REINHOLD ENVIRONMENTAL Ltd.

2011 NOx-Combustion Round Table & Expo Presentation

February 7-8, 2011, in Birmingham, AL / Hosted by Southern Company

COMBUSTION OPTIMIZATION

For T-Fired Boiler Applications

ALSTOM

POWER

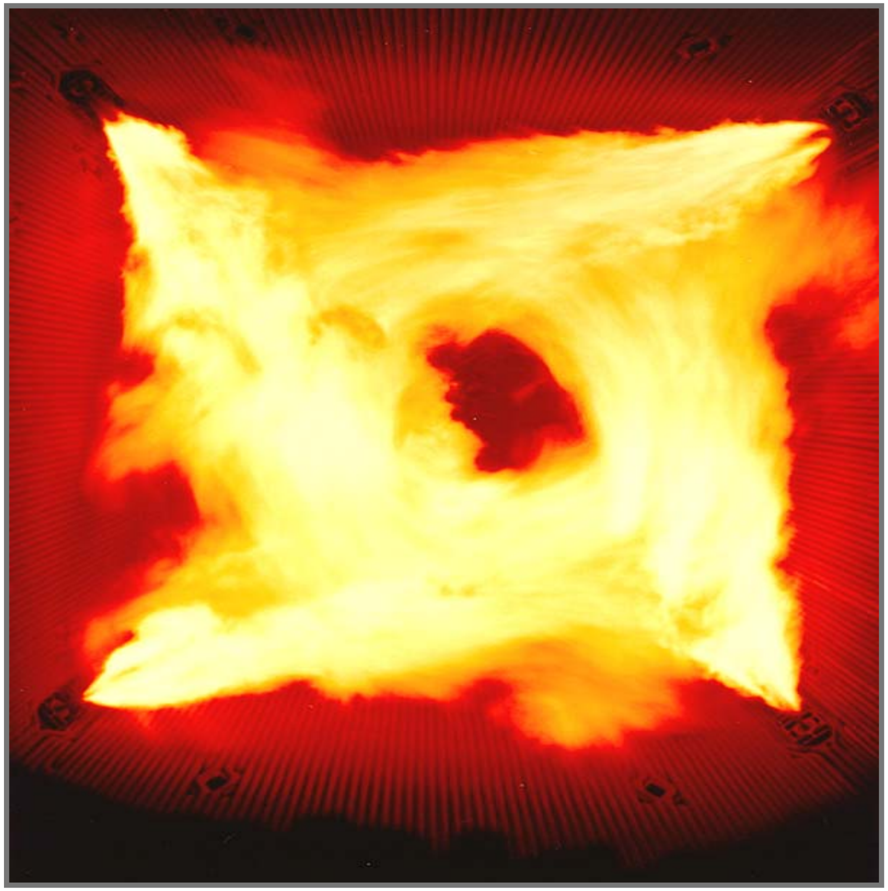
Tangential Firing System

Key Advantages

- Inherently Lower NOx Emissions
- Provides Horizontal Mixing of the Combustion Products
- Lower Combustion Temperature
- Tilting Nozzles Provide Extended
  Steam Temperature Control Range without FGR
- Minimizes the Need for Gas Recirculation

Tangential Firing System

Tangential Flame Pattern



Keys to Proper Combustion

- Fuel and PA Distribution
- Coal & PA Velocity
- Secondary Air Control
- Secondary Air Balance
- Secondary Air Velocity
- Tilt Control

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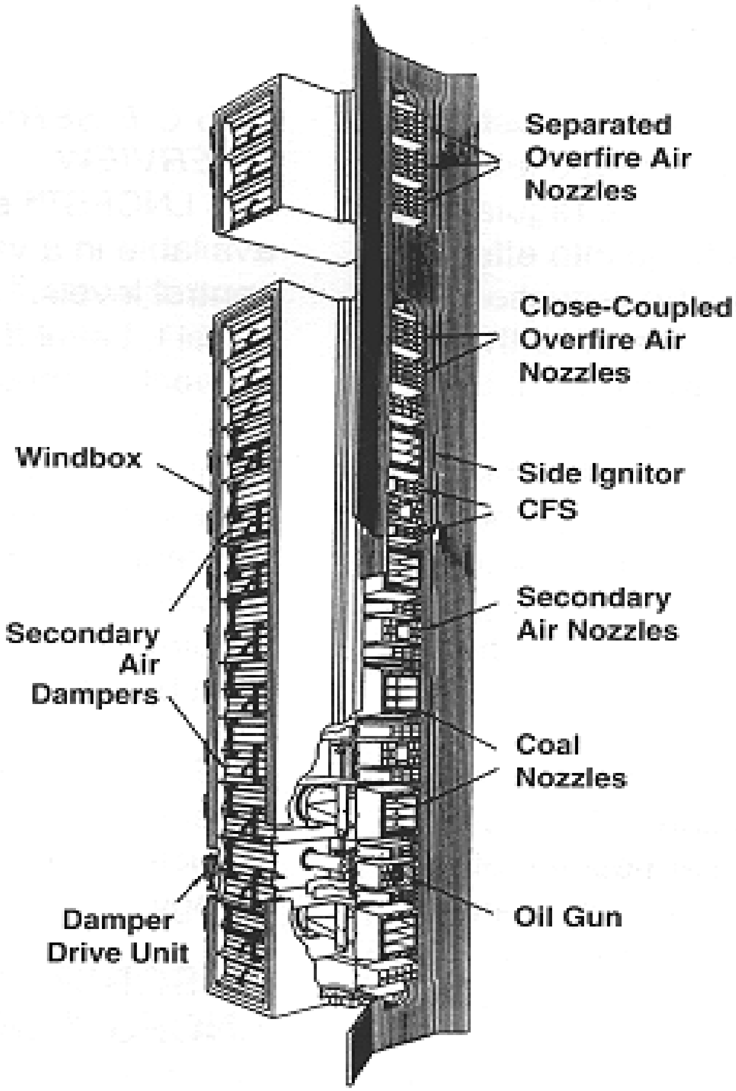
Example of a Low NOx Arrangement



Tangential Windbox Corner

Each windbox is a series of alternating air and fuel nozzle tips.

These nozzle tips introduce the air and fuel into the furnace.

Tangential firing produces turbulence.

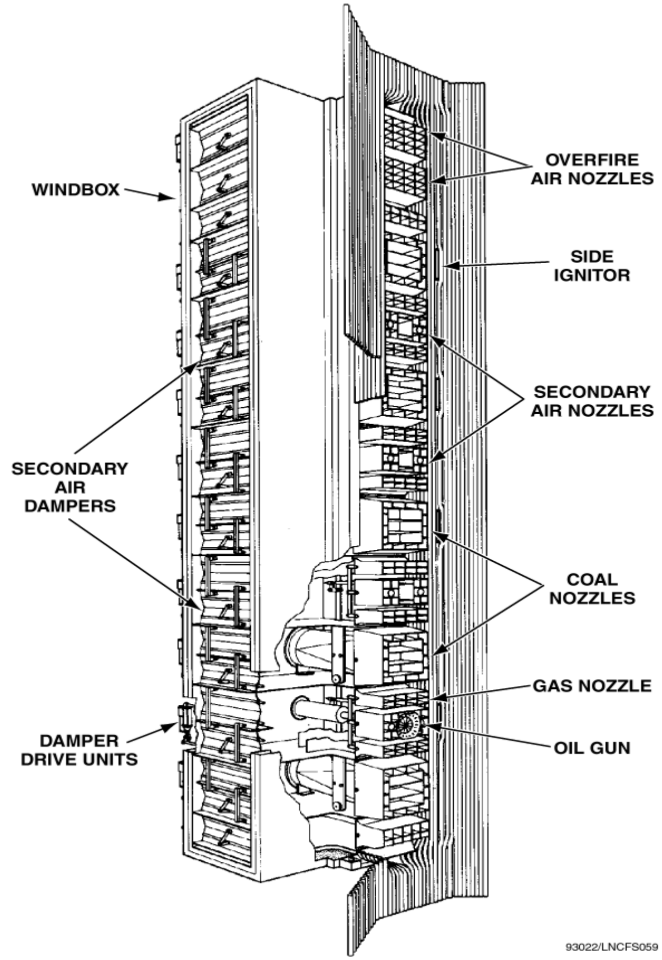
The furnace is the burner.

Windboxes Are Part of A System!

Windboxes are part of a system that includes:

- Coal Piping
- Secondary Air Connecting Ducts
- Buckstays
- Waterwall Tubes

These components are inter-related!



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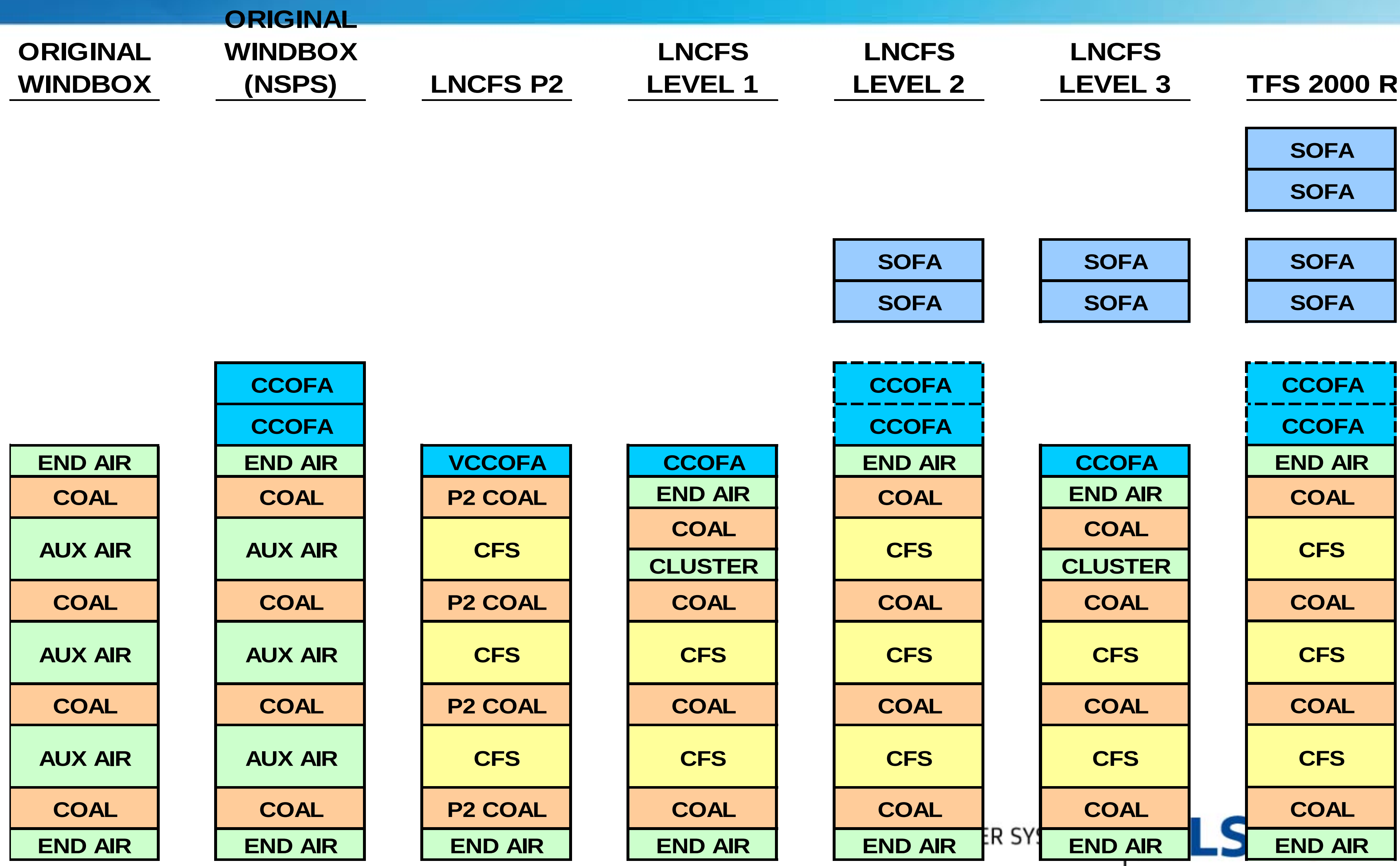
In-Furnace NOx Options



Windbox for a Tangentially-Fired Combustion System

Close Coupled Over-fire Air

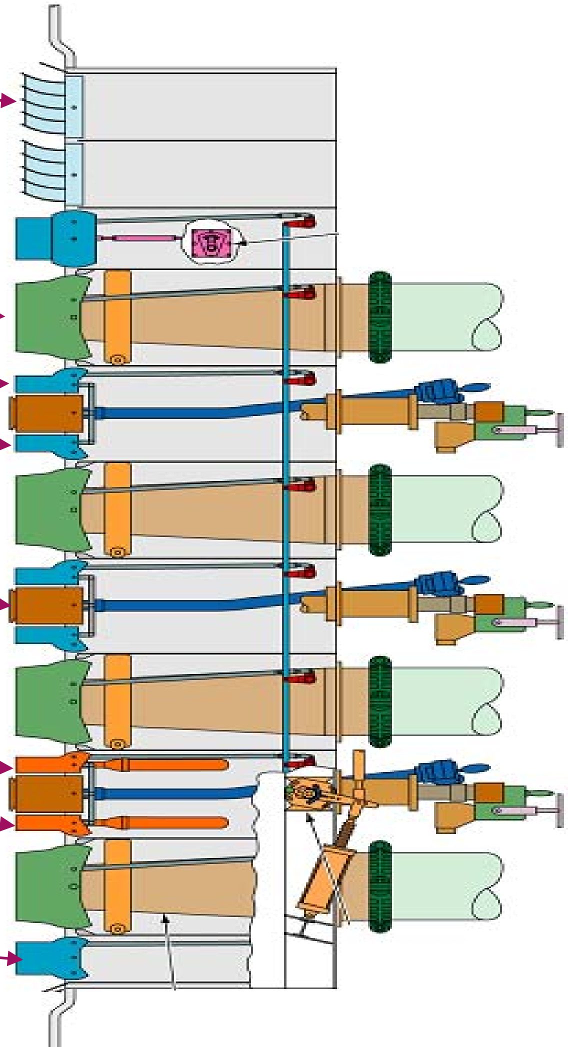
Coal Nozzle Tip and Compartment Assembly

