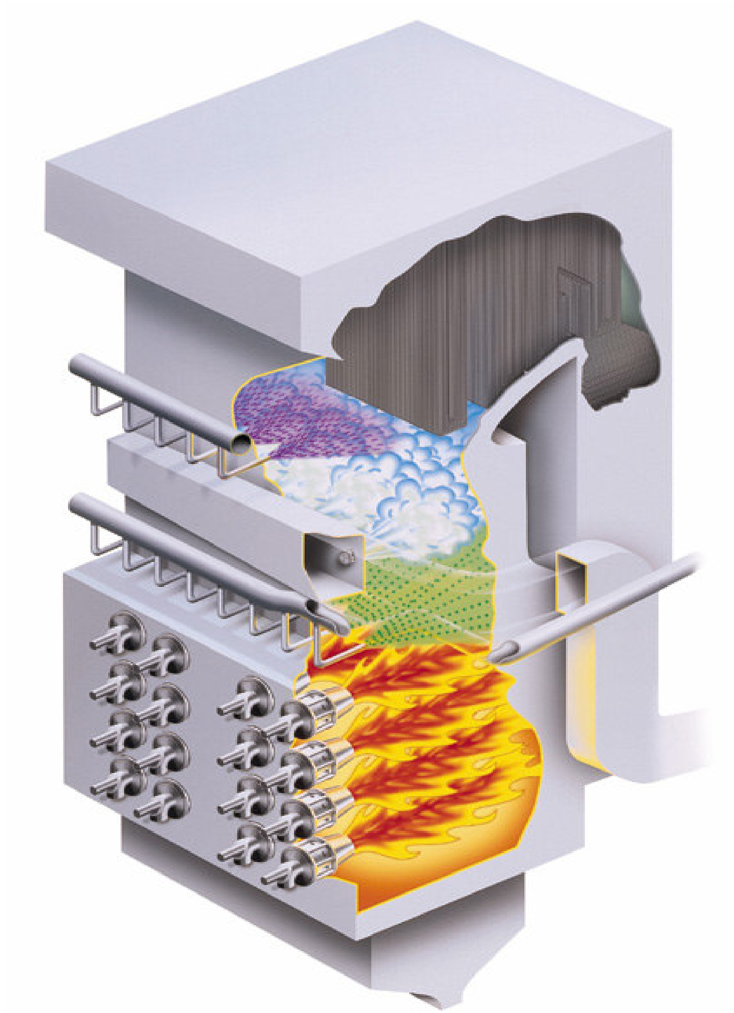
Impact of Combustion on Particulate Collection



Bob Taylor

May 2006

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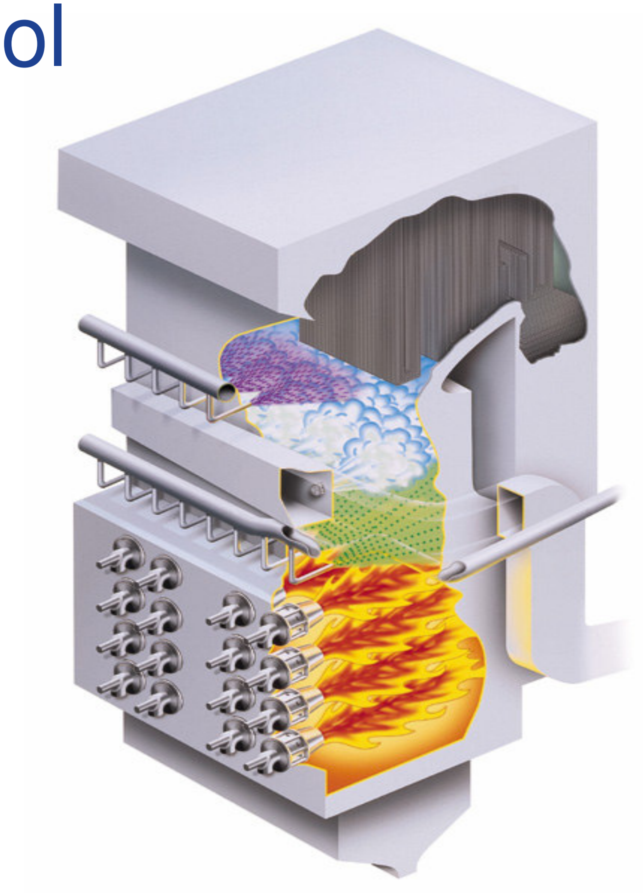
Combustion Impact on PM Collection

Areas of Impact

- Particulate Loading to Control Device
- Flue Gas Flow Rate
- Flue Gas Temperature
- Flue Gas Composition
- Particle Size Distribution
- Carbon Content of Ash



