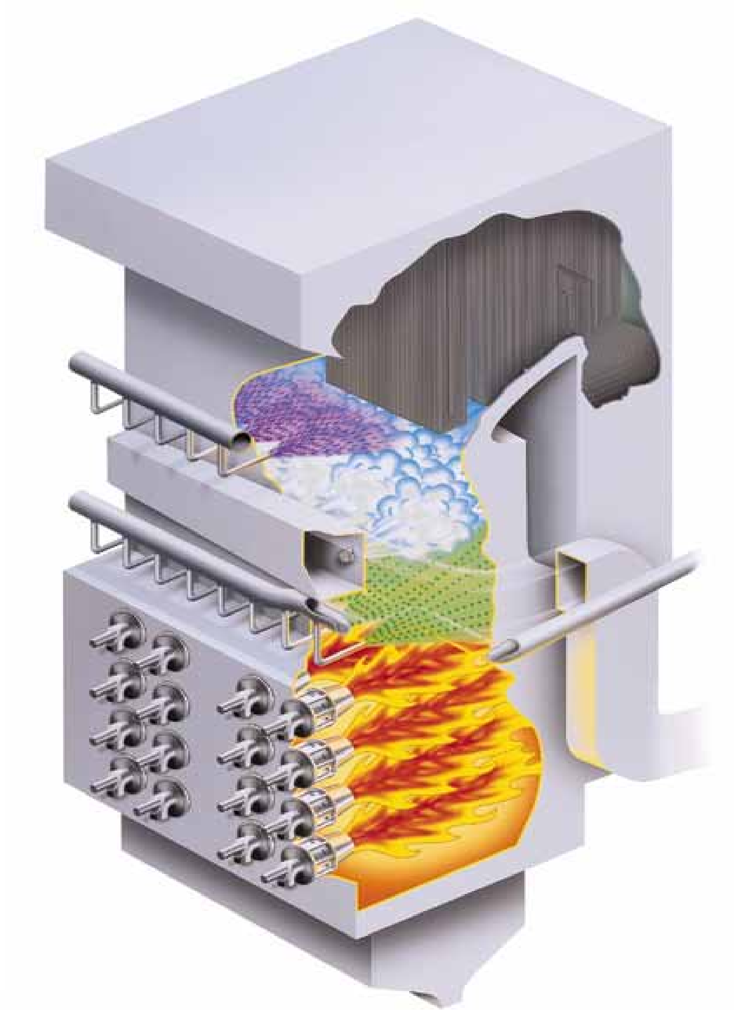
Reinhold Environmental Ltd.

2007 APC Round Table & Expo Presentation

July 8-10, 2007
Chattanooga, TN
Hosted by TVA

Impact of Combustion on Particulate Collection



Reinhold Seminar

Bob Taylor

July 2007

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Combustion Impact on PM Collection

- Continuous compliance with ever more stringent emission regulations is a mandate of utility boiler operators.
- Particulate collection efficiency is affected by multiple factors external to the PM control device .
- As a result, the ability to maintain continuous compliance is dependent on understanding the influence of external factors affecting particle collection.

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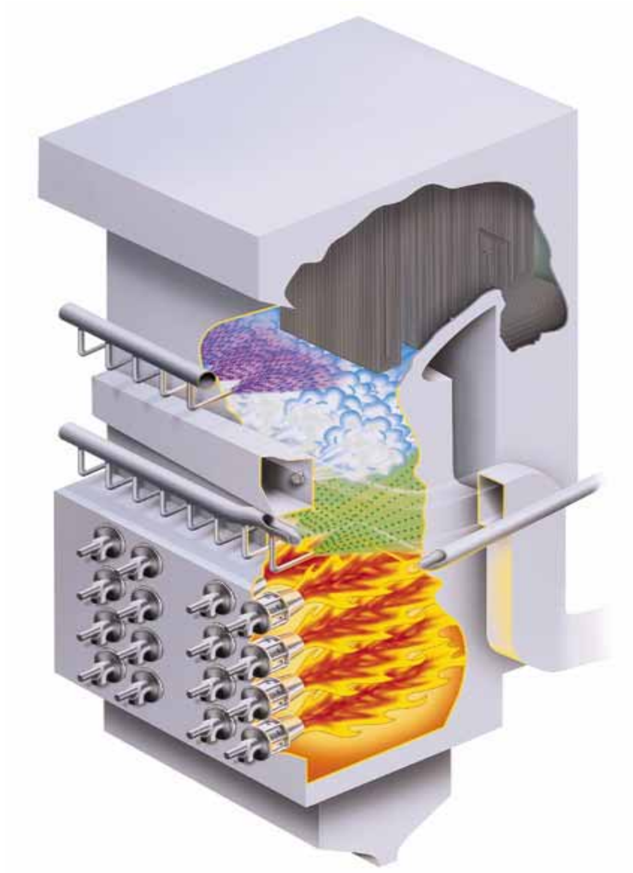
Combustion Impact on PM Collection

External Factors:

- Particulate Inlet Dust Load
- Flue Gas Flow Rate
- Flue Gas Temperature
- Flue Gas Composition
- Particle Size Distribution
- Carbon Content of Ash



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Particulate Inlet Dust Load

- Most inlet dust is an inorganic constituent of the fuel.
- Some additional particulate results from incomplete combustion.
- Alternate pollutant control technologies incorporating sorbent injection will add to the dust burden.
- Dust loading is generally proportional to fuel firing rate.
- Fuel Flow rate controlled by:
  - Unit load
  - Fuel characteristics
  - System Efficiency

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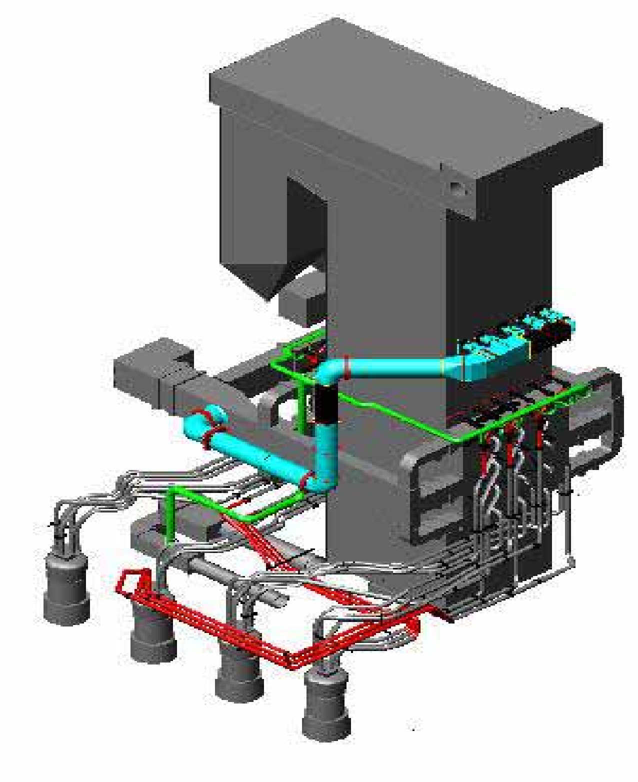
Impact of Combustion on Particulate Collection

