

Combustion Impact on Particulate Collection



Bob Taylor

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Combustion Impact on PM Collection

Areas of Impact

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

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

Particulate Loading

Power Plant Efficiency

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

Heat Rate ~10,000 Btu/KwHr

Example 240 MWe Plant

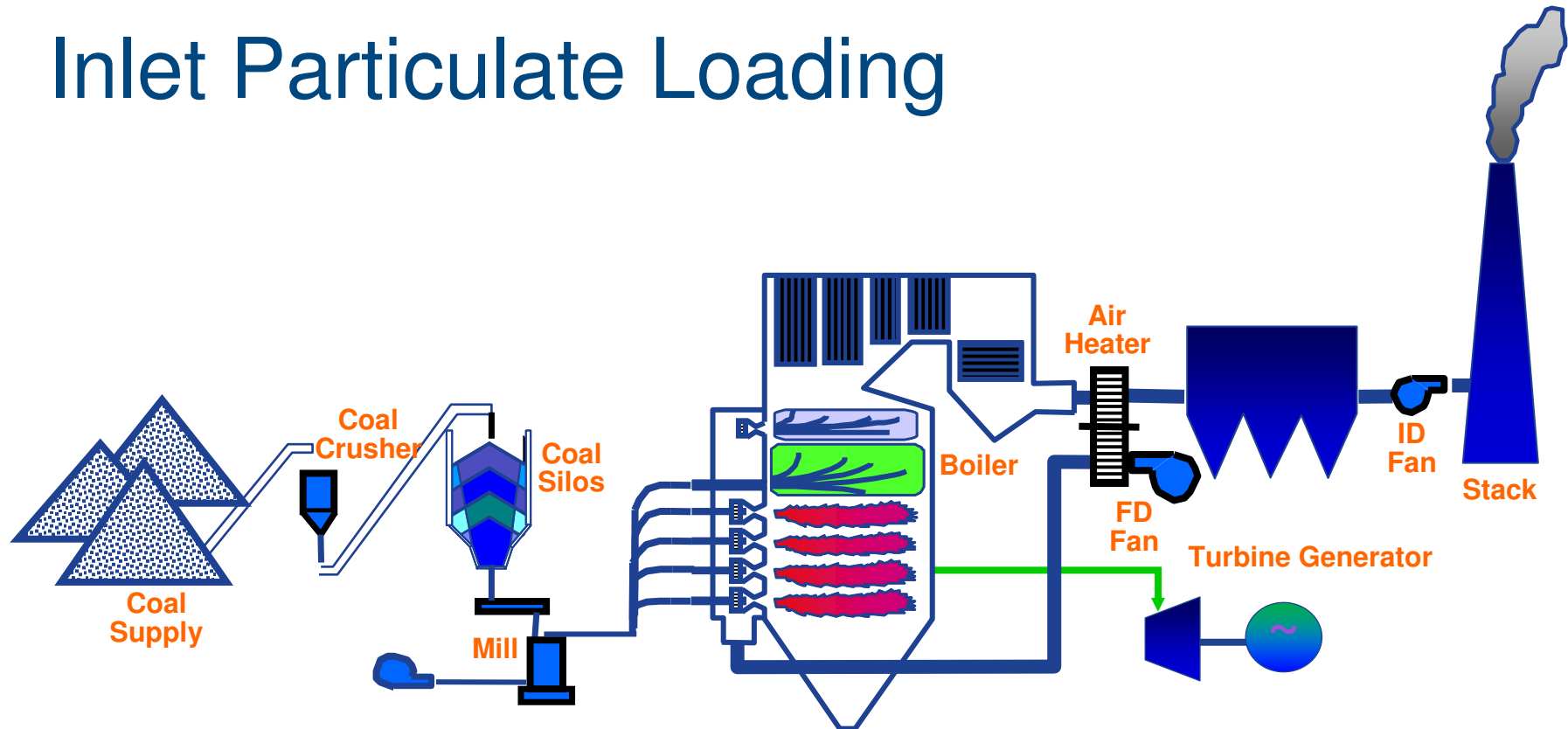
Coal HHV - ~12,000 Btu/lb (from Proximate Analysis)

