Worldwide Pollution Control Association
WPCA/TVA
Coal & Gas Seminar
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Introduction
Performance & Benefits
Gibson Enhanced SCR Performance Testing
Questions

Overview
Sorbent Injection Strategic Approach
SBS System Background

Introduction
“Everything effects SO₃ and SO₃ effects everything”

- Boiler/SCR SO₂ Oxidation, O₂%, SCR MOT, Nox Removal, ABS Formation/AH Pluggage, Heat Rate, HCl Removal, Mercury Capture, Precipitator Performance, FGD, Blue Plume
- Quantifying all benefits of Heat Rate improvement, less coal, less ash, less landfill, credits etc...
- No DSI requirements...hmmm...

Sorbent Injection systems need to be thought of as an integrated control technology not just a Sorbent Injection System as they have potential to impact the entire plant both positively and negatively.

- Siloed vs. Holistic

Past sorbent injection systems have fallen short on effective means of control and long term reliability

- As plants begin rely on these systems in order to operate they need to be reliable and the new 3rd Generation systems have proven to be reliable with availability greater than 99%
- 3rd Generation systems have much better controls that greatly reduce the amount of daily operator involvement in system operation from feedrate controls to system monitoring
Liquid sodium bisulfate forms between ~360-500°F with this temperature range occurring in the air heater and possibly in the air heater outlet duct.

The preferential reaction is to form solid sodium sulfate at higher temperatures, however sodium sulfate will continue to react with residual SO$_3$ so a high level of control (<3 ppm) is needed to prevent conversion to the liquid sodium bisulfate.

This was the primary reason URS relocated their process to the higher temperature region and maintains a high rate of control to capture residual SO$_3$ from the SCR.

Pre-SCR SO$_3$ control can also be achieved using hydrated lime DSI without risk of liquid byproduct, however, high rates of control (90+%%) can be difficult to achieve using DSI.
SBS System Background

Sorbent is injected at SCR inlet at a molar ratio adequate for total SO$_3$ generation plus some margin.

SO$_3$ generated in the catalyst on the order of 0.25-0.5% /layer.

Target SO$_3$ at air heater is <3-5 PPM SO$_3$ to prevent sodium bisulfate fouling.

Furnace generated SO$_3$ on the order of 0.8-1.5% depending on O$_2$ levels and slagging.
Performance & Benefits

- Reduced Catalyst MOT
- Air Heater Fouling / Enhanced Nox Removal
- Heat Rate Improvement
Low load SCR operation is constrained by Ammonia Bisulfate (ABS)
- Capillary condensation of ABS occurs in the micropores of the catalyst and can cause loss of activity that is reversible to a point

Variables affecting ABS condensation
- Flue gas temperature and the relative concentrations of NH₃ and SO₃
- Catalyst pore size (capillary condensation)

Variables affection SCR minimum operating load
- SCR inlet temperature and Nox distribution
- Load cycle and SCR operating strategy
- Boiler SO₃ concentrations can increase at lower loads due to high O₂

Options for low load SCR operation
- Reduce the NH₃ at the SCR inlet by reducing inlet Nox (gas co-firing) or NOx removal rate
- Increase the SCR inlet temperature at low load by economizer modifications and/or bypass systems either water/gas, would result in a full time or part-time heat rate penalty depending on the technology chosen
- Restrict the operating time below the MOT for limit the amount of ABS formed and operate at a set time at full load to “burn-off” the ABS essentially managing an ABS Inventory Calculation
- Remove the SO₃ prior to the SCR to low levels which can greatly reduce the MOT without heat rate penalty
Reduced Catalyst MOT

**SCR MOT reduces with reduced SO3 concentration**

**ABS dewpoint increases as catalyst pore diameter decreases**

- **NH3 = 315 ppm. H2O = 8%**
- **Pore diameter = 2 nm**
- **Pore diameter = 8 nm**
- **Bulk Phase**
Temperature vs. Load Comparison (2015)

- Lowest 1A SCR Inlet Zone
- Lowest 1B SCR Inlet Zone
- 1A Avg Econ Outlet
- 1B Avg Econ Outlet