Air Nozzle

Oil Nozzle Tip with Scanner

Gas Nozzle Tip

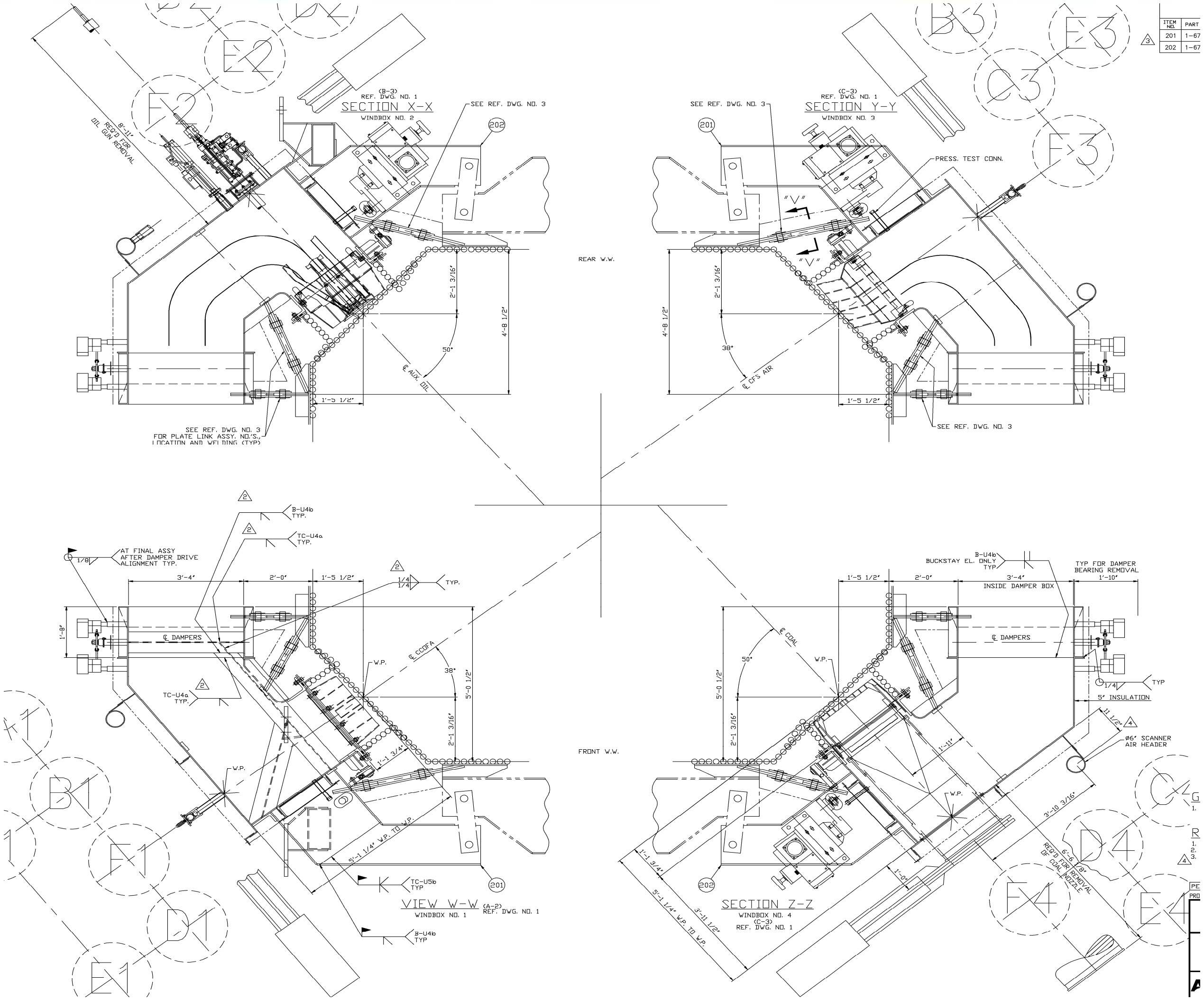
Straight Air Nozzle



Cross Windbox Arrangement

Oil Gun

Fixed CFS



Air Tip

Coal

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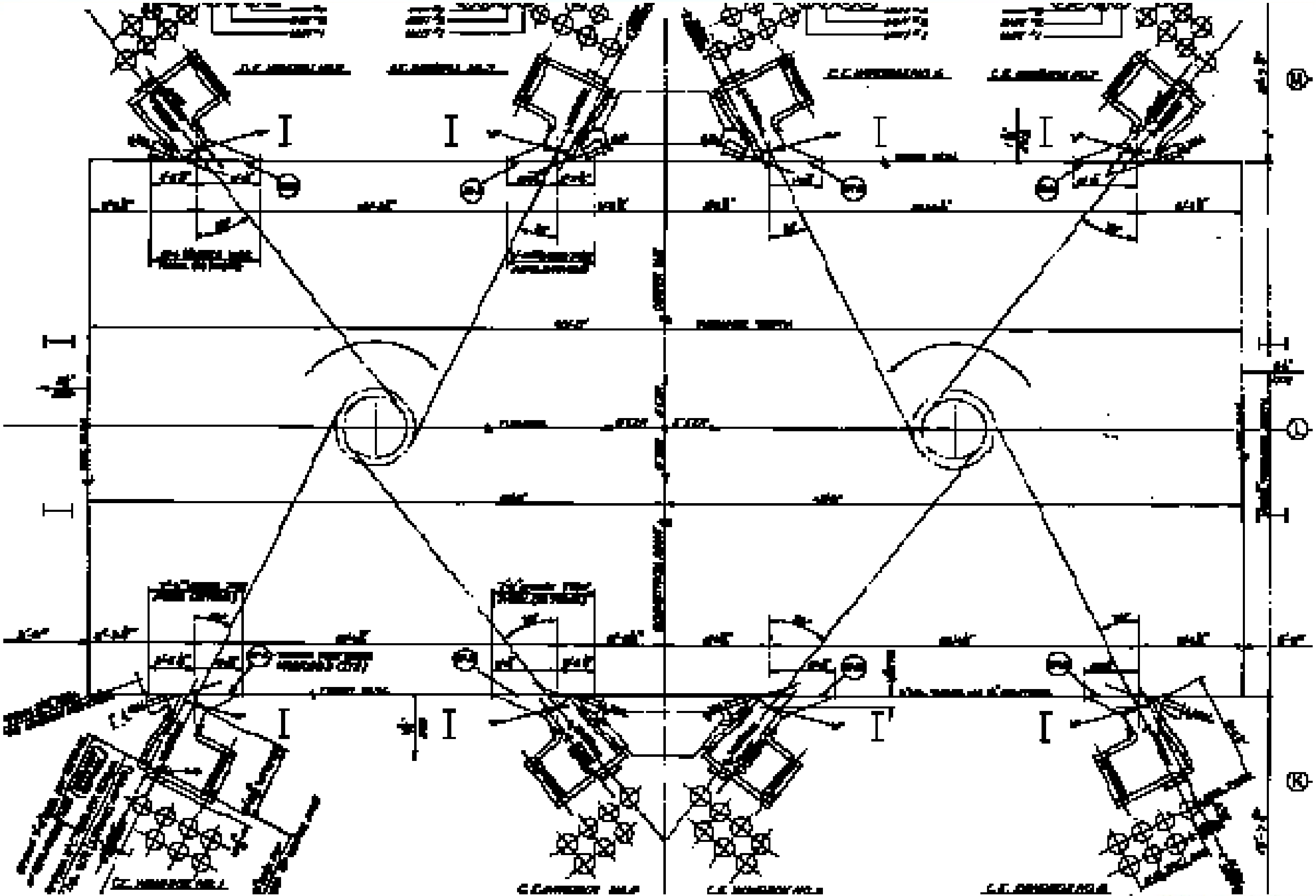
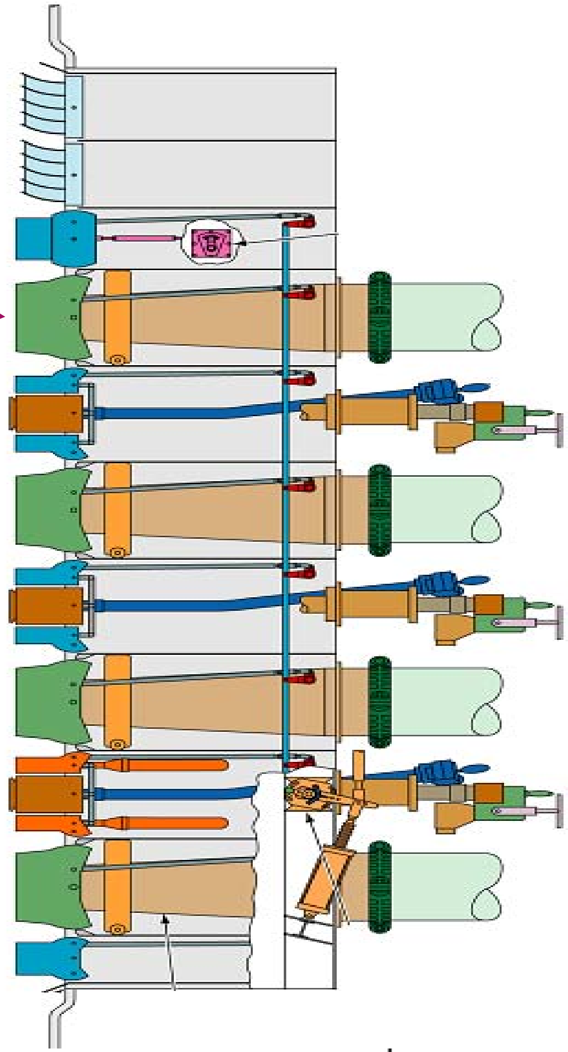
Plan View of Divided Furnace

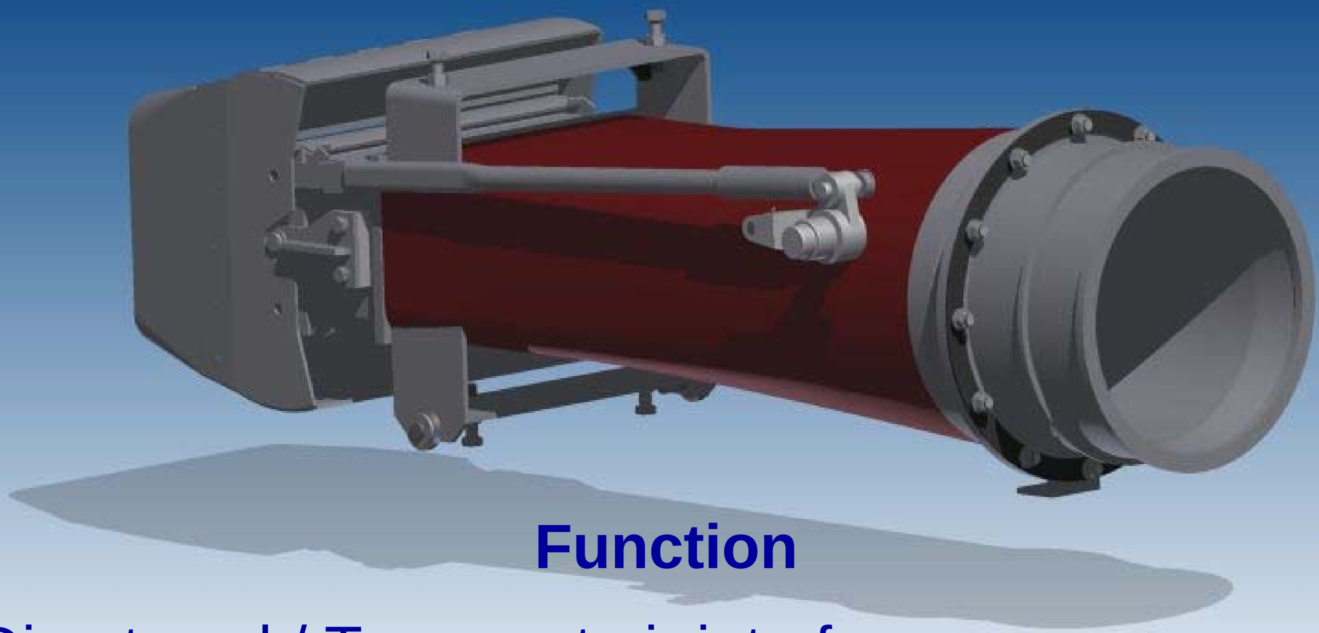


Coal Nozzle Tip and Compartment Assembly

Coal Tip and Compartment Assembly



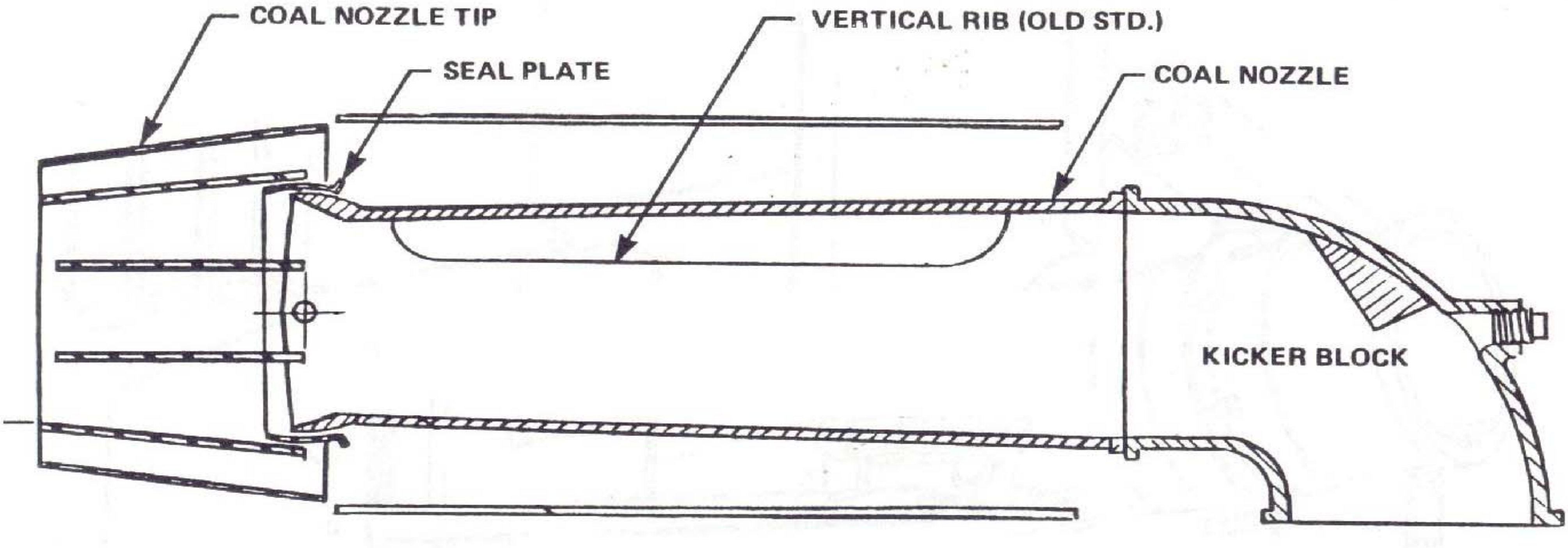
Coal Compartment Assembly



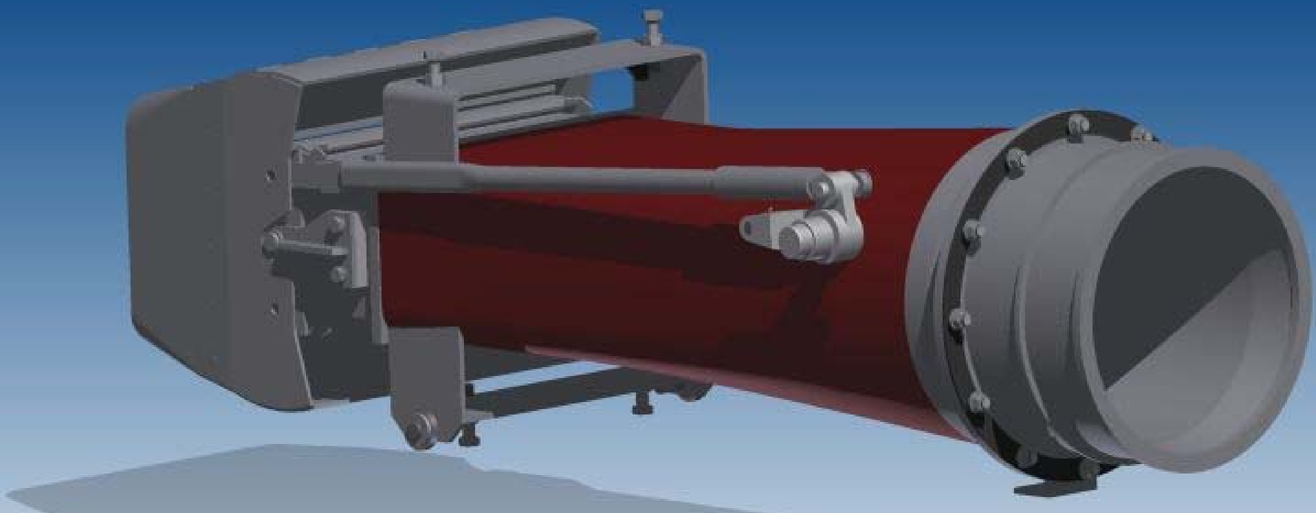
Function

- Direct coal / Transport air into furnace
- Establish Stable Combustion
- Control heat absorption by tilting action

Typical Coal Compartment Assembly



Coal Compartment Assembly



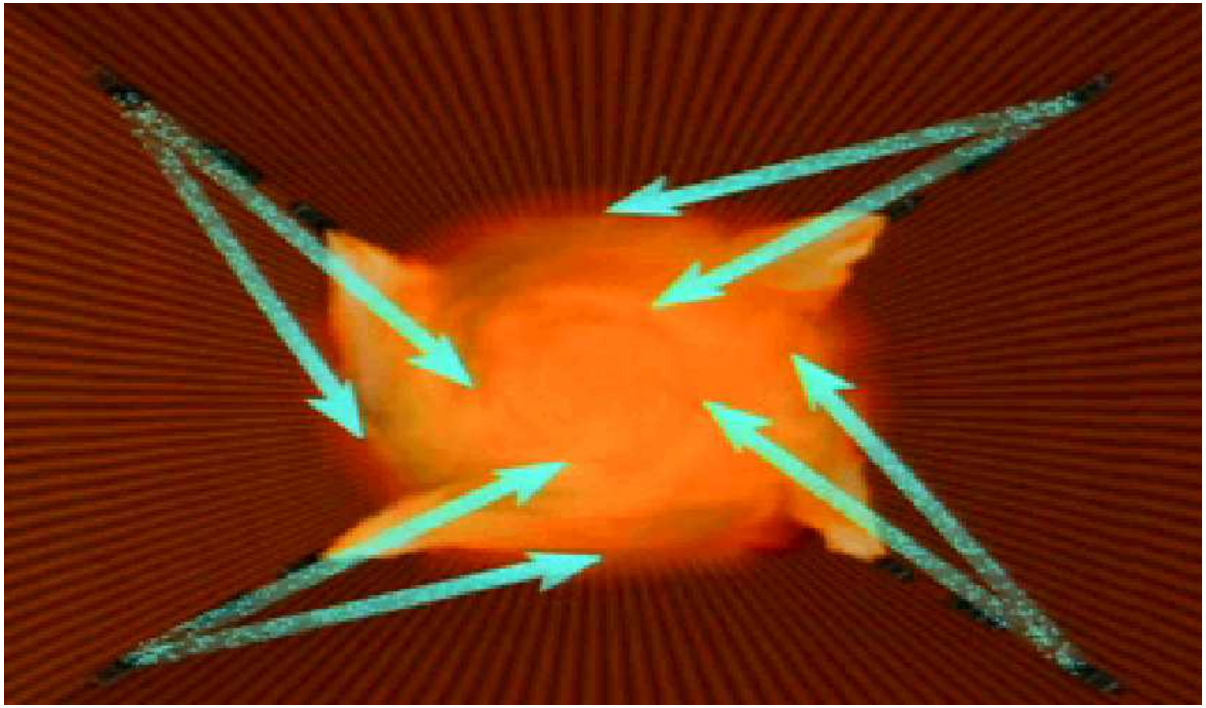
Typical Issues

- Matching Wear Life to Outage Schedules
- Overheating / Pluggage / Deposition
- Poor Carbon Burnout, NOx or CO

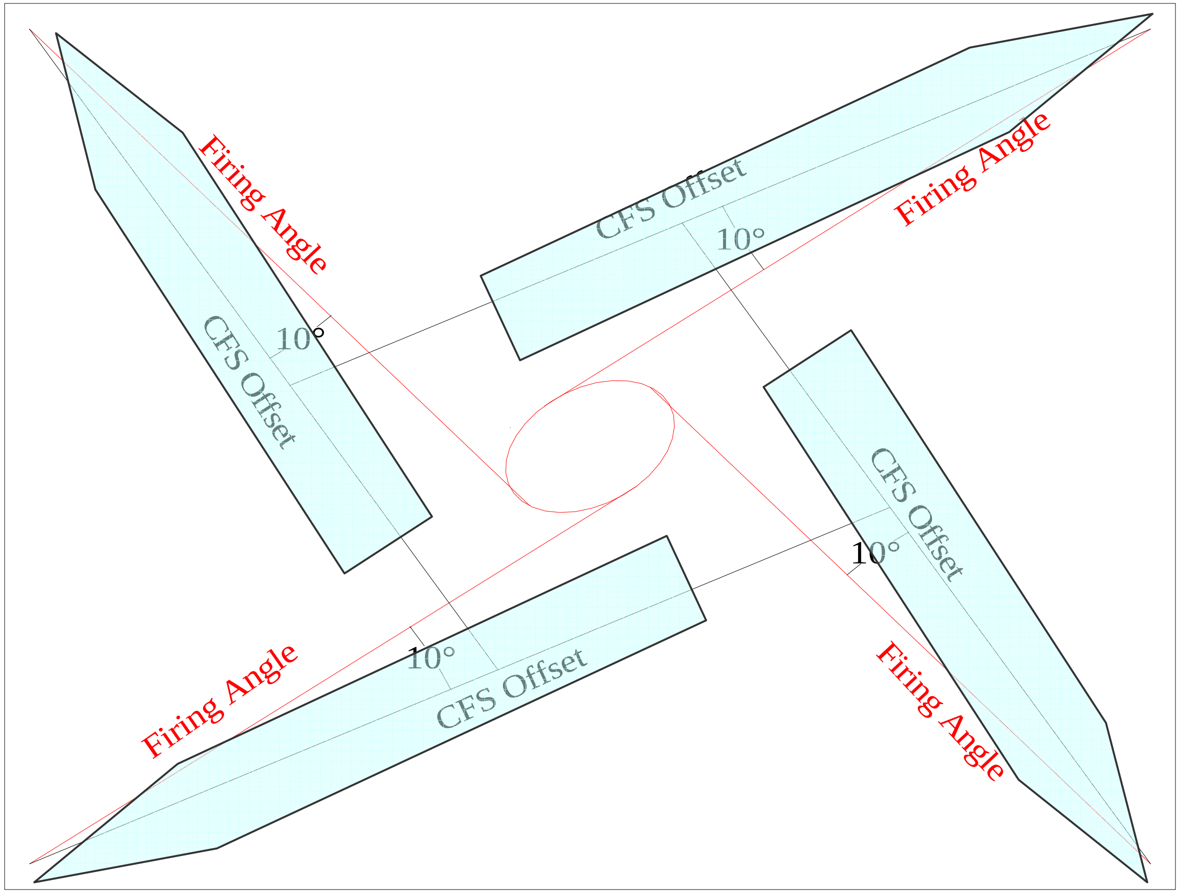
Concentric Firing System, CFS™

Creates an Oxidizing Near Wall Environment

- Decreases Slagging / Increases Waterwall Heat Absorption
- Promotes Oxidation of Sulfur Species for Reduced Waterwall Wastage