Fuel Use = $240,000 \text{ Kw} \times 10,000 \text{ Btu/KwHr} / 12,000 \text{ Btu/lb} / 2000 \text{ lb/ton} = 100 \text{ tons/hr}$

Coal Ash Content ~ 10%

PM = $100 \text{ tph coal} \times 10\% \text{ ash} = 10 \text{ tph PM}$

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

Impact of Increased Dust Burden

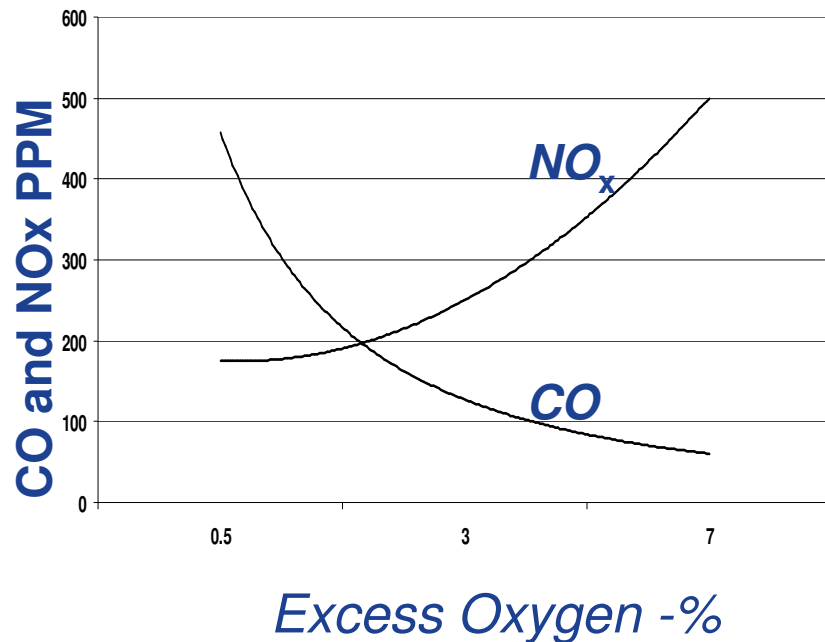
Electrostatic Precipitator

- 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 Multiplier	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										
			Stoichiometric	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

15750 scf/100 Lbs fuel (@3% O₂)

Flue gas flow

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

525,000 scfm

PM Loading

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

3.56 grains/ standard ft³ Equals the inlet dust burden

Mass burden at inlet to PM device varies based on dust quantity and gas volume.

Impact of Increased Gas Volume

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

Increased cleaning cycles

Reduced bag life

Inability of dust to settle

Electrostatic Precipitator

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

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

EFF = Fractional % Collected

A = Surface Area Collecting Electrodes

V = Volumetric Flow Rate

w = Particle Drift Velocity or Rate Parameter

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

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

a = Particle Radius

η = Gas Viscosity

π = 3.1416

Electrostatic Precipitator

- Collection efficiency is exponentially related to gas volume
- Small change in gas volume results in large reductions in PM efficiency.