For this presentation consider a 250 MW coal fired boiler burning a Powder River Basin coal:

- Coal burn rate: 306,000 lb/hr
- Heating value: 7,850 BTU/lb
- Ash content: 6.5%
- Gas volume: 995,000 ACFM
- Gas temperature: 325°F
- Gas pressure: -6” WC
- Dust burden: 6.6 lb/mmBTU
  3.25 gr/dscf



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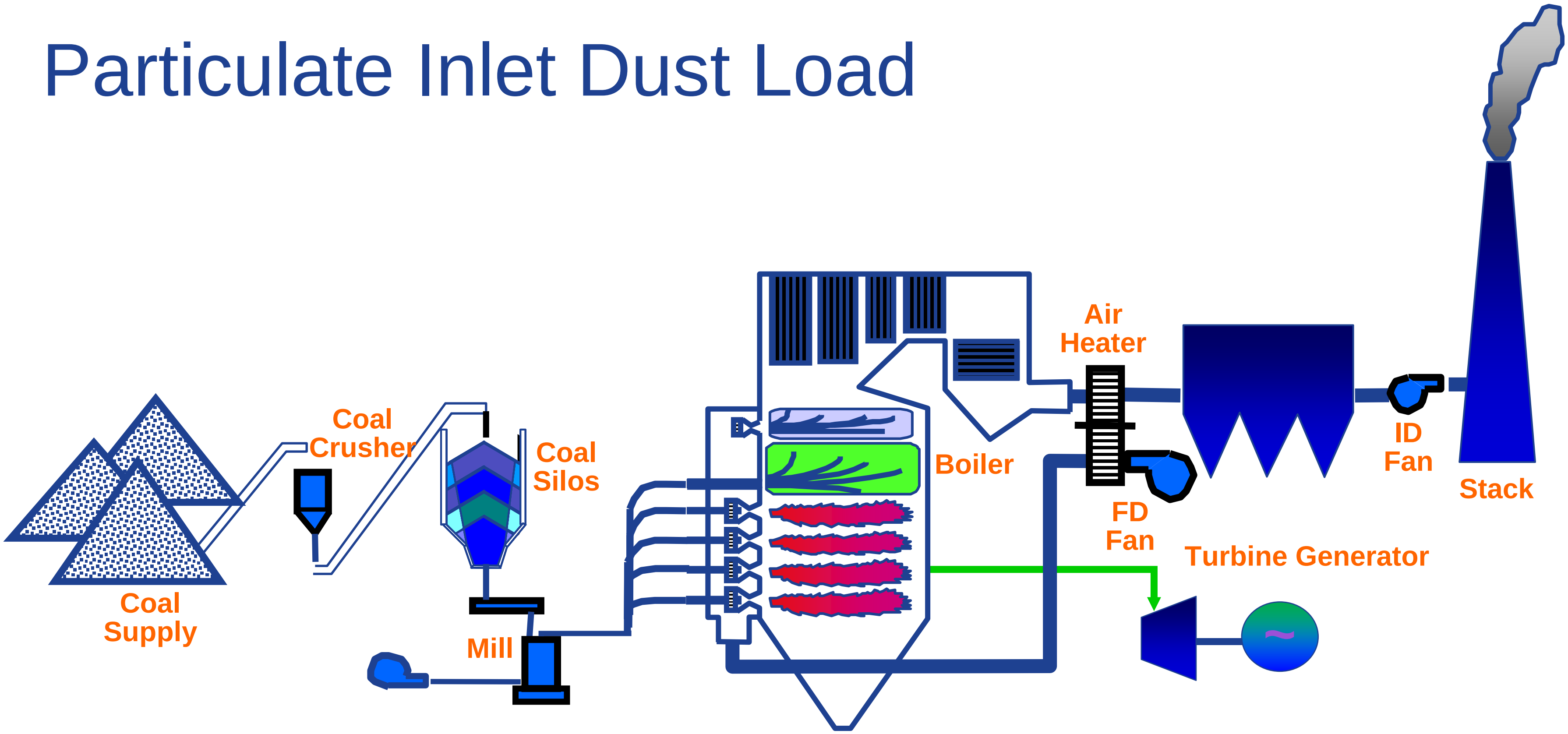
Particulate Inlet Dust Load



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

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

For the 250 MW Plant – 9.5 to 10.0 Tons/hr ash

7.5 to 8 Tons/hr fly ash

Particulate Inlet Dust Load

Example 250 MW Plant

Coal HHV - 7,850 BTU/lb (from Ultimate Analysis)

Heat input – 2,400 mmBTU/hr (Boiler rating)

Fuel burn rate = (2,400 mmBTU/hr) / (7,850 BTU/lb /1,000,000)

= 306,000 lb coal /hr or 153 tons coal /hr

Coal Ash Content 6.5%

Ash = 306,000 lb coal /hr * .065 lb ash/lb coal

=**19,890 lb ash/hr or 9.95 tons ash/hr**

At 80% conversion of ash to fly ash

=19,890 lb ash/hr * 0.8

=**16,000 lb fly ash/hr or 8 tons fly ash/hr @ 6.5% ash**

=24,615 lb fly ash/hr or 12.3 ton fly ash/hr @ 10%

Increased Particulate Inlet Dust Load

Electrostatic Precipitator

- Increased emissions
- Increased spark rate
- Constant pressure drop
- Need for increased rapping
- Potential for increased erosion.
- Reduced interval between hopper evacuation cycles.

Fabric Filter

- Constant emissions
- Increased pressure drop
- Need to reduce pulse cleaning interval
- Increased bag wear.
- Increased compressed air consumption.'
- Reduced interval between hopper evacuation cycles.