Particulate Loading

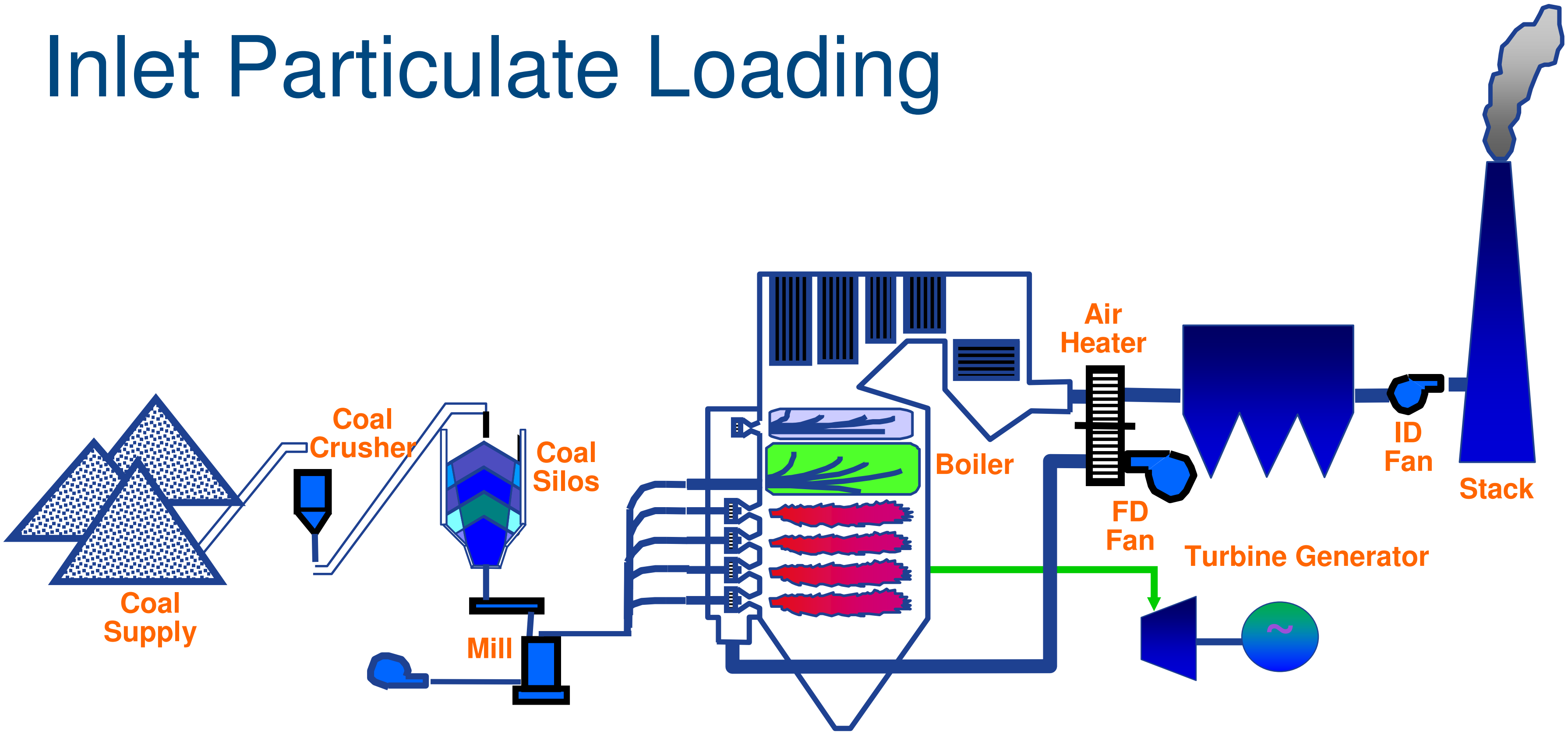
Most particulate is an inorganic constituent of the fuel.

PM mass loading generally proportional to fuel firing rate.

Fuel Flow rate controlled by:

- Power requirements
- Fuel characteristics
- System Efficiencies
  - Chemical to thermal energy conversion
  - Casing thermal losses
  - Stack sensible and latent heat loss
  - Steam turbine losses
  - Electrical generator losses

Inlet Particulate Loading



About 15% to 20% of Ash Falls out as Bottom Ash

About 80% to 85% Passes Through Boiler as Fly Ash

For Typical 240 MWe Plant – 8 to 8.5 Tons/hr Fly Ash

Inlet Particulate Loading

<u>Power Plant Efficiency</u>

Overall efficiency for coal-fired utility ~ 35 to 40%

Heat Rate ~10,000 Btu/KwHr

<u>Example 240 MWe Plant</u>

Coal HHV - ~12,000 Btu/lb (from Proximate Analysis)

Fuel Use = **240,000Kw x 10,000 Btu/KwHr/12,000 Btu/lb / 2000 lb/ton** = 100 tons/hr

Coal Ash Content ~ 10%

PM = 100 tph coal x 10% Ash = 10 tph

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Impact of Increased Dust Burden

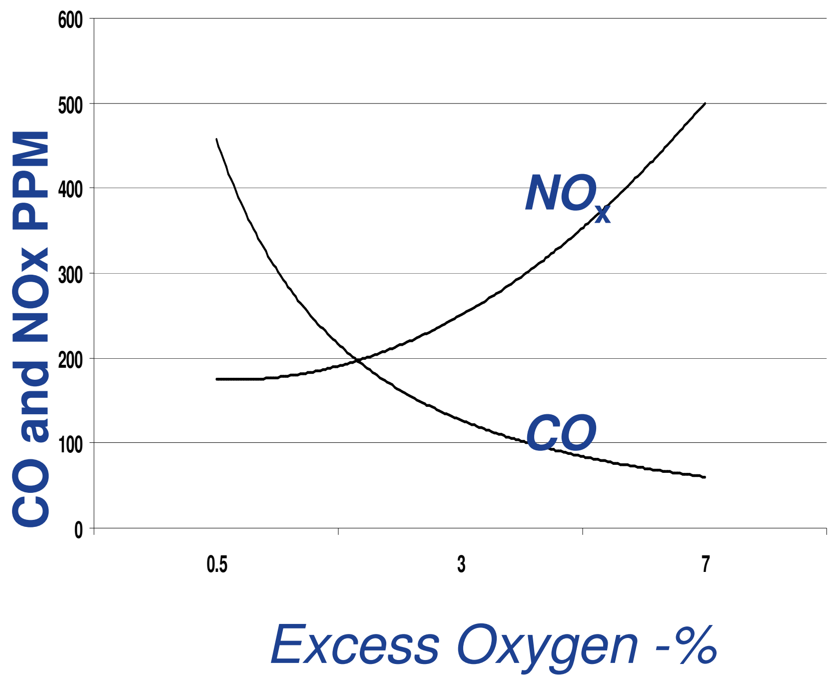
Electrostatic Precipitator

- Relatively constant efficiency
- Increased emissions
- Increased spark rate
- Constant pressure drop
- Need for increased rapping