Fabric Filter

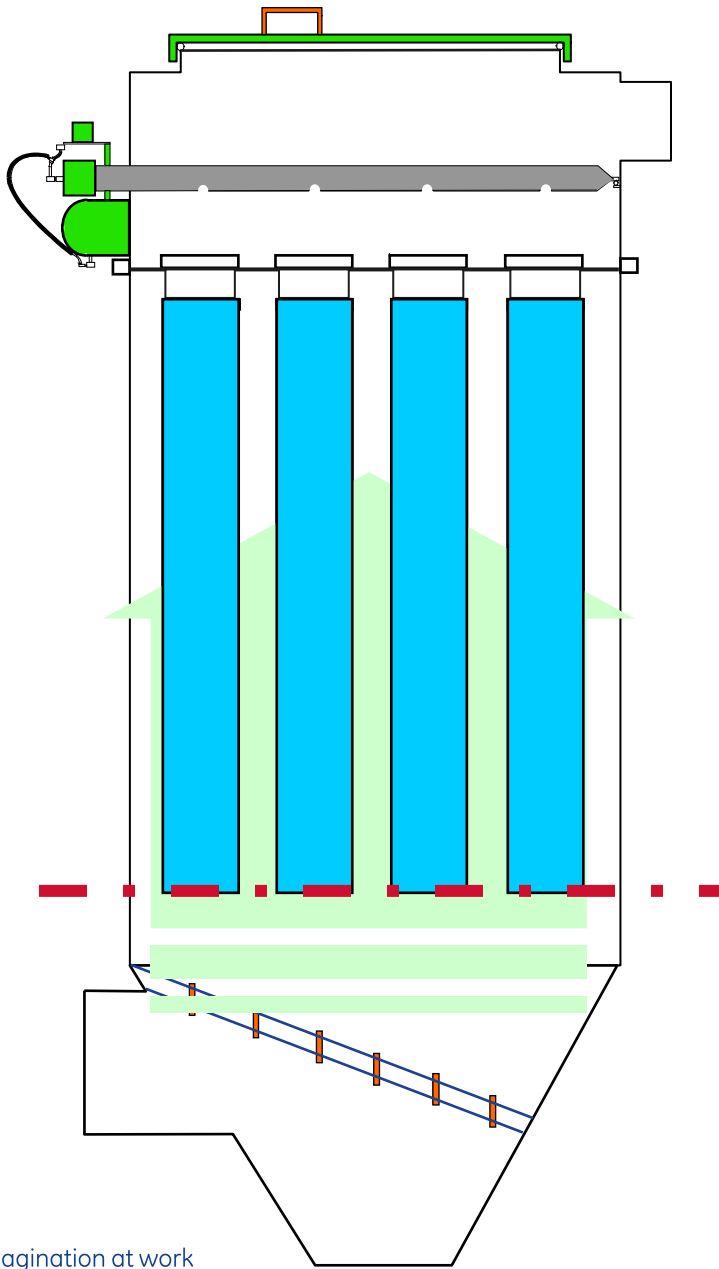
Air to Cloth Ratio

- 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 air to cloth ratios for utility boilers 2.0 through 8.0

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.



Causes of Increased Gas volume

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

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 ₂ O	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		