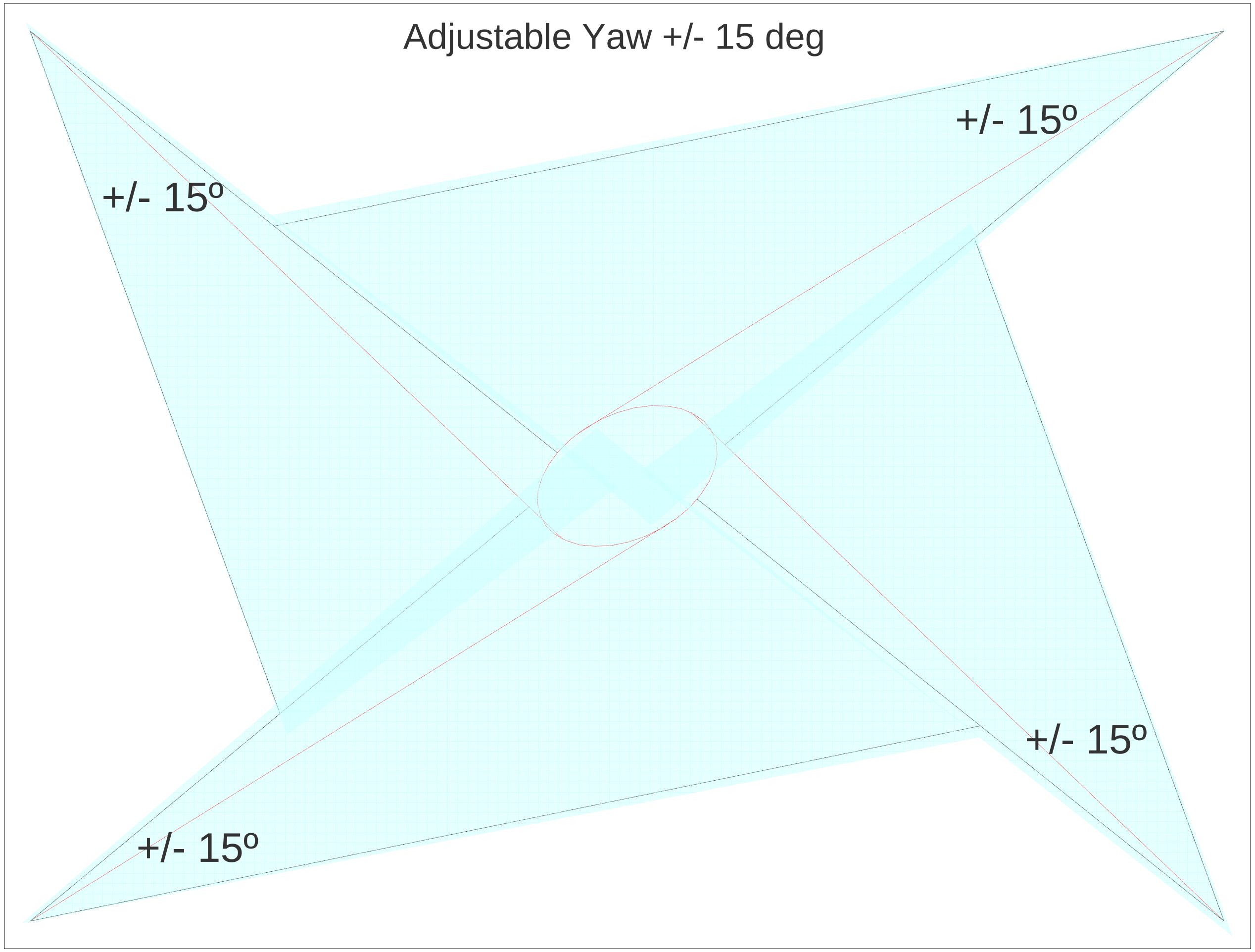


Fixed CFS Tips

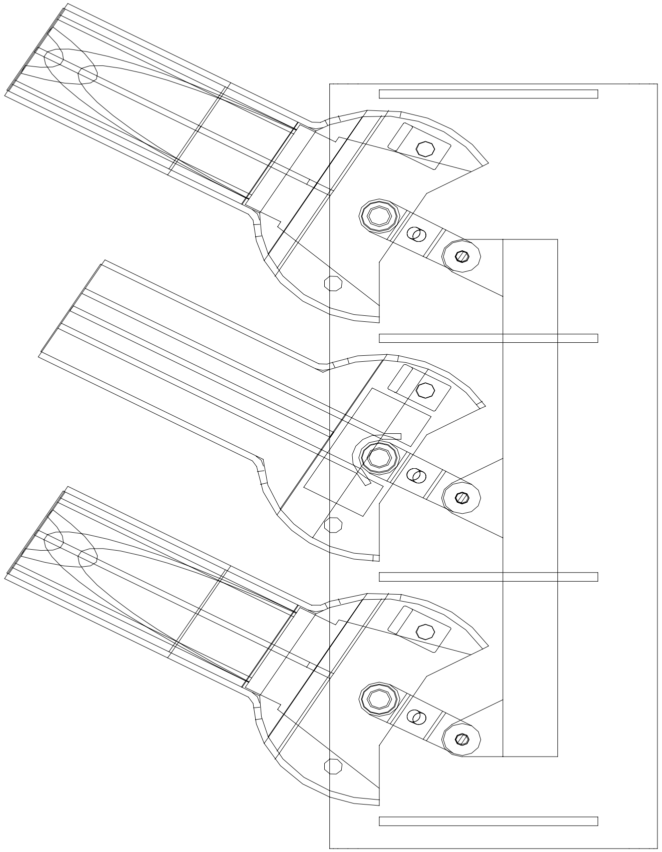


Adjustable Yaw CFS Tips

- Provides more adjustability
- Can provide more oxygen closer to the waterwalls
- Each compartment has it's own independent mechanism



Bulbous Nozzle Tips



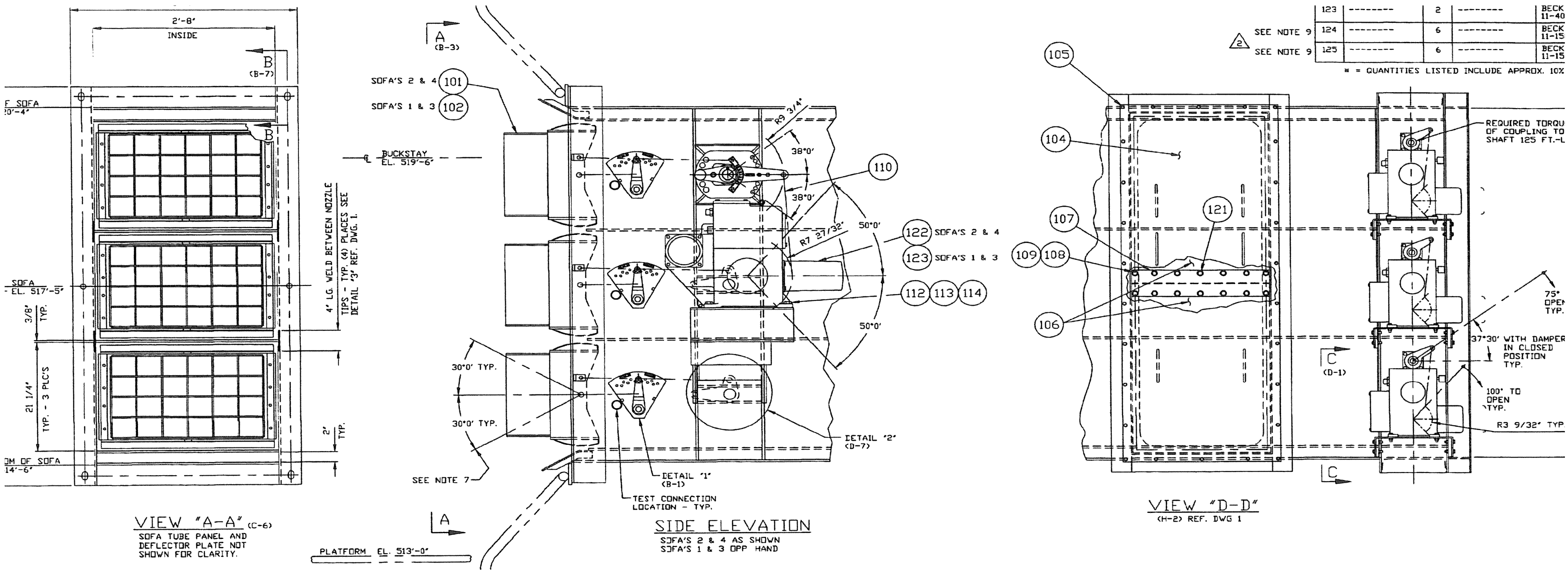
Features:

•Better Airflow Control (even under tilted conditions)

• Optimizes “Jet” Penetration

•Improves Combustion Performance

SOFA Side View



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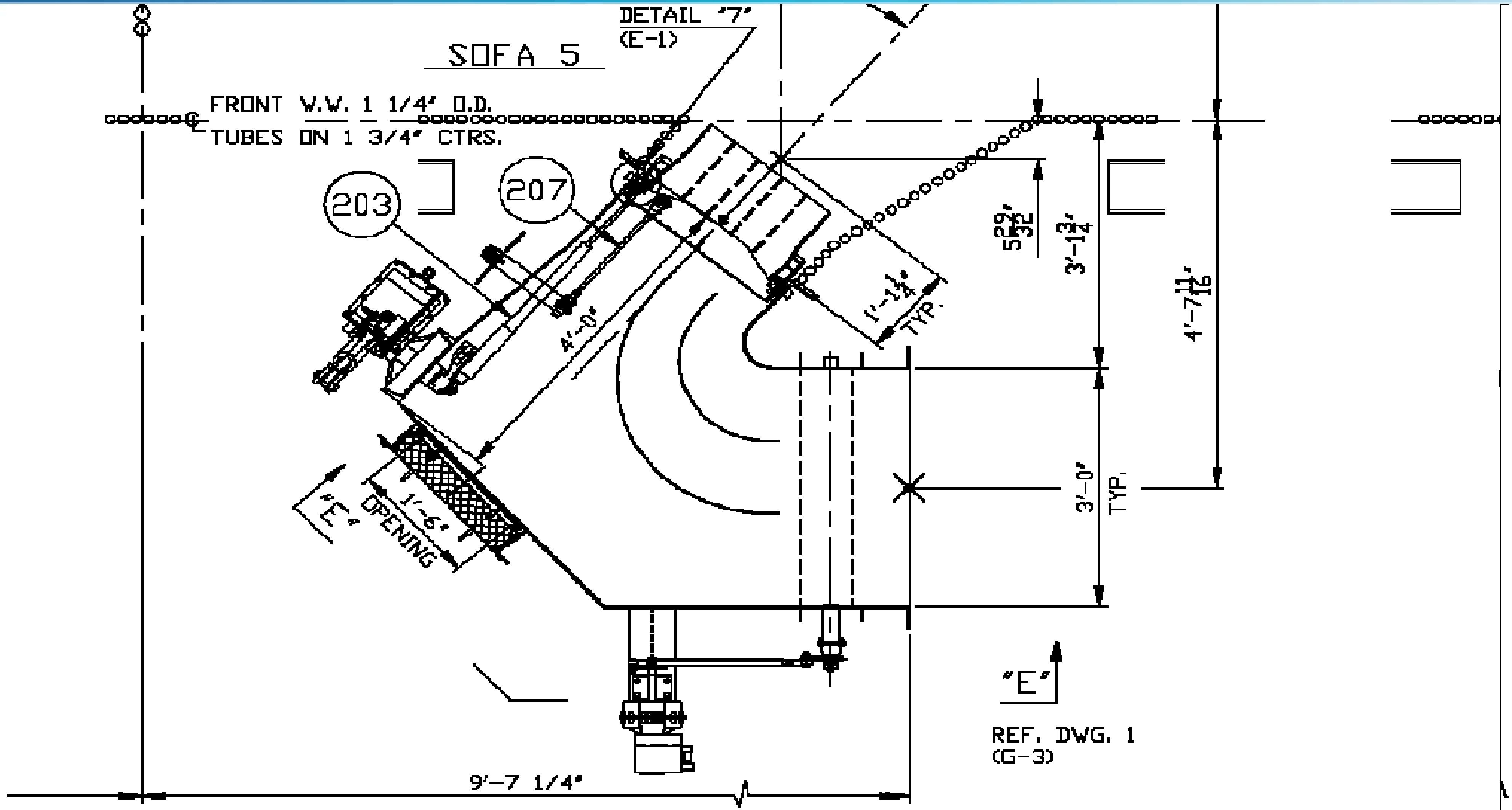
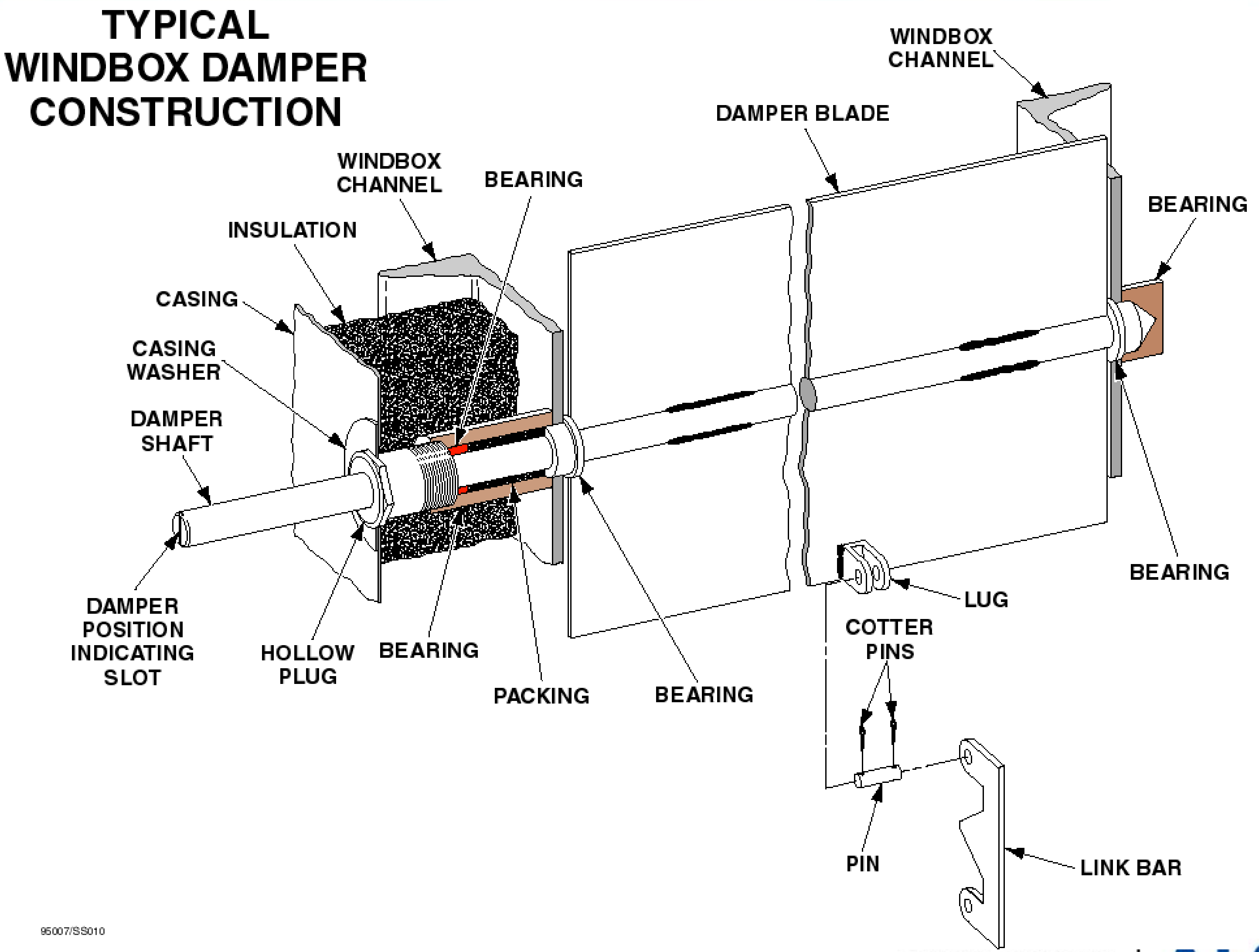
OFA Register - Plan View



Windbox Design:



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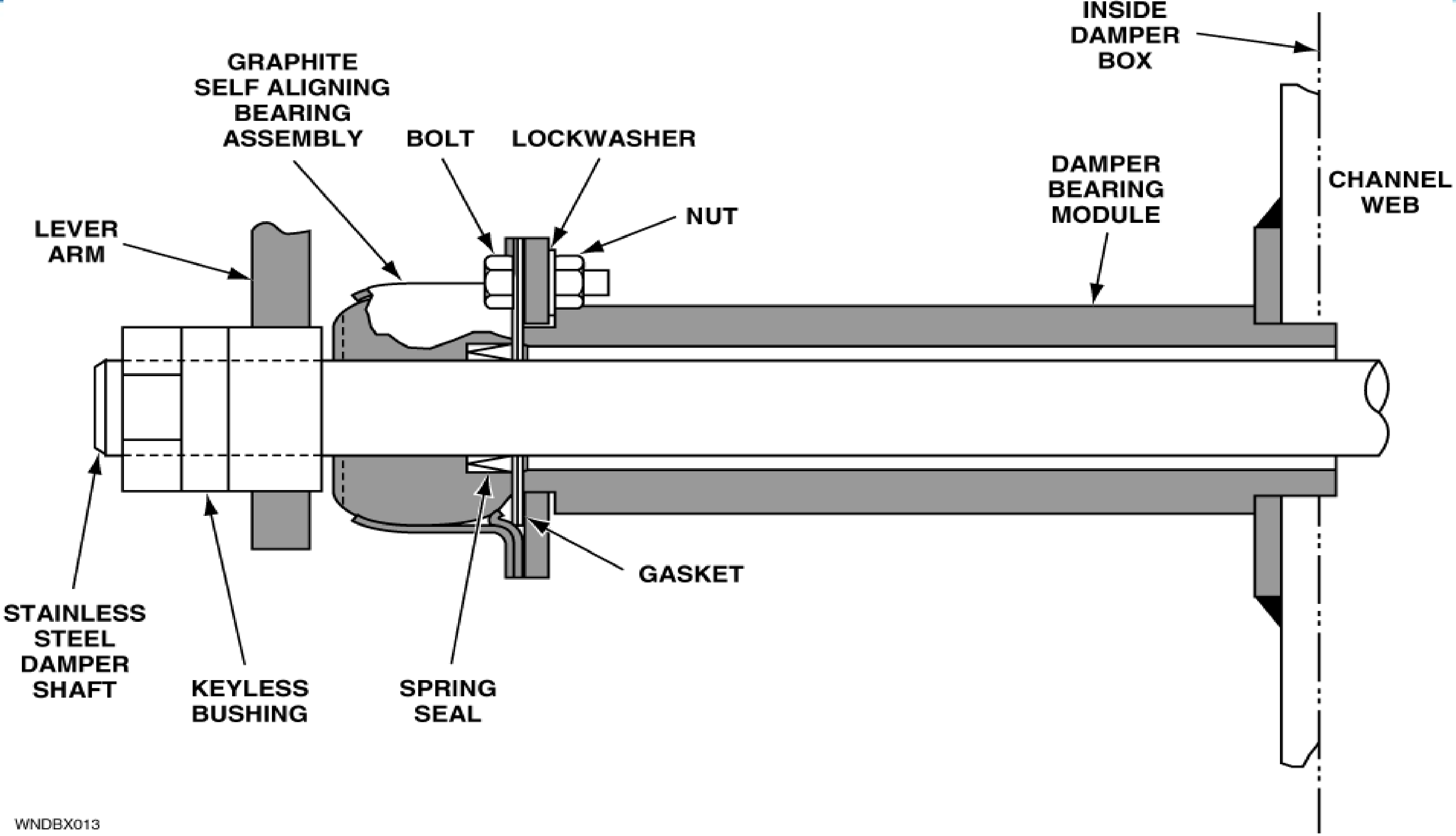
Windbox Design:



SPHERICAL GRAPHITE DAMPER BEARING

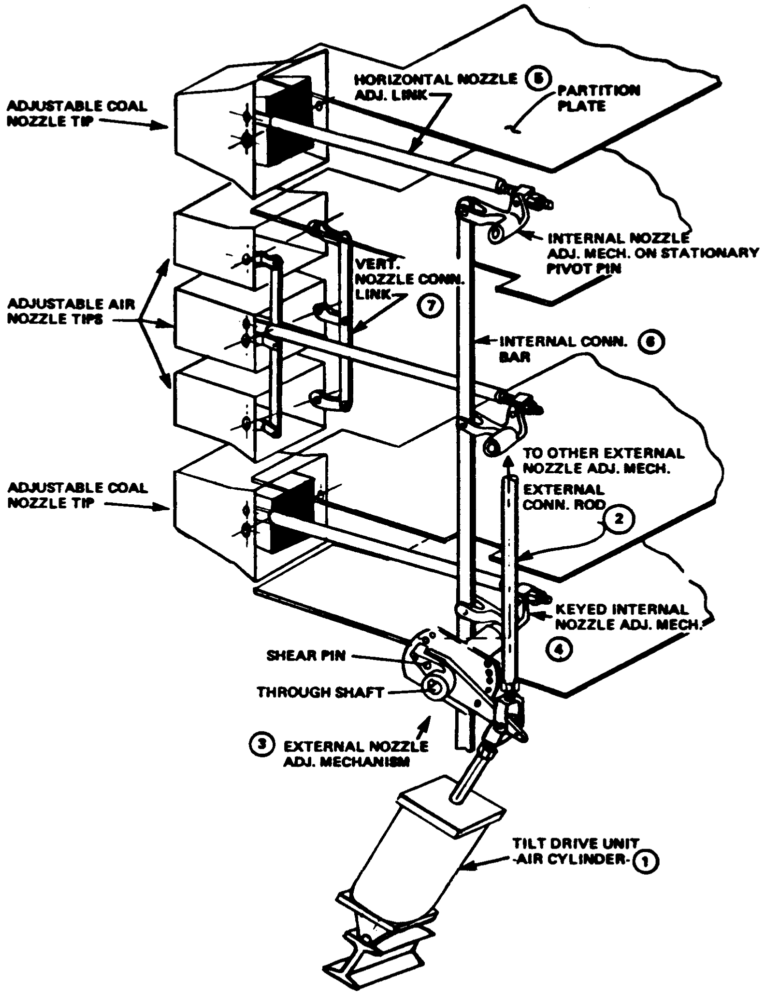
Indirect Drive Tilt Drive System

Major causes of tilt binding:

– Excess coal pipe loading on coal nozzle
– Faulty fabrication, modifications and/ or improper adjustment of windbox internals
– Corrosion and seizing of components
– Lack of trussing

Lesser Causes:

– Excessive slag build up around nozzle tips
– Distorted nozzle tips due to overheating
– Slag crushing



Background to NOx Emissions

Boiler Retrofits

Design Considerations Influencing NOx

Design Characteristics

- Heat Release Rates
- Burner Design & Spacing
- Residence Time
- Furnace Geometry

Fuel Properties

- FC/VM Ratio
- Fuel Nitrogen
- Coal Rank
- O/N Ratio
- Moisture and Ash

Boiler Operation

- Unit Load
- Air Staging – Quantity & Location
- Excess Air
- Air In-leakage
- Mills in Service
- Fuel Biasing
- WB Air Distribution
- PA/Fuel Ratio
- Tilt Position (Steam Temp Control)
- Slagging/Fouling Profiles
- Sootblower Control Sequence
- Other Parameters (CO, UBC, etc.)