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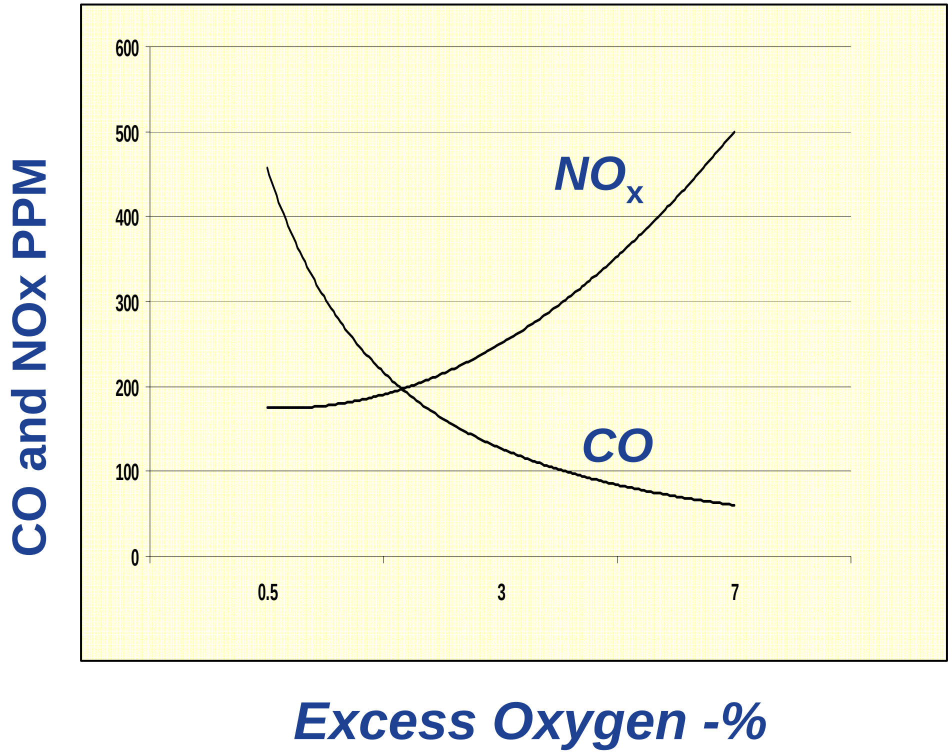
Flue Gas Flow Rate



- Most flue gas flow results 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

Ultimate Analysis

	AIR REQUIREMENT						FLUE GAS COMPOSITION						
	As fired	Burned					Moles Theoretical O2/100 lb. Fuel						
Fuel Component	Lbs/	Lbs/	Mole Wgt/	Moles/	O2	O2	CO2	SO2	O2	N2 Fuel	N2 Air	H2O	CO
Based per Pound	100 lbs.	100 lbs.	lb. Mole	100 lb	Multiple	Req'd							
C TO CO2	50.92	50.920											
C Unburned		0.000											0.000
Carbon burned		50.920	12.011	4.239	1.000	4.239	4.239						
C TO CO	0.00	0.000	12.011	0.000	0.500	0.000							
H2 TO H2O	3.62	3.620	2.016	1.796	0.500	0.898						1.796	
S TO SO2	0.30	0.300	32.066	0.009	1.000	0.009		0.009					
O2 (DEDUCT)	13.05	13.050	31.999	0.408	-1.000	-0.408							
N2 fuel	0.76	0.760	28.014	0.027		0.000				0.027			
CO2	0.00	0.000	0.000										
H2O	24.85	24.850	18.015	1.379		0.000						1.379	
ASH	6.50	0.050	0.000										
TOTAL	100.00	93.550	O2 Required Theoretical			4.739							
			O2 Excess			1.185			1.185				
			O2 Total			5.924							
			O2 In-leakage			0.592			0.592				
			N2 Supplied (O2 X 3.77)			24.565					24.565		
			Air Supplied, Wet			31.081							
			H20 In Air@ .013			0.650						0.650	
			Air Supplied, Wet			31.731							
			Total Flue Gas Constituents				4.239	0.009	1.777	0.027	24.565	3.825	0.000
			Total moles/100 lb. Fuel					Wet Flue Gas	34.443			Dry Flue Gas	30.618

Products of combustion

Combustion Calculation

GAS VOLUME PER 100 LB FUEL-DRY	11,530.82
GAS VOLUME PER 100 LB FUEL- WET	12,979.00

Calculated Data		
	English	Metric
Coal Burn Rate, lb/hr. (kg/hr)	305,732	138,678
Gas Flow, SCFM- Wet (Nm3/hr wet)	661,350	1,123,642
Gas flow, SCFM - Dry (Nm3/hr dry)	587,558	998,267
Gas Flow, ACFM (Am3/hr)	994,204	1,689,163
Ash in fuel, lb/mmBTU	8.280	N/A
Ash in gas, cyclone, lb/mmBTU @ 45%,	3.726	N/A
Ash in gas, PC, lb.mmBTU @ 80%	6.624	N/A
Ash in gas, P.C., gr/acf (g/Am3)	1.866	4.27
Ash in gas, P.C., gr/dscf (g/Nm3 dry)	3.157	7.22
Lbs SO2/mmBTU	0.764	

Combustion calculations can be used to define gas volume and dust loading when ultimate analysis of fuel is known

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Flue Gas Flow Rate

Example 250 Mw Plant

Gas Volume

From combustion calculations:

There are 115.3 Std ft^3/lb fuel and 305,733 lb coal / hr

(115.3 Std ft^3/lb fuel)*(305,733 lb coal / hr) / 60 min/hr

Gas volume = 587,517 Std ft^3 / min (dry)

Dust Loading

From previous slide there is 16,000 lb fly ash / hr.

$$\frac{(16{,}000 \text{ lb fly ash/hr} * 7{,}000 \text{ grains/lb})/60 \text{ min/hr}}{587{,}517 \text{ Std ft}^3 / \text{min}}$$

Dust burden = 3.16 gr/dscf

Inlet dust loading varies with dust content & gas volume.

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Deutsch Anderson ESP Efficiency Equation