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

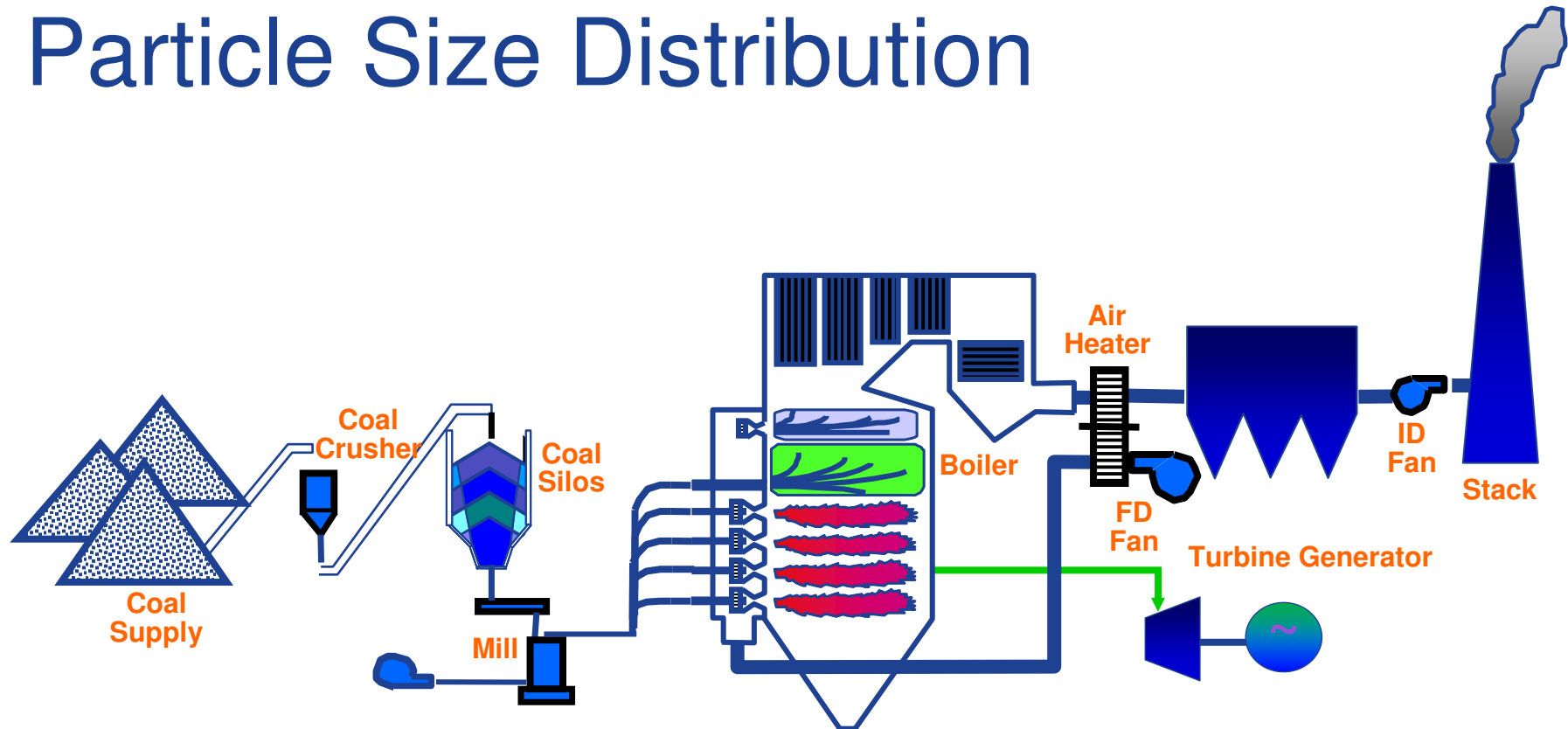
Increased acids can degrade fabrics

Excessive oxygen can degrade some fabrics

Excessive moisture can degrade some fabrics.