Typical Control Curve Characteristics

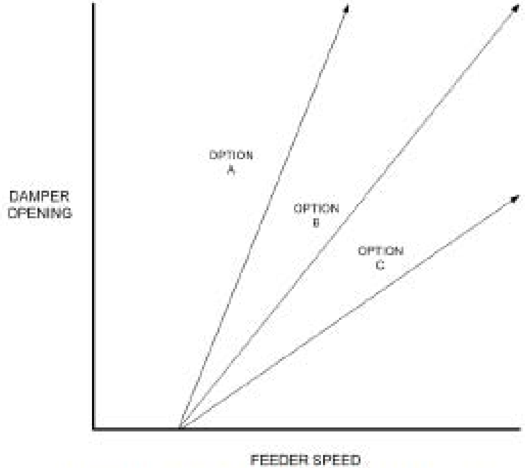


Figure 23: Possible Fuel Air vs. Feeder Speed

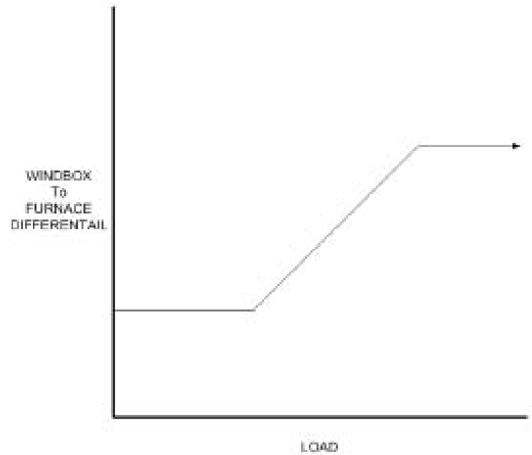


Figure 24: Possible Windbox-to-Furnace Pressure vs. Load

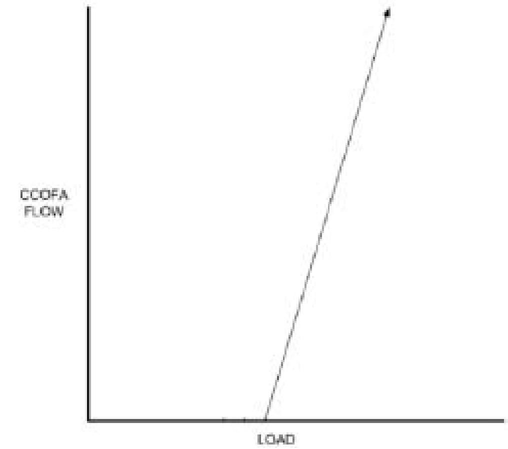


Figure 25: Possible CCOFA vs. Load

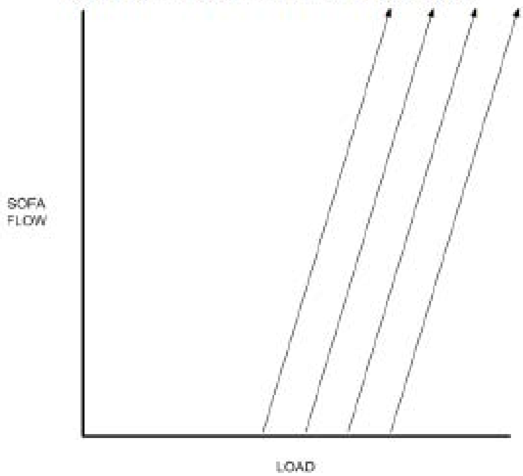


Figure 26: Possible SOFA vs. Load

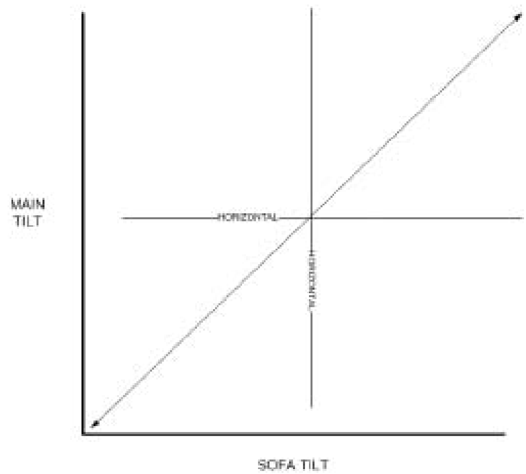


Figure 27: Possible Tilt Control Main vs. SOFA

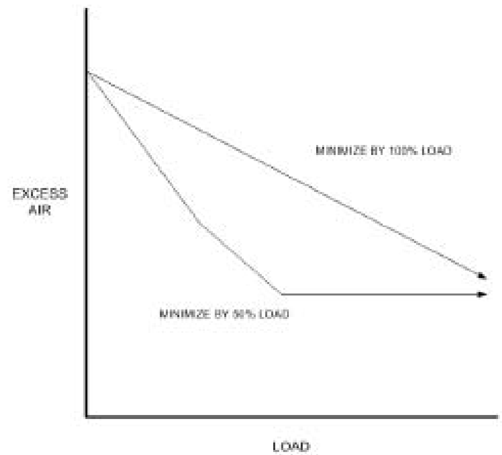
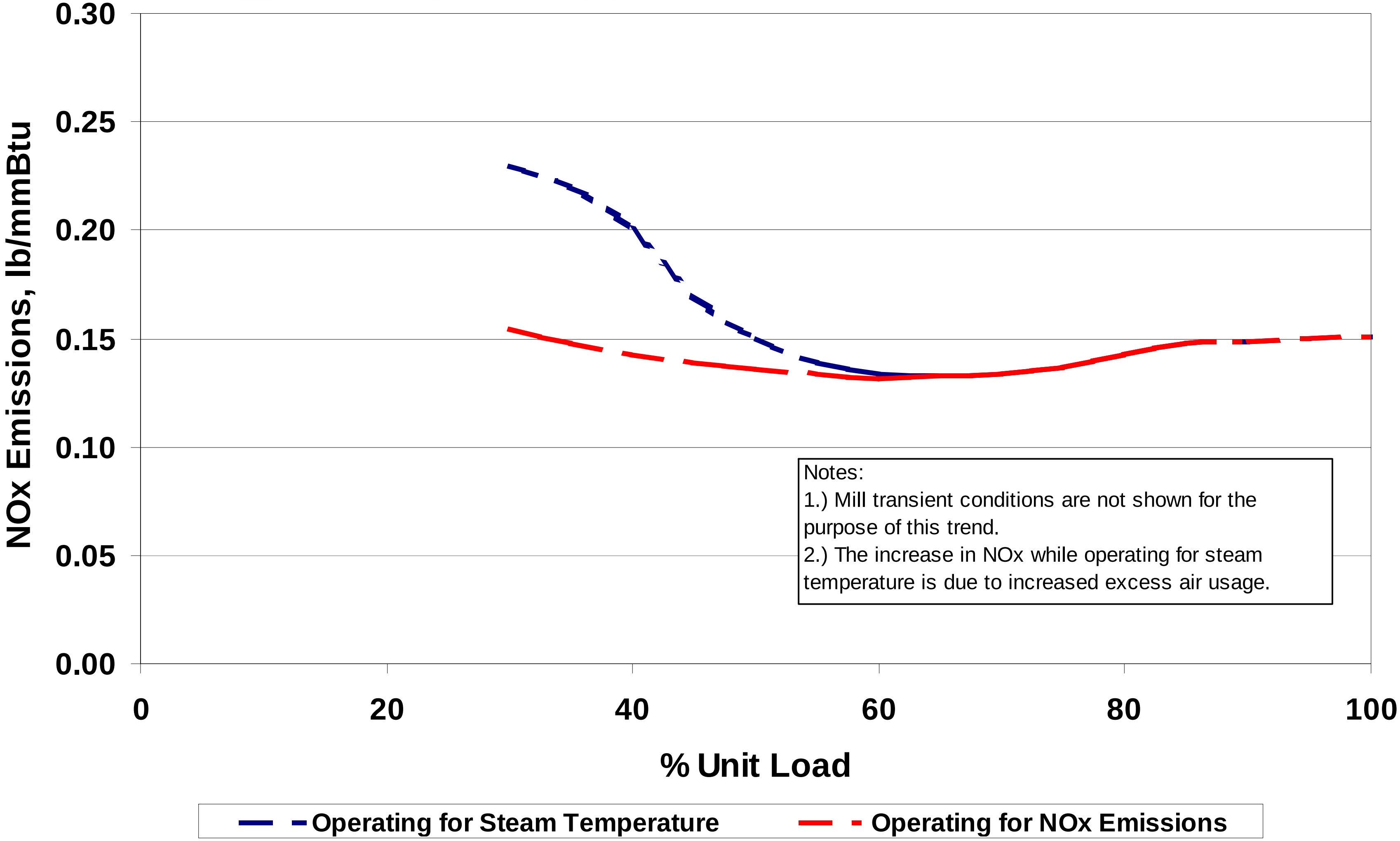
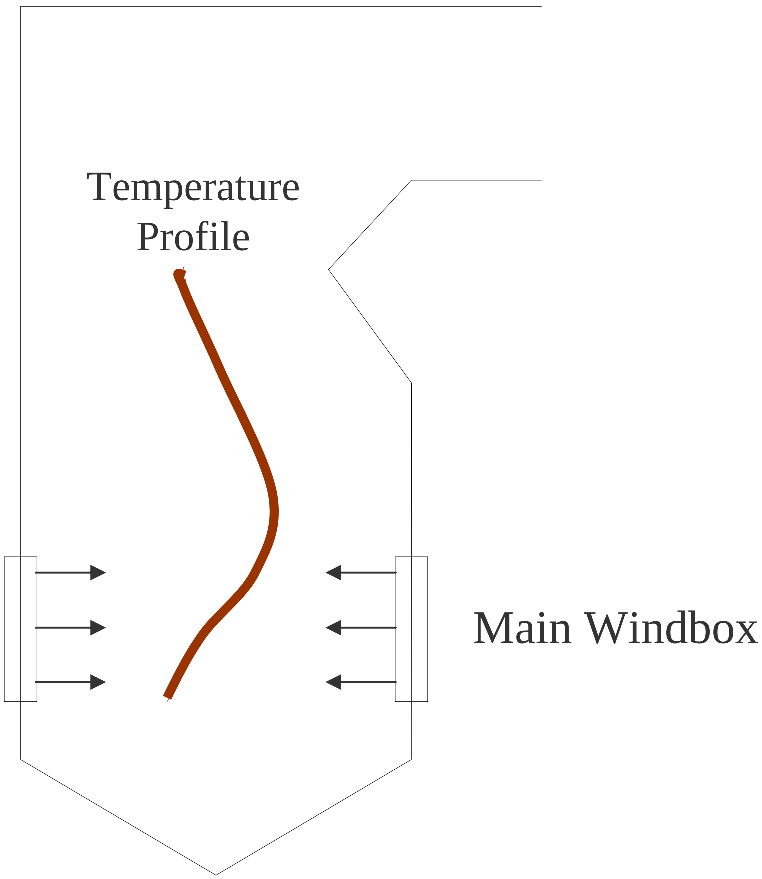


Figure 28: Possible Excess Air Setpoint vs. Load

Typical Trend of NOx versus Unit Load



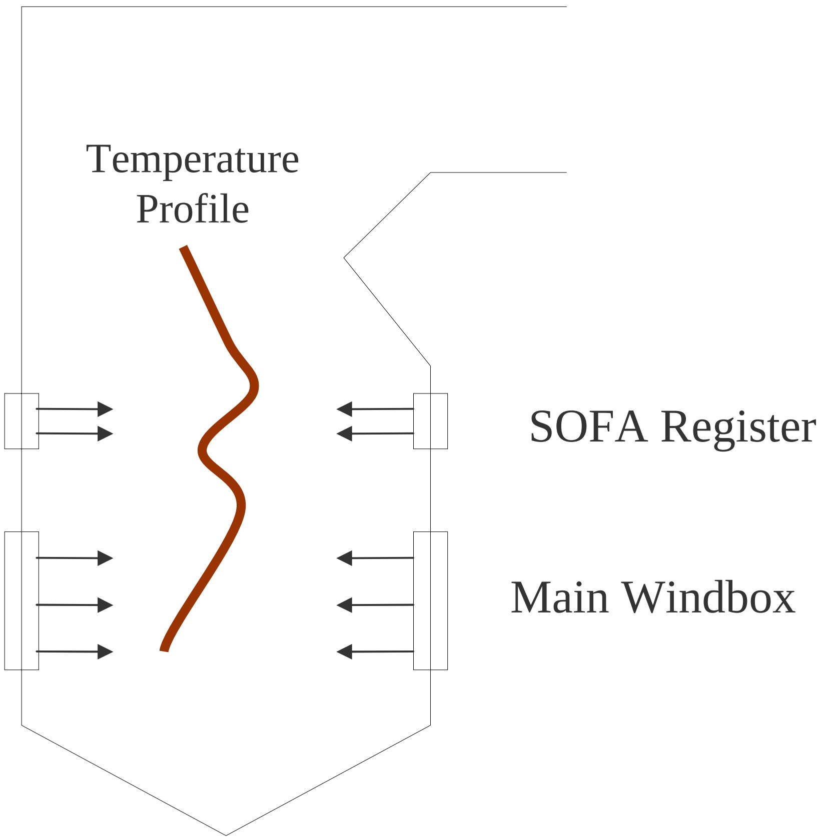
Typical Temperature Profile - Standard Firing System



Temperature Profile

- The temperature profiles to the left indicates the peak temperature occurs just above the main windbox

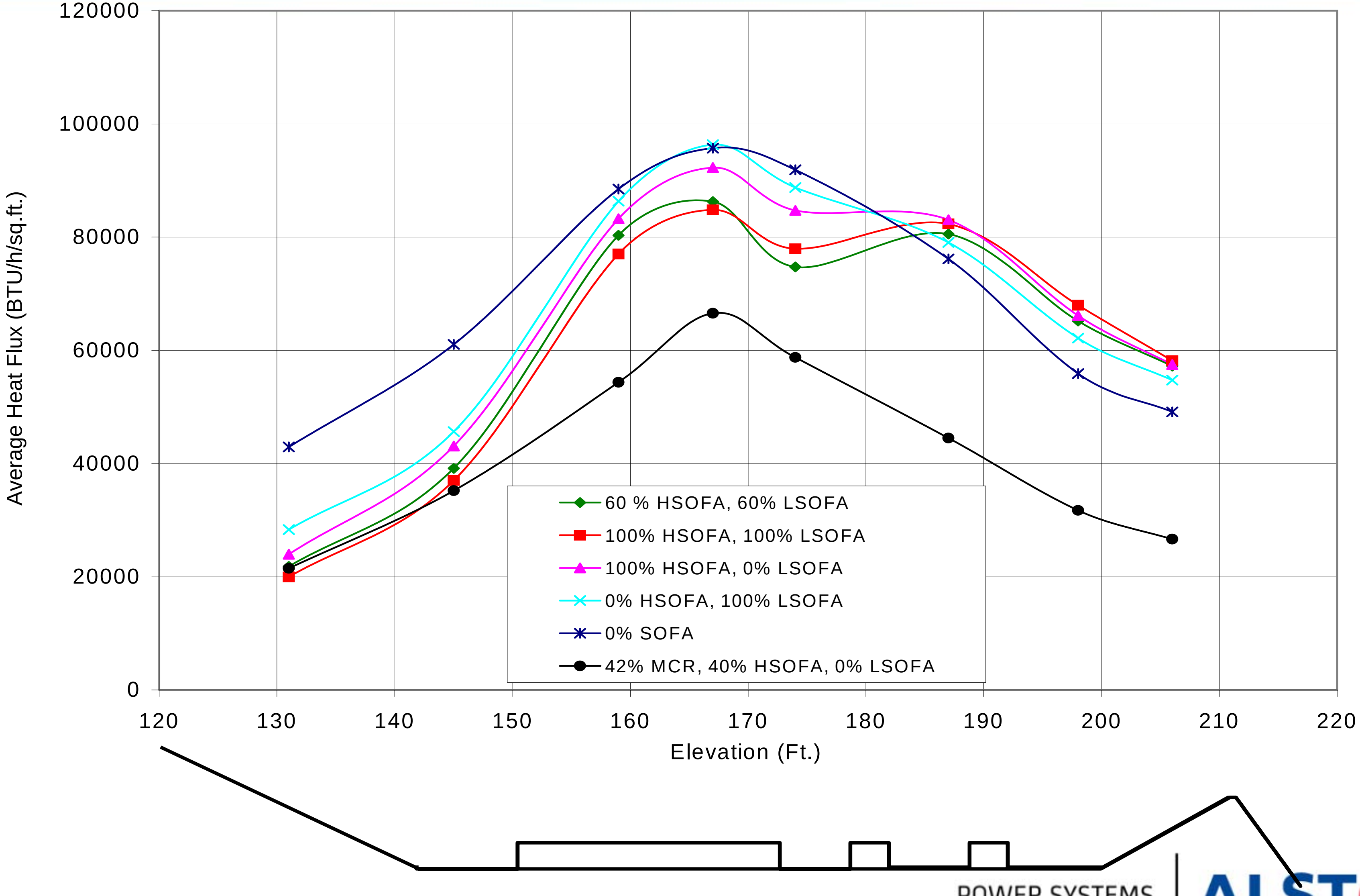
Typical Temperature Profile - Low NOx Firing System



Peak Temperature Reduction

- Same heat input as the unstaged system except the heat is distributed over a greater height

Comparison of Vertical Absorption Profiles

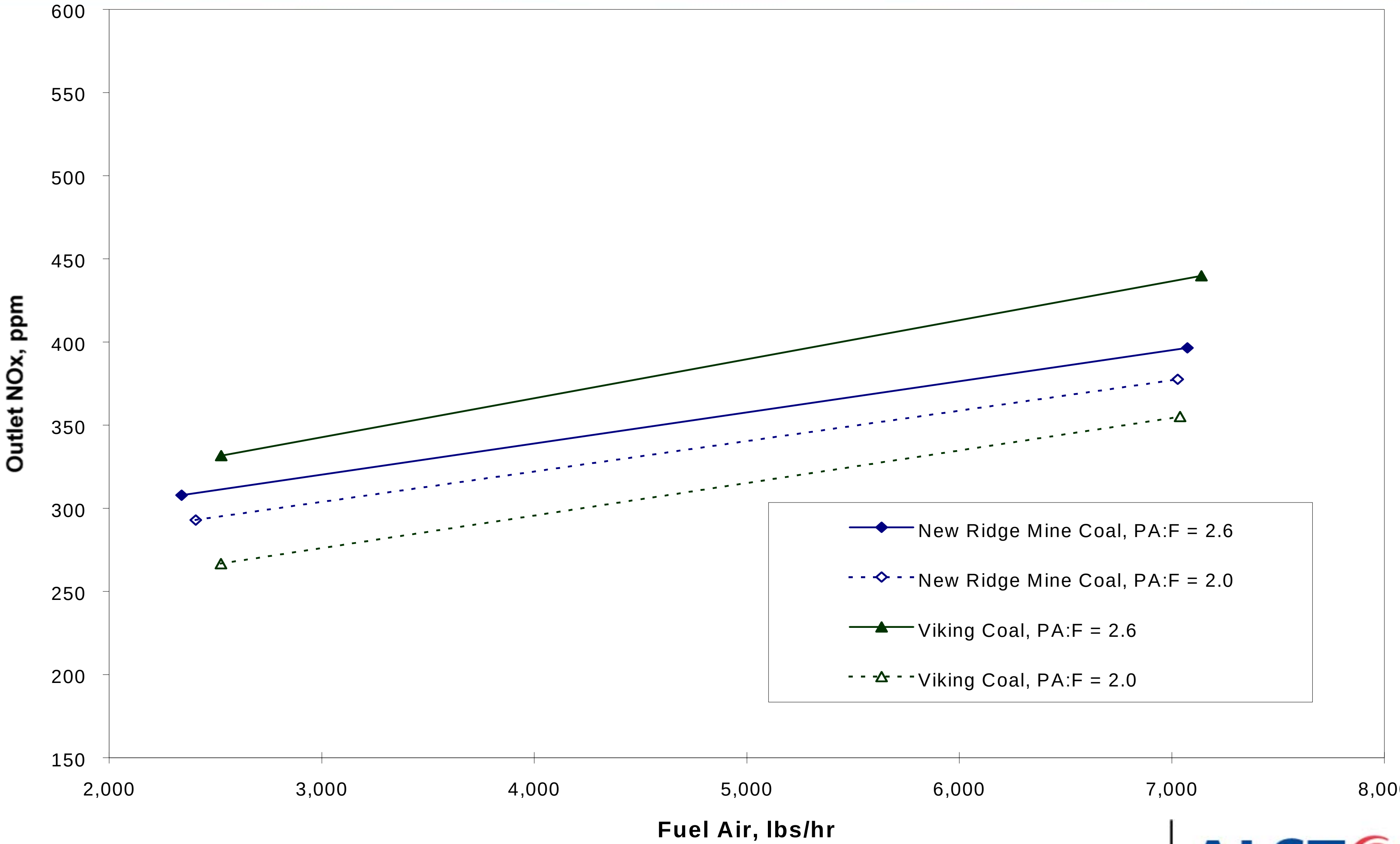


T-Firing Tuning Parameters

- SOFA Flow
- CCOFA Flow
- OFA Bias
- SOFA Tilt
- Main Tilt
- SOFA / Main Tilt Bias
- WB/Furn dP
- Fuel Air Damper