Fabric Filter

- Constant emissions
- Increased pressure drop
- Need to reduce pulse cleaning interval
- Increased bag wear

Flue Gas Quantity



Most flue gas mass derived from combustion air and in- leakage

Stoichiometric air defined by fuel composition (Ultimate Analysis)

Excess air required since fuel/air mixing less than perfect

Air in-leakage accounts for significant increase in volume

Combustion Calculation

Element	Formula	lb / 100lb	MW	Moles	O2 Multiplie	Stoichiometric O2 demand	Moles CO2	Moles H2O	Moles SO2	Moles N2
Carbon	**C**	**72**	**12**	**6.00**	**1**	**6.00**	**6**			**22.71**
Hydrogen	H2	4.4	2	2.20	0.5	1.10		2.2		4.16
Sulfur	S	1.6	32	0.05	1	0.05			0.05	0.19
Nitrogen	N2	1.4	28	0.05	0	0.00				0.05
Water	H2O	8	18	0.44	0	0.00		0.44		0.00
Oxygen	O2	3.6	32	0.11	-1	-0.11				-0.43
Ash		9								
						7.04	6.00	2.64	0.05	26.68
Stoichiometric Demand										
O2						**7.04**				
N2						**26.68**				
Moles Combustion Products										
	Stoichioemtric		**35.38**							
	With 3% O2		**40.865**							
Volume Flue Gas/100 lb fuel				**15733**	**scf**					

Rule of Thumb – 12 lbs air per lb coal

Flue Gas Quantity

Example 240 MW_e Power Plant

100 tons/hr fuel and ~15,750 scf/100 Lbs fuel (@3% O_2)

Flue gas flow

100 ton fuel/hr * 2000 lb/ton * 157.5 scfm/lb fuel

Standard Gas Volume ~525,000 scfm

PM Loading

8 tons PM/hr * 2000 lb/ton*7000 gr/lb/60 min/hr/525,000 scfm

Inlet Dust Loading 3.56 grains/ standard ft^3

Inlet dust loading to PM device varies with dust content & gas volume.

Impact of Increased Gas Volume

Electrostatic Precipitator	Fabric Filter
Reduced collection efficiency	Relatively constant emissions
Increased pressure drop	Increased pressure drop
Increased emissions	Increased cleaning cycles
Increased abrasion	Reduced bag life
Instability in high voltage system	Inability of dust to settle

Electrostatic Precipitator

$$EFF = 1 - e^{-\frac{A}{V}w}$$

$$W = \frac{Eo\ Ep\ a}{2\,\pi\,\eta}$$

EFF = Fractional % Collected

A = Surface Area Collecting Electrodes

V = Volumetric Flow Rate

w = Particle Drift Velocity or Rate Parameter

Eo = Charging Fields $\frac{\text{Volts}}{\text{Distance}}$

Ep = Collecting Field $\frac{\text{Volts}}{\text{Distance}}$

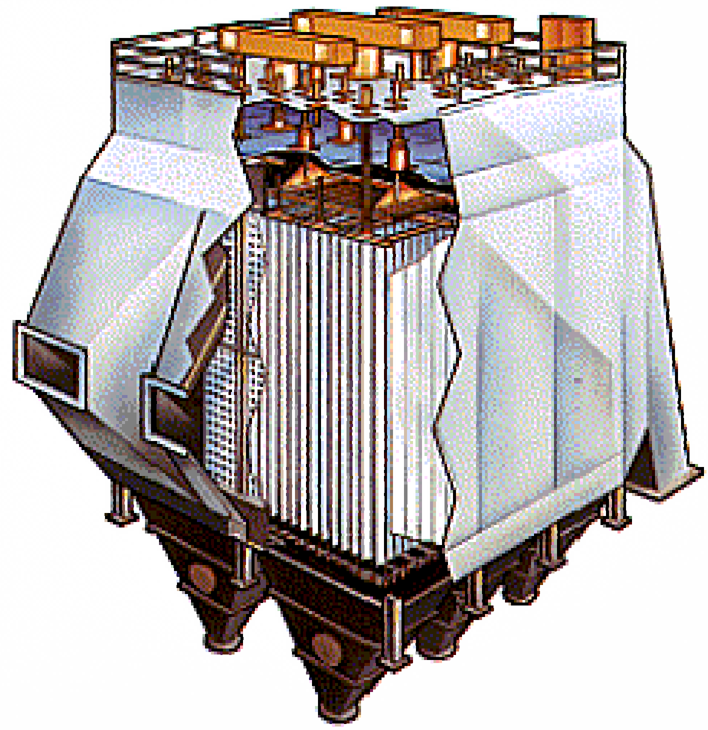
a = Particle Radius

η = Gas Viscosity

π = 3.1416

Electrostatic Precipitator

- ESP collection efficiency is exponentially related to gas volume
- A small change in gas volume results in a large reduction in PM efficiency.



