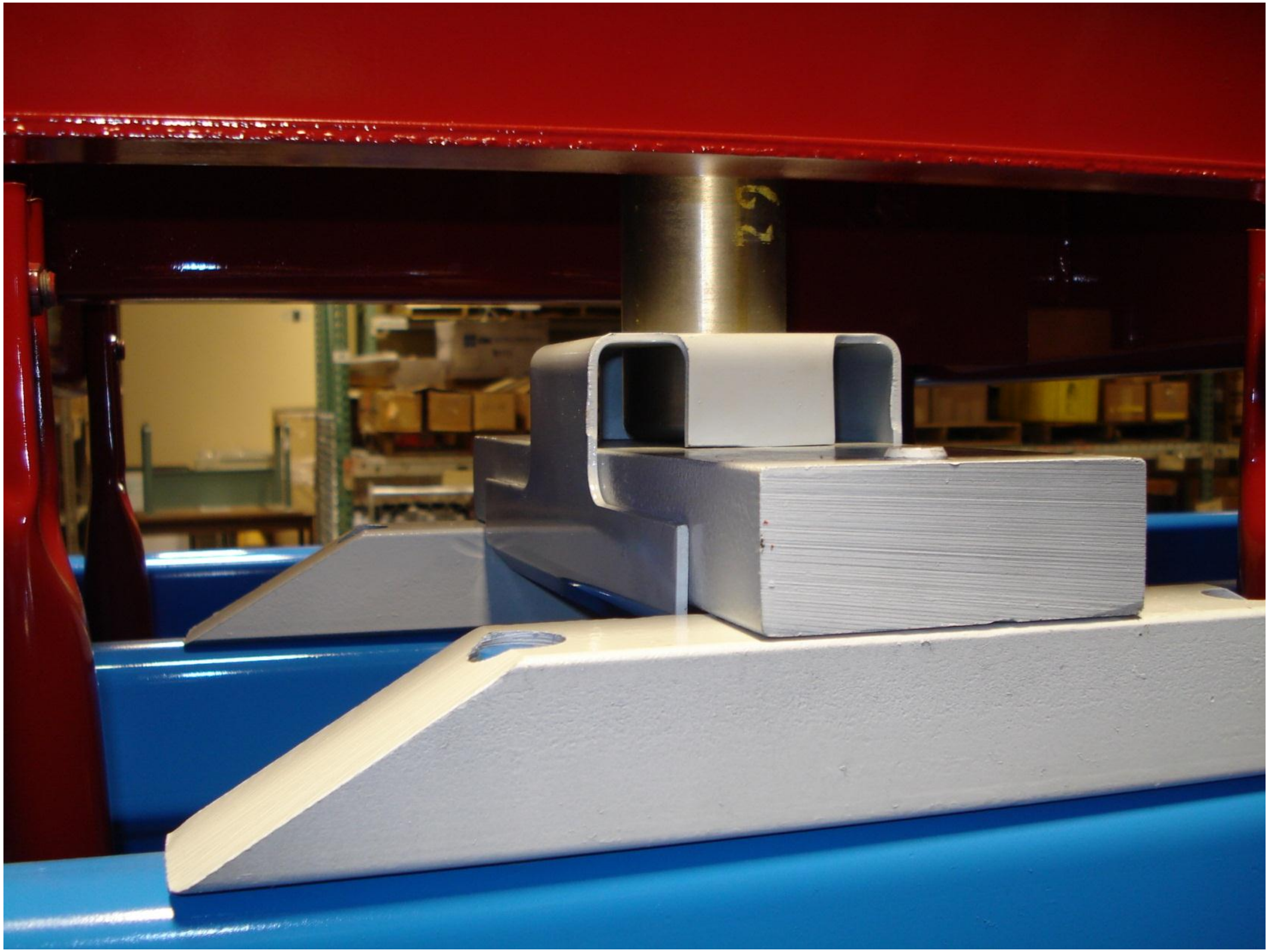


Rigitrode® Electrodes

- Does not exhibit the corona suppression associated with some rigid electrodes.
- Various pin configurations provide corona densities less than and greater than other designs
- The most energy efficient rigid electrode available