- Mills in Service
- Primary Air Flow
- Fuel Feed Bias
- Secondary Air Bias
- Sootblower Rate or Sequence
- Yaw Position
- Boiler Load
- Individual Corner Tilt Bias

ISBF Test Data - Effect of Primary Air



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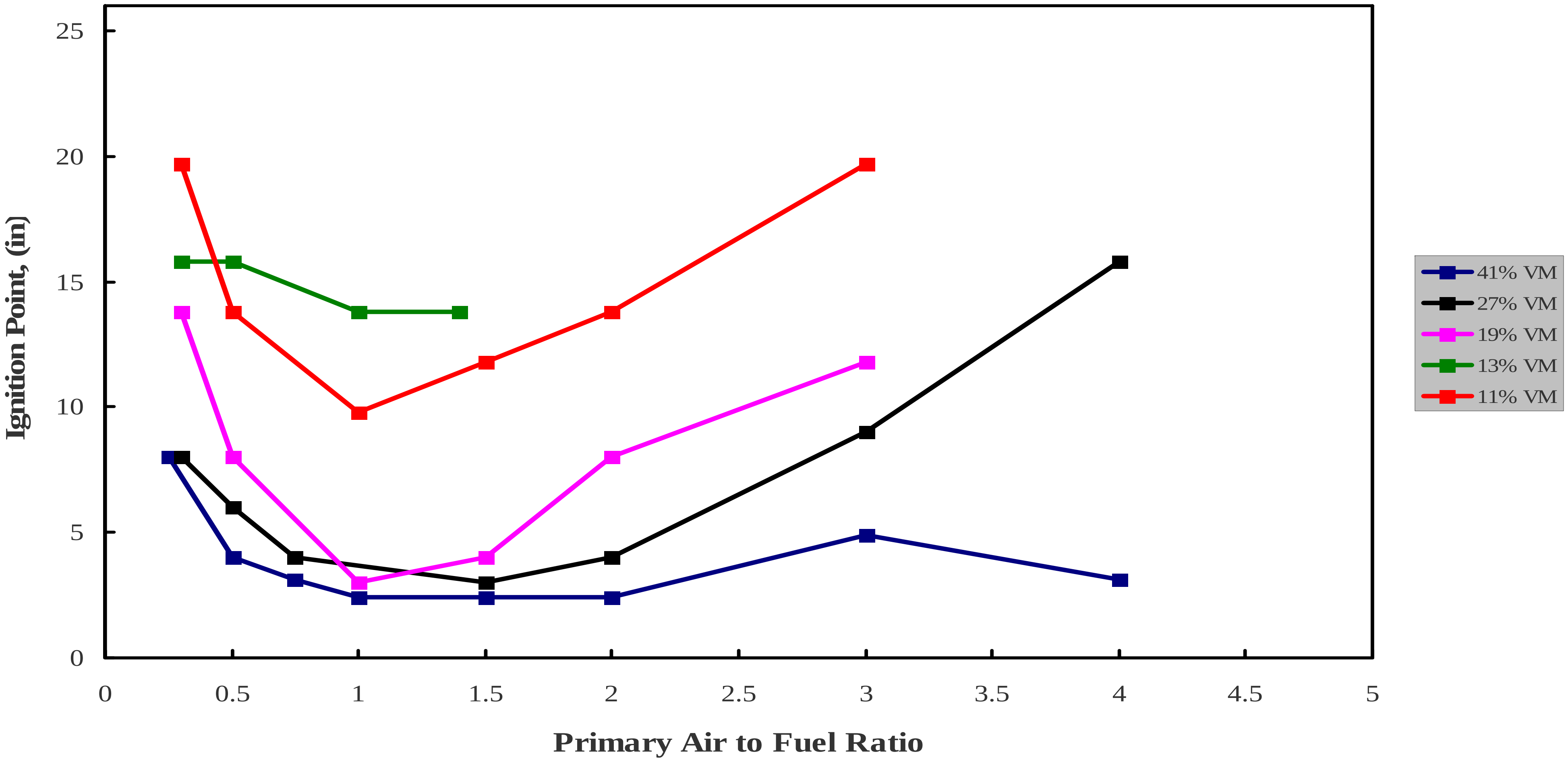
Effect of Primary Air Ratio on Ignition Point



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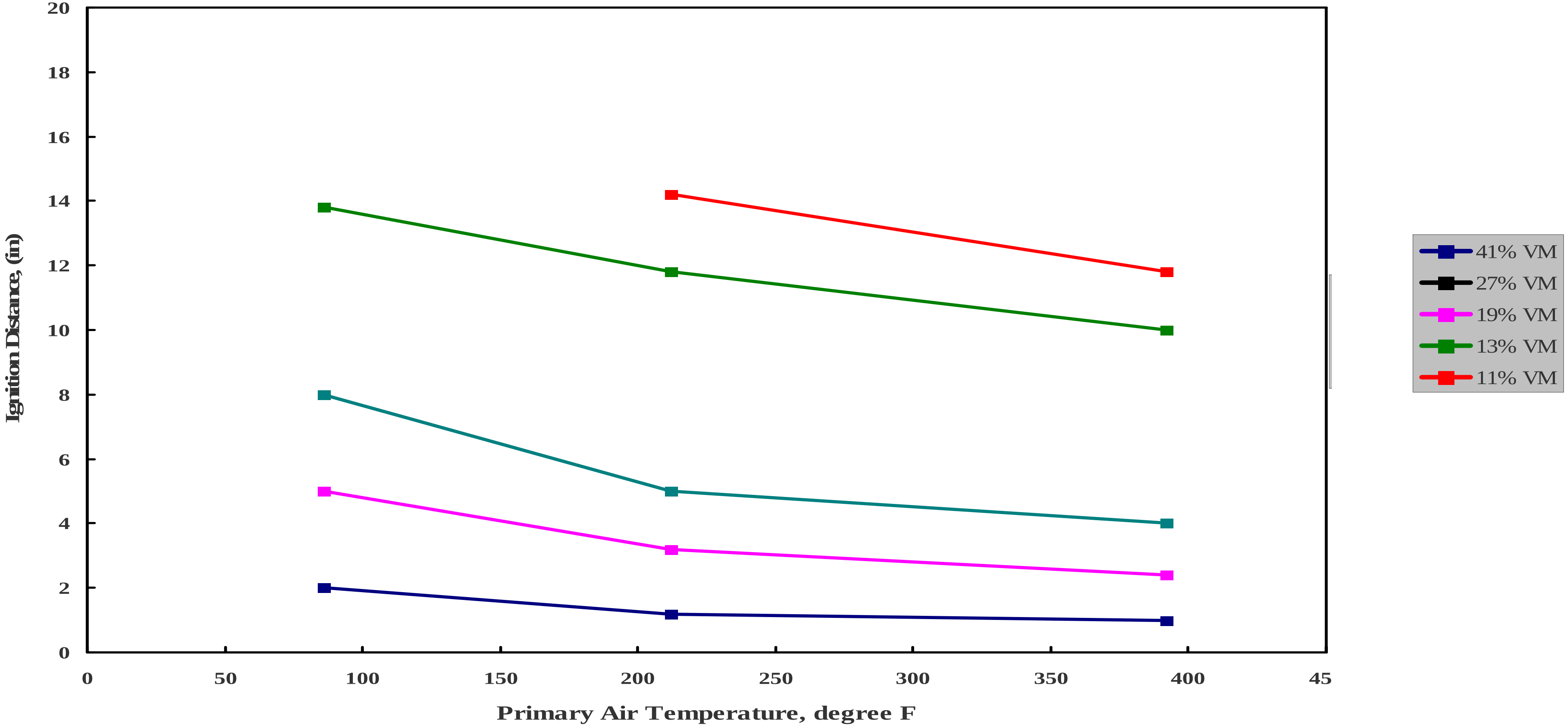
Effect of Primary Air Temperature on Ignition Point



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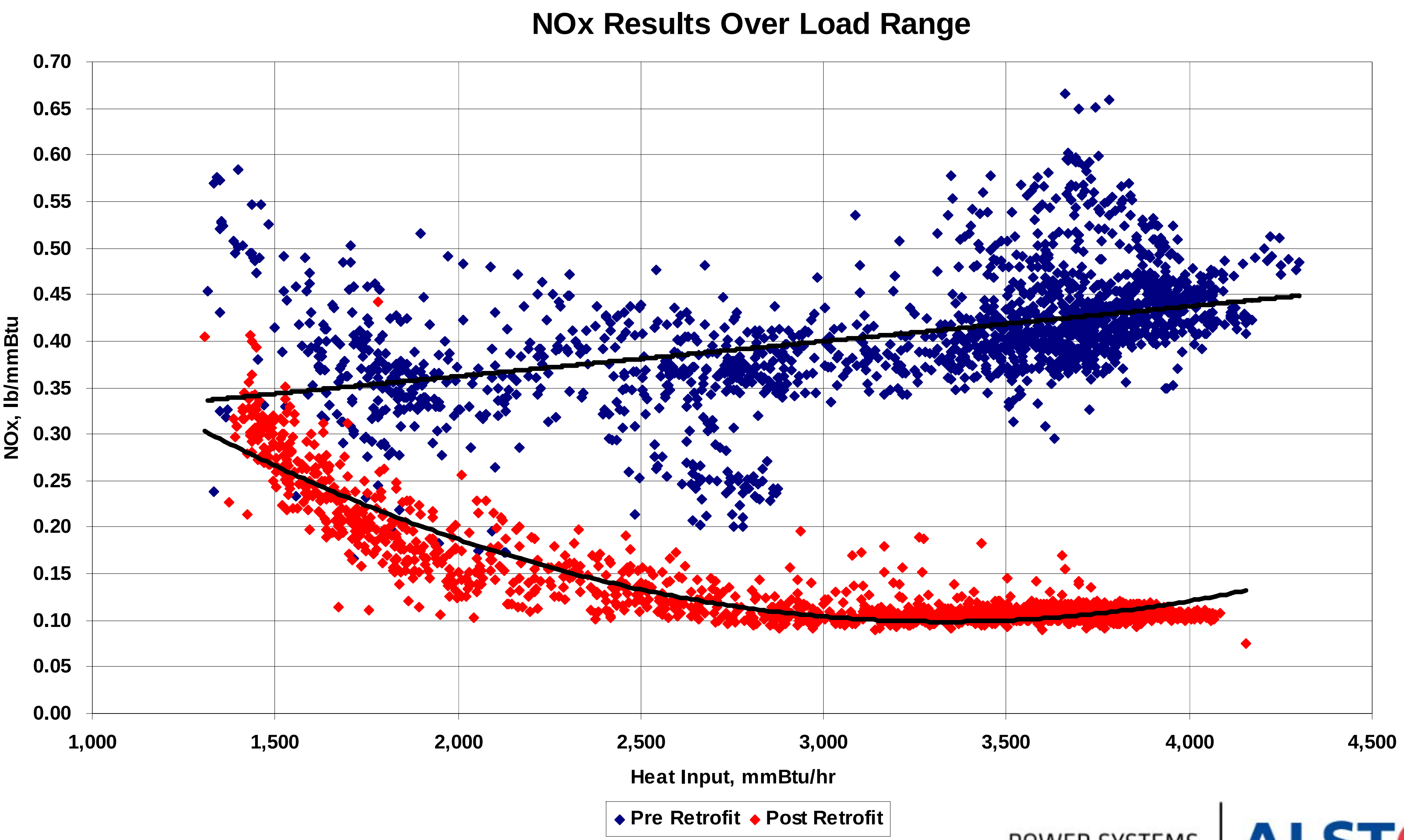
Why Balance Flows?

- Accurate control of coal and air flow distribution may provide benefits such as:
  - Lower NOx emissions
  - Reduced carbon-in-ash
  - Lower CO levels
  - Improve Temperature Profiles
  - Improve Flue Gas Distribution
- Operational problems and accelerated wear can be attributed to imbalanced coal flow.
- Existing riffle distributors and static orifices are difficult to set up, and have limited success

Why Balance Flows? (con't)

- Better secondary air flow control may allow the plant to operate at reduced O_2 (improved efficiency)
- Better control of the combustion process may help control slagging/fouling problems and help correct temperature imbalances
- The ability to precisely control firing system parameters will give operators the option to operate the unit for maximum economic advantage (i.e., NOx, efficiency, load…)

Pre & Post Low NOx – PRB Coal



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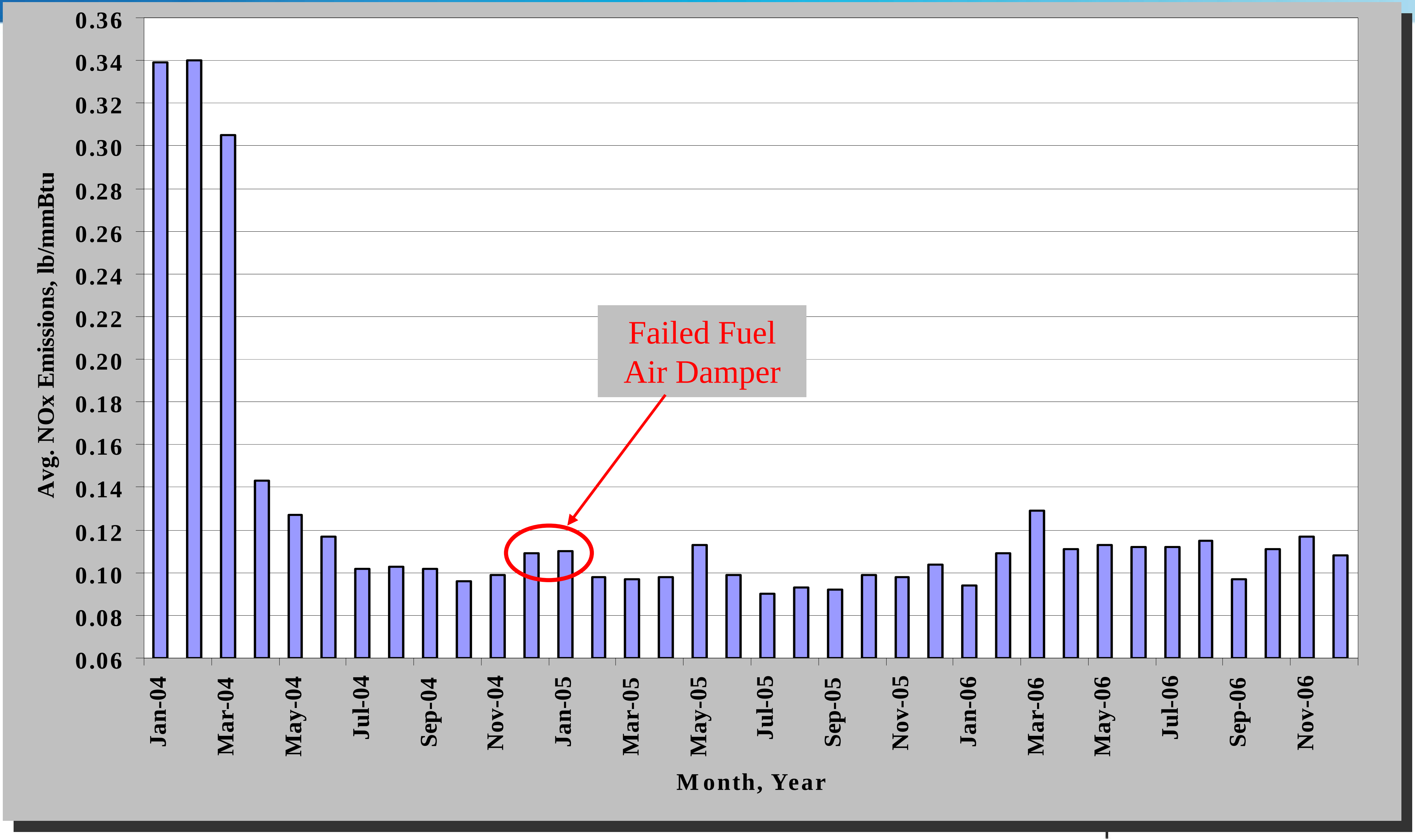
Possible Solutions for Improved Performance

- Increase Number of O2 Probes (Grid)
- Modify Excess Air Control from ‘Fixed’ to ‘Variable for Mills in Service’
- Add Stoichiometry Limit
- Add CO Trim
- Experiment with Individual Tilt Bias
- Evaluate Different Sootblowing Control Sequence
- Fuel and/or Air Balancing *
- Trend Data
- Dedicated Maintenance Program

Unit 'X' Average Monthly NOx Emissions



Background to CO Emissions

Boiler Retrofits

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Key Parameters Effecting CO Emissions

- $2C + O_2 \Rightarrow 2CO + heat + O_2 \Rightarrow 2CO_2 + heat$
- CO Emissions can be a Result of Being Diffusion Limited (Mixing) or Kinetically Limited (Temperature)
- CO Levels Below Approx. 1200 °F Become Kinetically Limited
  - Furnace Temperatures are Above 1200 °F
  - Therefore, CO Emissions Emitted from a Furnace are a Result of Being Diffusion Limited
- Mixing of the Products of Combustion with O2
  - Requires Sufficient O2 Concentration
  - Need for Turbulence (Mixedness)
  - Velocity of Fuel & Air Jets
  - Good Furnace Coverage
- Fact! - 1000ppm = 0.1% of all product gases

CO Emissions in Boilers

Primary Factors

- Boiler O_2
- Furnace In-leakage
- Turbulence (Mixing) - WB/Furn, damper settings, etc.

