Reinhold Environmental Ltd.

2007 NOx Round Table & Expo Presentation

February 5-6, 2007 in Cincinnati, OH

SCR Impacts on Boiler Systems

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Discussion Outline

- SCR Performance
  - *What impacts SCR performance?*
- Impacts of Adding an SCR
  - *How does the SCR affect boiler operation and air pollution control devices?*

SCR Performance – Boiler Operation

- Flue gas properties
  - Temperature → NOx capture, SO_2 oxidation
  - Composition → NOx, SO_2
  - Distribution → Catalyst effectiveness
- Fly ash properties
  - Plugging → Ash size and composition
  - Poisoning → Coal and ash composition
  - Blinding → Ash composition, size

SCR Performance – SCR Design

- AIG / ammonia distribution
  - Ideal is uniform NH_3/NO ratios entering catalyst
- Catalyst properties
  - NOx oxidation, SO_2 oxidation, poison tolerance, channel spacing

Impacts of Adding SCR

- Operation of boiler and air pollution control devices affected
  - NOx
  - SO_3
  - Ammonia
  - Hg

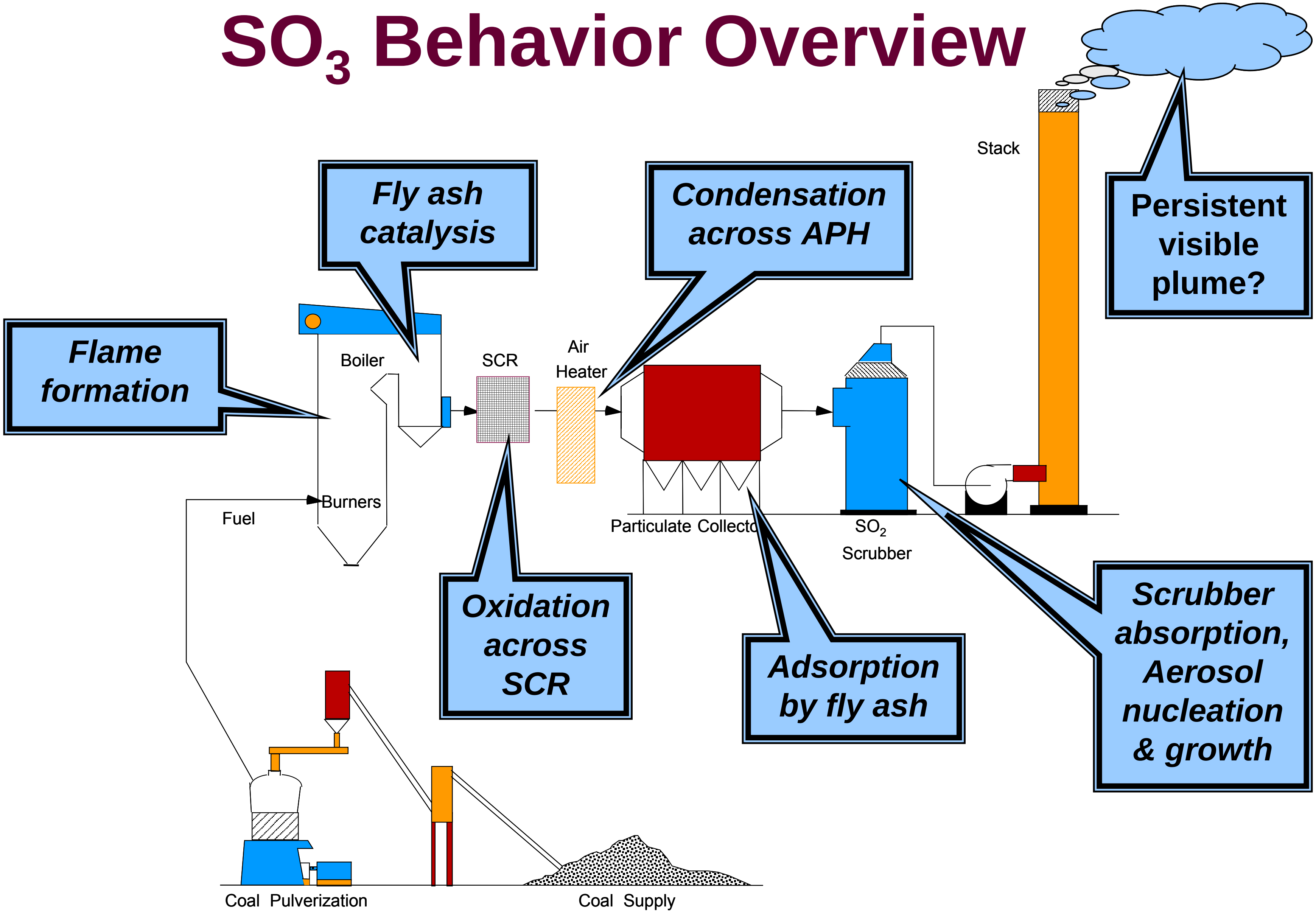
NOx

- NOx reduction capacity provides operational flexibility
  - Staging, low-NOx burners
  - Some fuel flexibility
  - Load range

SO_3

- SO_2 conversion throughout a boiler
- SO_3 impacts
  - Opacity, ABS, plume, corrosion
- SO_3 mitigation

SO_3 Behavior Overview



Flame formation

Fly ash catalysis

Condensation across APH

Persistent visible plume?

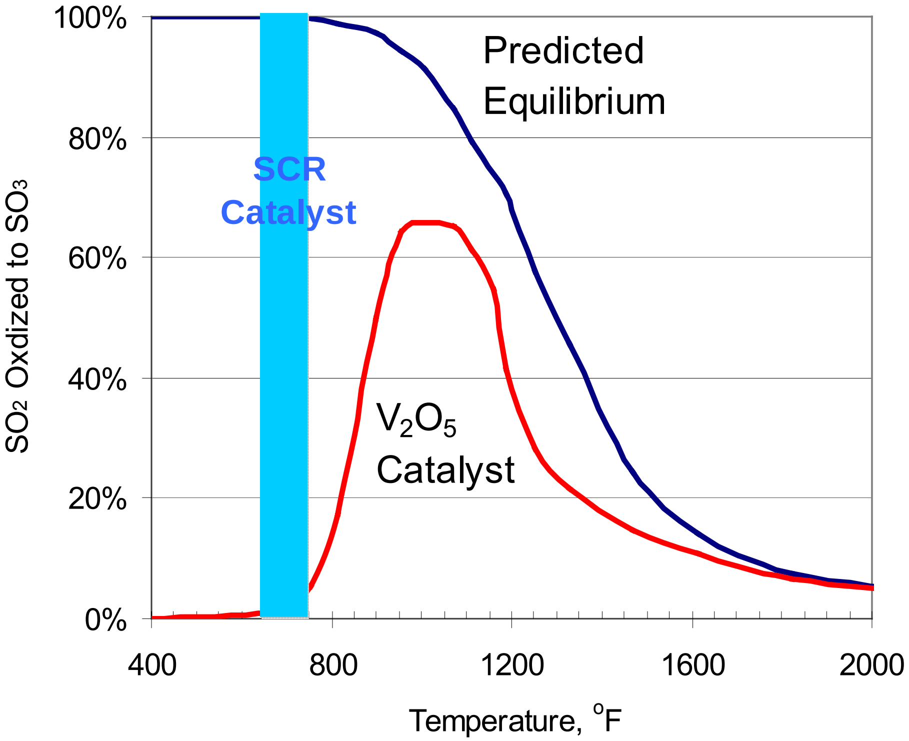
Oxidation across SCR

Adsorption by fly ash

Scrubber absorption, Aerosol nucleation & growth

SO_3 Behavior - SCR

- SO_3 is formed in SCR by conversion from SO_2
- Extent of conversion depends on:
  - SO_2 levels in flue gas
  - Catalyst type
  - Flue gas temperature (higher temperature = more conversion)
- Conversion is typically 0.5% to 1.5%