Rigitrodes

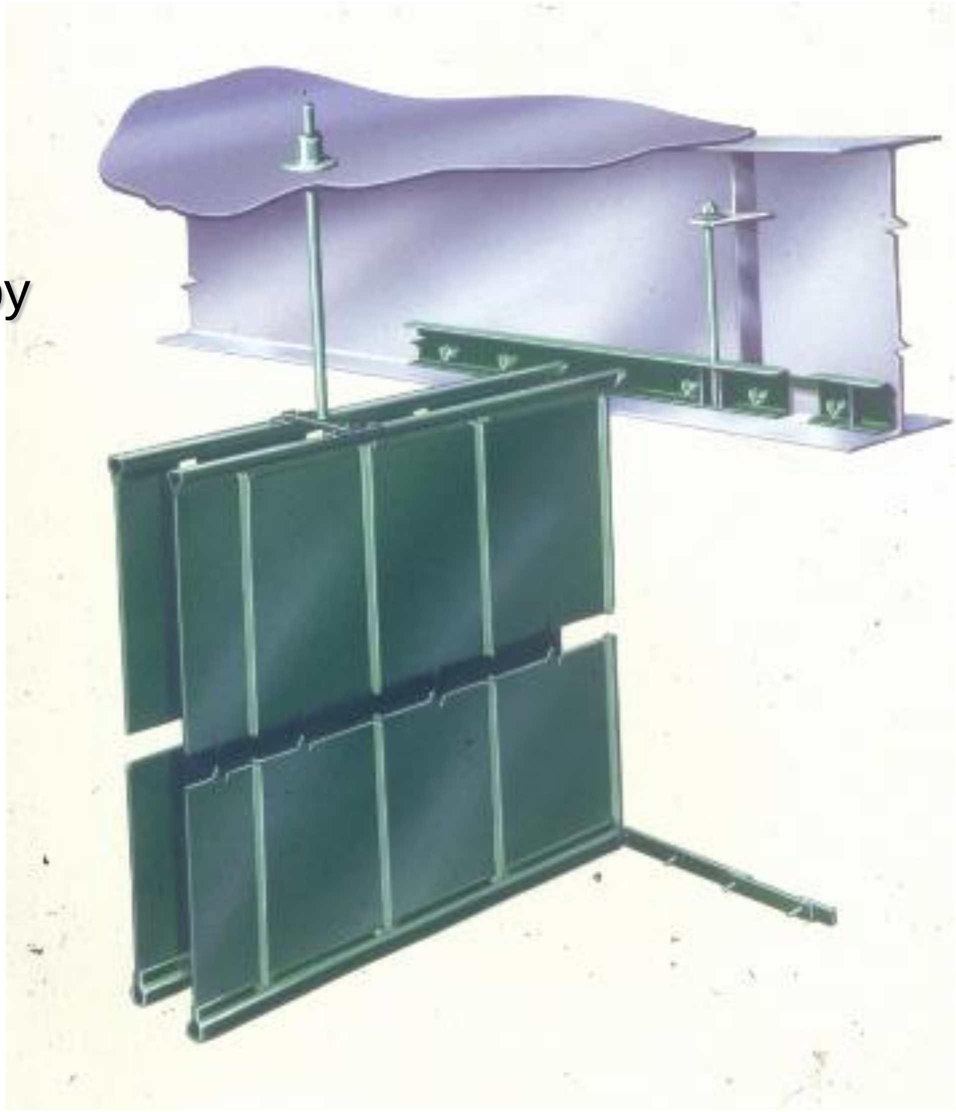
Direct Collecting Plate Rapper System



Collecting Plate Rapping

Provide energy directly into plate

- No disturbance to dust build-up on adjacent plates
- Rapping forces not dampened by mass of other plates/casing



RD 3000 Automatic Voltage Controls

- The latest innovation in improving an existing precipitator performance without mechanical modifications
- The best bang for the $
- Simple installation on existing esp sometimes while online with a field out of service (reduced production rate)
- Existing TR ***may*** be used

Controls – T/R

Metering:

