Worldwide Pollution Control Association

FirstEnergy ESP Seminar

November 27th – 28th, 2007

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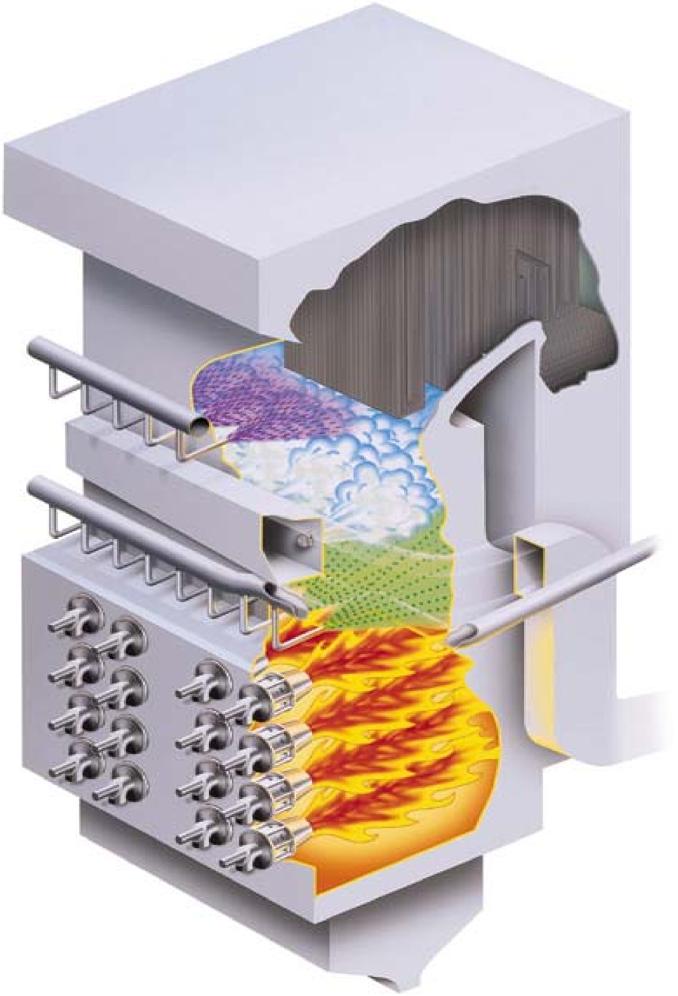
Impact of Combustion on Particulate Collection



First Energy

Reinhold Seminar

Bob Taylor

November 2007

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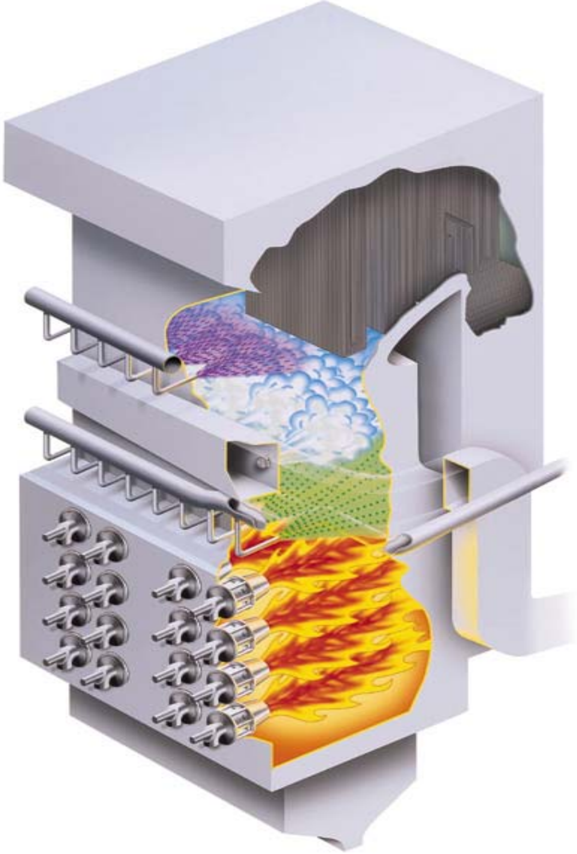
Combustion Impact on PM Collection

- Many of the problems experienced with ESP or Fabric Filter performance relate to external factors.
- The particulate control device can be in good shape, yet experience problems due to changes in fuel or process gas conditions.
- As a result, the ability to maintain acceptable performance is dependent on understanding the external factors which affect particle collection.