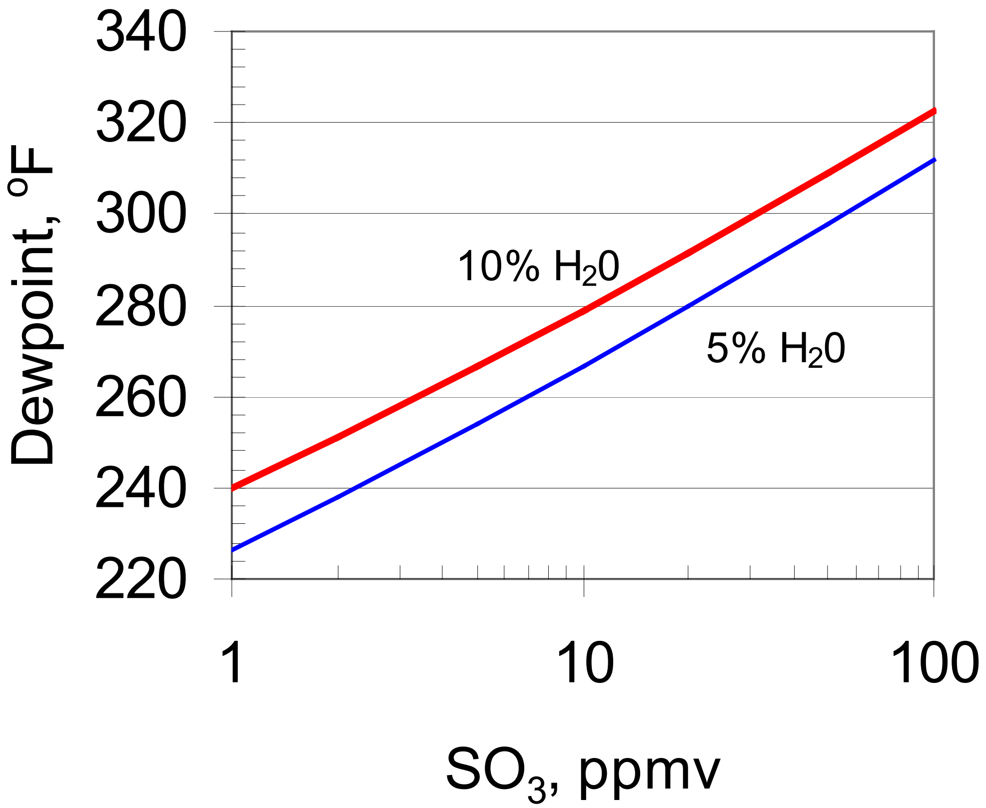


- Active catalyst in SCR is V_2O_5
- Catalysts operate at 650˚F - 750˚F
- Potential for conversion of ≤ 2%

Air Preheater

- Loss of SO_3 across Air Preheater (APH) via:
  - – Conversion to H_2SO_4 and condensation on surfaces
  - – Reaction with ammonia from SNCR or SCR slip to form condensible compounds
- Factors:
  - – Type of APH (regenerative vs. tubular)
    - Quench rate
  - – Cold-end temperature
  - – Ammonia concentration

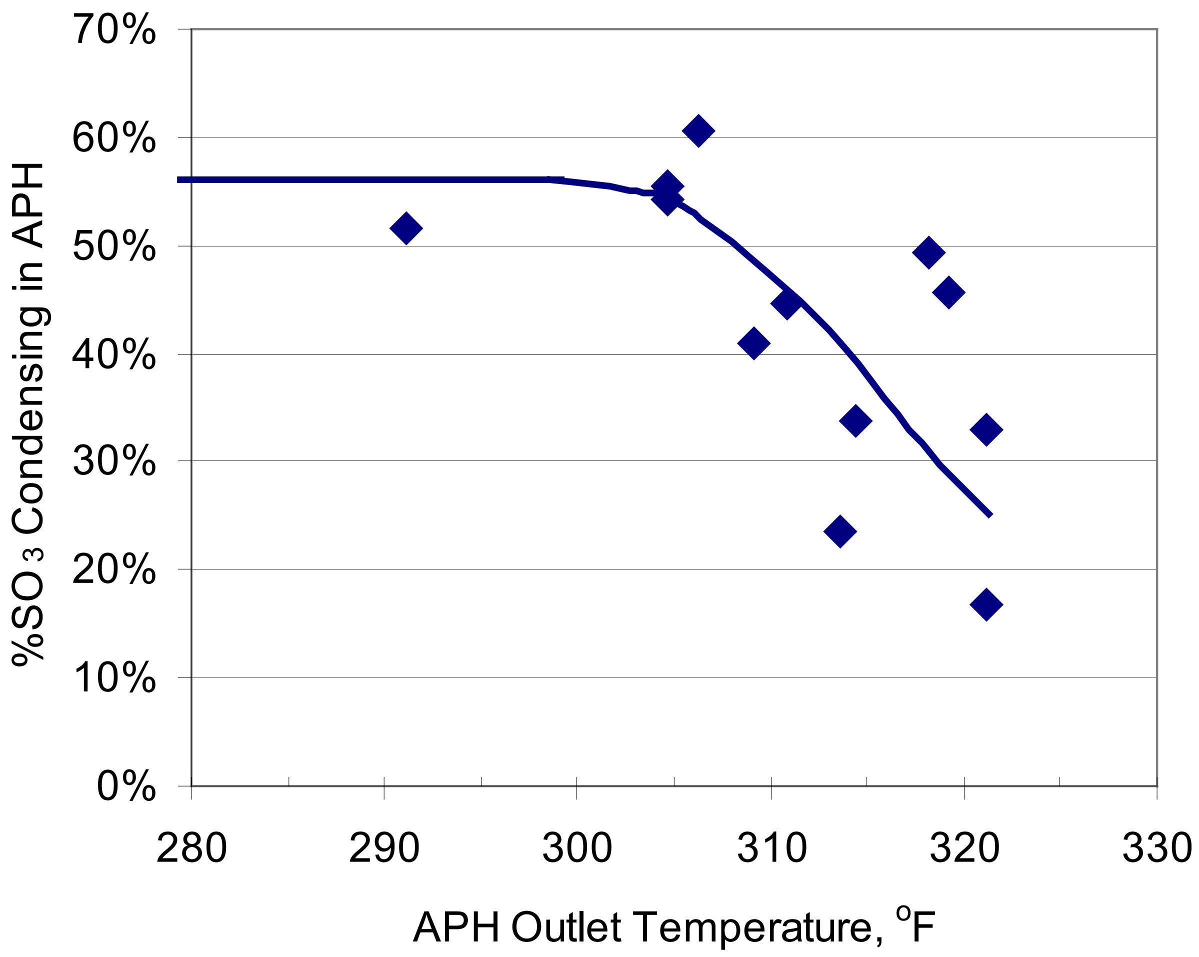
Dewpoint of SO_3 in Flue Gas



- SO_3 dewpoint depends on flue gas temperature and water content

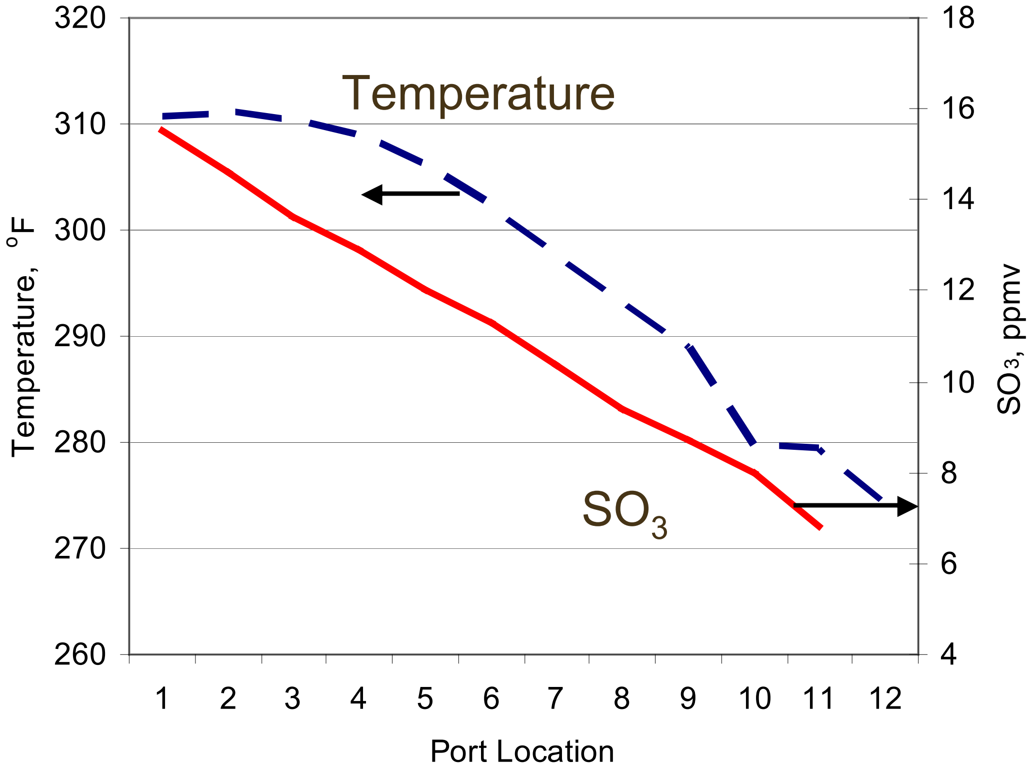
Condensation of SO_3 in APH

- More SO_3 condenses in APH at lower APH outlet temperatures
- Low temperature corrosion