Target minimum load with stable operation

Line added for minimum temperature

\( R^2 = 0.8671 \) for Lowest 1B SCR Inlet Zone
\( R^2 = 0.8477 \) for 1A Avg Econ Outlet
\( R^2 = 0.8525 \) for Lowest 1A SCR Inlet Zone
\( R^2 = 0.8905 \) for 1B Avg Econ Outlet

Temperature (Deg. F) vs. Load (Gross MW)
Reduced Catalyst MOT

- Why???
  - Solar and wind have created large amounts of peak generation that are priority
  - Coal must now load follow to a degree and be more nimble for turndown and ramp rate
  - New Ozone season limits will require pushing the SCR’s harder and keeping them in service longer
Air Heater Fouling / Enhanced NOx Removal

Benefits of pre-air heater removal of SO₃
- Converts SO₃ to the limiting reactant instead of NH₃
- Allows operation above the typical 2 ppm NH₃ slip increasing catalyst management plan flexibility
- Provides flexibility needed to reduce NOx outlet setpoint without fear of air heater pluggage
- Reduces the possibility of air heater pluggage due to ammonia bisulfate and/or sulfuric acid
- Can provide a heat rate benefit by allowing the air heater cold end average temperature to be reduced minimizing dry gas loss

Options for Enhanced NOx removal
- Perform more frequent SCR tuning and cleaning to ensure good distribution for higher catalyst utilization
- Increase the reactor potential by adding an additional layer or replacing layers more frequently which would result in higher catalyst life cycle costs, increased pressure drop and SO₃ generation
- Reduce the stack outlet NOx setpoint / increase the NOx removal rate effectively increases the reactor potential by allowing the NH₃ slip rise above the typical 2 ppm, however, air heater pluggage is likely without pre-airheater SO₃ mitigation
Air Heater Fouling / Enhanced Nox Removal

- Two different fouling mechanisms as a function of SO$_3$ & temperature
  - Ammonia & Sulfuric Acid
- Sorbent Injection works to reduce or eliminate air heater fouling by reducing the SO$_3$ in the flue gas
  - Assuming SO$_3$ is neutralized prior to the air heater
- Testing at Zimmer has shown Sulfuric Acid dewpoints down to 220-230F measured on Breen Probe with high injection rates
East Bend air heater basket plate dissected showing (NH₄)HSO₄ and H₂SO₄ build-up.

HSESP air heaters are more prone to pluggage as there is little ash for condensables to condense on which results in more condensation on the plates.

Increasing concentration raises the deposition location and amount.
Decreasing concentration lowers the deposition location and amount.
Air Heater Fouling / Enhanced Nox Removal

\[
\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4
\]

\[
\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} \rightarrow (\text{NH}_4)\text{HSO}_4
\]
Air Heater Fouling / Enhanced Nox Removal

- Gibson 5 SBS injection and condensables trends while being manually controlled from April 28th-30th
- Continuously adjusted the SBS injection molar ratio so no current was observed on the Breen probe (Green line) which indicates potential fouling
- Tested enhanced Nox removal by increasing the ammonia injection rate and increasing the removal from 85% to 93% for a period of 24 hrs

Figure 1
Air Heater Fouling / Enhanced Nox Removal

- Reduced air heater pluggage potential allows for increased NH$_3$ slip and catalyst management plan flexibility
  - Affects of increased NH$_3$ in FGD liquor would need to be evaluated for possible Hg re-emission effects and wastewater impacts
Air Heater Fouling / Enhanced Nox Removal

- Gibson has always struggled with Nox removal and air heater pluggage
- Trend shows air heater DP levels off when the SO₃ mitigation system was increased to make the condensable formation stop

![AH Inlet Condensable Plot](chart.png)
- Installed 4th layer in Fall ‘11, removed 3rd layer in Spring ‘12
  - Later discovered the 4th layer that was installed had double the SO₂ oxidation rate, increasing SO₃ to the AH
- Air heater rebuild with new seals and partial basket replacement
  - Tightened AH’s and dropped outlet temp
  - Started having significant sulfuric acid pluggage
- Fuel flexibility drove decision to reverse direction of rotation on tri-sector air heater for more PA temp
- Installation of an intermediate reheater reduce economizer outlet temps
  - Further reduced AH outlet temps
- Made the decision to move the current Sorbent Injection upstream of the SCR/AH to mitigate air heater pluggage