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

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

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

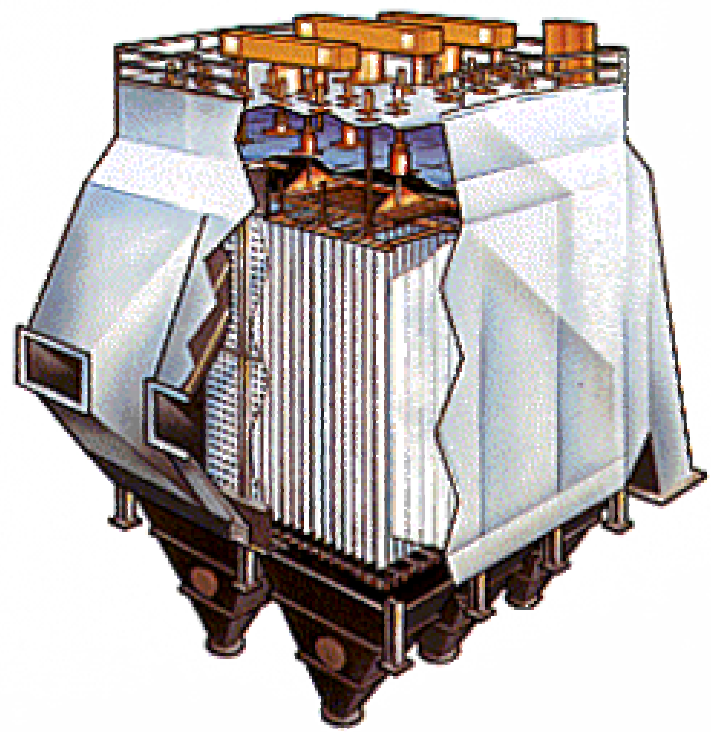
η = Gas Viscosity

π = 3.1416

Electrostatic Precipitator

Summary of Deutsch Anderson Equation

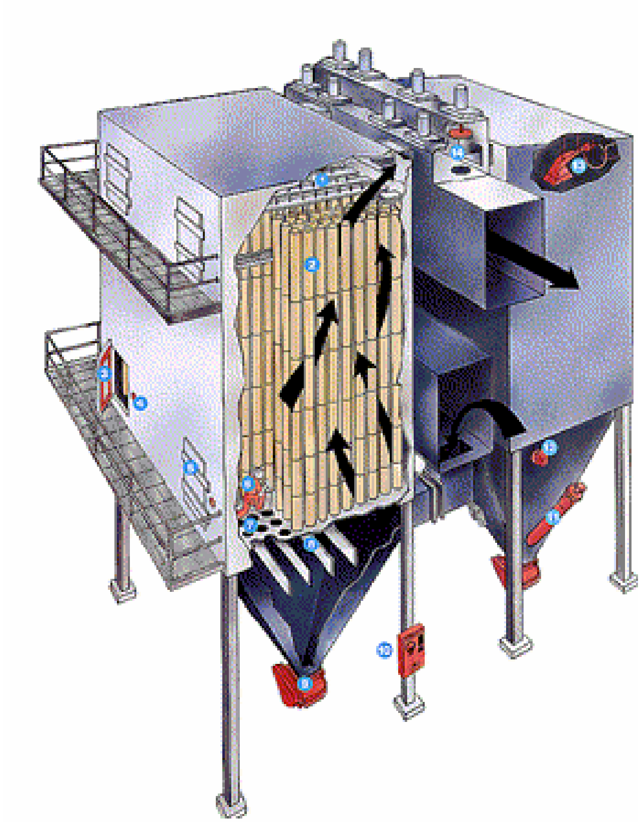
- ESP collection efficiency is exponentially related to gas volume
- Small changes in volume results in a large reduction in efficiency.



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.



Collection efficiency is not volume dependent.

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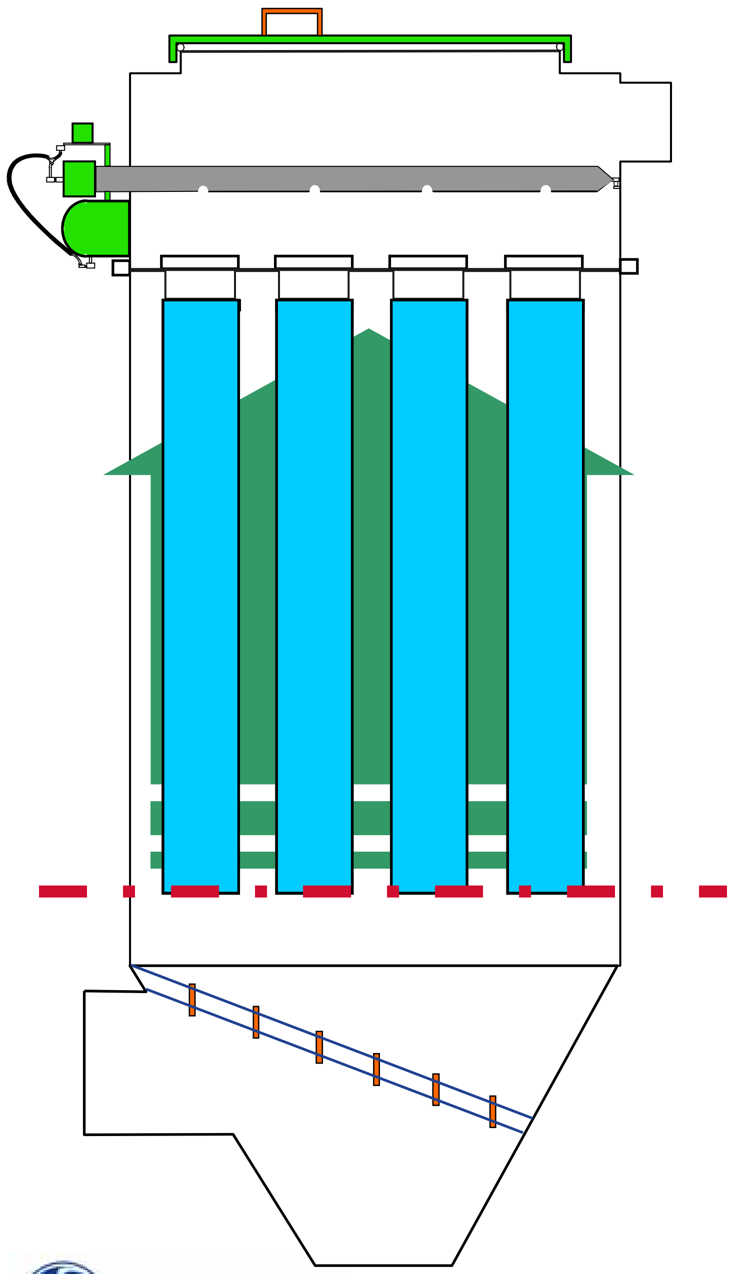

Can Velocity

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.

Excessive can velocity prevents dust from settling into hoppers.

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Typical Causes of Increased Gas volume

- Increased output
- Reduced thermal efficiency
- Increased in-leakage
- Elevated operating temperature
- Changes in fuel characteristics