Source: TVA, 2006

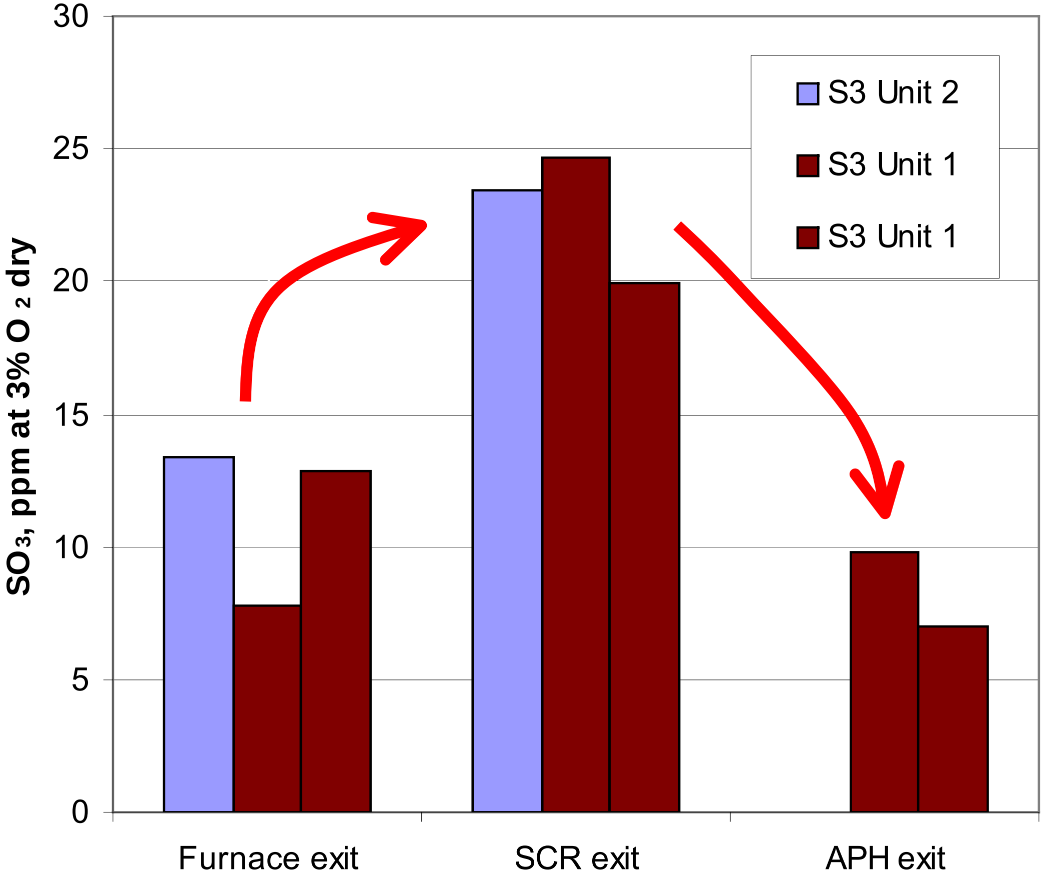
Effect of Temperature Variations



- Gas-phase SO_3 measurements at ESP inlet
- Flue gas temp varies across duct
- More SO_3 in flue gas at higher temperatures

Source: DeVito, 1998

Example: Effect of SCR

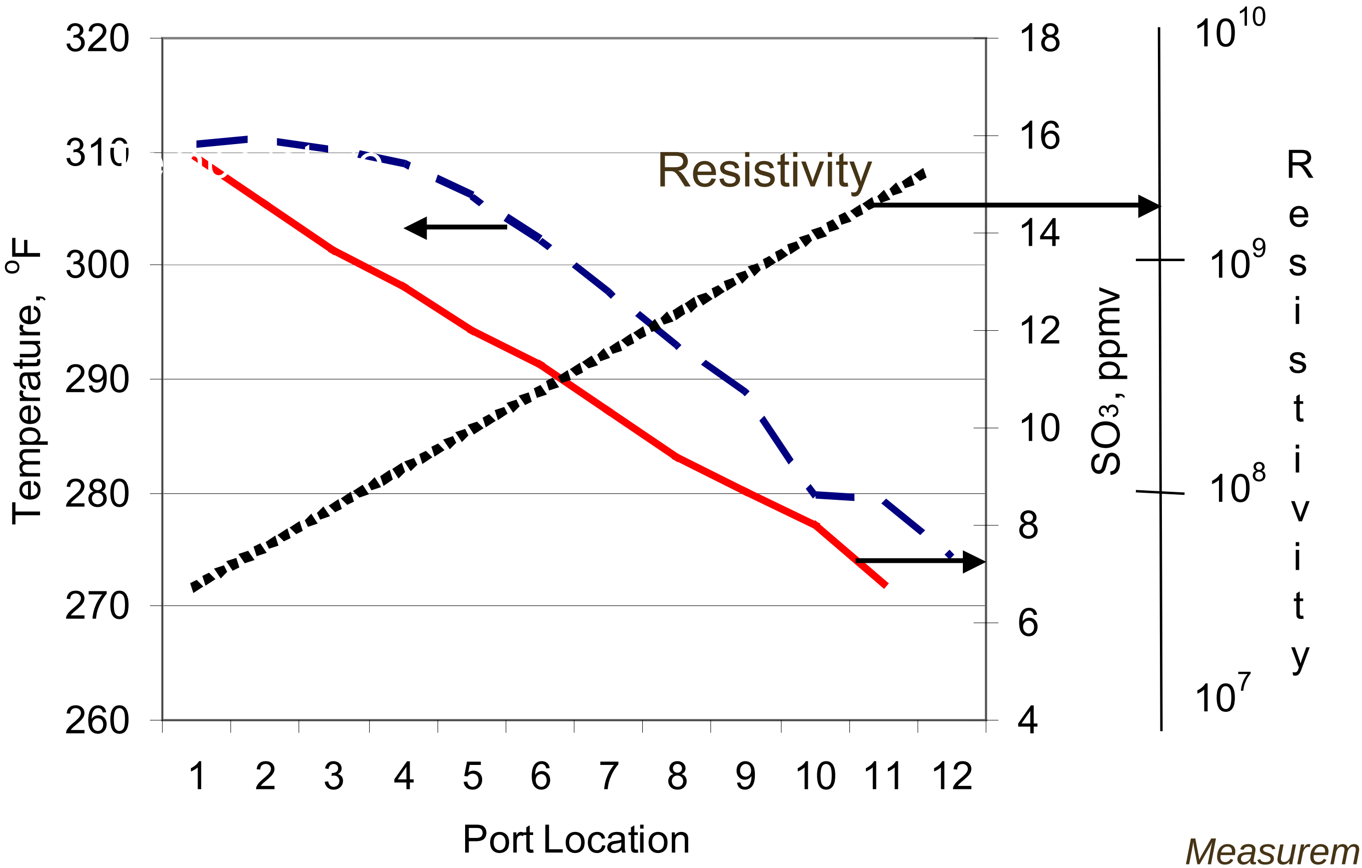


- DOE Hg sampling program, site S3
- Two units, each 750 MW with SCRs
- Eastern bituminous coal: 1.5-2.1 wt% S
- 0.5% to 1.3% SO_2 oxidation across SCR
- ~60% removal of SO_3 across APH

Particulate Control Devices

- Reaction of SO_3 with alkaline components in fly ash => H_2SO_4
  - Sulfuric acid increased resistivity of fly ash
  - Easier to collect fly ash in ESP
- Addition of SO_3 for fly ash conditioning for low SO_3 flue gas
- Corrosion in cold spots in ESPs, fabric filters => H_2SO_4