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



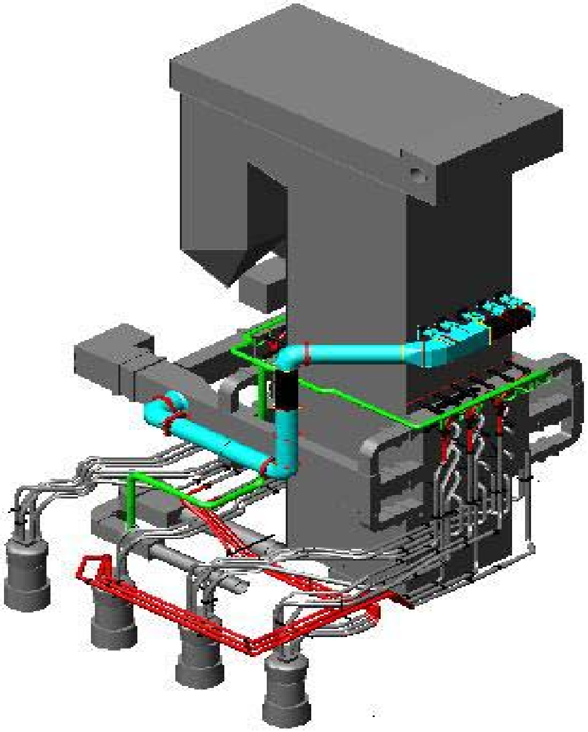
Particulate Inlet Dust Load

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

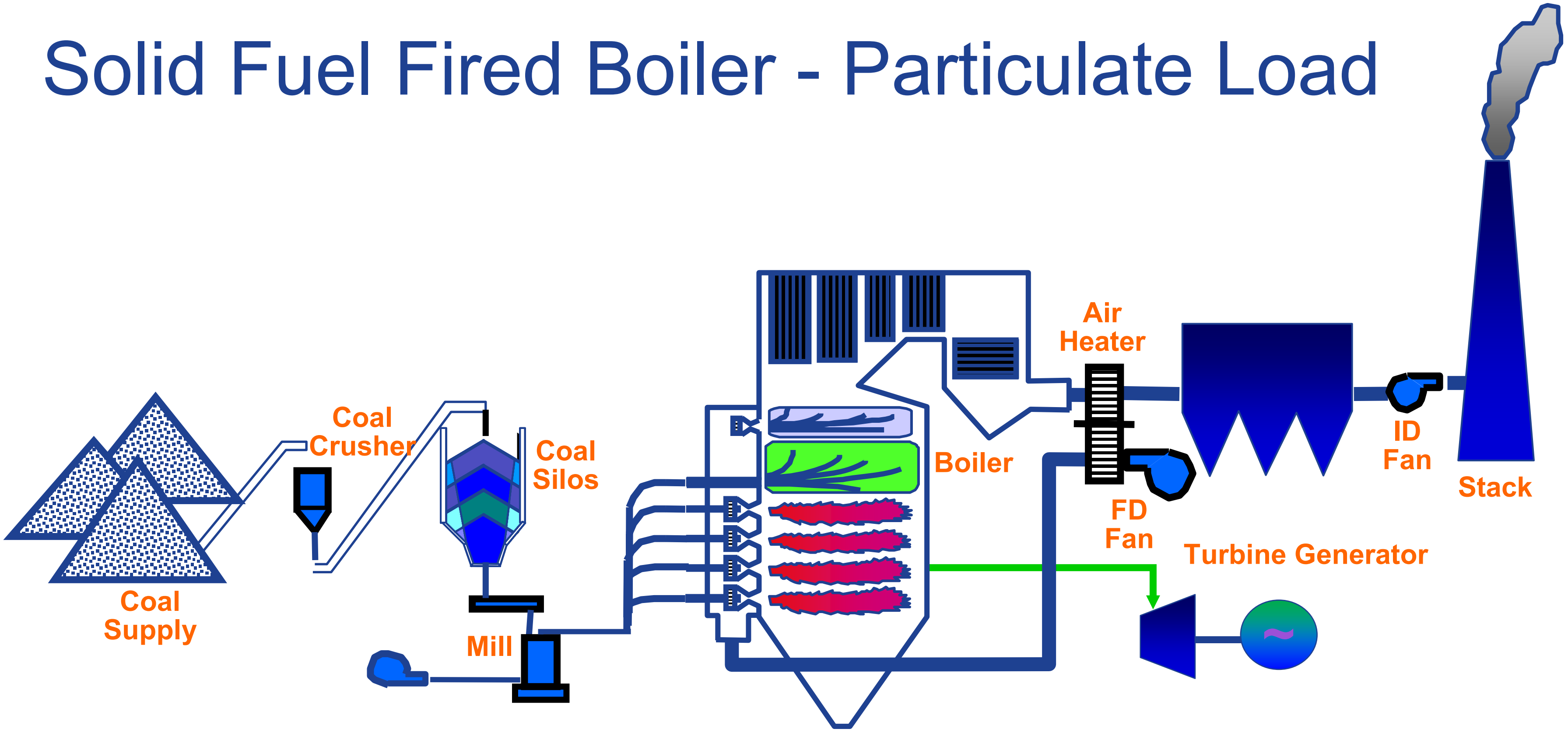
Impact of Combustion on Particulate Collection

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



Solid Fuel Fired Boiler - Particulate 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%

Impact of 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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Response to Increased Particulate Inlet Dust Load

Electrostatic Precipitator

- Increase hopper evacuation rate.
- Reduce inlet field collecting late rapping interval.
- Monitor second field to quantify impact of first field changes.
- If using flue gas conditioning, increase SO3 injection rate.