Increased Flue Gas Flow Rate

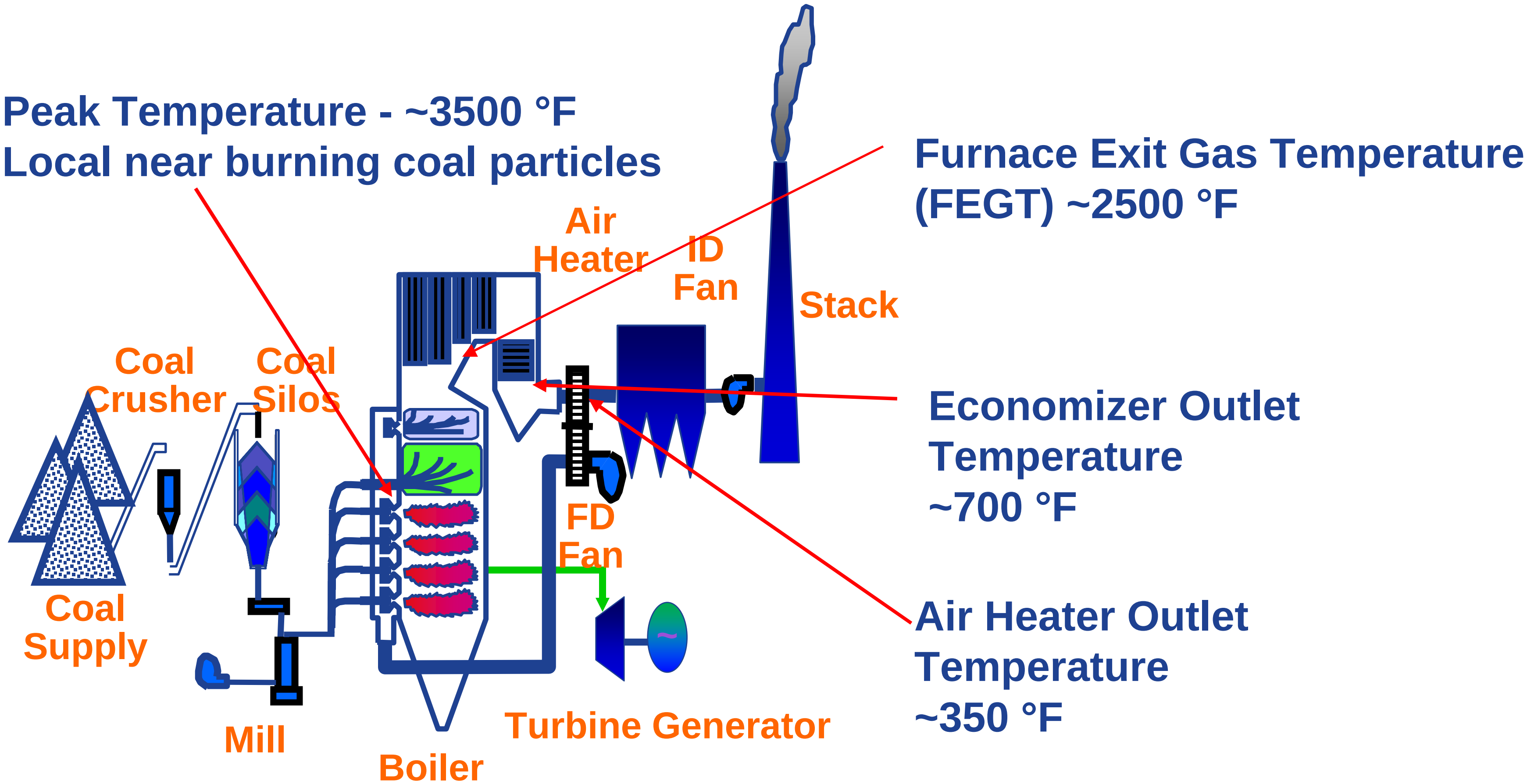
Electrostatic Precipitator

- Reduced collection efficiency
- Increased pressure drop
- Increased emissions
- Increased abrasion
- Instability in high voltage system

Fabric Filter

- Relatively constant emissions
- Increased pressure drop
- Reduction in cleaning cycle interval
- Reduced bag life
- Inability of dust to settle
- Abrasion from swinging bags

Flue Gas Temperature



Changes in operating temperature at any point may affect FEGT

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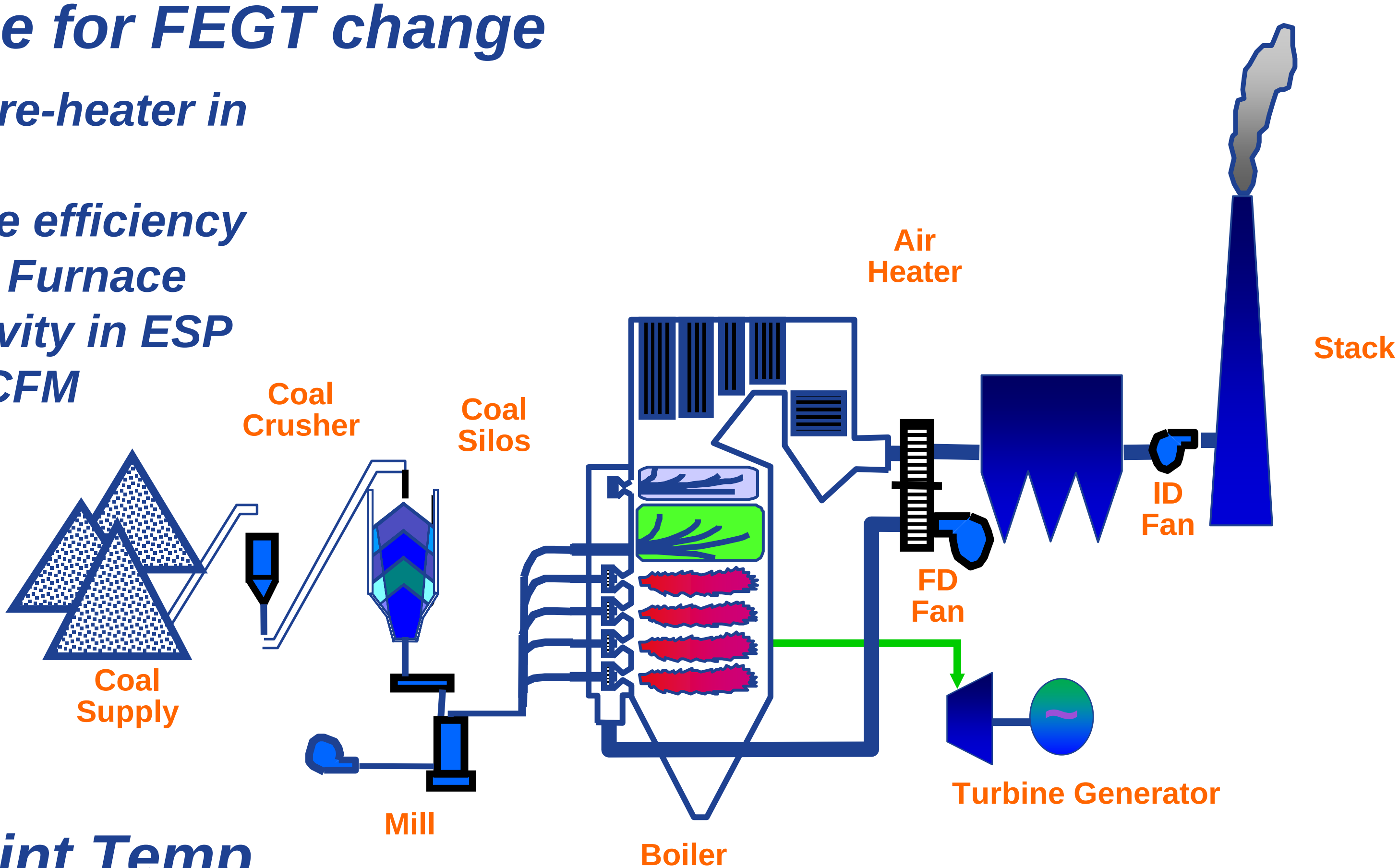
Flue Gas Temperature