Effect of SO_3 on Fly Ash Resistivity



Measurement at ESP inlet;
Source: DeVito, 1998

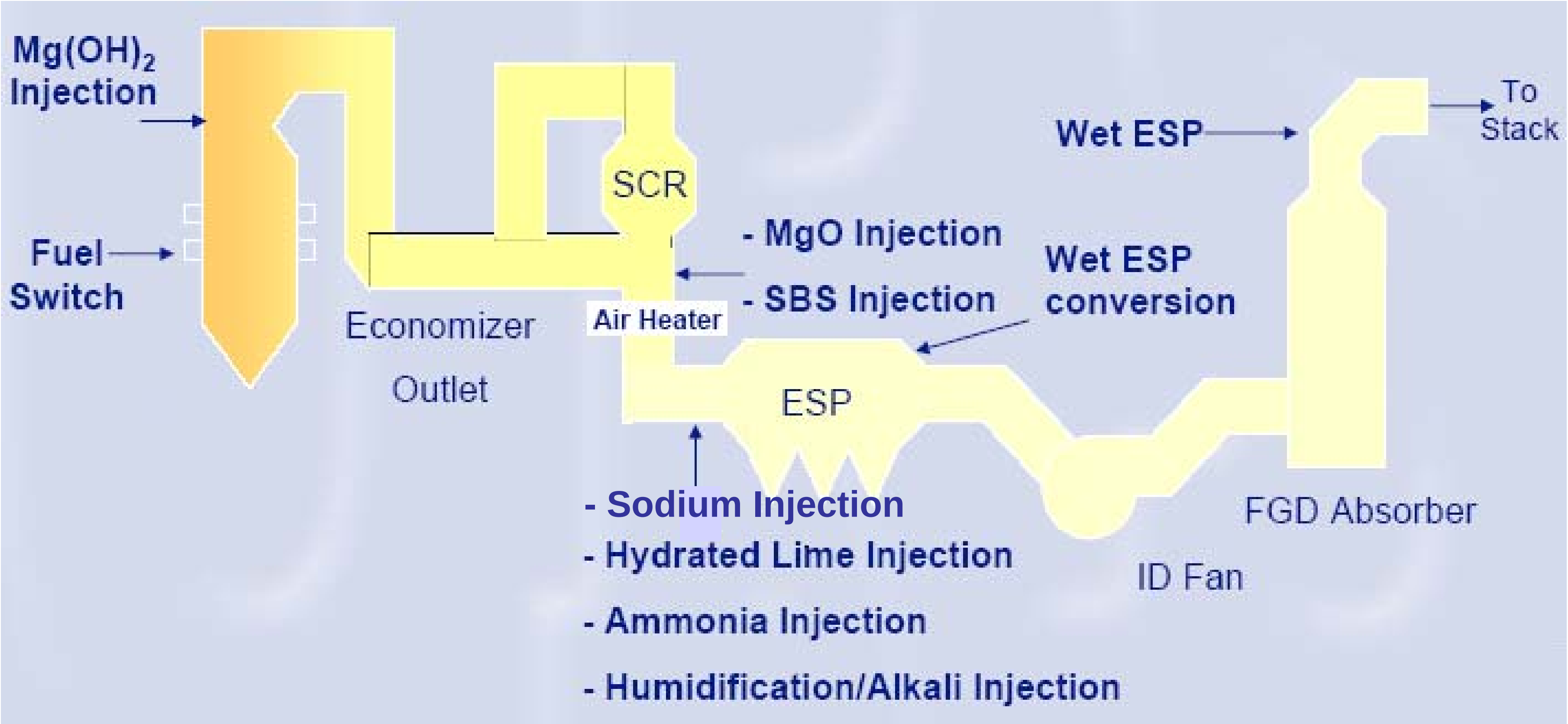
Summary: SO_3 Plant Behavior

Component	Factors	Impact
Furnace & back pass	Fuel sulfur, furnace O_2, fly ash composition, gas temperature	0.75% to 1.5% SO_2 oxidation
SCR	SO_2 level, catalyst type, gas temperature	0.5 to 1.5% SO_2 oxidation
Air Preheater	AH type, cold-end temperature, quench rate, ammonia level	20 to 65% SO_3 removal
ESP	Gas temperature, fly-ash composition	25% to 50% removal
Baghouse	Effective, but not used with high SO_3	~90% removal
Spray Dryer	Effective (lime injection)	>90% removal
Wet FGD (scrubber)	Flue gas temperature, conversion to H_2SO_4	20% to 60% removal (average ~50%)
Wet ESP	Effective H_2SO_4 capture	>90% removal

Summary: SO_3 Impacts

- Visible plumes aren't the only concerns
- Process impacts:
  - – Cold-end corrosion in air heaters, ductwork and APCDs
  - – Air heater plugging (in combination with SNCR/SCR systems)
  - – Negative impact on mercury sorbents
- SO_3 mitigation may be needed…

SO_3 Control Technology Overview



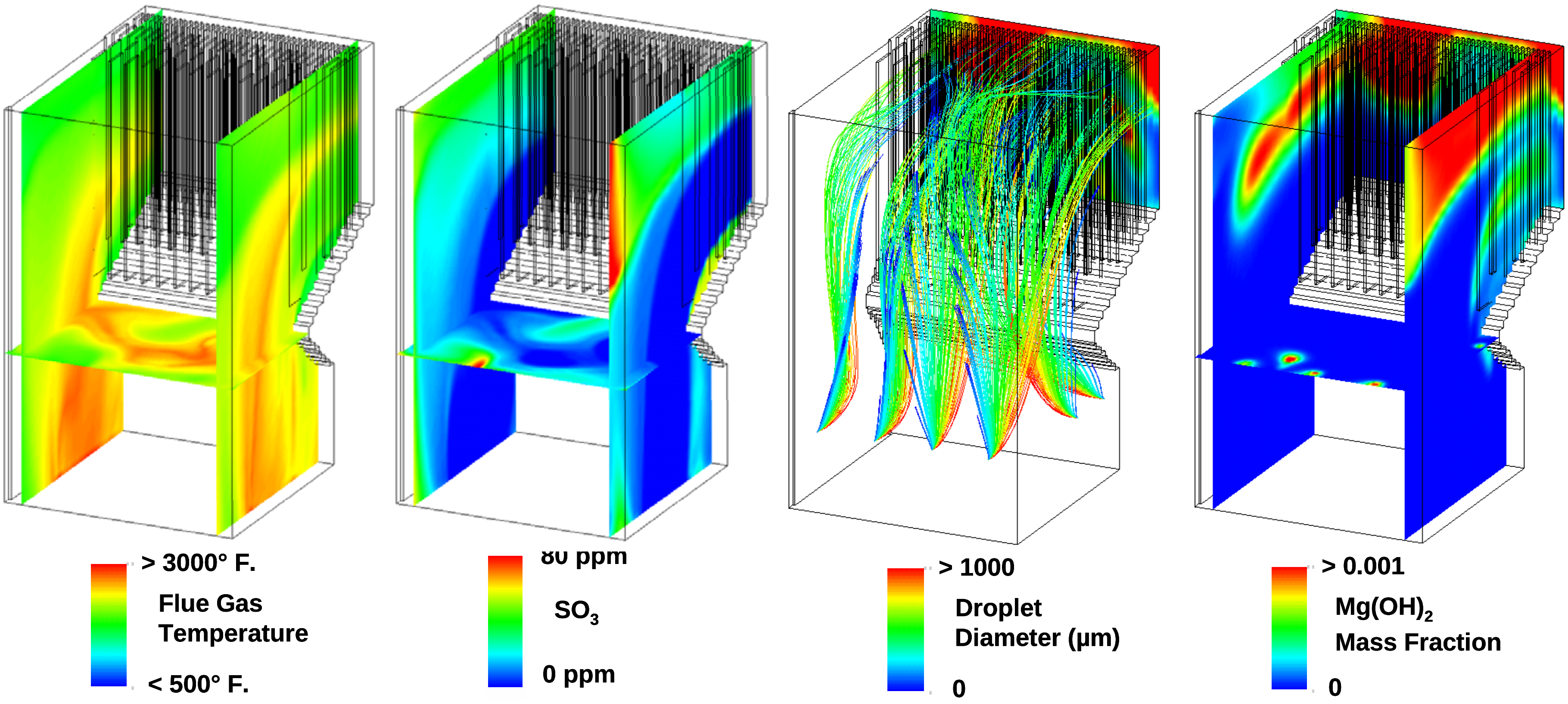
- Sodium Injection
- Hydrated Lime Injection
- Ammonia Injection
- Humidification/Alkali Injection

Source: Blythe, et. al, 2004

Example 1: $Mg(OH)_2$ Furnace Injection

- Use CFD Modeling to
  - Determine furnace temperature, flow, and species profiles including sulfur speciation
  - Determine design constraints
  - Quantify and optimize slurry injection efficiency
    - Nozzle quantity and locations
    - Droplet size distribution and slurry flow rate
- Assume extent of MgO distribution is indicative of effectiveness of SO_3 capture through plant

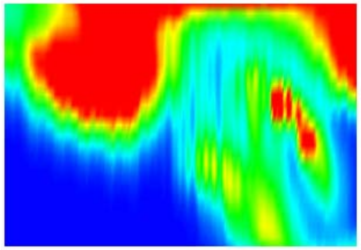
Conceptual Design Performance



Injection Sensitivities

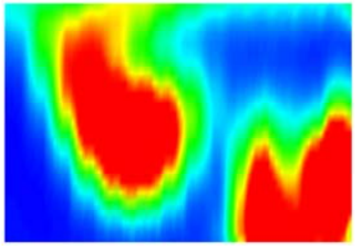
(injection design, load range)