Fabric Filter

- Increase hopper evacuation rate.
- If using POD, monitor upper pressure set point limit versus pulsing interval.
- If using timer pulsing, decrease interval between pulses.

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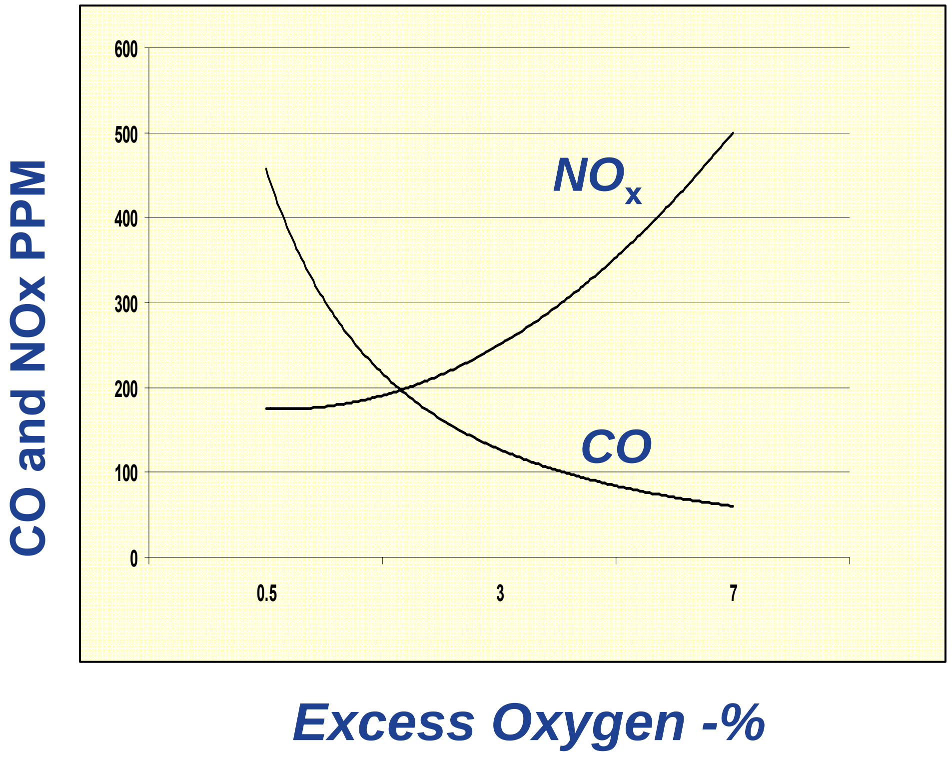
Flue Gas Flow Rate



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

Flue Gas Flow Rate and Mass Loading

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.

Impact of Gas Volume on ESP

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

Increased gas volume decreases efficiency.

$$W = \frac{E_o E_p a}{2 \pi \eta}$$

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 $\frac{\text{Volts}}{\text{Distance}}$

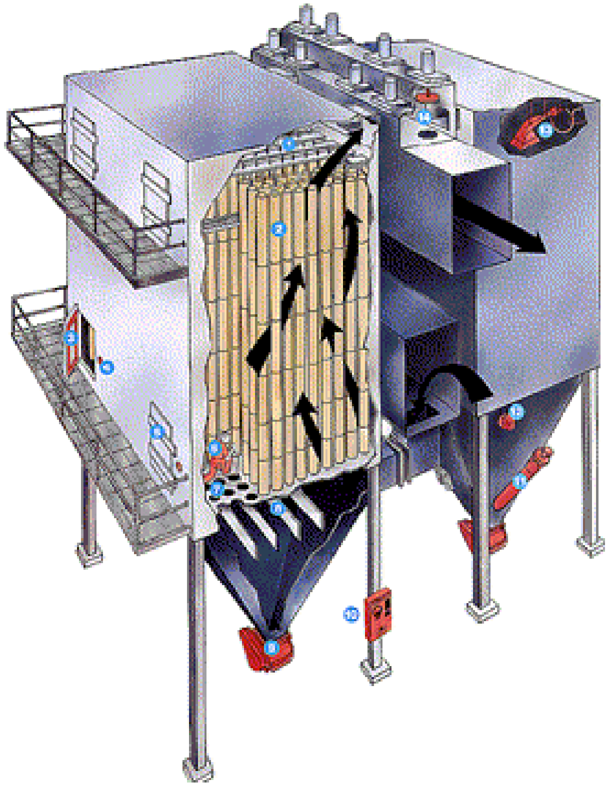
a = Particle Radius

η = Gas Viscosity

π = 3.1416

Impact of Gas Volume on 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.
- Increased gas volume results in increased ΔP