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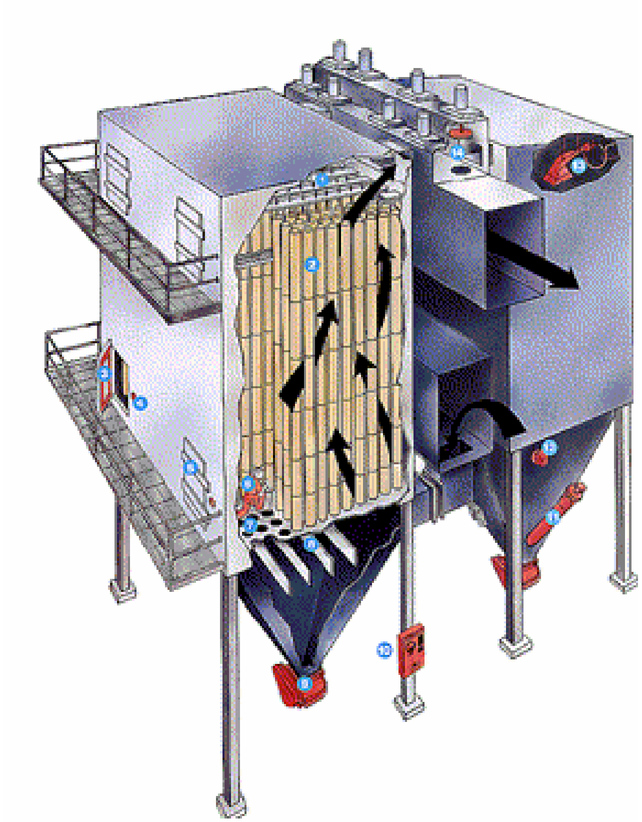
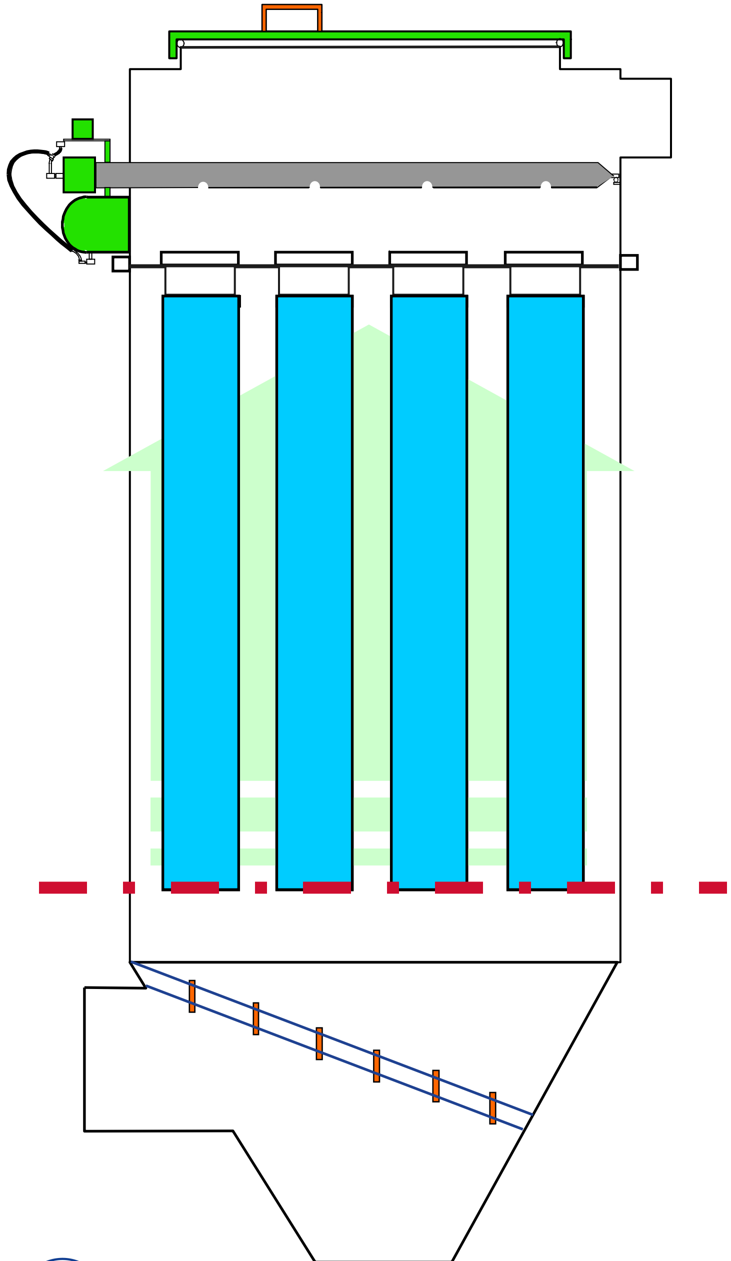
Fabric Filter

Air to Cloth Ratio

- •Air to cloth ratio = Total gas volume ACFM / Total filter area Ft2
- •Filter dia. X length x 3.1415 = Filter area
- •Total # Filters x Filter Area = Total Filter Area
- •Typical pulse jet air to cloth ratios for utility boilers 2.0 through 4.0 ft/min.





Can Velocity

In a pulse jet fabric filter, can velocity is the upward gas velocity between filter bags.

It is calculated at the horizontal cross section at the bottom of the filter bags.

High can velocity causes cleaning problems.