Elevated CO possible explosion

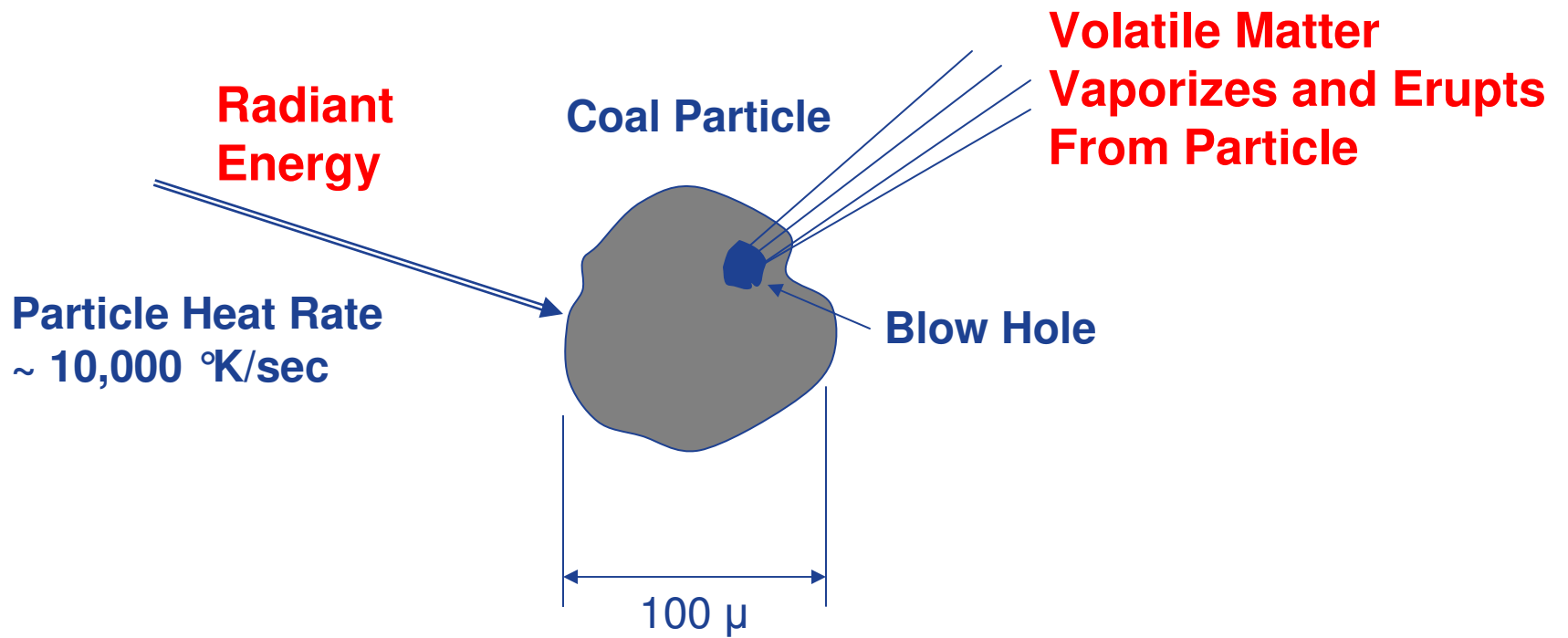
Particle Size Distribution



Crusher ~ 1" "particles"

Mills - 70% through 200 mesh screen – 125 microns

Coal Burning Processes



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 – these are the “baseballs”