<table>
<thead>
<tr>
<th>Air Heater Averages</th>
<th>Pre 2012 Outage</th>
<th>Post 2012 Outage</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Air Temp.</td>
<td>504</td>
<td>574</td>
<td>+70</td>
</tr>
<tr>
<td>Secondary Air Temp.</td>
<td>553</td>
<td>546</td>
<td>-7</td>
</tr>
<tr>
<td>Gas Inlet Temp.</td>
<td>653</td>
<td>644</td>
<td>-9</td>
</tr>
<tr>
<td>Gas Outlet Temp.</td>
<td>335</td>
<td>313</td>
<td>-22</td>
</tr>
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</table>
Heat Rate Improvement

- A reduction of 30 degrees F on air heater exit gas temp is approximately a 1% savings in unit heat rate.
- Improved heat rate has benefits beyond coal cost:
  - Decreased fuel handling
  - Decreased ash & waste handling and stabilization
  - Decreased CO₂ emissions
  - Better native Hg capture
  - Better precip performance
  - Decreased emissions overall
- Sustainability
  - People, Planet, and Profits

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Less 1% HR</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Rate (BTU/KWh)</td>
<td>10,000</td>
<td>9,900</td>
<td>100</td>
</tr>
<tr>
<td>Yearly Fuel (TN's)</td>
<td>1,368,750</td>
<td>1,355,063</td>
<td>13,688</td>
</tr>
<tr>
<td>Yearly Ash (TN's)</td>
<td>109,500</td>
<td>108,405</td>
<td>1,095</td>
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<tr>
<td>Coal &amp; Ash Cost ($)</td>
<td>87,600</td>
<td>86,724</td>
<td>876</td>
</tr>
<tr>
<td>CO₂ Emissions (TN's)</td>
<td>3,367,125</td>
<td>3,333,454</td>
<td>33,671</td>
</tr>
</tbody>
</table>

Assumptions:
500 MW Unit
12,000 BTU/lb fuel heating value
75% Capacity Factor
$60/ton coal cost
10% ash content
$50/ton ash processing cost
205 lb/Mmbtu CO₂ Emissions per EIA
Gibson Enhanced SCR Performance Testing
- Five Units, 660 MWg, 4.0-6.0 lb/Mmbtu coal
- High-dust Foster Wheeler SCR’s designed for 3 layers of catalyst and 85% Nox removal
  - Have historically had poor distribution
- Horizontal shaft air heaters with cold side ESP’s
- SBS was installed post AH in 2005 and relocated Pre-SCR from ‘09–’14
  - Original MOT was 622F and was modified to 550F with tiered Nox removal at low load based on the assumption of 5 ppm SO₃
  - Min load was changed from 440 MWg to 250 MWg
Testing Overview/Goals

- Laboratory catalyst testing performed by Cormetech
  - Demonstrated 72-hour operation to simulate a holiday weekend at full 85% Nox removal at 500F flue gas temp
- Two-week test program on Gibson Unit 1 (July 2016)
  - AECOM performed gas testing with modified CCS procedure to validate SO$_3$ concentrations around the SCR at full and low load
  - Breen probes for condensable monitoring
- Used Cormetech transient modeling coupled with the field and lab data to determine reasonable operating parameters

Test objectives and goals

- Quantify the boiler and SCR SO$_2$ conversion at full and low load
- Evaluate operation at elevated NH$_3$ slip and increased NOx removal
- Evaluate operation at reduced air heater gas outlet temperatures
- Measure SO$_3$ and Na compounds in the primary air stream for NH$_3$ dilution to possibly eliminate the in duct heat exchanger
- Evaluate the feasibility of permanently blanking the economizer bypass duct to eliminate an O&M burden
- Run a full scale 72 hour test at 200 MWg to simulate a long holiday weekend
Lab Results

The graph illustrates the change in $K/K_{720^\circ F}$ over time, with three distinct temperature phases: 720°F, 500°F, and 720°F again. The data is represented by red dots and a blue line indicating a transient model. The y-axis represents $K/K_{720^\circ F}$, ranging from 0.00 to 1.20, and the x-axis represents time in hours from -10 to 110.