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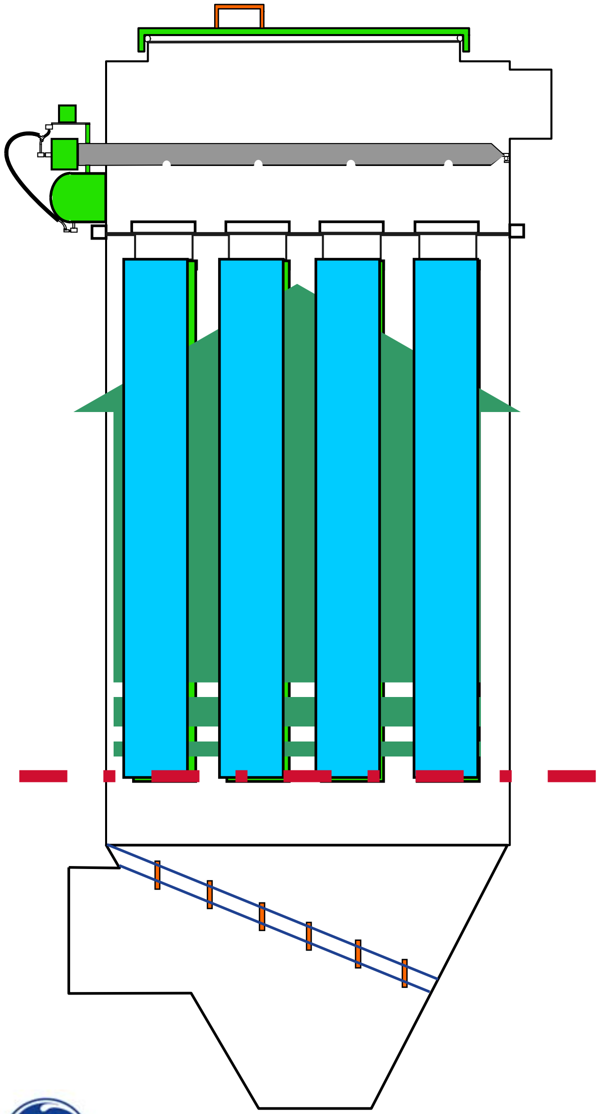
Impact of Gas Volume on Fabric Filter



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.

Increased gas volume results in increased can velocity.

Impact of Increased 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

Response to Increased Gas Flow Rate

Electrostatic Precipitator

- Identify and repair sources of in-leakage.
- Verify inlet gas temperature relative to normal conditions.
- Minimize outlet field rapping.
- Keep hoppers evacuated.
- Look for increased spark rate due to oscillation.