Full Load Cases



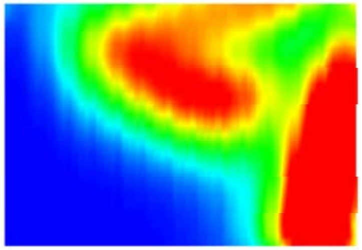
Design 1: 60 gpm, 400 μm SMD
Mixing Number = 0.65

75% Load Cases



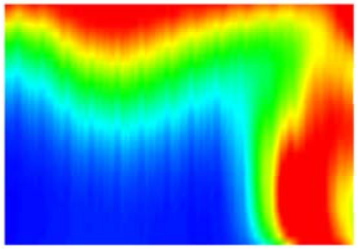
45 gpm, 200 μm SMD
Mixing Number = 0.63

50% Load Cases

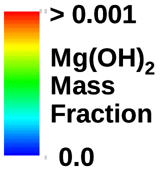


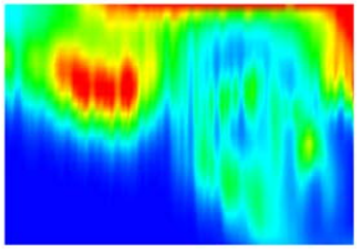
30 gpm, 200 μm SMD
Mixing Number = 0.66

Minimum (37.5%) Load Cases

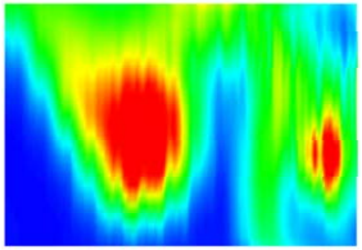


22.5 gpm, 200 μm SMD
Mixing Number = 0.71

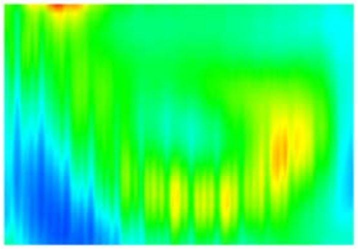




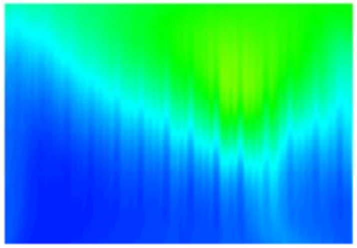
45 gpm, 475 μm SMD
Mixing Number = 0.65



45 gpm, 475 μm SMD
Mixing Number = 0.73



30 gpm, 600 μm SMD
Mixing Number = 0.87



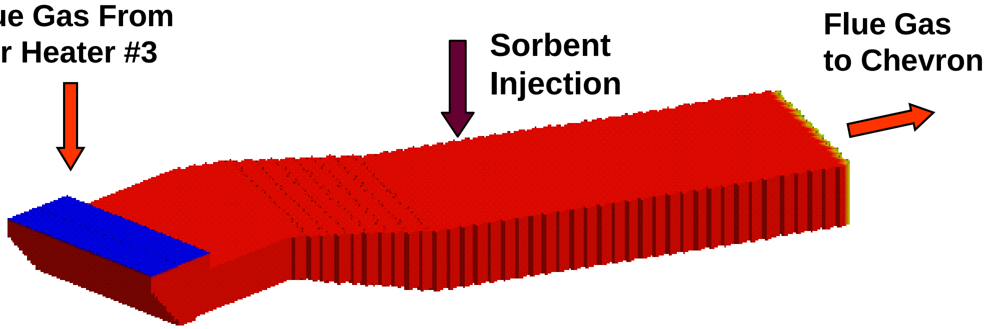
22.5 gpm, 800 μm SMD
Mixing Number = 0.75

Successful technology for 50-70% SO_3 reduction

Example 2: Post-APH Sorbent Injection

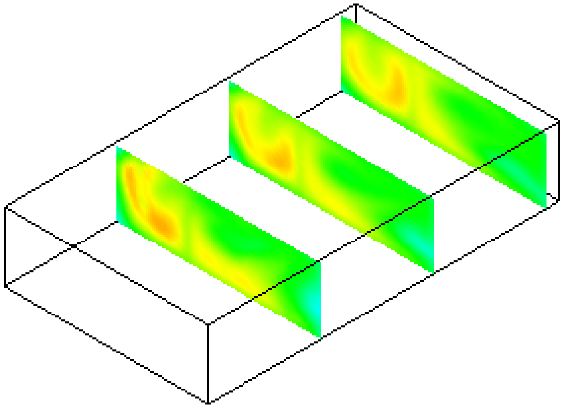
Use CFD to guide APH-ESP ductwork and sorbent injector design

- Improve uniformity of temperature field
  - Turning vanes
  - Quench air lances

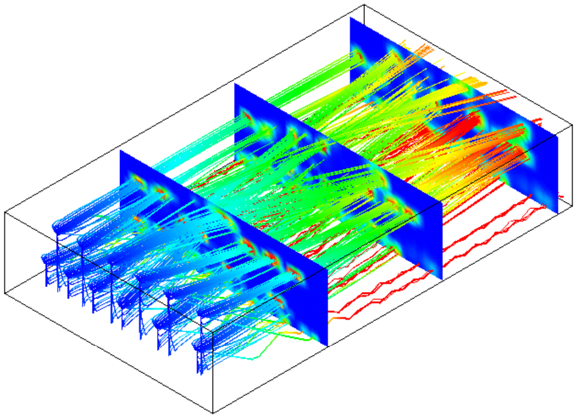


- Assess sorbent injection distribution
  - Optimize lance design and location for fixed number of lances, flue gas flow rate, sorbent injection & size)

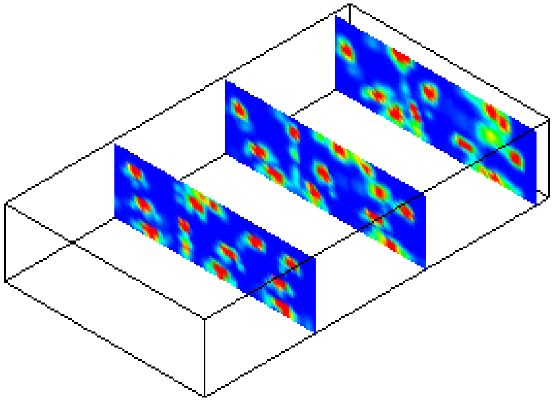
Sorbent Injection Summary



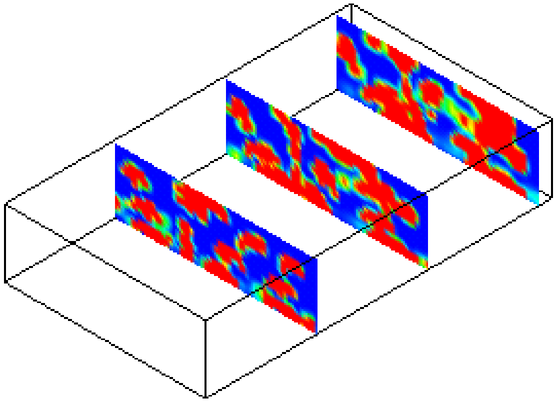
SO_3 Mole Flux (mol/m^2-s)



Sorbent Residence Time



Na Mole Flux (mol/m^2-s)



Na/SO_3 Flux Mole Ratio

- **Turning vanes help temperature uniformity, but still not completely uniform**
- **Quench air lances do not reduce all temperatures below 350 °F**
- **Sorbent injection constraints cause “spotty” distribution, suggesting non-optimal coverage/mixing (but maybe enough)**

SO_3 Impacts Summary

- SO_3 impacts plant operation as well as plume
- SO_3 behavior highly plant specific
- Control options should be tailored to plant needs
  - Assess status, emission goals, appropriate technologies
- CFD tools useful in designing SO_3 mitigation systems
  - Capture unique plant geometry and operating conditions
  - Describe and assess changes to flue gas environment
  - Design sorbent injection system and evaluate performance