Lab Performance Data Generated by Cormetech
Lab Results

Extent of ABS-induced deactivation increases

Lab Performance Data Generated by Cormetech
Amplitude of SO₃ spike increases
**Lab Results**

**Three Layers Cycle Test Data**

- **NH₃ Slip [ppmvd]**
- **Time [hours]**

- Full Load 720°F
- Low Load 500°F
- Full Load 720°F

*NH₃* slip spike from ABS decomposition and *NH₃* desorption.

Data will be used to calibrate the ABS deactivation model.
Data will be used to calibrate the ABS deactivation model.
Gibson Unit 5 full load test data from 2009 showing very low SCR inlet SO₃.
Full Scale Results

- Gibson Unit 1 full load test data from 2016 very similar to the Unit 5 data

[Bar chart showing average SO₃ concentration at different locations with baseline and with SBS results.]
Gibson Unit 1 low load test data shows very low inlet SO$_3$ and the effect of high O$_2$ on boiler SO$_3$. 

- **Gibson Unit 1 Low Load**
  - Baseline
  - With SBS

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline</th>
<th>With SBS</th>
<th>Average SO$_3$ Concentration, ppmvd @ 3% O$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economizer Outlet</td>
<td>17 17</td>
<td>20</td>
<td>51 51</td>
</tr>
<tr>
<td>SCR Inlet</td>
<td>17 15 0.3</td>
<td>51 0.5</td>
<td>46 47</td>
</tr>
<tr>
<td>Air Heater Inlet</td>
<td>2.3 2.4 1.0</td>
<td>2.4 1.0</td>
<td>46 47</td>
</tr>
</tbody>
</table>
### Gibson Preliminary SO3 Results

Results from the on-site titration analysis

<table>
<thead>
<tr>
<th>Date</th>
<th>Test #</th>
<th>Load</th>
<th>SBS</th>
<th>NH3</th>
<th>Air temp</th>
<th>Econ Out</th>
<th>SCR In South (Outside wall)</th>
<th>SCR In North (Inside wall)</th>
<th>APH In E</th>
<th>APH In W</th>
<th>Primary Air</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>07/14/16</td>
<td>1</td>
<td>Full</td>
<td>Off</td>
<td>Normal</td>
<td>Normal</td>
<td>15.8</td>
<td>15.1</td>
<td>14.5</td>
<td>57</td>
<td>46</td>
<td>47</td>
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<tr>
<td></td>
<td>2</td>
<td>Full</td>
<td>High</td>
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<td>Normal</td>
<td>20.9</td>
<td>21.0</td>
<td>19.9</td>
<td>17.0</td>
<td>2.7</td>
<td>2.1</td>
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<td>07/15/16</td>
<td>3</td>
<td>Full</td>
<td>Normal</td>
<td>Normal</td>
<td>Low</td>
<td>0.8</td>
<td>0.6</td>
<td>5.2</td>
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<td>7.1</td>
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<td>9.0</td>
<td>11.0</td>
<td>11.3</td>
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<td></td>
<td>5</td>
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<td>Normal</td>
<td>2.1</td>
<td>2.1</td>
<td>1.9</td>
<td>16.2</td>
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<td>14.5</td>
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<tr>
<td>07/16/16</td>
<td>6</td>
<td>250</td>
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<td>43.7</td>
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<td>50.3</td>
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<td>8</td>
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<td>Normal</td>
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<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>13.7</td>
<td>13.1</td>
<td>11.6</td>
<td>9.8</td>
<td>9.2</td>
<td>7.6</td>
</tr>
</tbody>
</table>

- If econ SO3 was 40-50ppm, then would expect to see condensation of ABS in bulk gas. It appears likely that this is what happened.
- This is not as good as we would like to see.
- These results look good for allowing reduction in MOT.
- Rising, but perhaps just back to the full load level at the normal ratio.
Field testing resulted in SO$_3$ numbers lower than the lab testing providing confidence in the enhanced operation mode.

Recommendation will be made to further modify the low load constraints from 250 MWg to 200 MWg with full NOx removal.

Economizer outlet SO$_3$ was much higher than expected due to the very low load and high O$_2$.

Approach will be implemented across remaining Gibson Units with minimal additional testing.