Fabric Filter

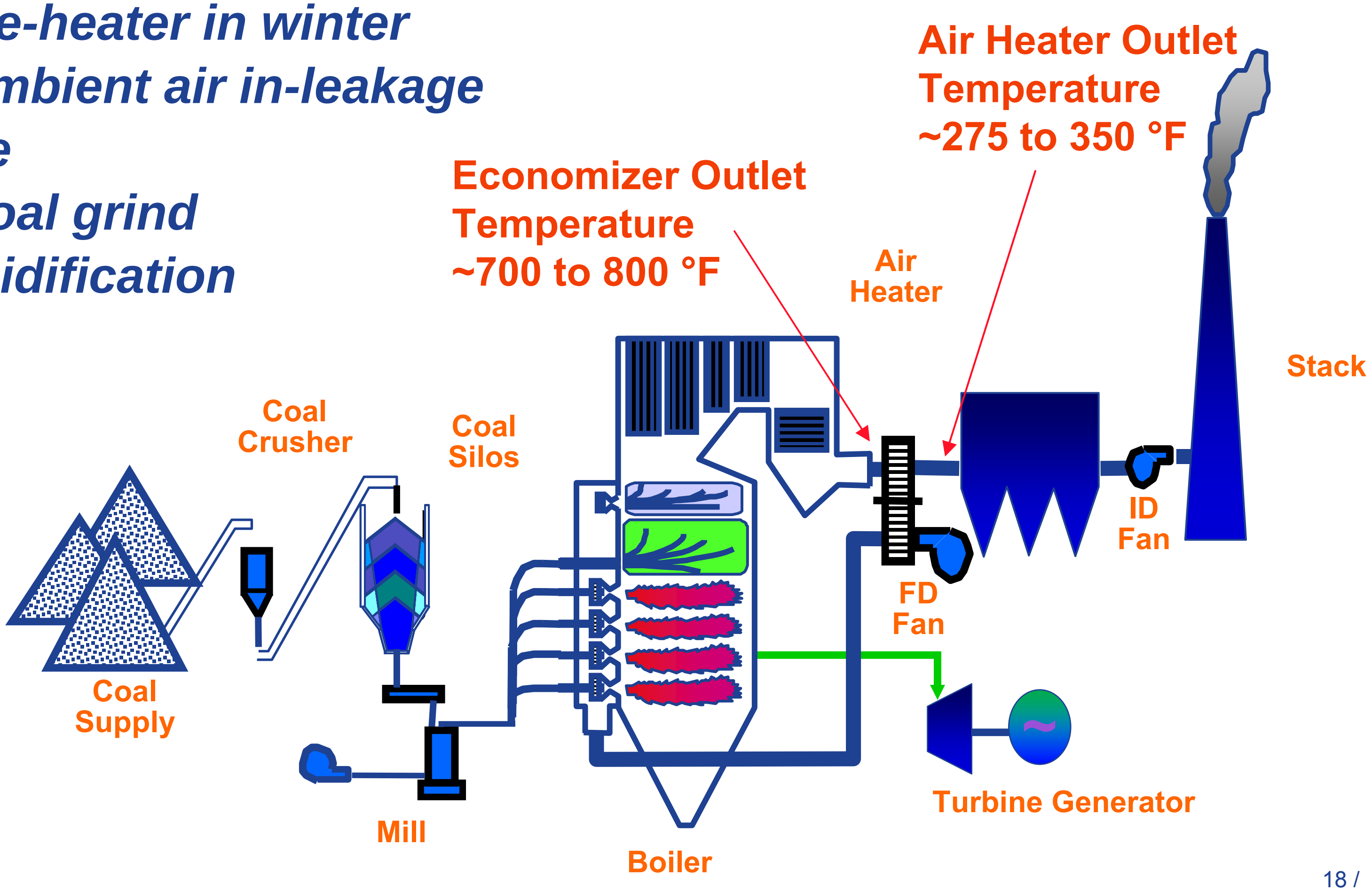
- Reduce interval between cleaning cycles, increase upper pressure set point.
- Identify and repair sources of in-leakage.
- Verify inlet gas temperature relative to normal conditions.
- Bring all compartments on-line.

Gas Temperature

Changes in PM device inlet temperature affects its' operation.

Temperature change may result from:

- *Slagging or fouling in furnace*
- *Use of air pre-heater in winter*
- *Excessive ambient air in-leakage*
- *Load change*
- *Change in coal grind*
- *Loss of humidification*



Impact of Temperature Change

Electrostatic Precipitator

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

Fabric Filter

- Increased gas volume
- Reduced fabric life
- Loss of filter bags
- Damage to elastomer seals
- Reduced sorbent effectiveness
- Possible increase in corrosion.

Response to Temperature Change

Electrostatic Precipitator

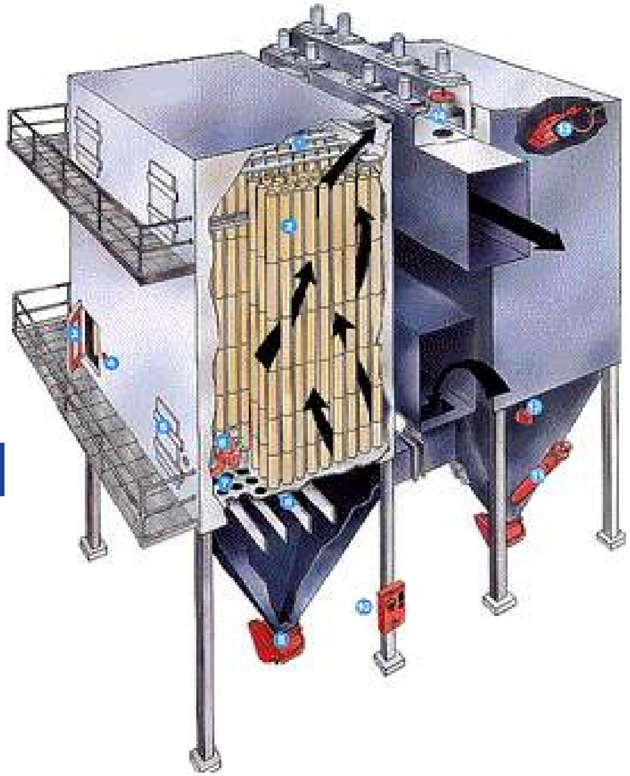
- Monitor secondary current and spark trends.
- If high resistivity;
    - Implement intermittent energization
    - Aggressive collecting plate rapping
    - Reduced power rapping
- Blow soot
- If temperature too low, reduce in-leakage.

