Flue Gas Conditioning
WPCA
September 3, 2008

William Hankins
VP Sales
Outline

• What is SO3 FGC
• Electrostatic Precipitation Fundamentals
• Ash Resistivity
• SO3 Process
• Design Principles
SO3 FGC Background

• Sulfur Trioxide Flue Gas Conditioning
• Corrects Ash Resistivity to Improve performance of Electrostatic Precipitators (ESPs)
• Small amount injected upstream of ESP
• Approximately 1500 units worldwide
• Commercialized by Wahlco in early 1970’s
## Sulfur Emissions

### Typical Sulfur Oxide Emissions from Coal-Burning Boilers

<table>
<thead>
<tr>
<th>Sulfur Oxides</th>
<th>3.5% Sulfur Content</th>
<th>0.5% Sulfur Content</th>
<th>0.5% Sulfur &amp; FGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPMV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entering Precipitator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>2600</td>
<td>370</td>
<td>371</td>
</tr>
<tr>
<td>SO₃</td>
<td>26</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Entering Stack</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>2600</td>
<td>370</td>
<td>375</td>
</tr>
<tr>
<td>SO₃</td>
<td>7</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

*Flue gas conditioning does not increase emission levels of sulfur oxides (SO₂ or SO₃).*
Sulfur Trioxide

• Toxic highly reactive gas
• Combines with water vapor to form sulfuric acid mist
• Gas above 500 deg F
• Generally produced by burning sulfur and catalytic oxidation of Sulfur Dioxide gas
• Typical inject 5 to 15 ppm in Flue Gas ~ 20 to 300 lb/hr sulfur - 50 to 800 mW
ESP Principles

• Charge the Particles
• Migration of Charged Particles to Collecting Plates
• Move the Collected Material to the Hopper for Removal
Dust Layer on Plates

Fig 8: The electric field in the dust layer

\[ E = R \times I \]

- **E**: Electric Field
- **I**: Ion Current Density
- **R**: Dust Layer Resistivity

Collecting Plate
High Resistivity Dust Layer

Fig 9: Back-corona in the dust layer
VI Curves - Normal

Chapter 4 - Electrostatic Precipitation Theory and Operations

Figure 4.13
Normal Precipitator Voltage-Current (V-I) Curves
VI Curves – High Resistivity

Figure 4.14
Abnormal Precipitator V-I Curves

Grounded high voltage electrode

Moderate back corona

Severe back corona

Dust deposits on discharge electrode

SPARK

Misalignment

Moderately high ash resistivity
Precipitator Efficiency vs. Power

EPRICS2908
ESP Efficiency vs. Resistivity for SCA 325 ft²/1000 acfm
Sulfur Trioxide FGC

- SO3 Reacts with moisture in flue gas
- Absorbed on surface of fly ash
- Improves surface conductance of ash
- Lowers the surface resistivity
Ash Resistivity

- Surface Conduction
- Volume Conduction
- Optimum is between
  - $1 \times 10^8$ ohm-cm
  - And
  - $1 \times 10^{10}$ ohm-cm
- Ash measured in Laboratory in Oven and High Voltage Cell
- Computer model developed based on Ash Analysis
Precipitator Efficiency vs. $\text{SO}_3$ for ESP of 325 SCA
Resistivity Model

- Laboratory measurement developed by WP
- Dr Bickelhaupt SRI developed mathematical model
- Based on Ash and Coal Chemistry
EXPECTED RESISTIVITY

ASH SPECTROGRAPHIC ANALYSIS

LI2O = 1
K2O = 1
CAO = 1
AL2O3 = 1
TIO2 = 1
SO3 = 20
NA2O = 0
MGO = 3
FE2O3 = 7
SIO2 = 28
P2O5 = 0.

TVA – Johnsonville
PRB – Average

LI2O =
K2O = 1.
CAO =
AL2O3 = 1
TIO2 = 1.
SO3 = 20.
NA2O = 0.
MGO = 3.
FE2O3 = 7
SIO2 = 28
P2O5 = 0.
Low Alkali

Graph showing the relationship between temperature (in degrees Fahrenheit) and ohm-cm for various SO3 concentrations: No SO3, Predicted Coal SO3, 1 PPM SO3, 4 PPM SO3, and 10 PPM SO3.
Dual Conditioning

- Inject both SO3 and Ammonia independently
- Ammonia improves attachment of SO3
- Extend performance at higher temperatures
- Reduces precipitator ash reentrainment
Nanticoke Dual FGC Results

• SO3 – Opacity reduced from 22 to 15%
• With Dual FGC opacity 8%
• Substantial increase in Particle Size
• Dramatic reduction in rapper spikes
• Reduction in opacity baseline
• No hopper ash removal problems encountered
Nanticoke Regular Coal – No FGC

NANTICOKE UNIT 2
OPACITY

REGULAR 50/50
TEST 4
S03 OFF
NH3 OFF
NANTICOKE UNIT 2
OPACITY

LOW SULFUR 50/50
TEST 43
SO3 OFF
NH3 OFF
Nanticoke SO3 Only

NANTICOKE UNIT 2
OPACITY

LOW SULFUR 50/50
TEST 35
SO3 5.5 ppm
NH3 OFF
NANTICOKE UNIT 2
OPACITY

Nov 15, 1988
512 MW
NH3 - 17 ppm
SO2 - 17 ppm

LOW SULFUR 50/50
TEST 33
SO3  17 ppm
NH3  17 ppm
Equipment Design Issues
SO3 Flue Gas Conditioning