- Primary Voltage and Current
- Secondary Voltage and Current

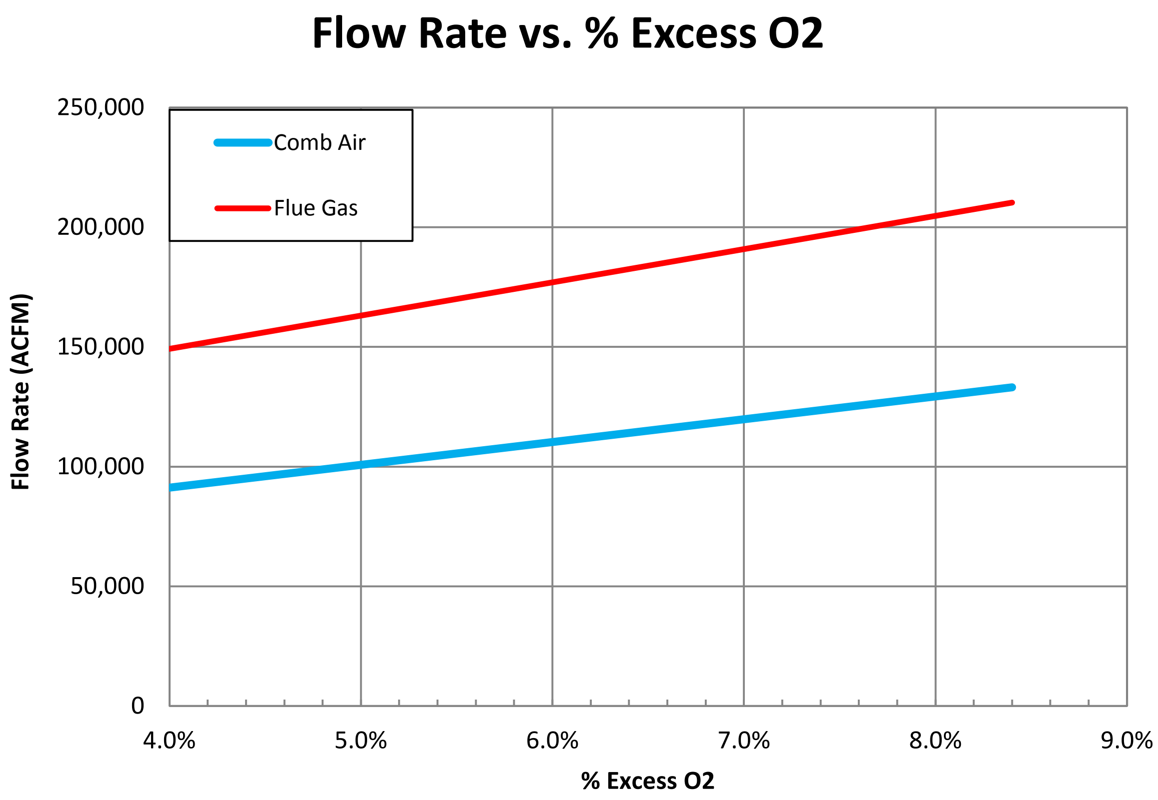
APC Performance Case Study

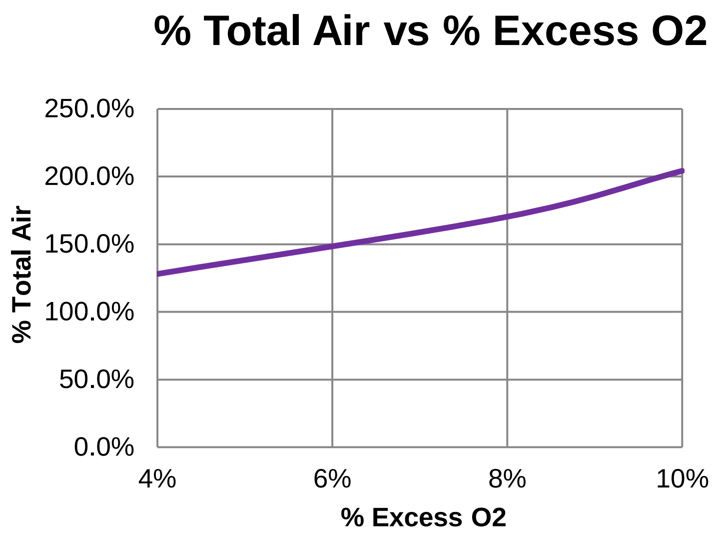
- Plant A
  - Steam flow:
    300 KPPH, 600 psig,750 F
  - PRB coal:
    ~26% moisture & 8911 Btu/hr
  - Fuel Emissions:
    0.21% Sulfur
    0.03% (max.) Chlorine
    0.10 ppm (max.) Mercury

Design Operating Conditions:

Excess O2	8.4% O2 ESP & DSI design	4% O2 SAS
Fuel Flow(#/h)	48,869	46,542
Heat Input(MMBtu/hr)	435.5	414.7
Comb.Air(ACFM@105F)	133,115	91,211
Flue Gas(ACFM@375F)	210,292	149,200
Boiler Efficiency (%)	80.0%	84.0%
HCl Emissions (lb/MMBtu)	0.035	0.035
HCl Emissions (lb/hr)	15.07	14.36
SO_2 Emissions (lb/MMBtu)	0.471	0.471
SO_2 Emissions (lb/hr)	123.15	117.29
Hg Emissions (lb/Tbtu)	11.22	11.22

Flue Gas and Combustion Air





- 29% reduction on flue gas, 32% reduction on combustion air
- Heat input reduce 20.8 MMBtu/hr