Typical cause for FEGT change

- *Use of air pre-heater in winter*
- *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*
- *Insufficient FEGT increases corrosion*

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Impact of Elevated Temperature

Electrostatic Precipitator

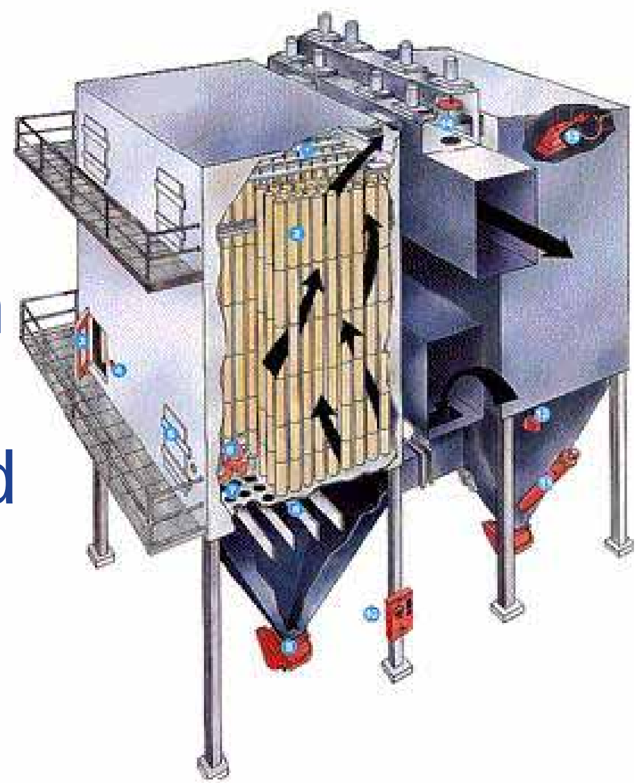
- Increased gas volume
- Possible dust resistivity increase
- Increased emissions
- Damage to insulators
- Damage to elastomer seals
- Reduced sorbent effectiveness

Fabric Filter

- Increased gas volume
- Reduced fabric life
- Loss of filter bags
- Damage to elastomer seals
- Reduced sorbent effectiveness

Coal Composition

- As shown previously, composition of the coal affects dust burden and gas volume.
- In addition, gas composition can affect other factors:
  - Sulfur & iron oxide affect acid dew point
  - Moisture affects volume and acid dew point
  - Incomplete combustion increases carbon monoxide



Bag House Basics Filter Media Selection

Oper. Vari.	Polyester	Acrylic	Fiberglass	Aramid	PPS	P84
Max. Oper. Temperature	275°F (134°C)	265°F (130°C)	500°F (259°C)	400°F (204°C)	375°F (190°C)	500°F (259°C)
Abrasion	Excellent	Good	Fair	Excellent	Good	Fair
Filtration Properties	Excellent	Good	Fair	Excellent	Very Good	Excellent
Moist Heat	Poor	Excellent	Excellent	Good	Excellent	Good
Alkalines	Fair	Fair	Fair	Good	Excellent	Fair
Mineral Acids	Fair	Good	Poor**	Fair	Excellent	Good
Oxygen(15%+)	Excellent	Excellent	Excellent	Excellent	Poor	Excellent
Relative Cost	X	XX	XXX	XXXX	XXXXXX	XXXXXXX

Impact of Coal 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

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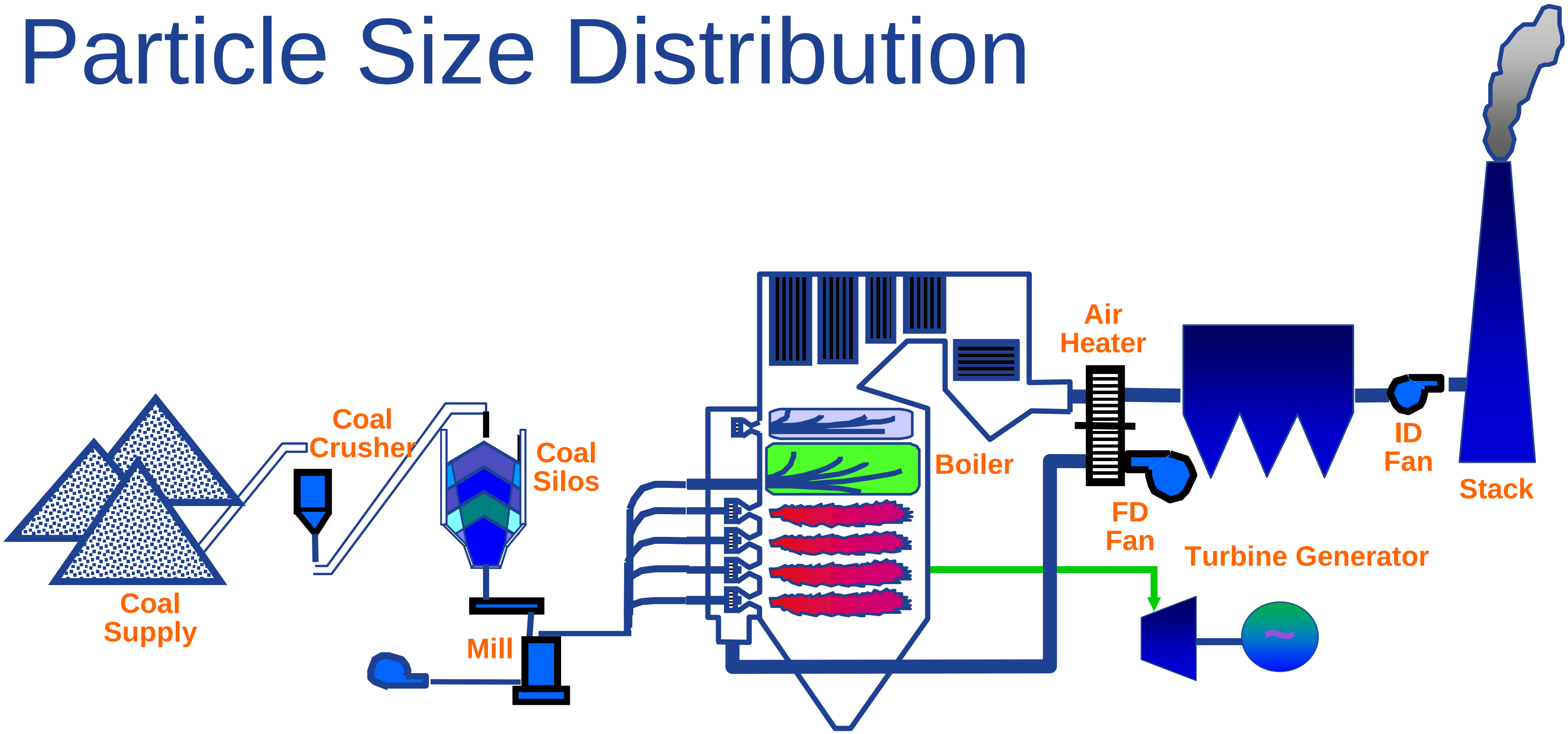
Particle Size Distribution