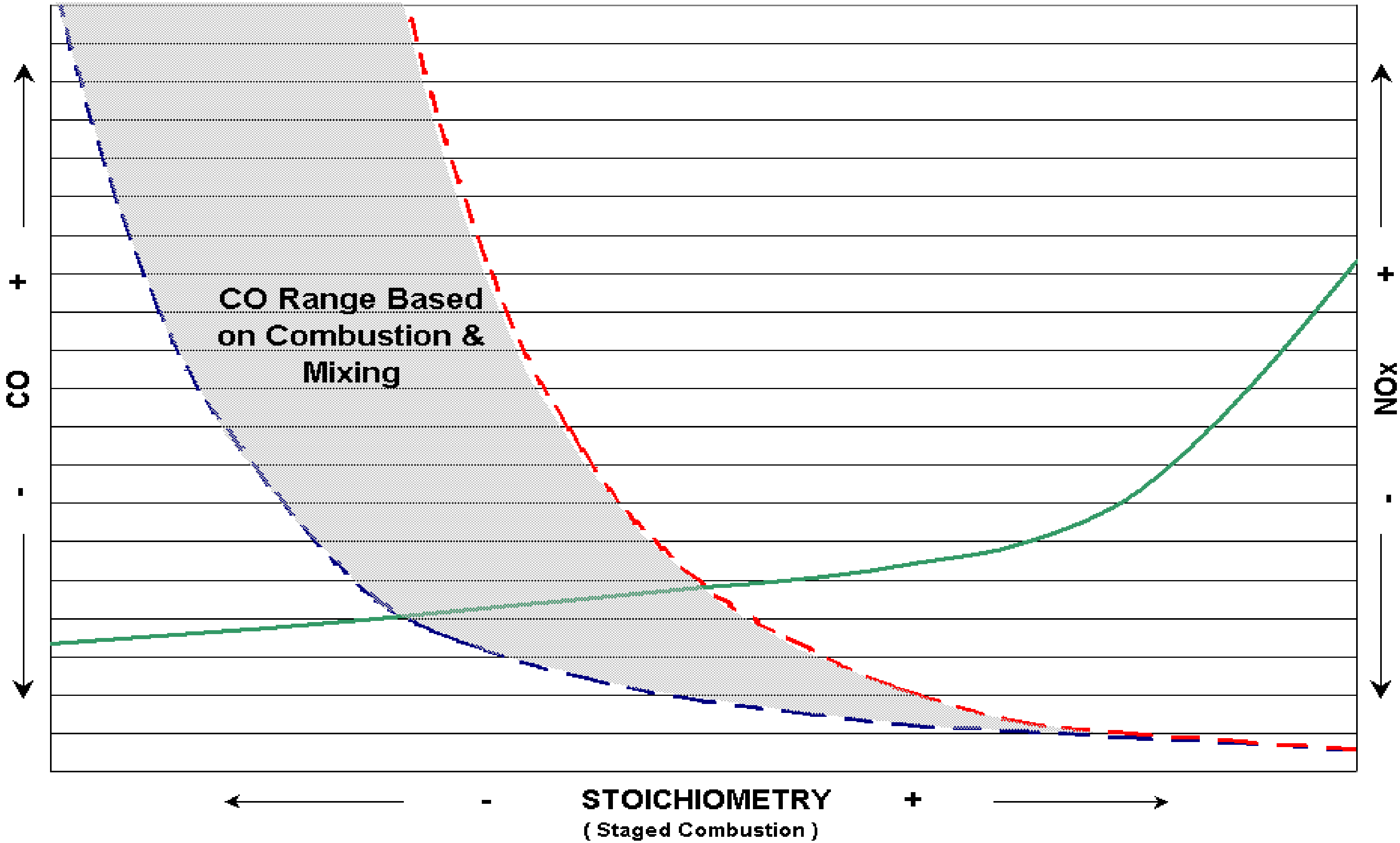
Secondary Factors

- Residence Time - Tilt, burners in service
- Balancing - Fuel and/or Air
- Mill Performance - Primary air flow
- Coal Fineness

Possible Solutions to Mitigate CO Emissions

- New, Improved Burner Design
- New or Re-tipped FD Fan
- Incorporate a Boost Fan
- Operate with Higher Excess Air Level
  - May Necessitate New, or Re-tipped Fan
  - Adversely Affects NOx Emissions
- Reduce the Amount of Air Infiltration (if balanced draft)

Typical Trend of CO versus NOx Emissions



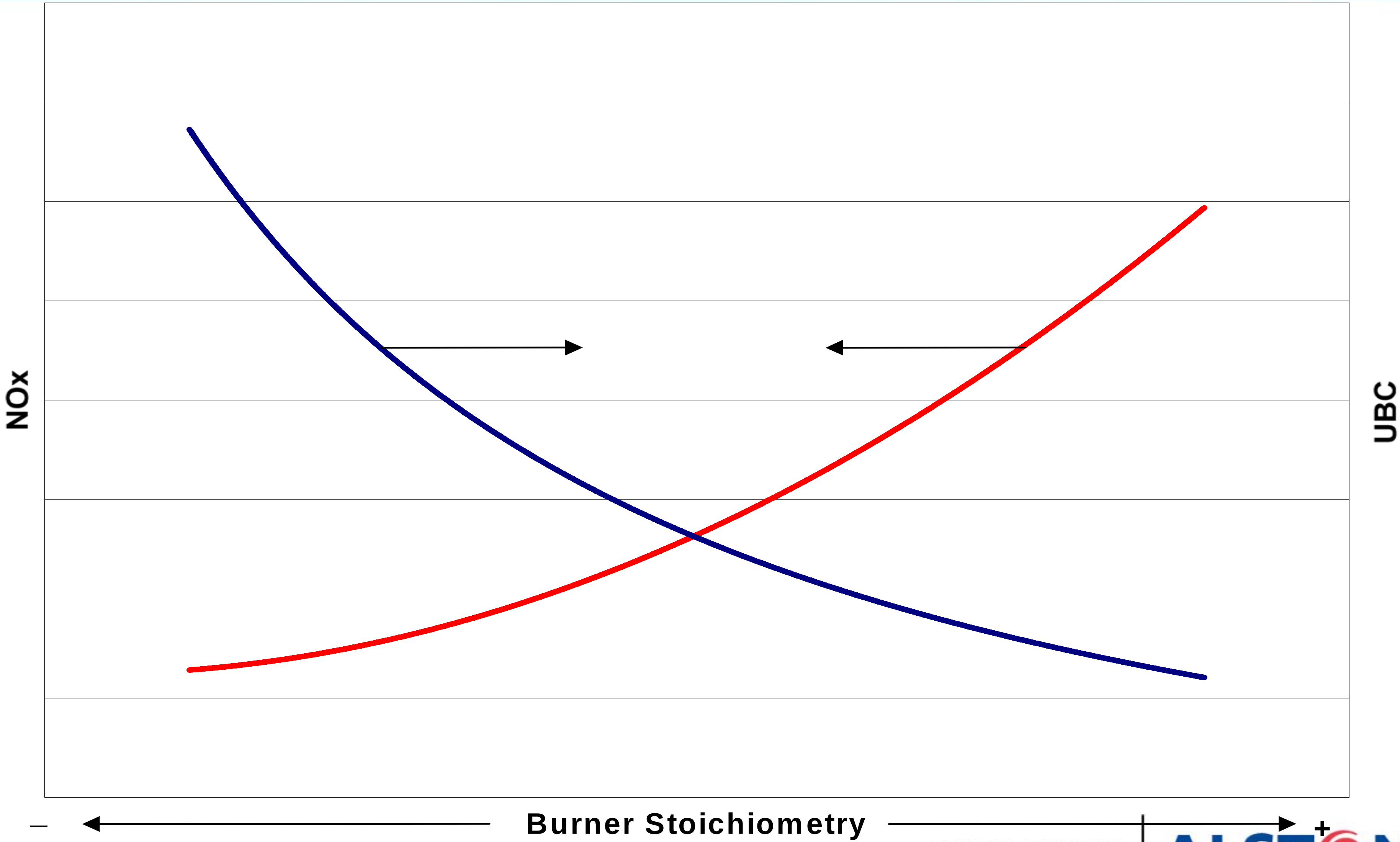
Background to UBC in Fly Ash

Boiler Retrofits

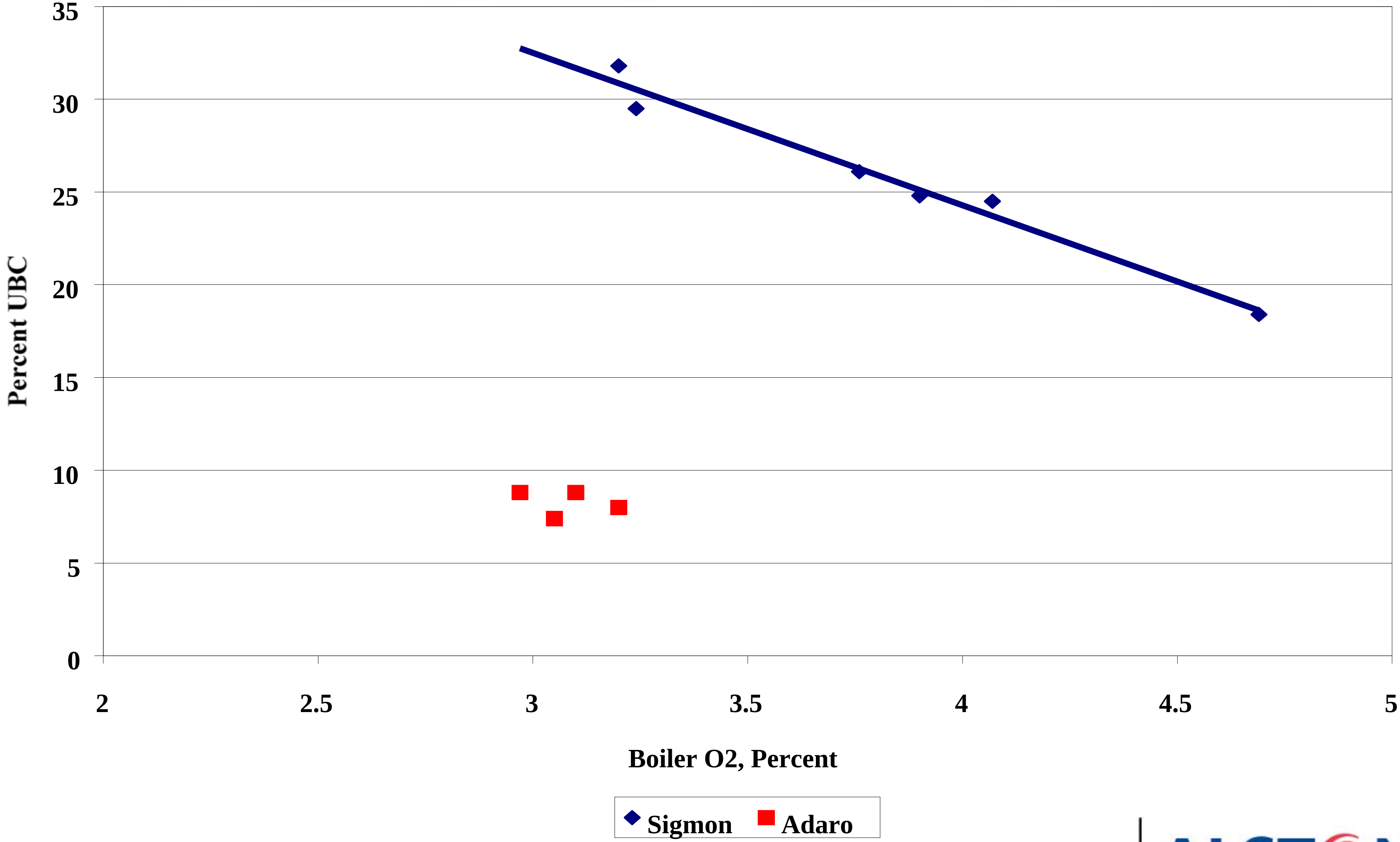
Factors Affecting UBC in Fly Ash

- Fuel Rank / Reactivity
- Ash Content (Ash Loading lb/mmBtu)
- Fineness
- Residence Time (Tilt)
- Excess Air
- Turbulence
- Localized Air-to-Fuel Ratio

Relationship of NOx and UBC vs Stoichiometry



UNIT 'X' Test Burn Results - UBC vs O_2



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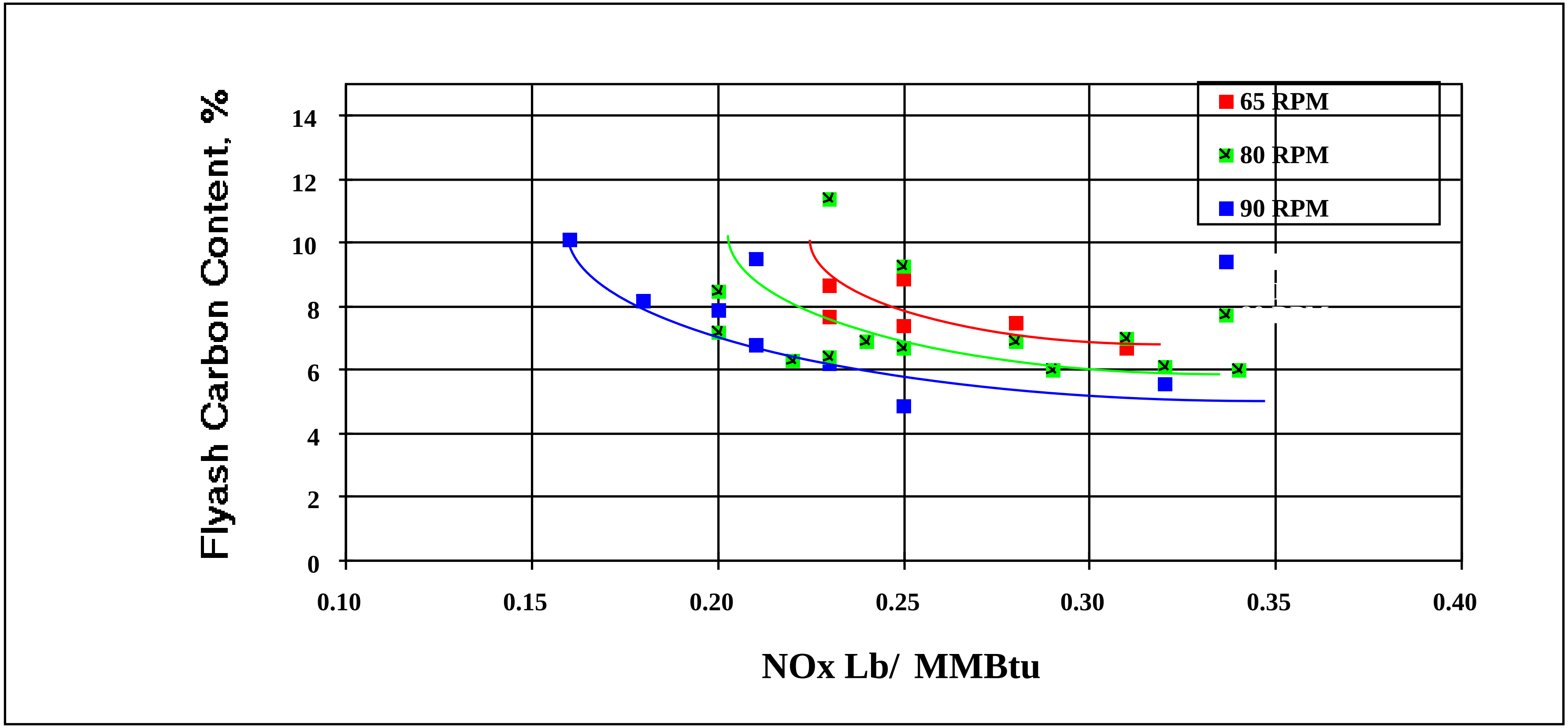
Effect of Particle Size

Finer Coal Particles Improve:

- Flame Stability by increasing overall surface area for oxygen diffusion and heating of coal
- Unburned carbon levels in fly ash

NOx and UBC Results with an Eastern Bit. Coal

Carbon in Flyash vs . NOx at MCR
Dynamic Classifier Operation



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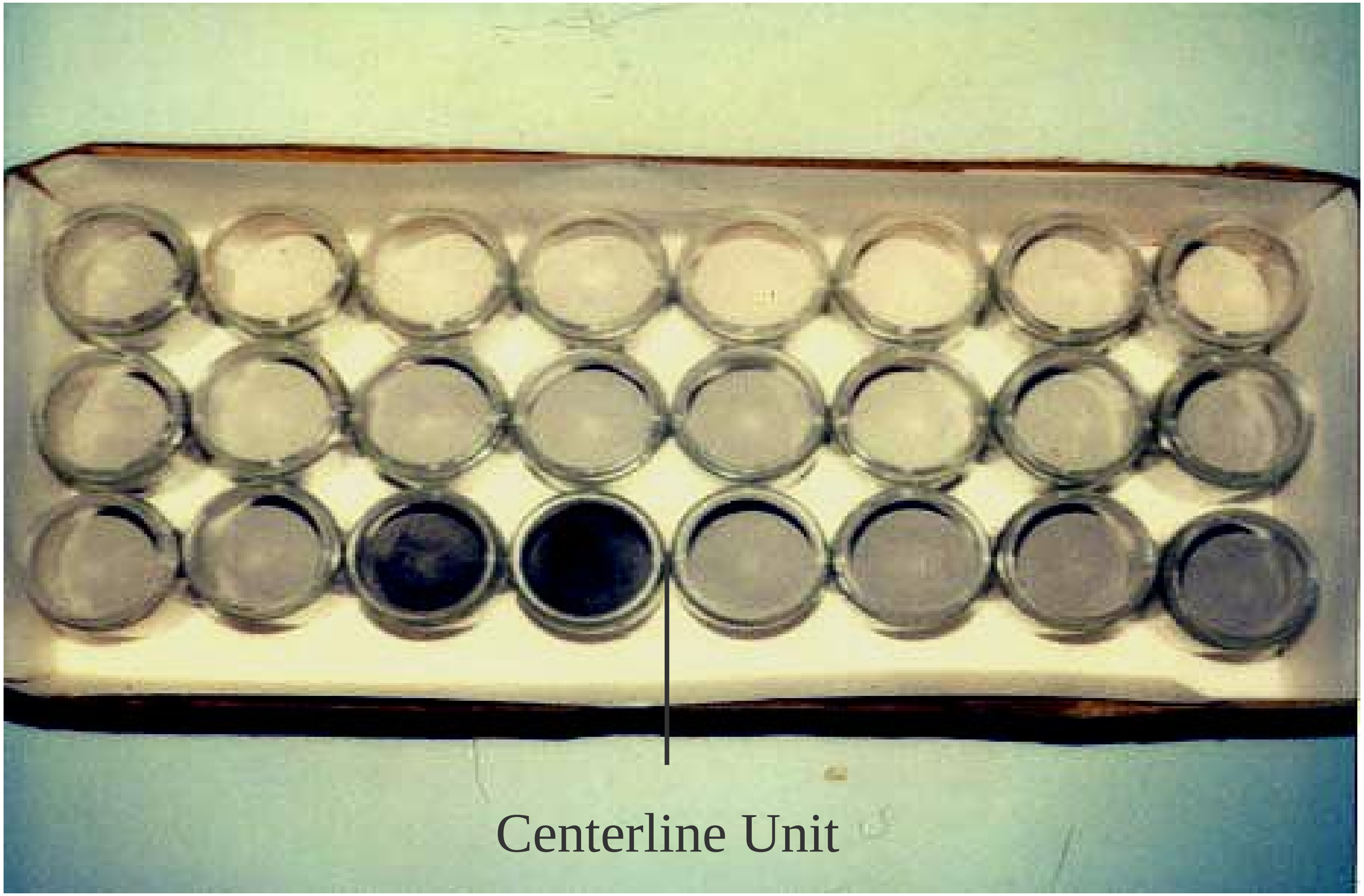
PRECIPITATOR HOPPER
FLY ASH SAMPLES

Precipitator Hopper

Third Field

Second Field

First Field



Gas Flow

Left

Eight (8) Hoppers

Right

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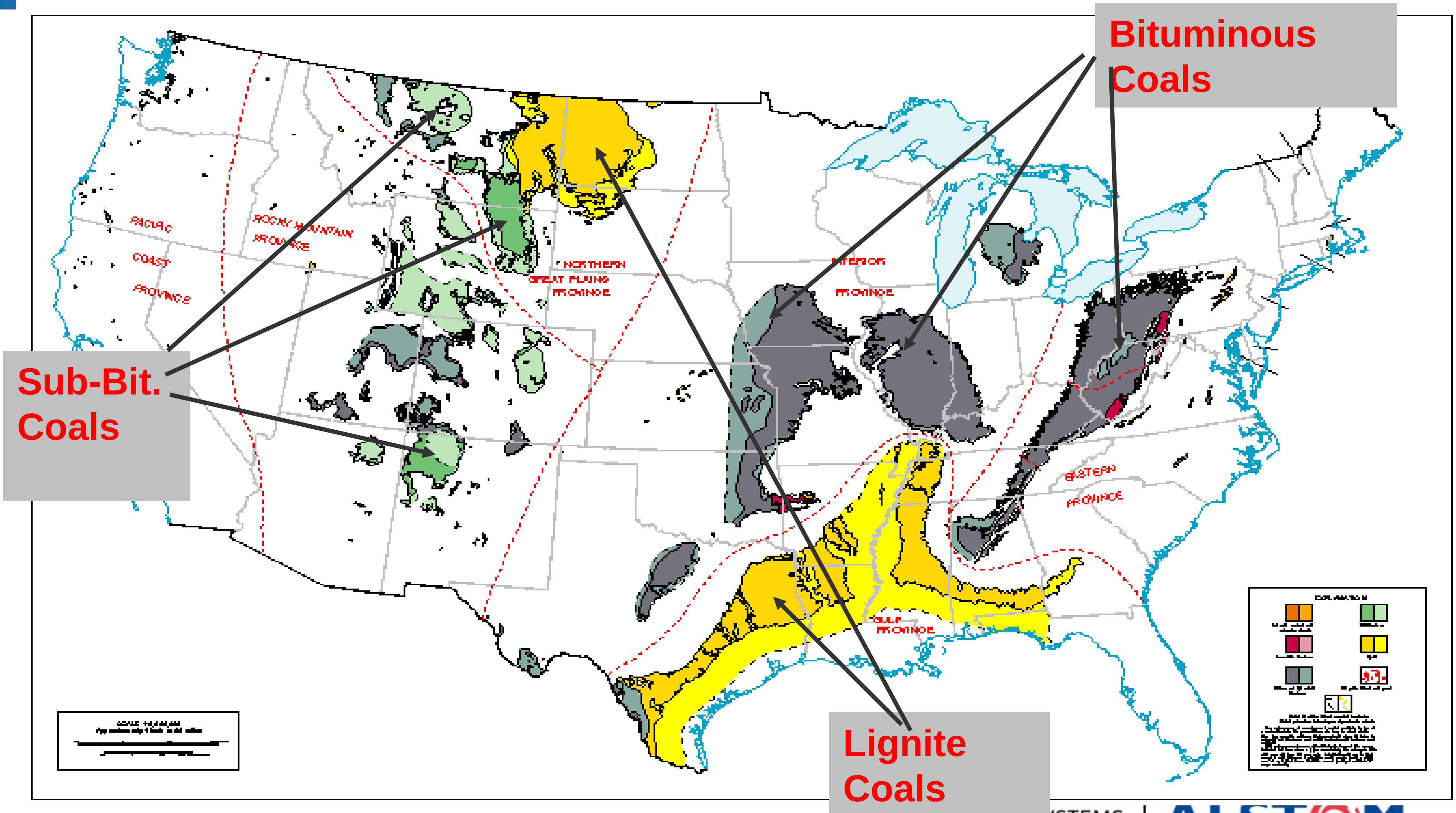
Coal Fundamentals

Boiler Retrofits

Coal Facts

- Coal and Coal Ash are Very Heterogeneous
- The ASTM Test Procedure for Ash Composition Just Provides Standard Mineral Matter Oxides
- Much of Our Knowledge About Problematic Coals is Empirical
- Blending Coals Can Form Eutetics
- There is No Known Single Indice for Problematic Coals

Coal Fields of the U.S.