1. Ambient Air In
2. Filter
3. Main Air Blower
4. Air Heaters
5. Sulfur Burner: $S + O_2 = SO_2$
6. Converter: $SO_2 + \frac{1}{2} O_2 = SO_3$
7. Saturated Steam: At 35-40 PSIG (2.4-2.75 Bar)
8. Molten Sulfur: 265-295°F (130-145°C)
9. Molten Sulfur + Water = H_2SO_4
10. Flue Gas
11. Precipitator
Critical Design Principles

• Injection into Flue Gas
  – Must remain above Dew Point
    • Piping Heat Loss Issues
    • Energy Consumption
  – Proper Distribution

• SO3 Converter Inlet Temperature
  – Conversion Efficiency
  – Catalyst Life

• Burner Issues
  – Sulfur Purity
  – Complete Combustion
Injection Location Criteria

• Achieve > 1 second residence time
• Nozzle Spacing < 1/10\textsuperscript{th} Mixing Distance
• Hot Gas Piping not excessive length
• Accessible Location
• Hot Side / Cold Side
Injector Sizing Principles

- Achieve Uniform Distribution
- Mixing
- Maintain Adequate Injection temperatures
- Maintain Injection velocities
SO3 Distribution Issues

• Generally strive for uniform concentration
• If SO3 concentration were varied within a duct what would the parameters be:
  – Gas temperature
  – Velocity
  – Dust Loading Concentration
  – Particle Size
Injector and Nozzle Spacing

- Inject into Centroid of Square Equal Areas
- Adequate Injection Points
- Minimize Number of Injectors
- Injectors Usually about 3 feet apart
Square Duct Injector Spacing
Rectangular Duct Injector Spacing
Improper Nozzle Spacing
Typical ‘Old Style’ Design

Typical 'Old Style' Design Diagram
Improvements in Design

- Less nozzles
- Larger nozzles
- Improved Purging
- Nozzle at End of Injector
- Clean Out Path
New Design

COLD SIDE PROBE DETAIL

PLAN

INTERNAL PIPE REDUCTION

SEE DETAIL "A"

REMOVABLE THERMOWELL

ELEVATION

END MOUNTED INJECTION ORIFICE

DETAIL "A"
Design Improvements
Equilibrium Conversion for SO2 Oxidation
High Efficiency Converter

- **Low SO2 Gas Concentration**
  - Improved Equilibrium Conversion

- **Design Converter Gas Velocity Low < 3 fps**

- **High Activity First Catalyst Layer**
  - Lower Light off temperature
  - Lower Outlet Temperature
  - Higher Conversion

- **Second Layer Conventional Catalyst**
SO3 System in Enclosure
Advanced Ring Main Sulfur Pumping System

- Constant speed centrifugal pumps
- Robust low maintenance design, highly reliable, industry standard
- Redundant sulfur pumps
- Sulfur metered with Coriolis Flow Element
- Controlled at each sulfur burner with flow control valve
Air Heater Features

- Over sized air Heaters
- Rapid Startup
- Operating watt density less than design of 20 watts/ sq in
- Small easy to handle modules
- Vertical design assures good air distribution
• Air Heater
Hot Side Injection

- Increased SO3 Residence time
- Minimal Injector Plugging
- Improved SO3 Distribution
- SO3 always above dewpoint – no injector corrosion
- Ideal for Tubular Air Heaters
Low Energy Consumption Design

• Significant Energy Savings
• Air Flow Varies with Sulfur Rate
• High Gas Volume for Rapid Startup
• Air Heater off at about 60% of Design
Advantages of Molten Sulfur Feed

- Molten Sulfur $\frac{1}{5}$ to $\frac{1}{2}$ Cost
- Less Manpower Intensive
  - 20 tons unloaded in half hour
  - No Silo to Maintain
- Lower Energy Consumption
  - Sulfur is delivered molten
- More tolerant of Impurities
  - Large settling capacity of Tank
Advantages of Molten Sulfur Feed

- More tolerant of Impurities
  - Large settling capacity of Tank
- Safer
  - No sulfur dust hazards
- Molten Sulfur Readily Available
- Less Mechanical Equipment
- Hybrid Design has worst of both designs
Sulfur Properties

- Heat of Fusion ~ 17 Btu/lb
- Specific Heat 0.16 Btu/lb/deg F
- Molten Sulfur Viscosity of Wide Temperature Range
- 3952 Btu/lb
Sulfur Viscosity

Centipoise

Temperature °F
Typical Molten Sulfur Specification

- Sulfur: 99.9570%
- Ash: 0.0007%
- Organic: 0.0036%
- Moisture: 0.0872%
- Selenium: < 1 ppm
- Tellurium: < 1 ppm
Summary

- Approximately 1500 FGC units installed worldwide
- Refined over 30 years
- Many units over 25 years still operating
- New systems use only 10% of the energy of older system
- Application of the technology is predictable
- Successful and competitive ash resistivity correction
Questions