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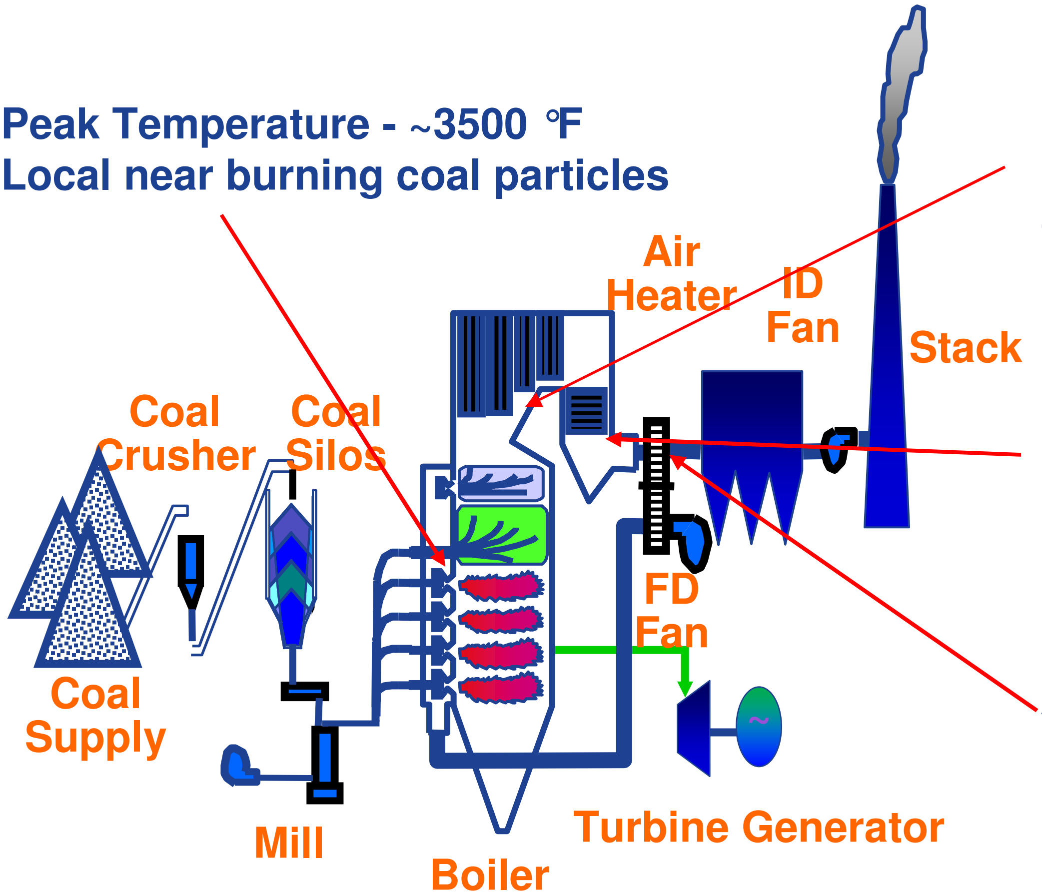
Causes of Increased Gas volume

- Increased through put
- Reduced thermal efficiency
- Increased in-leakage
- Elevated operating temperature
- Changes in fuel characteristics.

Flue Gas Temperature Patterns

Peak Temperature - ~3500 °F
Local near burning coal particles



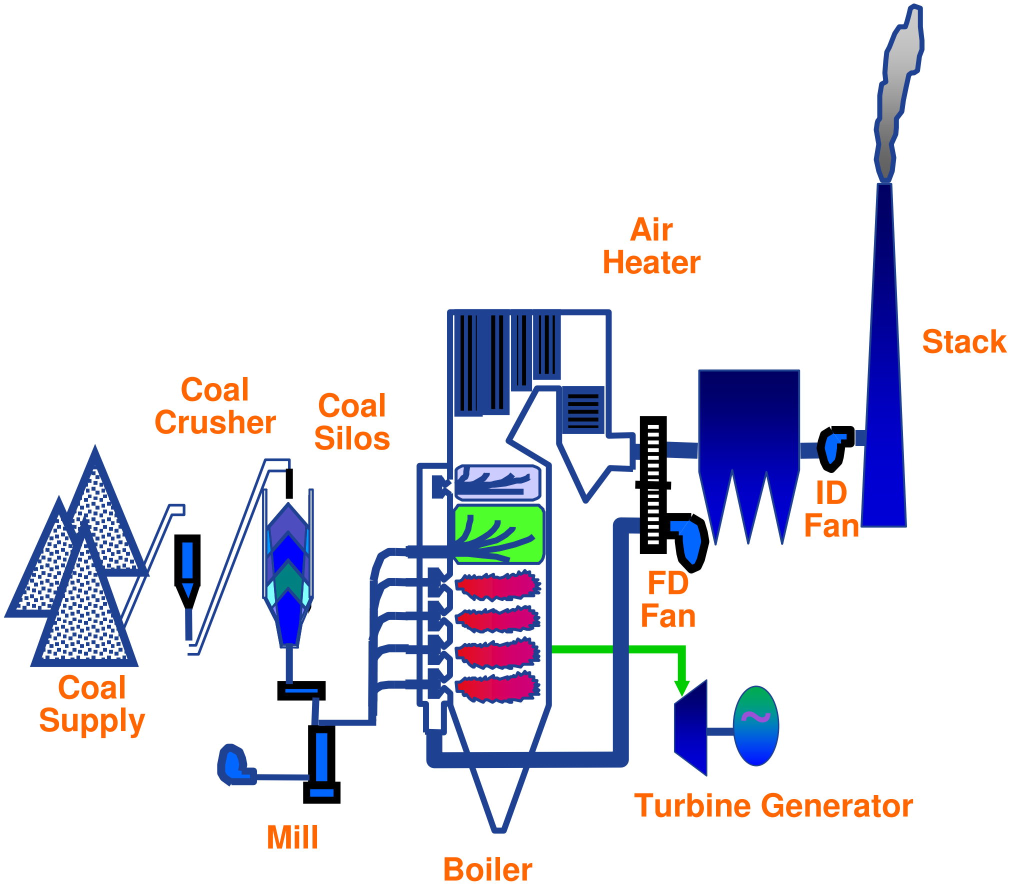
Furnace Exit Gas Temperature
(FEGT) ~2500 °F

Economizer Outlet Temperature
~700 °F

Air Heater Outlet Temperature
~350 °F

Increasing combustion air preheat 100 °F increases peak flame temperature by about 50 °F

Temperature Patterns



Changing air preheat

Power Cycle efficiency
Slagging in Furnace
Ash resisitivity in ESP
Flue gas ACFM

SO_3 Dew Point Temp.