Coal Analysis

Proximate Analysis

- Moisture
- Volatile Matter
- Fixed Carbon
- Ash

HHV (Higher Heating Value)

Ultimate Analysis

- Moisture
- Hydrogen
- Carbon
- Sulfur
- Nitrogen
- Oxygen
- Ash

HHV

Ash Composition

- SiO_2
- Al_2O_3
- Fe_2O_3
- CaO
- MgO
- Na_2O
- K_2O
- TiO_2
- P_2O_5
- SO_3

Fusion Temp.s

- I.T
- S.T.
- H.T.
- F.T.

Hardgrove Grindability Index (HGI)

Typical Coal Analyses

	E. bit.	Hi-vol B bit.	Hi-vol C bit.	Sub bit. A	Sub bit. B	Sub bit. C	TX Lignite
H_2O	5.00	6.28	13.12	14.09	25.00	27.30	33.06
VM	33.10	37.49	34.91	33.75	32.43	31.90	26.75
FC	53.50	46.35	45.78	37.58	38.23	36.40	27.47
Ash	8.40	9.88	6.19	14.58	4.00	4.40	12.72
Hydrogen	5.00	4.68	4.22	4.12	3.72	3.49	3.02
Carbon	71.70	67.70	61.58	55.70	53.88	51.18	39.45
Sulfur	1.30	0.48	0.36	0.48	0.34	0.21	1.99
Nitrogen	1.60	1.38	1.23	0.98	0.72	0.73	0.67
Oxygen	7.10	9.60	13.30	10.05	12.32	12.71	9.09
HHV	12,959	12,000	10,861	9,674	9,350	8,800	6,935
HGI	45	55	55	50	50	60	50
FC/VM	1.62	1.24	1.31	1.11	1.18	1.14	1.03
HHVdaf	14964	14313	13461	13562	13169	12884	12790
lb S/MBtu	1.00	0.40	0.33	0.50	0.36	0.24	2.87
lb N/MBtu	1.23	1.15	1.13	1.01	0.77	0.83	0.97
lb A/MBtu	6.5	8.2	5.7	15.1	4.3	5.0	18.3

Coal Analysis

	Mine / Seam	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
Proximate	Moisture	6	5.88	15.69	25.7	25.3	31.8
	VM	32.4	33.79	31.9	32.2	32.43	27.9
	FC	53.4	51.66	37.11	38.1	38.23	23.7
	Ash	8.2	8.67	15.29	4	4	16.6
HHV	HHV	13110	13009	9526	9004	9350	6476
Ultimate	H	4.8	4.92	3.83	3.4	3.72	2.8
	C	73.2	71.65	53.37	52.3	53.58	37.7
	S	1	2.66	0.84	0.2	0.34	1.6
	N	1.4	1.54	0.99	0.8	0.72	0.8
	O	5.4	4.69	9.98	13.6	12.32	8.7
	Coal Classification	Hi. Vol. A	Hi. Vol. A	Sub Bit A	Sub C / PRB	Sub C / PRB	TX Lignite
	Grindability (HGI)	45	61		46	55	64
	Chlorine					0.02	
	Free Swelling Index (ASTM D720-91)		6.5				
Ash Fusion Temperatures (Reducing)	Initial Deformation Temp., °F	2700	2460	2365	2220	2078	2130
	Softening Temp., °F	2700	2520	2458	2245	2109	2215
	Hemi-spherical Temp., °F	2700	2560	2489	2260	2126	2225
	Fluid Temp., °F	2700	2610	2538	2285	2159	2280
	T250 Temp., °F						
Ash Composition	SiO2 (acid)	55.9	46	60.13	31.6	29.74	42.9
	Al2O3 (acid)	29.4	24	21.08	15.1	17.67	16.4
	Fe2O3 (base)	6.5	16.14	5.61	5.1	4.8	7.5
	CaO (base)	0.9	4.03	3.86	25.8	15.98	14.8
	MgO (base)	0.8	0.75	1	5	4.42	1.7
	Na2O (base)	0.4	0.67	0.7	1.3	8	0.2
	K2O (base)	1.9	1.54	0.99	0.2	0.63	0.5
	TiO2 (acid)	1.5	1.3	0.98	1.5	1.21	1.2
	P2O5	0.1	0.54	0.04	0.8	0.31	0.1
	SO3	1.0	2.98	3.85	10.9	15.09	13.4
	BaO	0.1	0.1	0.18	0.6	1.31	0.1
	Cr2O3						
	SrO	0.1	0.22	0.09	0.2	0.73	0.2
	Mn3O4	0.1	0.03	0.06	0.1		0.1
	Undetermined	1.3	1.7	1.4	1.8	0.11	0.9

Coal – Emissions and Performance Effects

Emissions

- **NOx – Fuel Rank, Reactivity (FC/VM Ratio), Nitrogen Content, HHV**
- **CO – Fuel Rank, Reactivity**
- **SO_2 – Sulfur Content**

Unburned Carbon (UBC) in Fly Ash

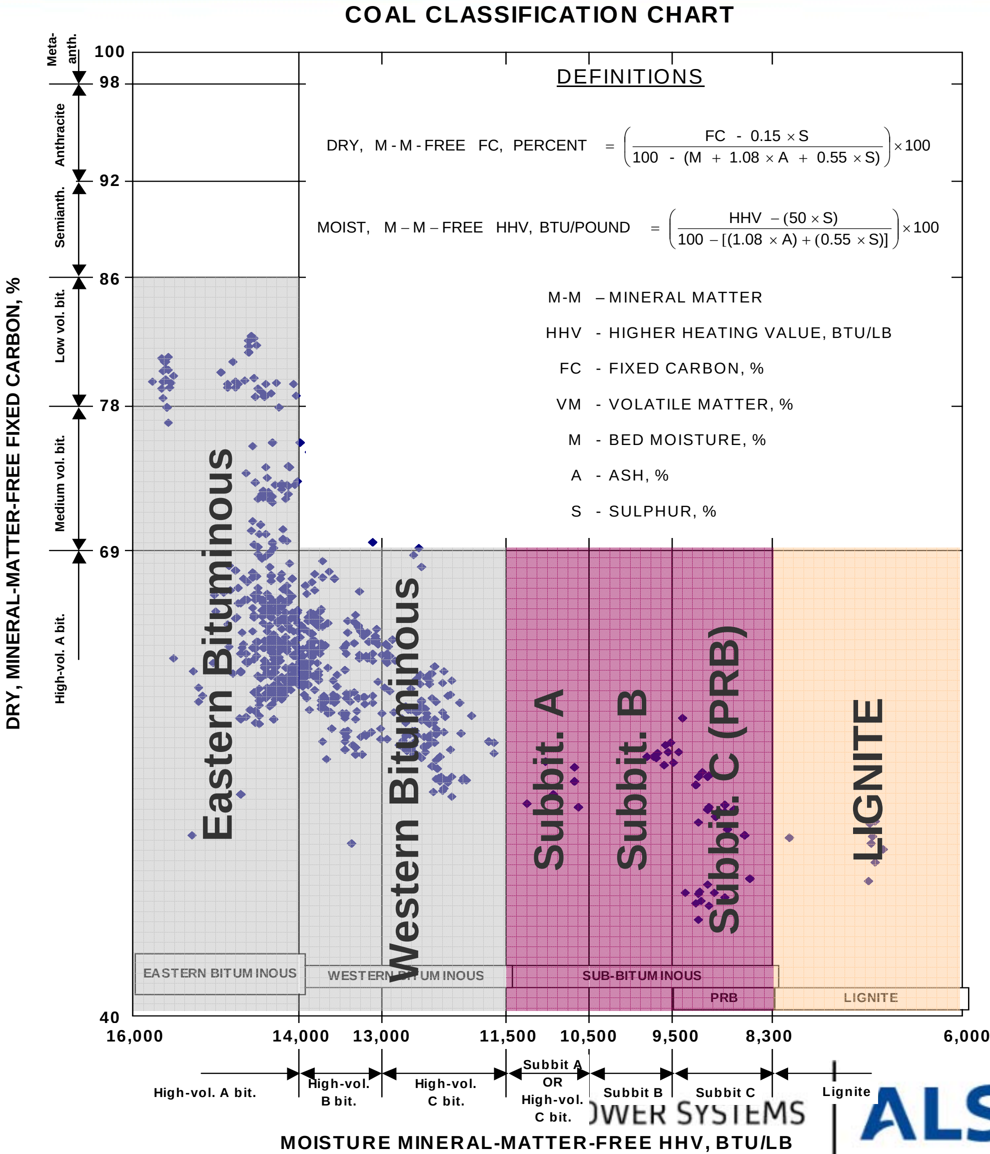
- **Fuel Rank / Reactivity**
- **Ash Content**
- **Fineness (HGI)**

Slagging and Fouling Characteristics

- **Ash Content**
- **Ash Composition – Slagging, Fouling & Erosion Potential**

ASTM Coal Rank Classification

ASTM Coal Rank



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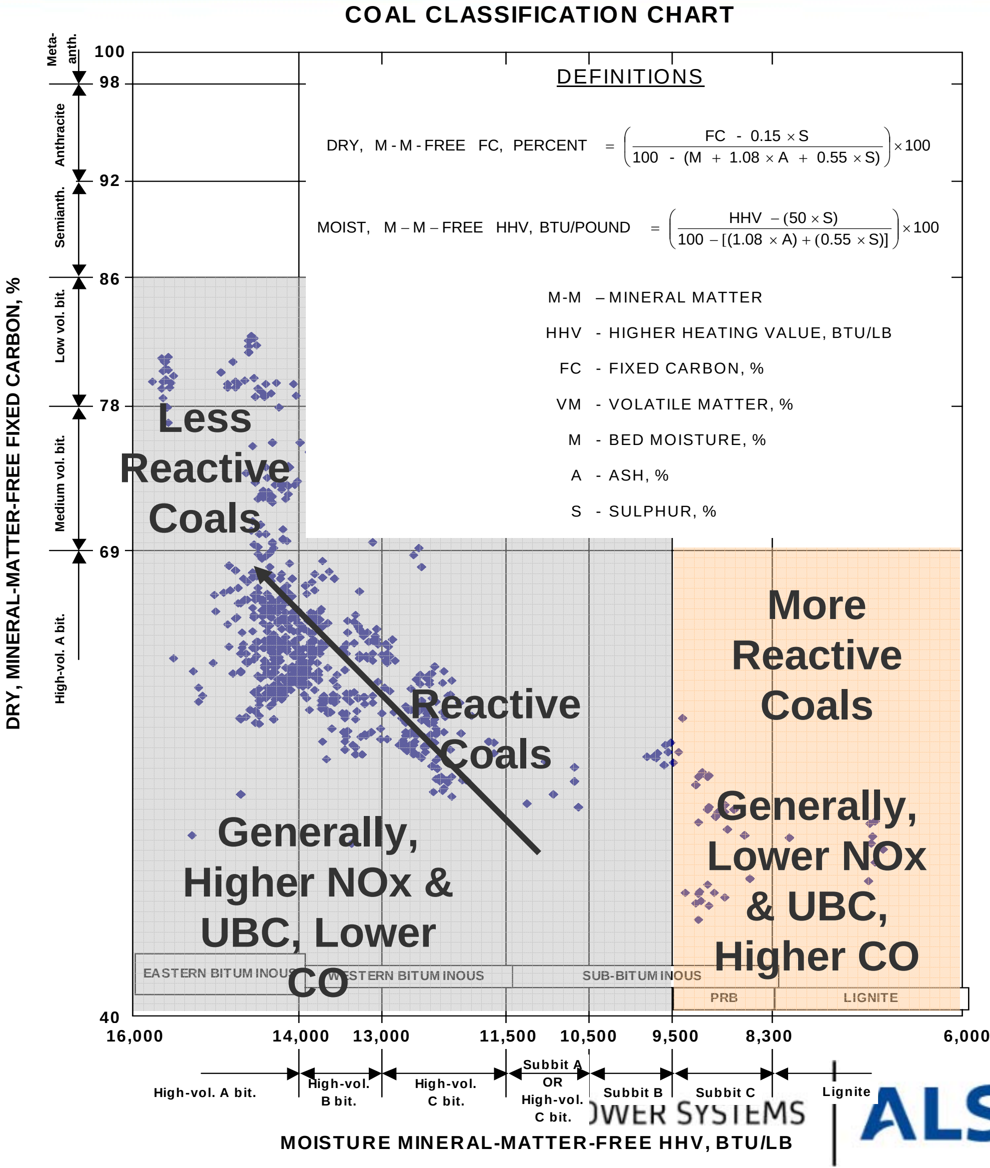
ASTM Coal Rank Characteristics on Emissions

Coal Rank

Impact on Emissions



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Coal Reactivity

- Actual coal reactivity can only be determined by laboratory analysis
- Common indices of reactivity are available from a coal's proximate & ultimate analysis
  - FC/VM or VMdaf
  - HHVdaf
  - Coal rank
- Higher reactivity coals produce lower NOx emissions and higher combustion efficiencies than lower reactivity coals
- Lower ranked coals typically have higher reactivity than bituminous coals

Coal Comparison Chart - Reactivity

	Mine / Seam	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
Proximate	Moisture	6	5.88	15.69	25.7	25.3	31.8
	VM	32.4	33.79	31.9	32.2	32.43	27.9
	FC	53.4	51.66	37.11	38.1	38.23	23.7
	Ash	8.2	8.67	15.29	4	4	16.6
HHV	HHV	13110	13009	9526	9004	9350	6476
Ultimate	H	4.8	4.92	3.83	3.4	3.72	2.8
	C	73.2	71.65	53.37	52.3	53.58	37.7
	S	1	2.66	0.84	0.2	0.34	1.6
	N	1.4	1.54	0.99	0.8	0.72	0.8
	O	5.4	4.69	9.98	13.6	12.32	8.7
Normalized Values	Theoretical Air (lb/mmBtu)	765.7	769.0	753.2	745.5	752.6	783.4
	Theoretical Air (lb air/lb fuel)	9.87	9.83	7.05	6.60	6.91	4.99
	SO2 Emissions	1.52	4.09	1.76	0.44	0.73	4.94
	FCdmmf	63	62	55	54	54	47
	HHVmmmf	14416	14439	11423	9411	9773	7878
	Coal Classification	**Hi. Vol. A**	**Hi. Vol. A**	**Sub Bit A**	**Sub C / PRB**	**Sub C / PRB**	**TX Lignite**
	VM daf	**37.8**	**39.5**	**46.2**	**45.8**	**45.9**	**54.1**
	Specific Volatile Index (SVI)	166	163	130	108	117	109
	HHV of the VM	5584	5729	4296	3635	3962	3136
	FC daf	62.2	60.5	53.8	54.2	54.1	45.9
	FC/VM	**1.65**	**1.53**	**1.16**	**1.18**	**1.18**	**0.85**
	Total % combustibles	85.8	85.5	69.0	70.3	70.7	51.6
	H daf	5.6	5.8	5.5	4.8	5.3	5.4
	C daf	85.3	83.9	77.3	74.4	75.8	73.1
	S daf	1.2	3.1	1.2	0.3	0.5	3.1
	N daf	1.6	1.8	1.4	1.1	1.0	1.6
	O daf	**6.3**	**5.5**	**14.5**	**19.3**	**17.4**	**16.9**
	HHV daf	**15280**	**15224**	**13802**	**12808**	**13225**	**12550**
	S dry	1.1	2.8	1.0	0.3	0.5	2.3
	Ash Loading (lb/MBtu)	6.25	6.66	16.05	4.44	4.28	25.63
	Grindability (HGI)	45	61		46	55	64
	Chlorine					0.02	
	Free Swelling Index (ASTM D720-91)		6.5				

Indices

Coal Rank

FC/VM

Vmdaf

HHVdaf

Odaf

Coal Comparison Chart - Slagging

	Mine / Seam	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
Proximate	Moisture	6	5.88	15.69	25.7	25.3	31.8
	VM	32.4	33.79	31.9	32.2	32.43	27.9
	FC	53.4	51.66	37.11	38.1	38.23	23.7
	Ash	8.2	8.67	15.29	4	4	16.6
HHV	HHV	13110	13009	9526	9004	9350	6476
Ultimate	H	4.8	4.92	3.83	3.4	3.72	2.8
	C	73.2	71.65	53.37	52.3	53.58	37.7
	S	1	2.66	0.84	0.2	0.34	1.6
	N	1.4	1.54	0.99	0.8	0.72	0.8
	O	5.4	4.69	9.98	13.6	12.32	8.7
Estimated LHV	LHV	12601	12490	9007	8421	8741	5885
	SO2 Emissions	1.52	4.09	1.76	0.44	0.73	4.94
	Coal Classification	Hi. Vol. A	Hi. Vol. A	Sub Bit A	Sub C / PRB	Sub C / PRB	TX Lignite
	S daf	1.2	**3.1**	1.2	0.3	0.5	**3.1**
	S dry	1.1	2.8	1.0	0.3	0.5	2.3
	Ash Loading (lb/MBtu)	6.25	6.66	**16.05**	4.44	4.28	**25.63**
	Free Swelling Index (ASTM D720-91)		6.5				
Ash Fusion Temperatures (Reducing)	**Initial Deformation Temp., °F**	2700	2460	2365	**2220**	**2078**	**2130**
	Softening Temp., °F	2700	2520	2458	2245	2109	2215
	Hemi-spherical Temp., °F	2700	2560	2489	2260	2126	2225
	Fluid Temp., °F	2700	2610	2538	**2285**	**2159**	**2280**
	dT = Fluid minus Softening	0	90	80	**40**	**50**	**65**
	T250 Temp., °F						
Ash Composition	SiO2 (acid)	55.9	46	60.13	31.6	29.74	42.9
	Al2O3 (acid)	29.4	24	21.08	15.1	17.67	16.4
	Fe2O3 (base)	6.5	16.14	5.61	5.1	4.8	7.5
	CaO (base)	0.9	4.03	3.86	25.8	15.98	14.8
	MgO (base)	0.8	0.75	1	5	4.42	1.7
	Na2O (base)	0.4	0.67	0.7	1.3	8	0.2
	K2O (base)	1.9	1.54	0.99	0.2	0.63	0.5
Normalized Ash Composition Loading	lb SiO2/mmBtu	3.50	3.07	9.65	1.40	1.27	11.00
	lb Al2O3/mmBtu	1.84	1.60	3.38	0.67	0.76	4.20
	lb Fe2O3/mmBtu	0.41	1.08	0.90	0.23	0.21	1.92
	lb CaO/mmBtu	0.06	0.27	0.62	1.15	0.68	3.79
	lb MgO/mmBtu	0.05	0.05	0.16	0.22	0.19	0.44
	lb Na2O/mmBtu	0.03	0.04	0.11	0.06	0.34	0.05
	lb K2O/mmBtu	0.12	0.10	0.16	0.01	0.03	0.13
Ash Factors	Ash Classification	Bituminous Ash	Bituminous Ash	Bituminous Ash	Lignitic Ash	Lignitic Ash	Lignitic Ash
	Base/Acid	0.12	0.32	0.15	0.78	0.70	**0.41**
	Fe2O3/CaO	7.22	4.00	1.45	0.20	0.30	**0.51**