ID and FD Auxiliary Power Savings

The ID and FD power savings are based on electricity rate $0.06/KWh

Fan Savings	8.4% to 4% O2	
	ID (360 F)	FD (105F)
Flow Rate (ACFM)	61,092	41,904
Pressure Drop (in)	10	10
Fan Efficiency	70%	70%
Motor HP	133.5	91.6
$/y	$ 50,205	$ 34,436
Total $/y	**$ 84,641**	

ESP – SAS Economic Analysis

	8.4% to 4% O2
Fuel Savings (MMBtu/h) (85% capacity) equivalent	17.7
Steam Increase (kpph) (85% capacity) equivalent	12.7
Fuel Saved per year(MMBtu/y) (85% capacity)	148,512
Savings ($/y):	
PRB Coal ($2/MMBtu)	$297,024
Aux Power	$84,641
Other (Maintenance, Operations, etc.)	$80,000
Annual Savings Estimate	+$460,000
ESP Size Price differential $5.47M to $4.65M	+820,000
SAS Cost	-$1,200,000
ROI (years)	**0.82**

Conclusions for ESP Impact

- For this unit(~300 kpph), current operating is 8.4% excess O2, with SAS can operate at 4% excess O2 with this type of coal (PRB ~26% moisture).
- Flue gas can be reduced from ~210,000 ACFM to 149,000 ACFM which is ~30% reduction due to a more efficient combustion obtained 4.0% with the installation of SAS.
- According to our boiler efficiency estimates, can be explained by
  - a reduction of excess O2 level from 8.4% to 4%
  - lower CO emissions due to combustion improvement by SAS (~2500 ppm to ~500 ppm)
  - a reduction in total unburned fuel to 1.5% to 2.5% from much higher inefficient burnouts
- Return on investment is less than one year for the new SAS system with a reduced size ESP and 2.5 years with same size ESP.

SAS Impact on ACI/DSI Design

ACI – SAS Performance Analysis

Mercury Emissions Design:

Excess O2	8.4% O2 ESP & DSI design	4% O2 SAS
Flue Gas(ACFM@375F)	**210,292**	**149,200**
Hg Emissions (lb/TBtu)	**11.22**	**11.22**
Hg Outlet (lb/TBtu)	**5.70**	**5.70**
Reduction %	**49%**	**49%**
PAC Consumption Rate (lb/mmacf)	**4.0**	**4.0**
PAC Consumption Rate (lb/hr)	**51**	**36**
PAC Consumption Rate (lb/yr)	**446,760**	**315,360**
PAC Cost ($/yr) @ $1.00/lb	**$446,760**	**$315,360**
Sorbent Savings from SAS ($/yr)	**N/A**	**$131,400**

Note: ACI equipment scope and capital cost remains unchanged

- SAS Improvements:
  - Boiler Efficiency
  - Reduction of Comb. Air
  - Reduction of Flue Gas volumetric flow rate
- SAS Savings:
  - Reduction of Sorbent consumption rate
  - Total Sorbent consumption savings per year

DSI – SAS Performance Analysis

Acid Gas Emissions Design:

Excess O2	8.4% O2 ESP & DSI design	4% O2 SAS
Heat Input(MMBtu/hr)	**435.5**	**414.7**
HCl Emissions (lb/MMBtu)	**0.035**	**0.035**
HCl Emissions (lb/hr)	**15.07**	**14.36**
HCl Outlet (lb/MMBtu)	**0.022**	**0.022**
Reduction %	**52%**	**52%**
Trona Consumption Rate (lb/hr)	**321**	**305**
Trona Consumption Rate (tons/yr)	**1,406**	**1,336**
Trona Cost ($/yr) @ $200/ton	**$281,200**	**$267,200**
Sorbent Savings from SAS ($/yr)	**N/A**	**$14,000**

Note: DSI equipment scope and capital cost remains unchanged

- SAS Improvements:
  - ➔ Boiler Efficiency
  - ➔ Reduction of Heat Input
  - ➔ Reduction of Acid Gas Emissions (Mass Flow Rate)
- SAS Savings:
  - ➔ Reduction of Sorbent consumption rate
  - ➔ Total Sorbent consumption savings per year

CONCLUSIONS

Conclusions for ESP, ACI and DSI Impact

SAS Improvements:

- Boiler Efficiency
- Reduction of Heat Input
- Reduction of Acid Gas Emissions (Mass Flow Rate)

ESP

- Reduced Foot print
- Reduced Operating Costs

ACI

- Reduction of Sorbent consumption rate
- Total Sorbent consumption savings per year

DSI

- Reduction of Sorbent consumption rate
- Total Sorbent consumption savings per year

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