Ammonia Impacts

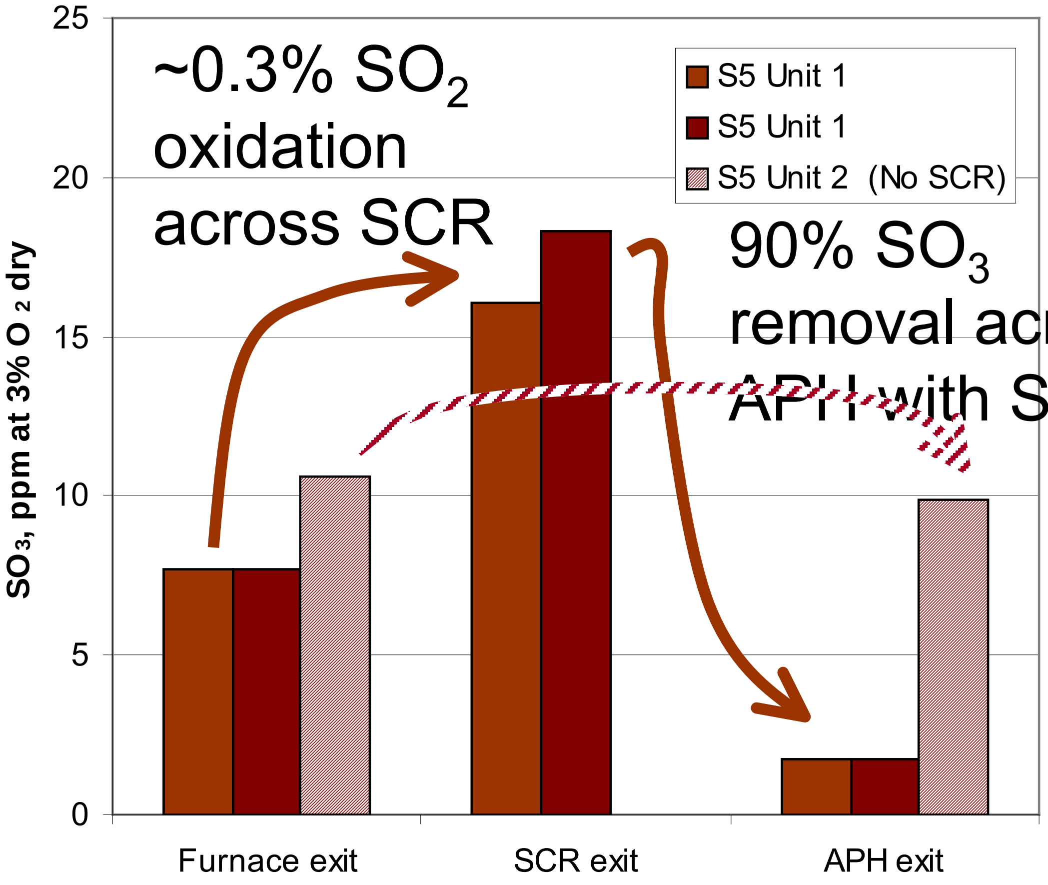
- Slip
  - Interaction with SO_3 (ABS)
  - Fly ash contamination

Ammonia-SO_3 Interactions

- $2\ NH_3 + SO_3 + H_2O \text{ -->} (NH_4)2SO_4$
  - Ammonium sulfate (AS)
  - Slow
- $NH_3 + SO_3 + H_2O \text{ -->}\ NH_4HSO_4$
  - Ammonium bisulfate (ABS)
  - Fast: forms before AS at high quench rate
- ABS combined with fly ash forms sticky deposit in APH
  - Fouling and pressure drop result

Example: Effect of SCR, APH

- DOE Hg program
- Two 675 MW units - one with, one without SCR
- Eastern bituminous coal: 3.8 wt% S



~0.3% SO_2 oxidation across SCR

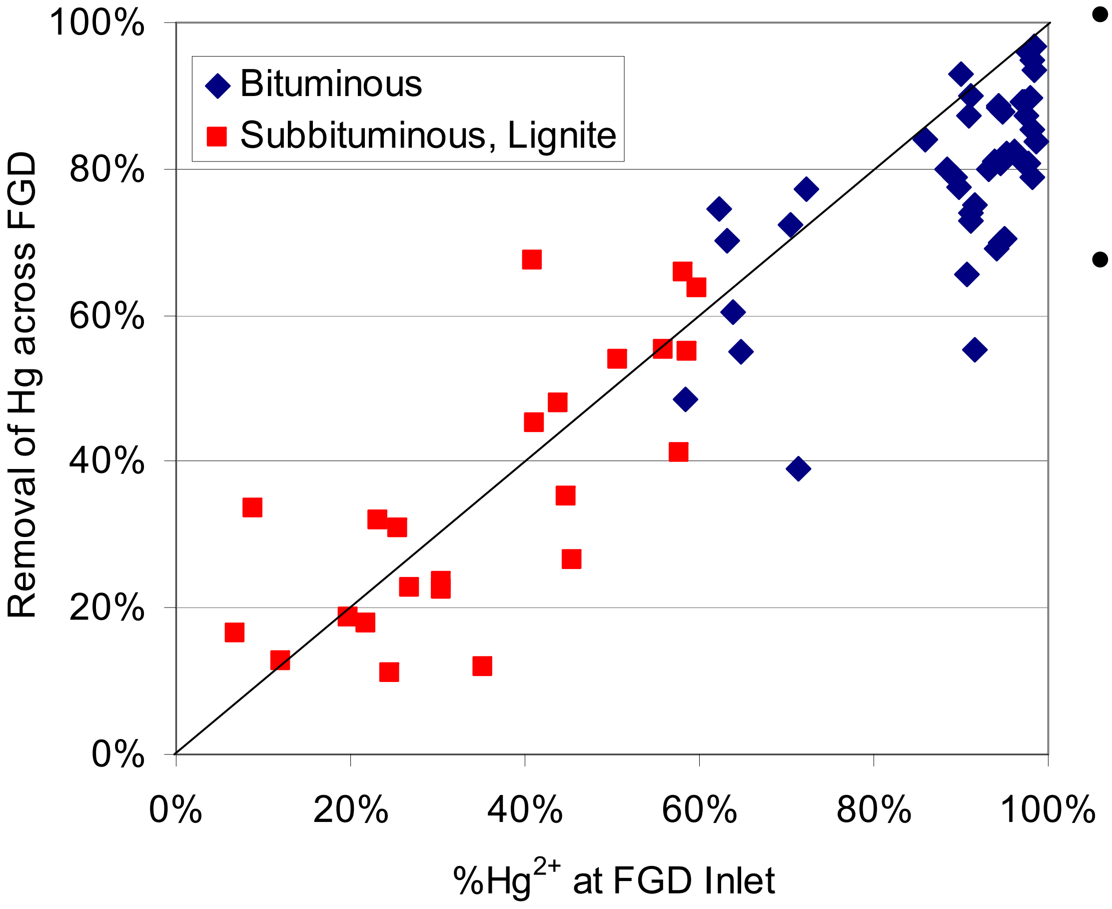
90% SO_3 removal across APH with SCR

7% SO_3 removal across APH without SCR (no ammonia)

Hg Impacts

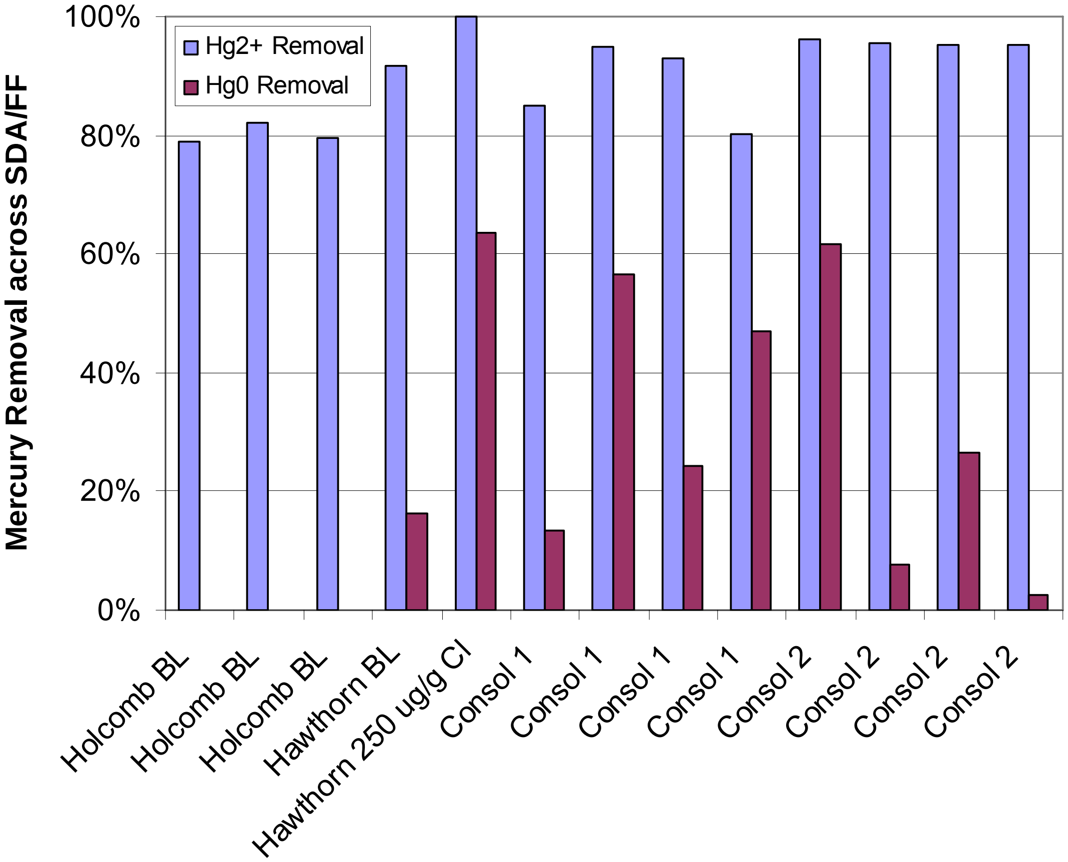
- Maximizing oxidized mercury in flue gas
- Impact of SCRs on Hg oxidation
- Impact of SO_3 on Hg removal by activated carbon