Crusher ~ 1" "particles"

Mills - 70% through 200 mesh screen – 125 microns

Fly ash particle size is a function of coal grind and coal characteristics

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Particle Size Distribution

Particle size is partially a function of coal characteristics:

Volatile matter

- Volatile matter burns like a gas flame.
- Rapid oxidation but MAY form soot based on local oxygen deficiency.
- Increased volatile content associated with 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

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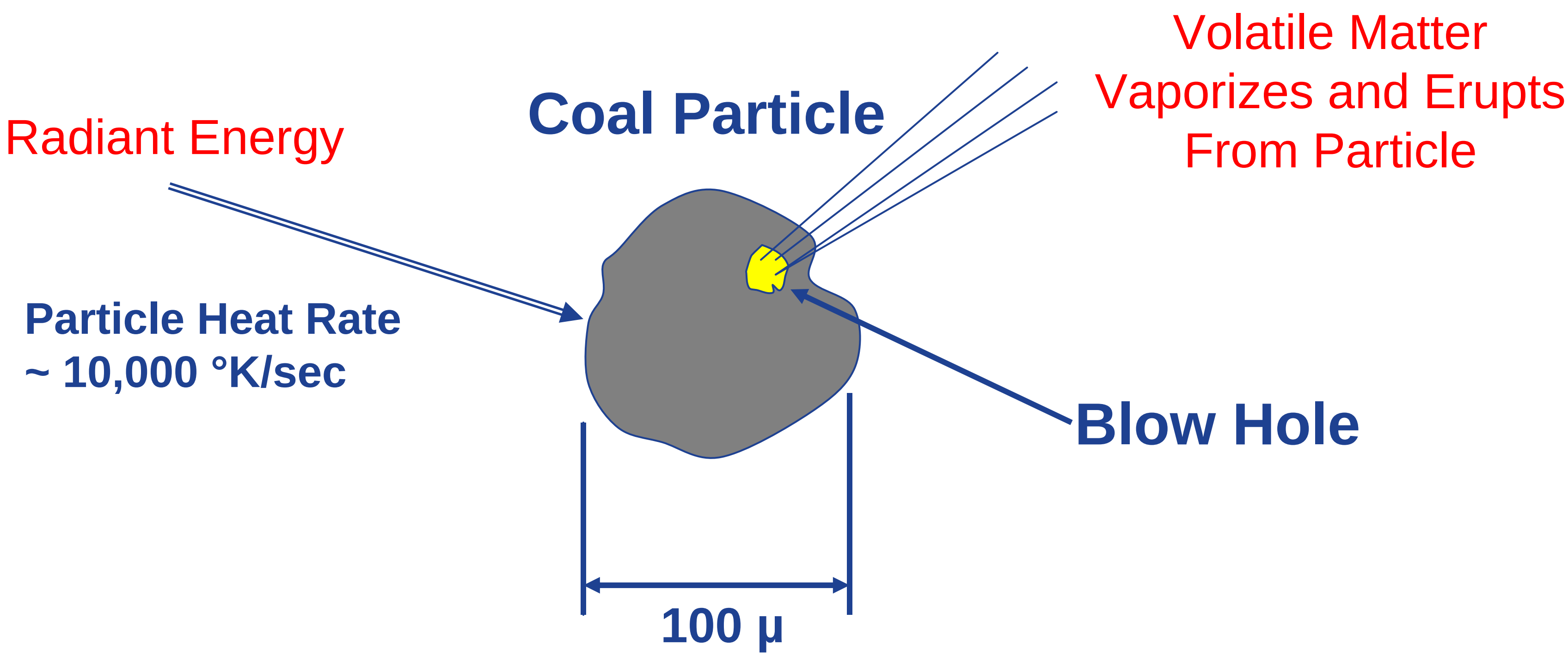
Particle Size Distribution



Typical coal combustion of volatile matter

Impact of Reduced Particle Size Composition

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

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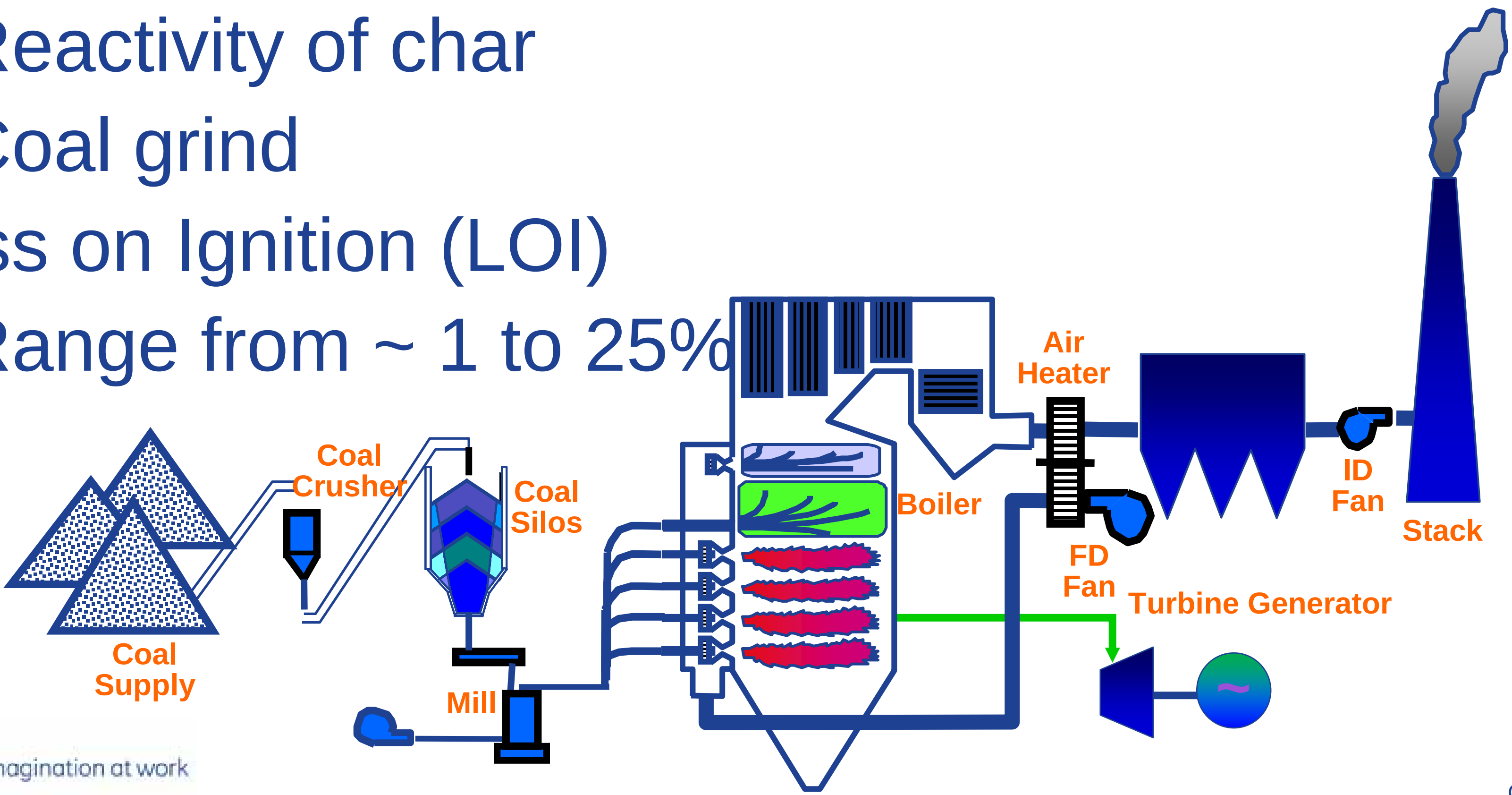
Carbon Content of Ash