Fabric Filter

- Monitor temperature relative to media limits.
- If temperature too high, bleed in ambient air or introduce EGC.
- If temperature too low, reduce in-leakage or reduce water injection rate.

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 and carbon content of ash.



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

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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

Response to Coal Composition

Electrostatic Precipitator

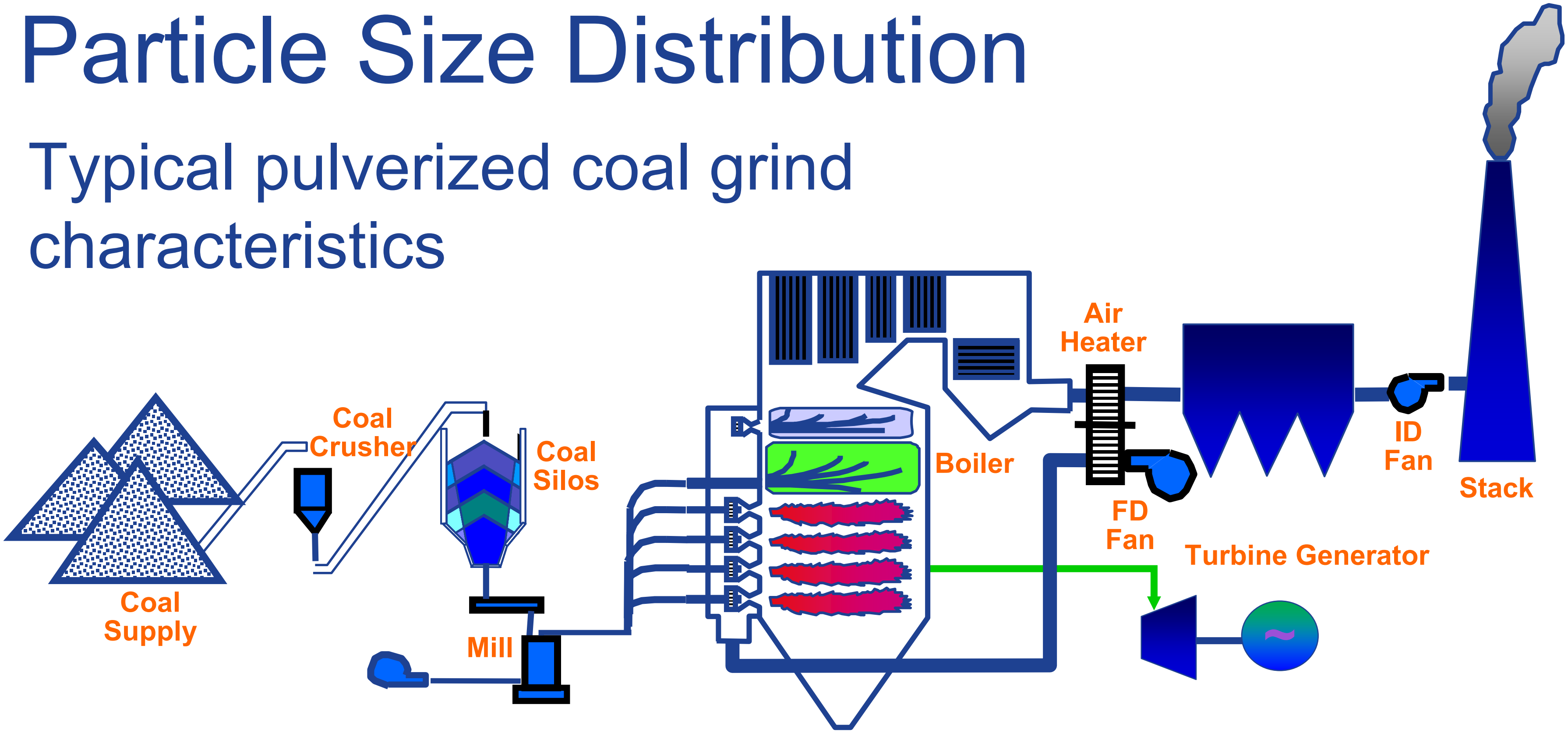
- Monitor dew point of gas stream and adjust inlet temperature.
- Adjust rapping intensity and frequency when dust resistivity changes.
- Modify flue gas conditioning system injection rates based on secondary current and spark rates.

Fabric Filter

- Increase pulse frequency when moisture make dust sticky.
- Monitor change in acids relative to media capabilities.
- Improve coal grind to lower excess air.
- Inject alkali ahead of FF to react with acids.