~235 to 300°F depending on moisture and SO_3 level

Air Pre-heater Coils

Use of air pre-heaters in winter increases ESP inlet temperature

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Impact of Elevated Temperature

Electrostatic Precipitator

Increased gas volume

Possible dust resistivity increase

Increased emissions

Damage to insulators

Damage to seals

Reduced sorbent effectiveness

Fabric Filter

Increased gas volume

Reduced fabric life

Loss of filter bags

Damage to seals

Reduced sorbent effectiveness

Flue Gas Composition

Based On Typical Ultimate Analysis

Flue Gas Species	Moles of Product	Concentration Wet	Concentration Dry
CO_2	6	14.7%	15.7%
H_2O	2.64	6.5%	0.0%
O_2	1.15	2.8%	3.0%
SO_2	0.05	1225 ppm	1308.22
N_2	31.02	75.9%	81.2%
Total - wet	40.86		
Total - dry	38.22		

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Impact of Gas Composition

Electrostatic Precipitator

Increased moisture can benefit dust resistivity.

Increased acids can benefit dust resistivity

Excessive moisture or acids can degrade rapping and increase corrosion

Elevated CO possible explosion

Fabric Filter

Increased moisture can lead to bag blinding

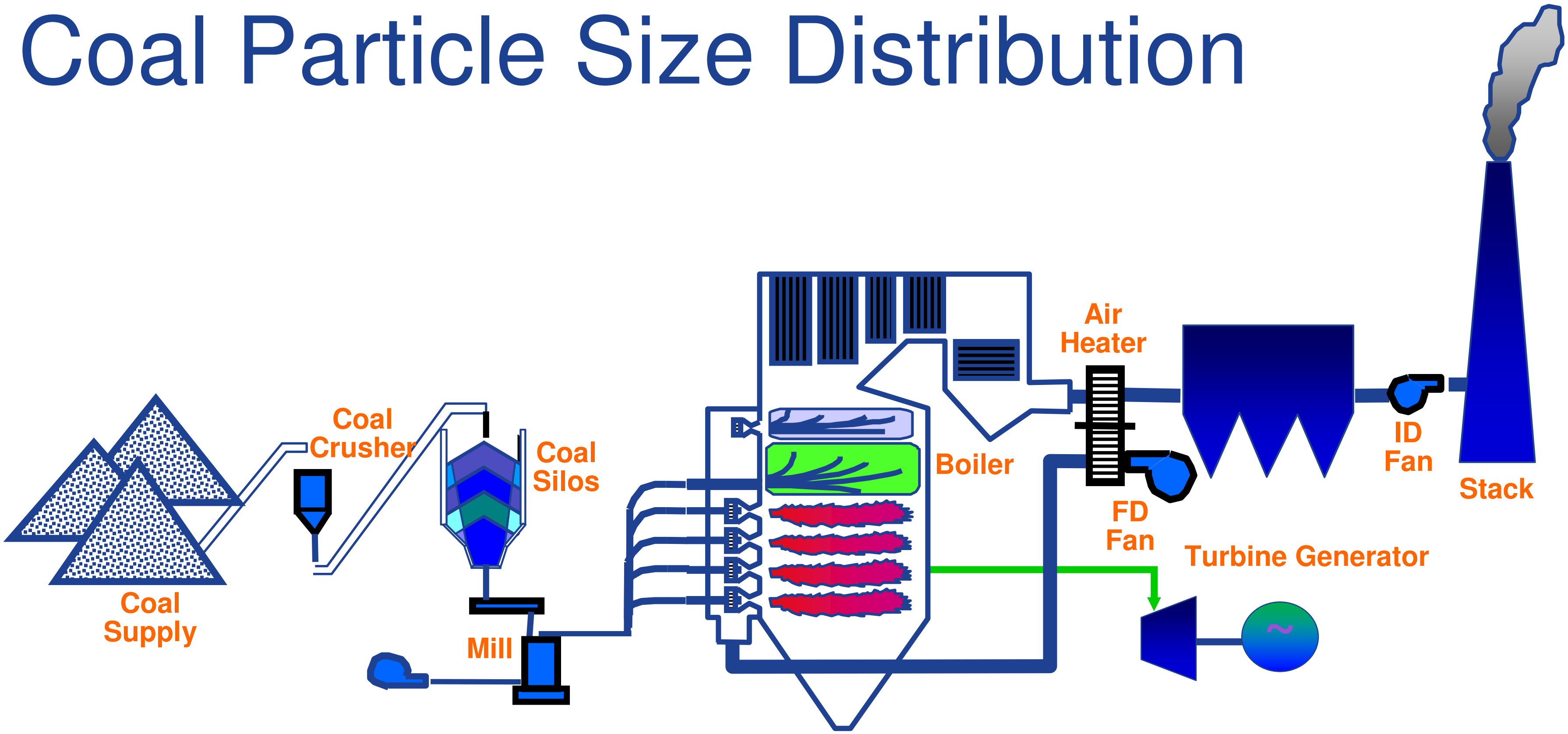
Increased acids can degrade fabrics

Excessive oxygen can degrade some fabrics

Excessive moisture can degrade some fabrics.

Elevated CO possible explosion

Coal Particle Size Distribution



Crusher ~ 1" "particles"

Mills - 70% through 200 mesh screen – 125 microns

Particle Size is a function of combustion efficiency and coal characteristics

Coal Particle Size Distribution

Proximate Analysis

- Percent of coal that is volatile vs “fixed carbon”