Key Indices

Fusion Temp's

Differential Temp's

Sulfur Content

Iron Content (Tenacity)

Ash Quantity

Ash Factors

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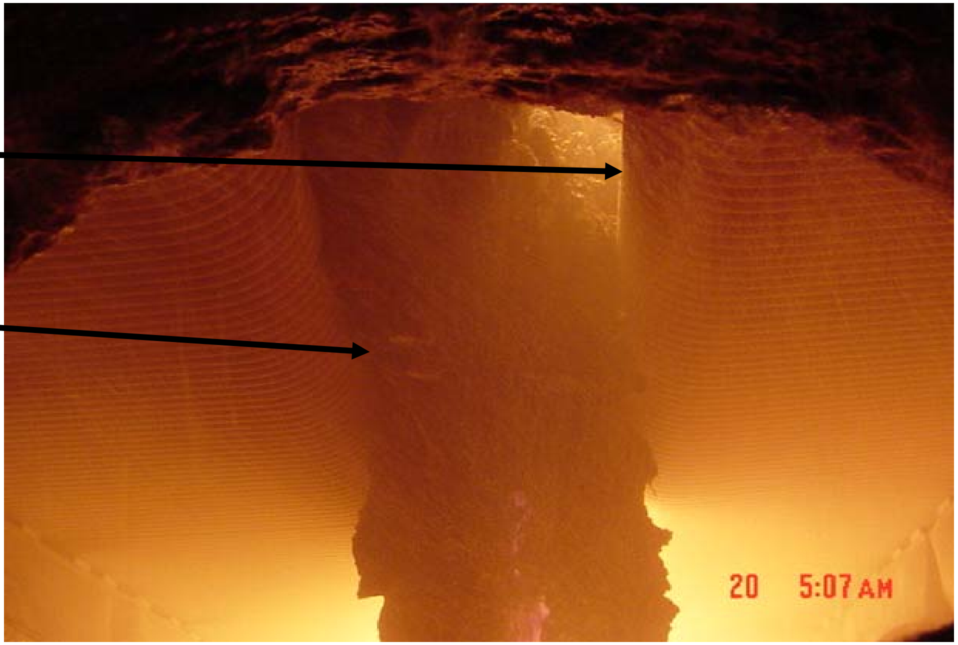
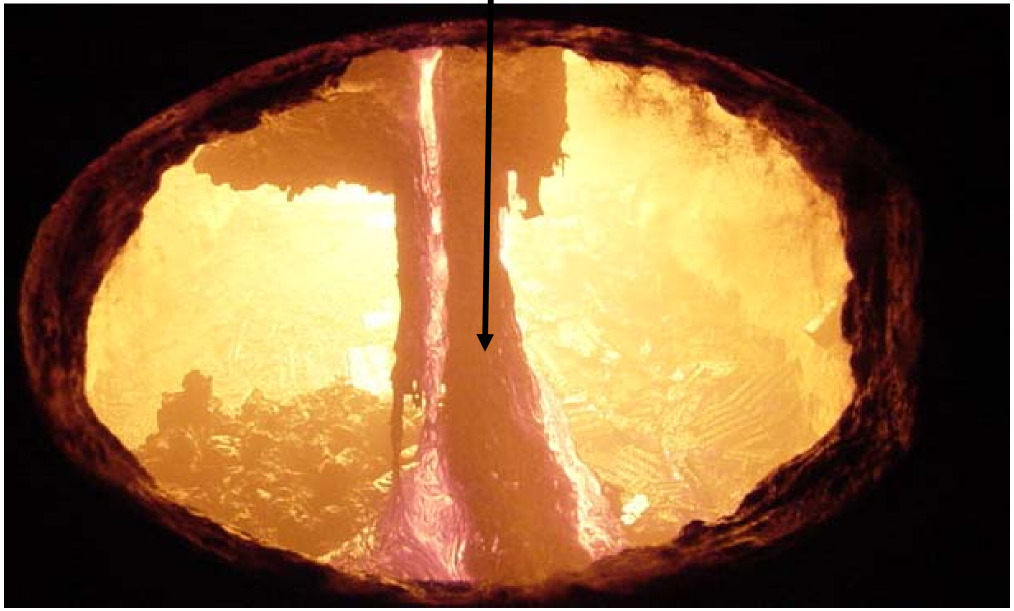
Coal Slagging – Low Fusion Temperatures

Coutant Opening

Running Slag





Waterwall Slag – High Iron

Magnet

Common Potential Slagging Indices

Potential

Indices	Low	Medium	High	Severe
CAO (%)	<10	10 to 20	20 to 40	>40
Na_2O(%)	<1	1 to 3	3 to 5	>5
Fe_2O_3(%)	<7	7 to 15	15 to 25	>25
IDT ^{O}F		<2190	<2100	<2010
FT ^{O}F	>2550	2280<FT<2550	2100<FT<2280	<2100

Slagging Potential

NHI/PA Range MBtu/hr-ft2	Coal Slagging Potential	Wall Sootblower Comments
1.3 - 1.6	Low	Normal wall blower can maintain clean walls with **occasional** use
1.6 - 1.9	Medium	Normal wall blower can maintain clean walls with **continuous** use
1.9 - 2.4	High	Normal wall blowers may **not** keep the walls clean. Addition of water lances or canons may be required

Coal Comparison Chart - Fouling

	Mine / Seam	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
Proximate	Moisture	6	5.88	15.69	25.7	25.3	31.8
	VM	32.4	33.79	31.9	32.2	32.43	27.9
	FC	53.4	51.66	37.11	38.1	38.23	23.7
	Ash	8.2	8.67	15.29	4	4	16.6
HHV	HHV	13110	13009	9526	9004	9350	6476
Ultimate	H	4.8	4.92	3.83	3.4	3.72	2.8
	C	73.2	71.65	53.37	52.3	53.58	37.7
	S	1	2.66	0.84	0.2	0.34	1.6
	N	1.4	1.54	0.99	0.8	0.72	0.8
	O	5.4	4.69	9.98	13.6	12.32	8.7
Normalized Values	Coal Classification	Hi. Vol. A	Hi. Vol. A	Sub Bit A	Sub C / PRB	Sub C / PRB	TX Lignite
	Ash Loading (lb/MBtu)	6.25	6.66	16.05	4.44	4.28	**25.63**
	Chlorine					0.02	
Ash Fusion Temperatures (Reducing)	Initial Deformation Temp., °F	2700	2460	2365	2220	2078	2130
	Softening Temp., °F	2700	2520	2458	2245	2109	2215
	Hemi-spherical Temp., °F	2700	2560	2489	2260	2126	2225
	Fluid Temp., °F	2700	2610	2538	2285	2159	2280
	dT = Fluid minus Softening	0	90	80	40	50	65
Ash Composition	SiO2 (acid)	55.9	46	60.13	31.6	29.74	42.9
	Al2O3 (acid)	29.4	24	21.08	15.1	17.67	16.4
	Fe2O3 (base)	6.5	16.14	5.61	5.1	4.8	7.5
	CaO (base)	0.9	4.03	3.86	25.8	15.98	14.8
	MgO (base)	0.8	0.75	1	5	4.42	1.7
	Na2O (base)	0.4	0.67	0.7	1.3	8	0.2
	K2O (base)	1.9	1.54	0.99	0.2	0.63	0.5
Normalized Ash Composition Loading	lb SiO2/mmBtu	3.50	3.07	9.65	1.40	1.27	11.00
	lb Al2O3/mmBtu	1.84	1.60	3.38	0.67	0.76	4.20
	lb Fe2O3/mmBtu	0.41	1.08	0.90	0.23	0.21	1.92
	lb CaO/mmBtu	0.06	0.27	0.62	1.15	0.68	3.79
	lb MgO/mmBtu	0.05	0.05	0.16	0.22	0.19	0.44
	lb Na2O/mmBtu	0.03	0.04	0.11	0.06	**0.34**	0.05
	lb K2O/mmBtu	0.12	0.10	0.16	0.01	**0.03**	**0.13**
Ash Factors	Ash Classification	Bituminous Ash	Bituminous Ash	Bituminous Ash	Lignitic Ash	Lignitic Ash	Lignitic Ash
	Base/Acid	0.12	0.32	0.15	0.78	0.70	0.41
	Fe2O3/CaO	7.22	4.00	1.45	0.20	0.30	0.51
	Fe2O3/(CaO+MgO) Dolomite Ratio	3.82	3.38	1.15	0.17	0.24	0.45
	SiO2/Al2O3	1.90	1.92	2.85	2.09	1.68	2.62
	Total Alkali (Na+K)	2.30	2.21	1.69	1.50	**8.63**	0.70
	"Fouling Index"	0.05	0.67	0.10	1.30	**8.00**	0.20

Key Indices

Fusion Temp's

Na & K Content

Ash Quantity

Ash Factors

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Fouling in the Convective Pass

Common Potential Fouling Indices

Fouling potential	None	Medium	High	Severe
Na_2O(%)	<1	<2.5	2.5 to 5	>5
CaO(%)	<5	5 to 10	$\geq$ 10	
F=%Na_2OxB/A	<0.1	01. to 0.5	> 5	

Coal Comparison Chart - Erosion

	Mine / Seam	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
Proximate	Moisture	6	5.88	15.69	25.7	25.3	31.8
	VM	32.4	33.79	31.9	32.2	32.43	27.9
	FC	53.4	51.66	37.11	38.1	38.23	23.7
	Ash	8.2	8.67	15.29	4	4	16.6
HHV	HHV	13110	13009	9526	9004	9350	6476
Ultimate	H	4.8	4.92	3.83	3.4	3.72	2.8
	C	73.2	71.65	53.37	52.3	53.58	37.7
	S	1	2.66	0.84	0.2	0.34	1.6
	N	1.4	1.54	0.99	0.8	0.72	0.8
	O	5.4	4.69	9.98	13.6	12.32	8.7
Estimated LHV	LHV	12601	12490	9007	8421	8741	5885
Normalized Values	Coal Classification	Hi. Vol. A	Hi. Vol. A	Sub Bit A	Sub C / PRB	Sub C / PRB	TX Lignite
	Ash Loading (lb/MBtu)	6.25	6.66	**16.05**	4.44	4.28	**25.63**
	Grindability (HGI)	45	61		46	55	64
Ash Composition	SiO_2 (acid)	55.9	46	60.13	31.6	29.74	42.9
	Al_2O_3 (acid)	29.4	24	21.08	15.1	17.67	16.4
	Fe_2O_3 (base)	6.5	16.14	5.61	5.1	4.8	7.5
	CaO (base)	0.9	4.03	3.86	25.8	15.98	14.8
	MgO (base)	0.8	0.75	1	5	4.42	1.7
	Na_2O (base)	0.4	0.67	0.7	1.3	8	0.2
	K_2O (base)	1.9	1.54	0.99	0.2	0.63	0.5
Normalized Ash Composition Loading	lb SiO_2/mmBtu	3.50	3.07	**9.65**	1.40	1.27	**11.00**
	lb Al_2O_3/mmBtu	1.84	1.60	**3.38**	0.67	0.76	**4.20**
	lb Fe_2O_3/mmBtu	0.41	1.08	0.90	0.23	0.21	1.92
	lb CaO/mmBtu	0.06	0.27	0.62	1.15	0.68	3.79
Ash Factors	Ash Classification	Bituminous Ash	Bituminous Ash	Bituminous Ash	Lignitic Ash	Lignitic Ash	Lignitic Ash
	%alpha quartz	1.7	1.5	**5.4**	0.6	0.4	**3.9**
	Erosion Potential based on %alpha quartz	Low	Low	**High**	Low	Low	**Moderate**
	Erosion Potential based on SiO_2 Loading	Moderate	Moderate	**Bad**	Low	Low	**Bad**
	Erosion Potential based on Ash Loading	Moderate	Moderate	**High**	Low	Low	**Severe**

Key Indices

Ash Loading

Silica

Alumina

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Coal Tip Erosion – High Si,& Al, or Ash

Coal Comparison Chart

	Mine / Seam	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
Proximate	Moisture	6	5.88	15.69	25.7	25.3	31.8
	VM	32.4	33.79	31.9	32.2	32.43	27.9
	FC	53.4	51.66	37.11	38.1	38.23	23.7
	Ash	8.2	8.67	15.29	4	4	16.6
HHV	HHV	13110	13009	9526	9004	9350	6476
Ultimate	H	4.8	4.92	3.83	3.4	3.72	2.8
	C	73.2	71.65	53.37	52.3	53.58	37.7
	S	1	2.66	0.84	0.2	0.34	1.6
	N	1.4	1.54	0.99	0.8	0.72	0.8
	O	5.4	4.69	9.98	13.6	12.32	8.7
Normalized Values	Coal Classification	Hi. Vol. A	Hi. Vol. A	Sub Bit A	Sub C / PRB	Sub C / PRB	TX Lignite
	VM daf	**37.8**	**39.5**	46.2	45.8	45.9	54.1
	Specific Volatile Index (SVI)	**166**	**163**	130	108	117	109
	HHV of the VM	5584	5729	4296	3635	3962	3136
	FC daf	62.2	60.5	53.8	54.2	54.1	45.9
	FC/VM	1.65	1.53	1.16	1.18	1.18	0.85
	S daf	1.2	3.1	1.2	0.3	0.5	3.1
	HHV daf	15280	15224	13802	12808	13225	12550
	Ash Loading (lb/MBtu)	6.25	6.66	16.05	4.44	4.28	25.63
	Free Swelling Index (ASTM D720-91)		**6.5**				
Ash Composition	SiO2 (acid)	55.9	46	60.13	31.6	29.74	42.9
	Al2O3 (acid)	29.4	24	21.08	15.1	17.67	16.4
	Fe2O3 (base)	6.5	16.14	5.61	5.1	4.8	7.5
	CaO (base)	0.9	4.03	3.86	25.8	15.98	14.8
	MgO (base)	0.8	0.75	1	5	4.42	1.7
	Na2O (base)	0.4	0.67	0.7	1.3	8	0.2
	K2O (base)	1.9	1.54	0.99	0.2	0.63	0.5
Normalized Ash Composition Loading	lb SiO2/mmBtu	3.50	3.07	9.65	1.40	1.27	11.00
	lb Al2O3/mmBtu	1.84	1.60	3.38	0.67	0.76	4.20
	lb Fe2O3/mmBtu	0.41	**1.08**	0.90	0.23	0.21	1.92
	lb CaO/mmBtu	0.06	0.27	0.62	1.15	0.68	3.79
	lb MgO/mmBtu	0.05	0.05	0.16	0.22	0.19	0.44
	lb Na2O/mmBtu	0.03	0.04	0.11	0.06	0.34	0.05
	lb K2O/mmBtu	0.12	0.10	0.16	0.01	0.03	0.13

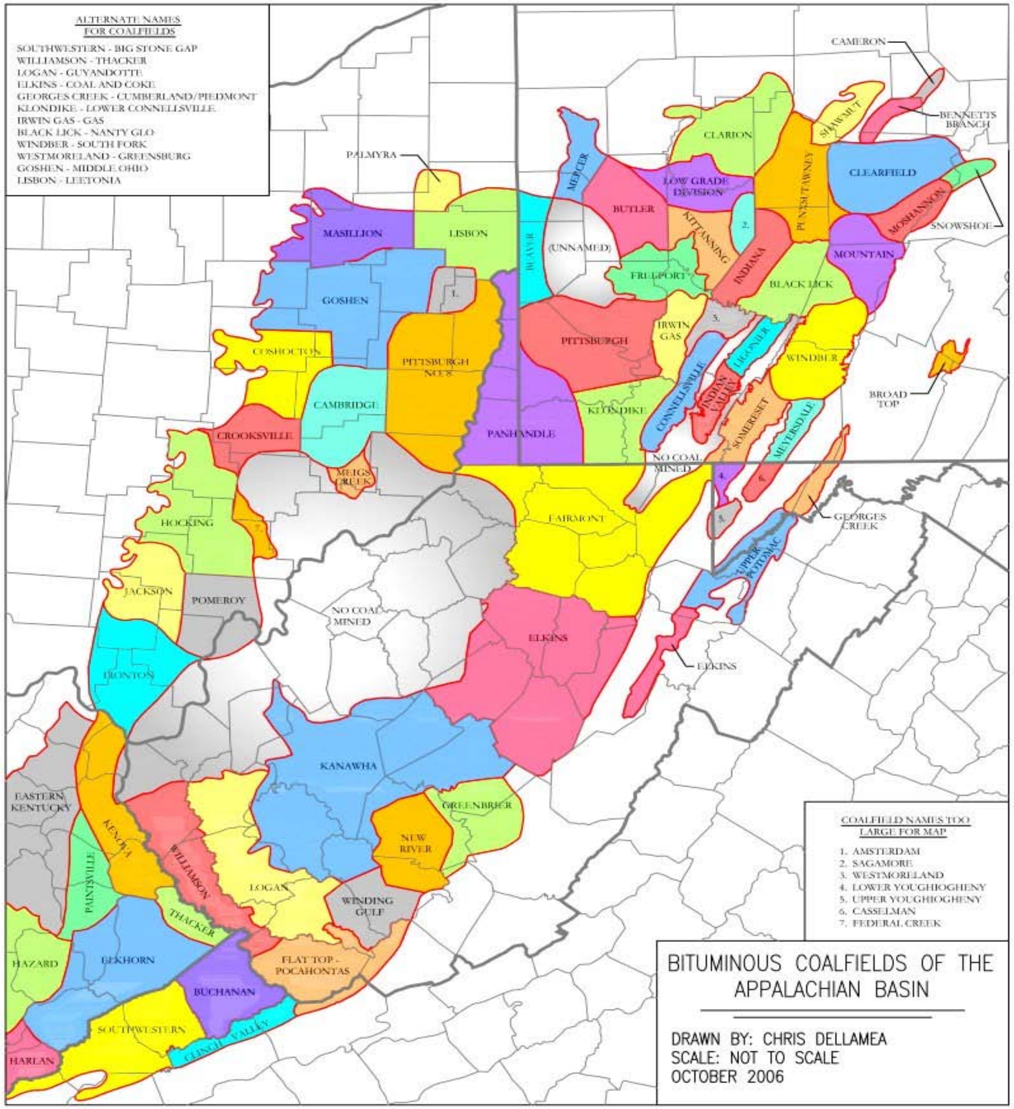
Indices for Burner Slagging / Deposition

- Sulfur Content - $\%S_{ar}$ > 1.5 increases concern
- Free Swelling Index > 4.0 High, > 7.0 Extreme Problems
- Specific Volatile Index > 160 with Vmdaf > 40 = “Gas” Coals
- Pyrite (FeS_2) Content - 3.5 X density of coal and 2 X density of quartz
- Iron Oxide - Fe_2O_3 > 15%
- Base/Acid Ratio
- Slagging Index - (B/A * %S) >2.0
- Ash Fusion Temperatures - IT < 2400° F
- Fe/Ca Ratio
- Cl Content

Coal Tip Deposition – High S & Fe

Coal Tip Deposition – High S & Fe

Northern Appalachian Coal Sources



Damaged Coal Compartments – Gas Coals

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