Particle Size Distribution

Typical pulverized coal grind characteristics



Crusher ~ 1" "particles"

Mills - 70% through 200 mesh screen – 125 microns

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

Particle Size Distribution

Particle size is partially a function of coal characteristics:

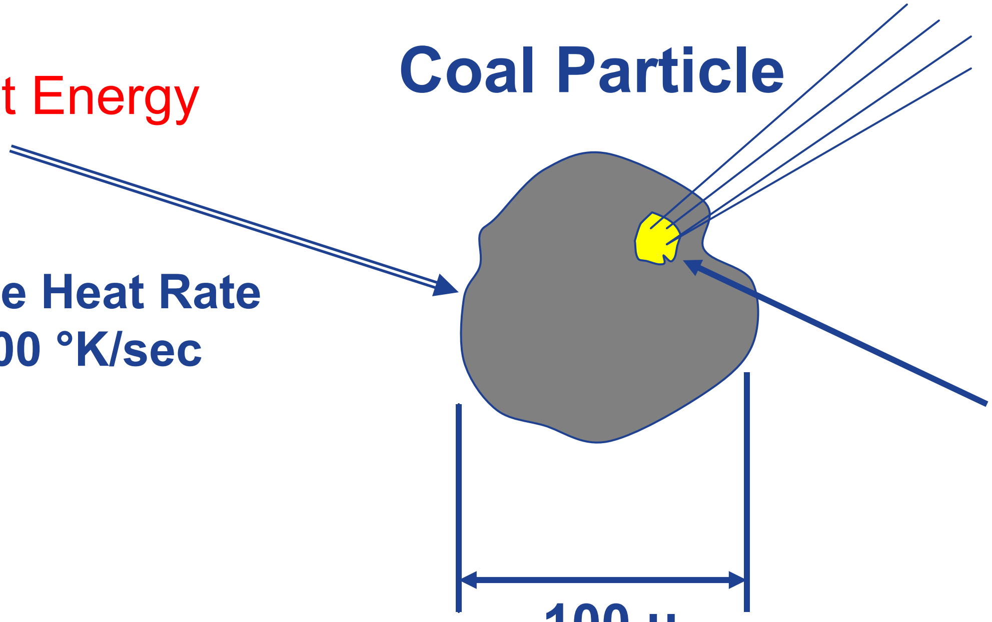
Volatile matter

- 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

Particle Size Distribution



Radiant Energy

Coal Particle

Volatile Matter
Vaporizes and Erupts
From Particle

Particle Heat Rate
~ 10,000 °K/sec

Blow Hole

100 μ

Typical coal combustion of volatile matter

Impact of Gas Volume on ESP

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

Reduced particle size decreases efficiency.

$$W = \frac{E_o\, E_p\, a}{2 \pi \eta}$$

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

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

Response to Reduced Particle Size

Electrostatic Precipitator

- Improve gas flow uniformity.
- Monitor spark rates and space charge.
- Eliminate sneakage or sweepage.
- Increase rapper off times to maximize agglomeration.