Factors Affecting Complete Burn Out

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

Loss on Ignition (LOI)

- Range from ~ 1 to 25%



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Carbon Content of 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
- Switch in coal source

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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.

Carbon Content of Ash

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.
- Injecting after ESP has major impact on dust burden. (Polishing mode)
- Other mechanisms must exhibit greater impact on ESP performance.

Carbon Content of Ash

- An ESP is not as effective at removing carbon as compared to fly ash.
- Field testing indicates ESP emissions may increase when carbon based PAC is utilized.
- Performance is a function of number of electrical fields and general condition of ESP.
- Carbon has lower reflectance when compared to fly ash. (Visible emissions)
- Field testing indicates carbon based PAC can create potential for hopper fires.

Carbon Content of Ash

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 can have an impact on ESP visible emissions
- ESP performance may be compromised when high efficiency mercury removal is required.

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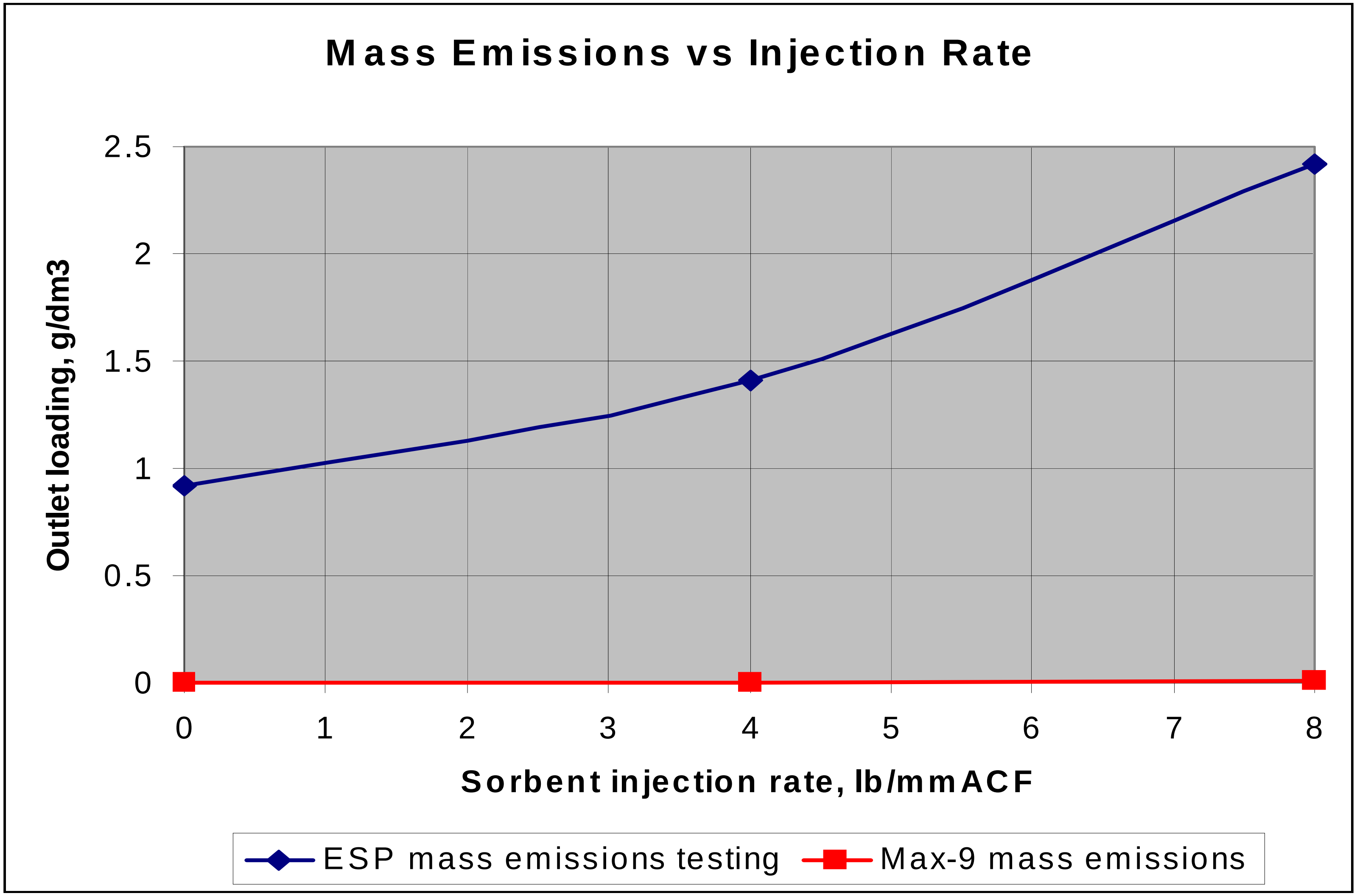
Carbon Content of Ash



- ESP emissions increase as inlet dust loading increases.

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Carbon Content of Ash

Electrostatic Precipitator

- Increased spark rate
- Increased re-entrainment
- Potential for insulator tracking
- Potential for hopper fires
- Inability to sell fly ash
- Decreased effectiveness of activated carbon
- Potential increased dust resistivity.

Fabric Filter

- Hydrocarbons can blind filter bags
- Potential for hopper fires
- Inability to sell fly ash
- Decreased effectiveness of activated carbon

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Summary

The combustion process affects many aspects of PM control:

- 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

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