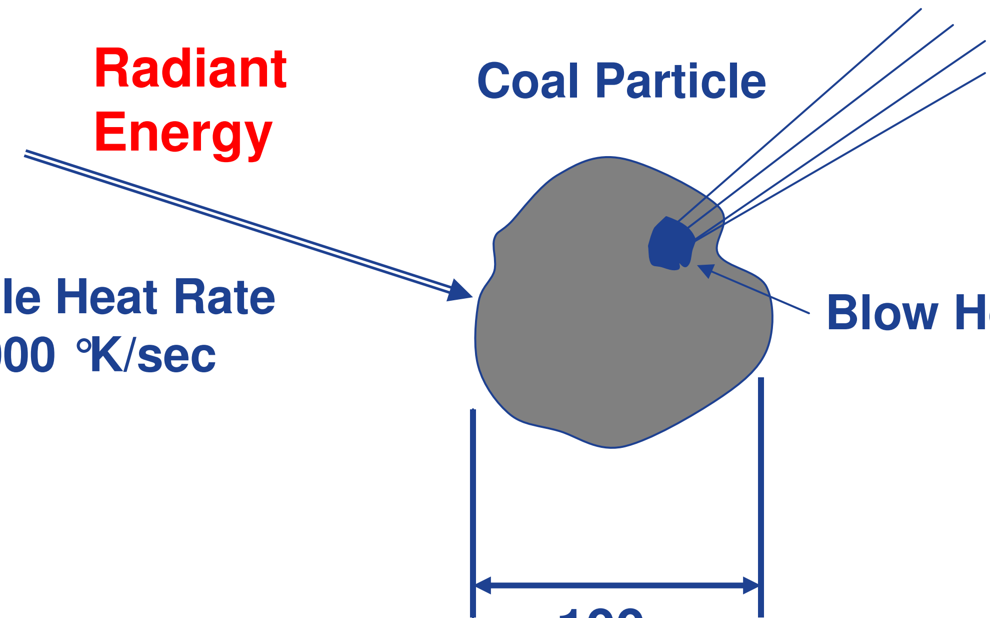
Volatile Matter burns like a gas flame

- Rapid oxidation but MAY form soot since there can be local oxygen deficiency conditions
- Creates fine dust

Fixed Carbon

- Often referred to as “Char”
- Burns by surface reaction - oxygen diffusion
- End product is a burned out hulk of inorganic material
- Lattice structure generally broken as they pass through convective sections – coarse dust

Coal Burning Processes



Impact of Reduced particle Size

Electrostatic Precipitator

Reduced collection efficiency

Excessive space charge conditions; current suppression

Increased potential for re-entrainment.

Elevated impact on opacity

Fabric Filter

Potential bag blinding

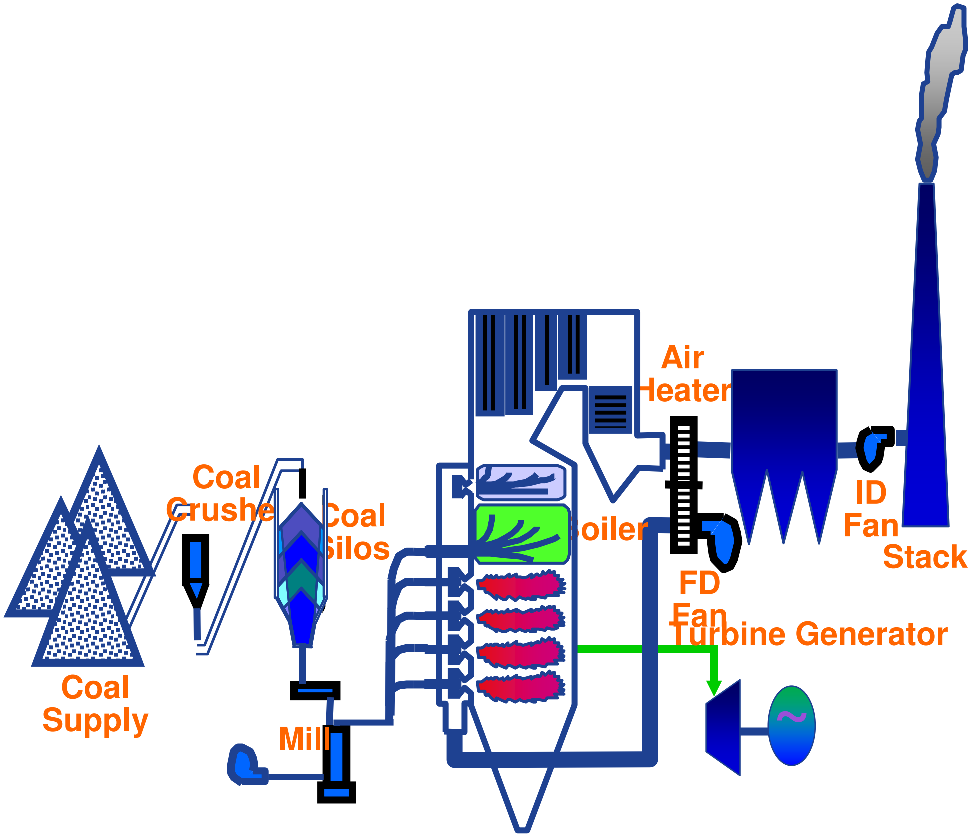
Fabric “bleed Thru”

Possible increased emissions

Increased pressure drop due to lack of settling

Elevated impact on opacity

Carbon in Ash



Burnout of Carbon in Char

- Residence time from burners to nose
- Effectiveness of fuel/air mixing
- Reactivity of char

LOI

- Range from ~ 1 to 20%

Carbon in Fly Ash

Carbon levels in fly ash can increase due to:

- Low NOx burners
- Inadequate mixing of combustion air and fuel
- Staging of combustion air
- Change in coal grind

Carbon in Fly Ash

Other Sources of Carbon in Fly Ash

•Incomplete combustion is not the only reason for carbon in ash.

•Mercury control strategies utilizing carbon based sorbents are another reason.

•Powdered activated carbon is injected into the gas stream ahead of the PM control device.

ESP – Impact on Inlet Dust Loading

PAC Rate Lb/mmACF	Inlet Burden Gr/ACF	PAC Injection gr/ACF	Total Burden gr/ACF	% Change
1.5	1.5	0.011	1.511	0.73
3.0	1.5	0.022	1.522	1.50
7.0	1.5	0.049	1.55	3.33

- Injecting BPAC ahead of ESP has minimal impact on inlet dust burden
- Other mechanisms must exhibit greater impact on ESP performance.