Fabric Filter

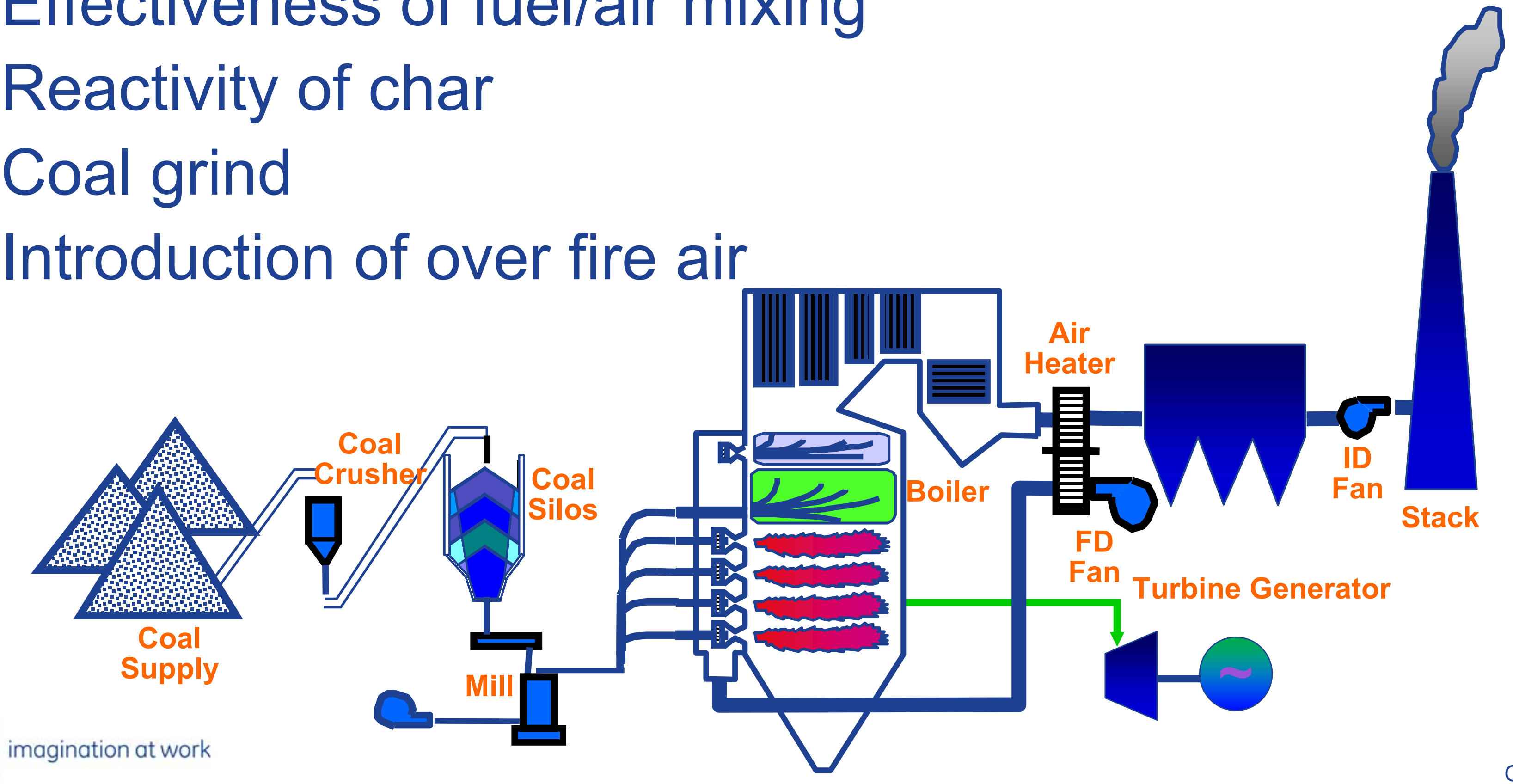
- Pre-coat filter bags.
- Consider membrane laminated filter media.
- Decrease pulse cycles.
- Improve internal gas distribution.

Carbon in Fly Ash

Incomplete burn out results in increased unburned carbon in fly ash.

Factors Affecting Complete Burn Out

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



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.
- This process increases the dust burden to the PM control device.

Impact of PAC Injection on Dust Burden

Total Dust Burden				
PAC Rate lb/mmBTU	Inlet Dust gr/acf	PAC Injection gr/acf	Total Burden gr/acf	% Increase
1.5	1.5	0.011	1.511	0.73
3	1.5	0.022	1.522	1.50
7	1.5	0.049	1.55	3.33
Polishing Mode				
PAC Rate lb/mmBTU	Inlet Dust gr/acf	PAC Injection gr/acf	Total Burden gr/acf	% Increase
1.5	0.015	0.011	0.026	173.00
3	0.015	0.022	0.037	247.00
7	0.015	0.049	0.064	427.00

- Injecting PAC ahead of ESP has minimal impact on FF inlet dust burden.
- Injecting after ESP has major impact on FF dust burden. (Polishing mode)

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 PAC is utilized.
- Performance is a function of the number of electrical fields and general condition of ESP.
- Carbon has lower reflectance when compared to fly ash. (Visible emissions)
- Field testing indicates PAC can create potential for hopper fires.

Impact of Carbon in Fly 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

Response to Carbon in fly Ash

Electrostatic Precipitator

- Maintain elevated secondary current densities.
- Minimize outlet field rapping.
- Eliminate hopper in-leakage.
- Monitor operation of hopper heating equipment.
- Eliminate internal stabilizer insulators.
- Pressurize support insulators.
- Evacuate hoppers frequently.
- Verify proper coal grind.
- Balance primary and over fire air.

Fabric Filter

- Pre-coat new filter bags to avoid blinding.
- Consider membrane laminated filter media.
- Empty hoppers frequently.
- Minimize hopper in-leakage.
- Monitor operation of hopper heating equipment.
- Verify proper coal grind.
- Balance primary and over fire air.

Summary

- Multiple external factors impact operation of the PM control device. The PM device has no direct influence over these parameters.
- Typical factors which affect PM devices.
    - Inlet PM Loading
    - Gas volume
    - Particle size distribution
    - Flue gas composition and temperature
    - Carbon content of ash
- Some operating parameters of the PM device can be modified to accommodate the process changes.
- Establishing an operation baseline and knowing how PM device reacts to change will help determine necessary adjustments.