Impact of Reduced particle Size

Electrostatic Precipitator

Reduced collection efficiency

Excessive space charge conditions; current suppression

Elevated impact on opacity

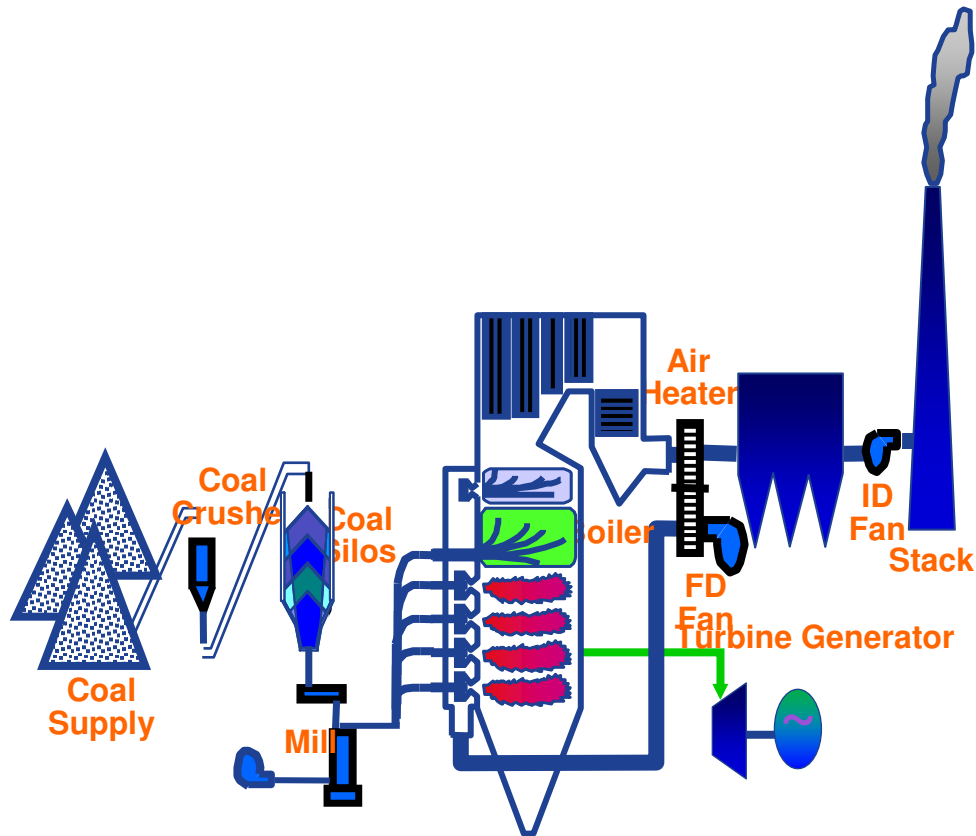
Fabric Filter

Potential bag blinding

Possible increased emissions

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%

Impact of Elevated Carbon

Electrostatic Precipitator

Increased spark rate

Increased re-entrainment

Potential for insulator tracking

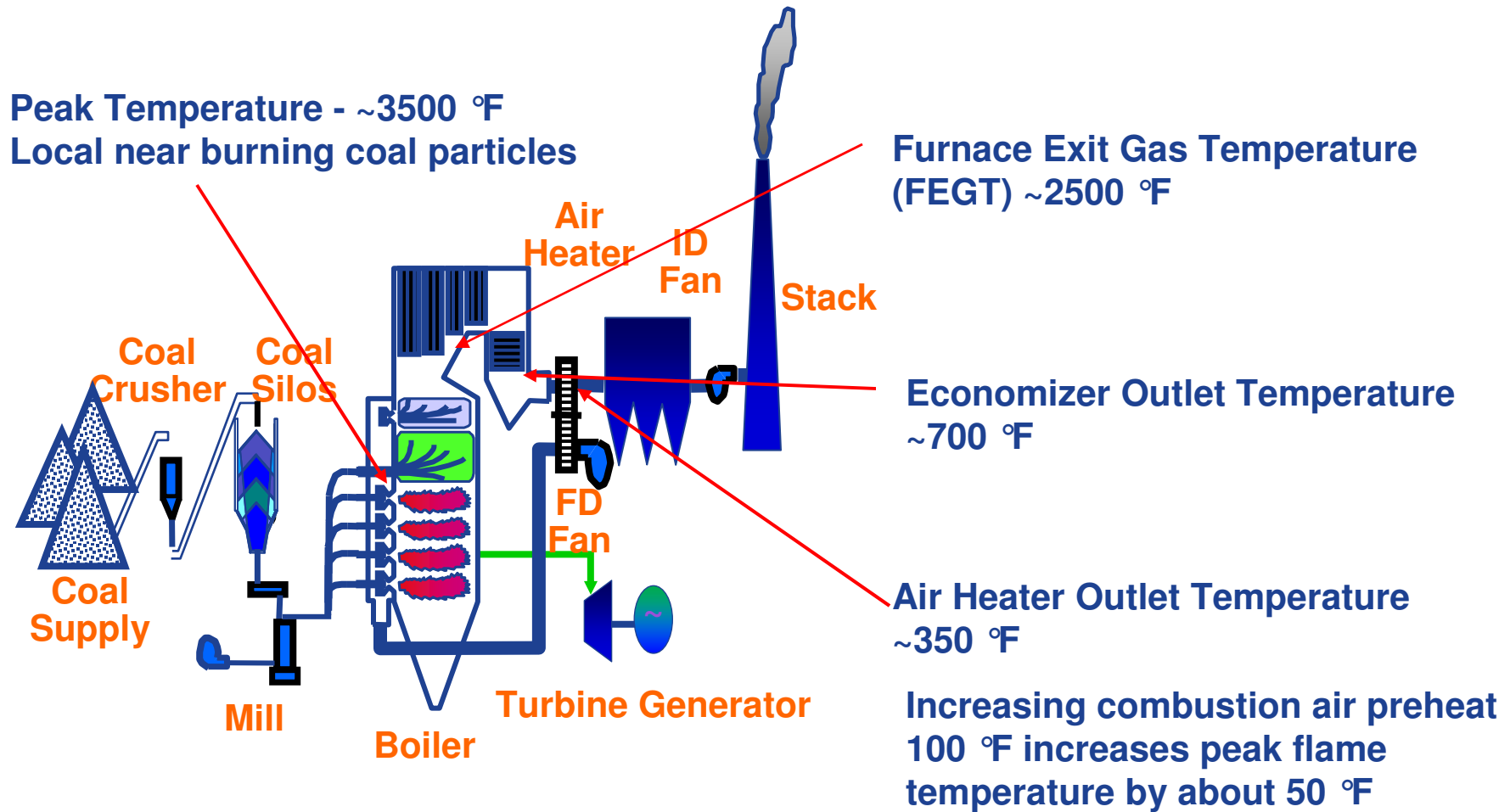
Potential for hopper fires