Oxidized Hg & FGDs



- Full-scale data on removal of Hg across wet FGDs
- More Hg^{2+} = More Hg Removal

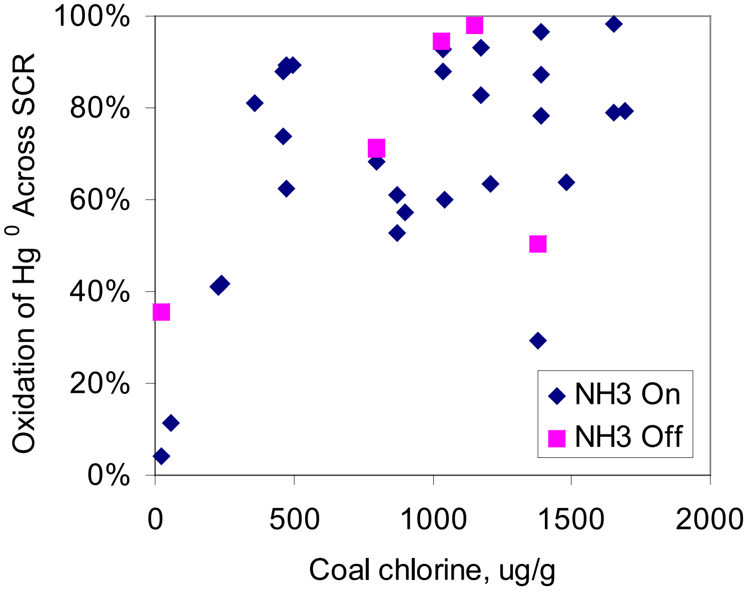
Oxidized Hg & SDAs

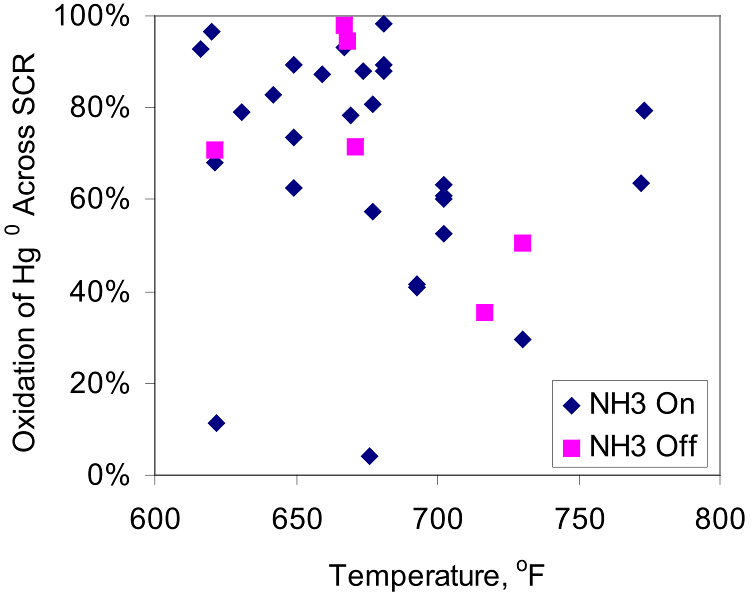


- Full-scale data on removal of Hg across SDA/FFs
- Hg^{2+} removal: 80% to 95%
- Hg^0 removal: 0% to 60%
- More Hg^{2+} = More Hg Removal

Hg Oxidation Across Full-Scale SCRs

- Full-scale data
- Large variation in observed oxidation





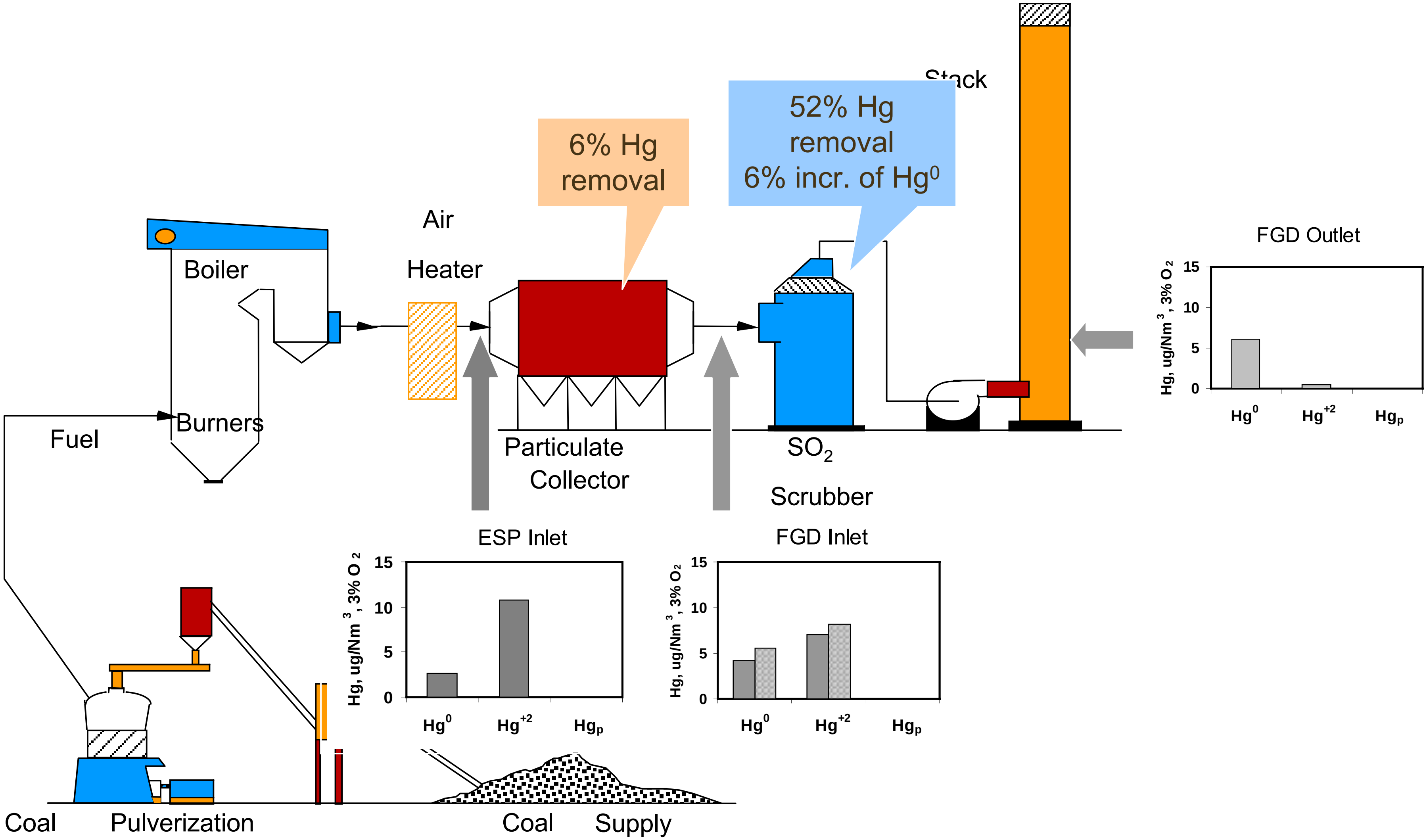
Effect of Cl: Low oxidation with PRB (low chlorine coal)

Effect of T: Lower oxidation at higher temperatures

Example: Adding SCR to FGD

- Two units @ 680 MW
  - One wall-fired boiler with SCR-ESP-FGD
  - One wall-fired boiler with ESP-FGD
- Eastern Bituminous coal
  - 0.15 µg/g Hg, 480 µg/g Cl, 3.8% S
  - LOI in ESP fly ash: 4% (unit with no SCR); 5.2% (unit with SCR)
- Plate SCR
  - ~3700 hr^{-1}
  - 344^{o}C (650^{o}F)
  - 80% NO_x reduction
- Scrubber
  - Mg-enhanced limestone
  - 99% SO_2 removal