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ESP Performance & Sorbent Injection Rates

- An ESP is not as effective at removing carbon as compared to fly ash.
- Field testing indicates ESP emissions increase significantly when carbon based PAC is utilized.
- Carbon has lower reflectance when compared to fly ash. (Visible emissions)
- Field testing indicates carbon based PAC has minimal impact on emissions from Max-9.

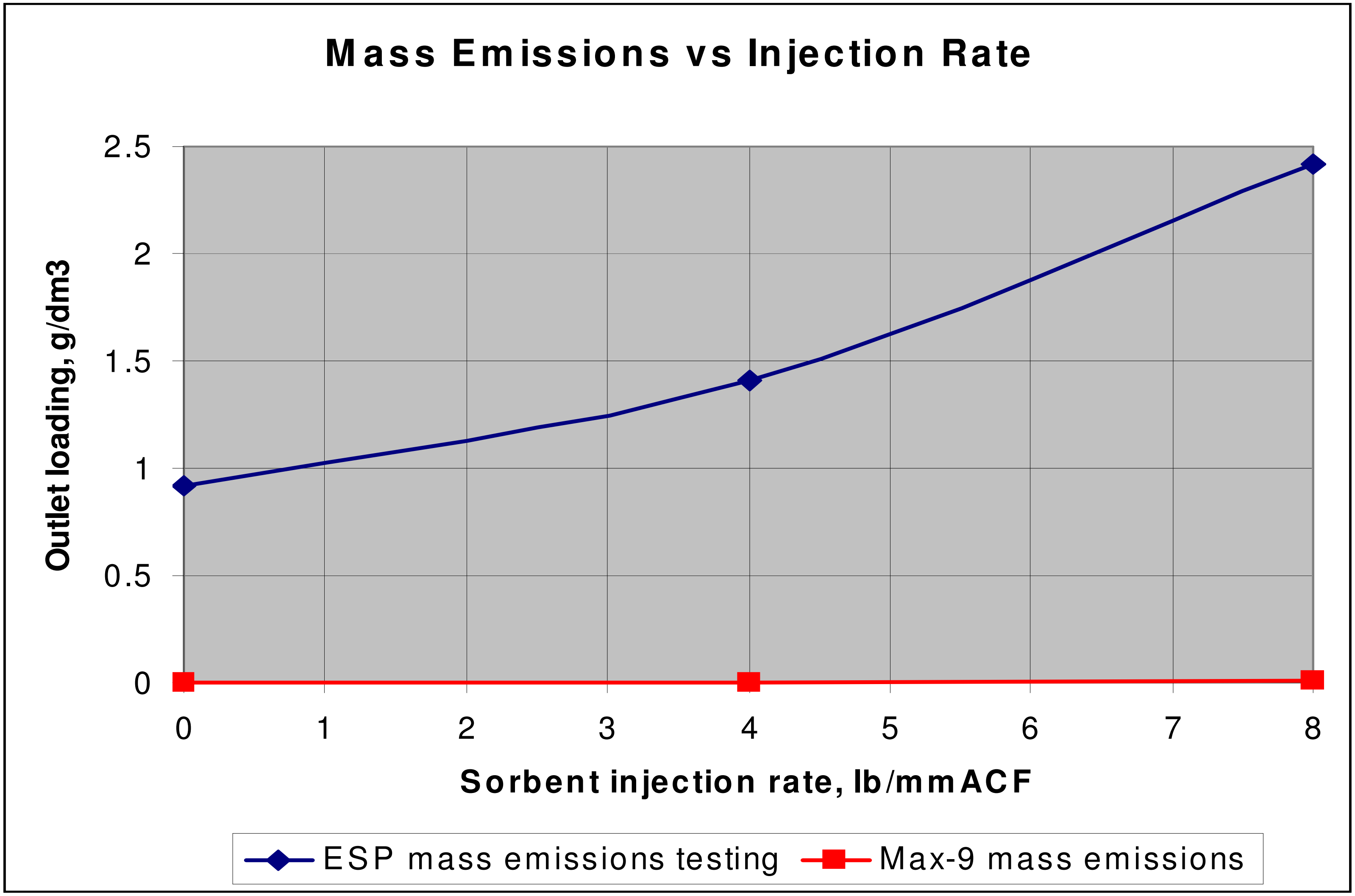
ESP – Impact on Visible Emissions

PAC Rate	Expected Outlet	PAC Removal	PAC Outlet	Total Outlet	Opacity
Lb/mmACF	Gr/ACF	%	gr/ACF	gr/ACF	%
0.0	0.01	75	0.000	0.010	7.0
1.5	0.01	75	0.003	0.013	10.5
3.0	0.01	75	0.006	0.016	12.5
7.0	0.01	75	0.012	0.022	17.0

•BPAC injection has significant impact on ESP visible emissions

•ESP performance may be comprised when high efficiency mercury removal is required.

ESP – Impact on Outlet Dust Emissions



- ESP emissions increase as inlet dust loading increases.

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Impact of Elevated Carbon

<u>Electrostatic Precipitator</u>

Increased spark rate

Increased re-entrainment

Potential for insulator tracking

Potential for hopper fires

Inability to sell fly ash

<u>Fabric Filter</u>

Hydrocarbons can blind filter bags

Potential for hopper fires

Inability to sell fly ash

Summary

Combustion controls many aspects of PM operation:

- Inlet PM Loading
- Flue gas flow rate (acfm and scfm)
- Particle size distribution
- Flue gas composition and temperature
- Carbon content of ash

Changing combustion conditions must be carefully considered

- NO_x production
- CO emissions
- Boiler cycle efficiency
- Slagging and fouling
- Boiler tube wastage rates
- Acid precipitation
- LOI
- Mercury control