Fabric Filter

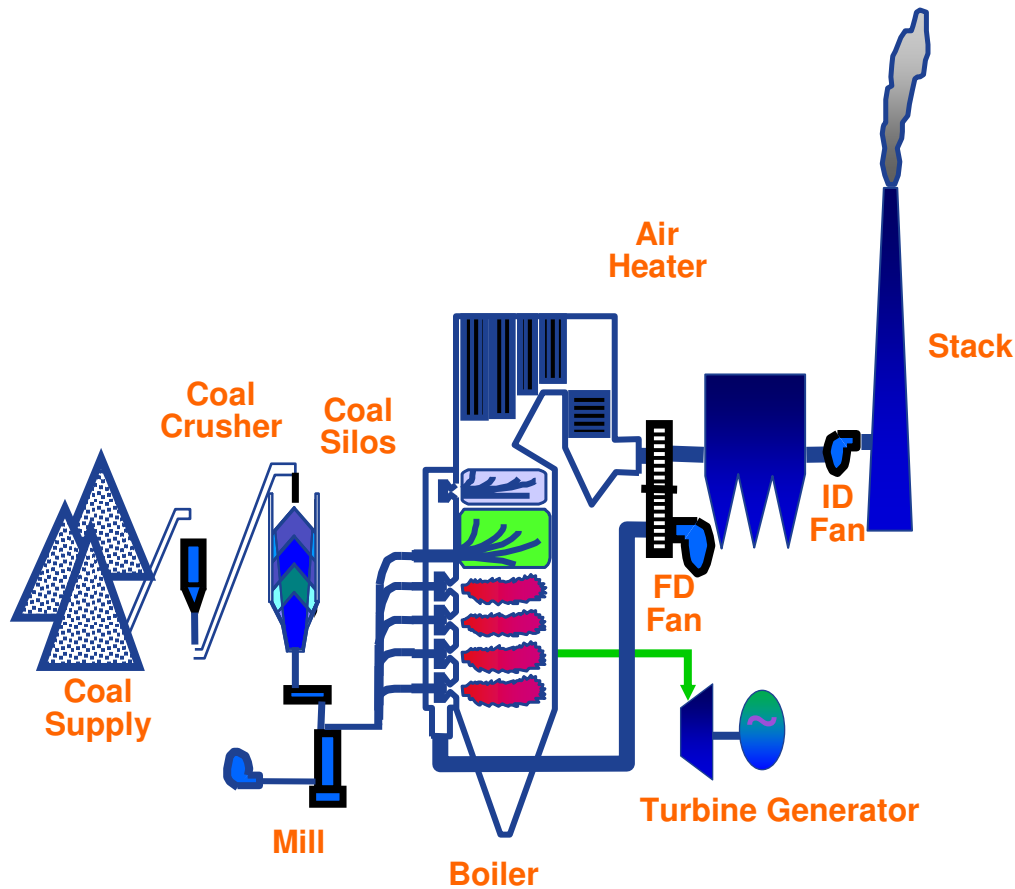
Hydrocarbons can blind filter bags

Potential for hopper fires

Flue Gas Temperature Patterns



Temperature Patterns



Changing air preheat

*Power Cycle efficiency
Slagging in Furnace
Ash resistivity in ESP
Flue gas ACFM*

*SO₃ Dew Point Temp.
~235 to 300°F depending on
moisture and SO₃ level*

Air Pre-heater Coils

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

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

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