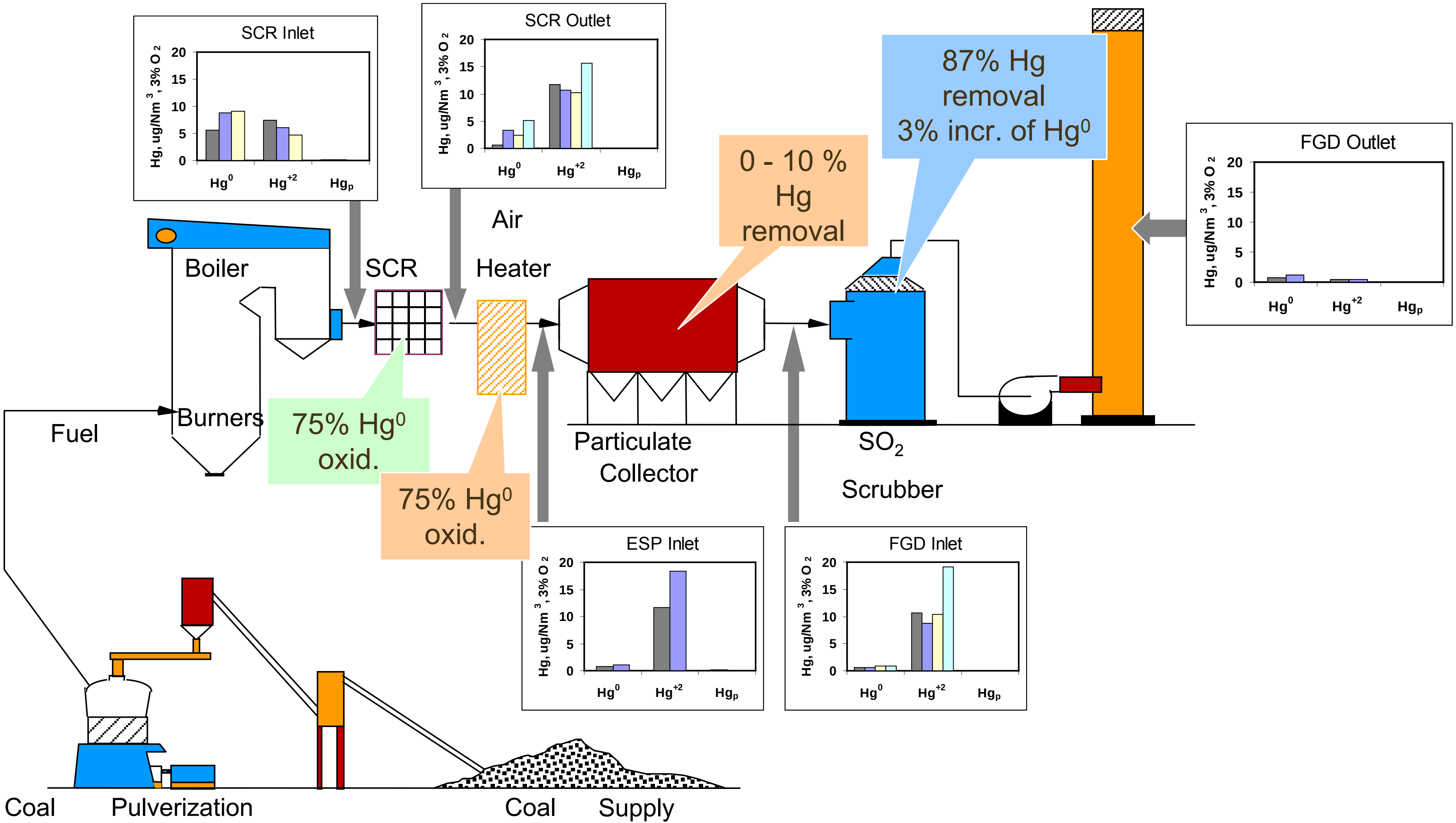
Behavior of Unit without SCR



6% Hg removal

52% Hg removal
6% incr. of Hg^0

Behavior of Unit with SCR



75% Hg^0 oxid.

75% Hg^0 oxid.

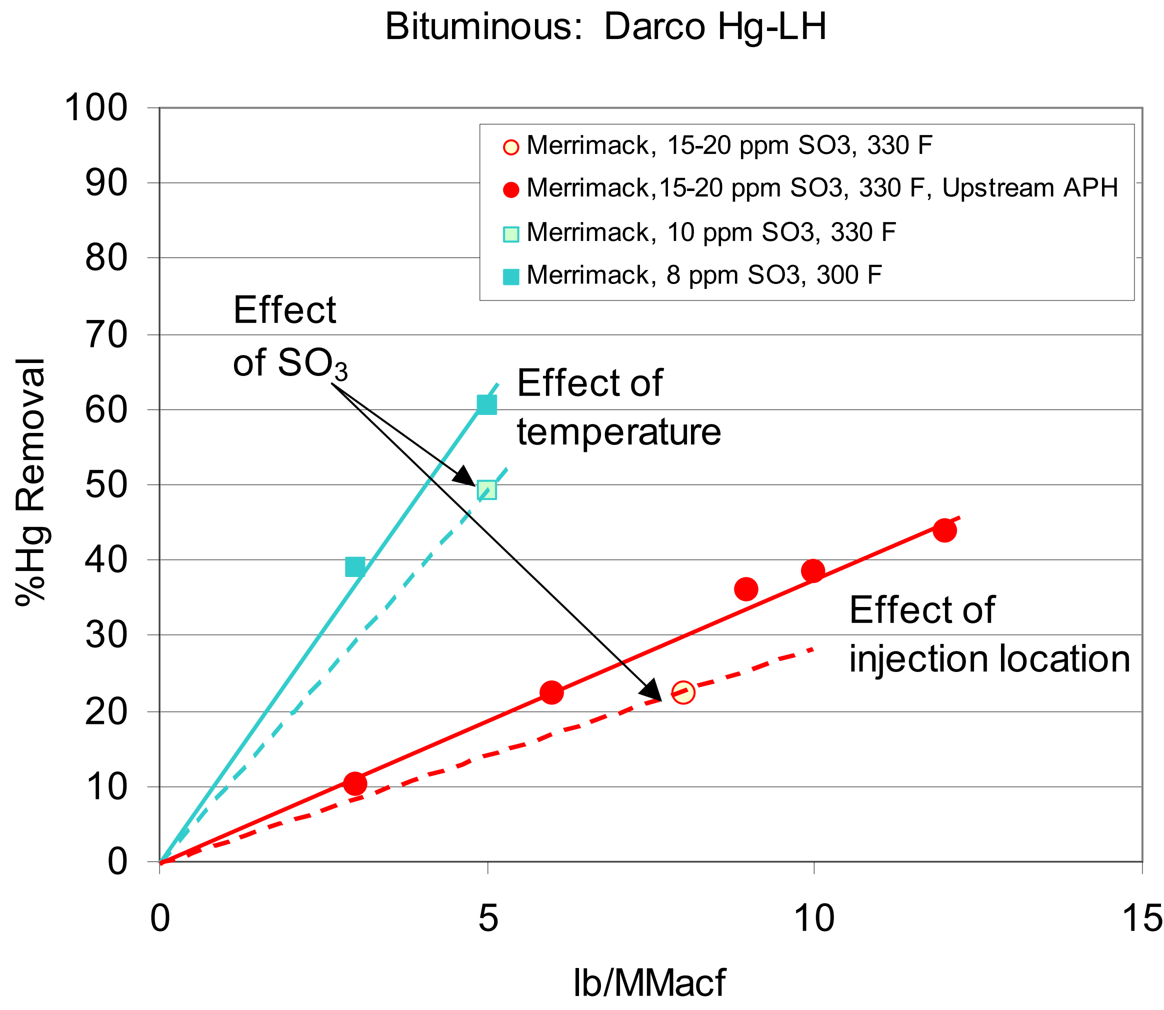
0 - 10 % Hg removal

87% Hg removal
3% incr. of Hg^0

Summary: Adding SCR to FGD

- APH oxidizes ~75% Hg^0, but doesn't convert Hg to to Hg$_p$
- Little Hg removed across ESP (<10%)
- FGD removes 94-96% of Hg^{2+}; re-emission of Hg^0 low (3-6%)
- SCR oxidizes 75% Hg^0
- Combination of SCR+FGD increased FGD removal of Hg from 52% to 87%

Example: Impact of SO_3 on ACI



- DOE Hg control demonstration
- PSNH Merrimack 1
    - 320 MW cyclone
    - 1.2% sulfur coal
    - 4-layers of SCR
    - Tubular APH
    - AC injected upstream and downstream of APH
    - Trona injected upstream of APH to lower SO_3

Discussion Topics

- SCR Performance
  - *What impacts SCR performance?*
- Impacts of Adding an SCR
  - *How does the SCR affect boiler operation and air pollution control devices?*

Discussion & Questions