Broaden the Operating Range of Coal Fired Units by Lowering the Minimum Operating Temperature

Reinhold Environmental 2016 NO\textsubscript{x}-Combustion-CCR Round Table

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Agenda

• Introduction
• Basics of SCR Minimum Operating Temperature (MOT)
• Variety of solutions to reduce MOT
• Conclusions
Improving unit dispatch in an ever changing coal electricity generation market place requires the lowest possible unit load.

The boiler is often limited by the Minimum Operating Temperature of the SCR system.
• The Minimum Operating Temperature is the temperature below which ammonia and sulfur trioxide combine to form ammonium bisulfate (ABS).

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

• ABS deposits in the micro pores and reduces the catalyst activity.

• The ABS deposits can be removed at higher temperatures.

• The MOT depends on the NH\textsubscript{3} and SO\textsubscript{3} concentration in the flue gas.
Example
Economizer Temperature Characteristic

Temperature VS Load

Load MW

Temperature °F

MOT
Solutions

• Verify operating data at low loads
• Operate below MOT
• Increase economizer outlet temperature
• Reduce ammonia concentration in the flue gas
• Reduce sulfur trioxide concentration in the flue gas
• Combination of the above
NO$_x$ VS Load
Economizer Temperature Characteristic

Temperature VS Load

Load MW

Temperature F

635 F

Design MOT

150 MW
Verification of Low Load Operating Data

- $\text{NO}_x$ inlet
- $\text{NO}_x$ distribution
- $\text{SO}_2$ inlet
- $\text{SO}_2$ distribution
- $\text{SO}_3$ inlet
- $\text{SO}_3$ distribution
- Temperature inlet
- Temperature distribution
- Ammonia slip
Verification of Low Load Operating Data

Temperature VS Load

- Temperature F
- Load MW

- Design MOT
- 610 F
- 120 MW

Graph showing temperature versus load with markers for 610 F and 120 MW.
Verification of Low Load Operating Data

Temperature VS Load

Design MOT

590°F
90 MW
Reduce Ammonia concentration
Economizer Temperature Characteristic

Temperature VS Load

MOT

Design MOT

80 MW with reduced NOx removal efficiency
Operation Below MOT

- Deterioration of Ammonia/NO$_x$ profile inside the catalyst mostly on high sulfur units
- Time dependent
- Other sulfite formation
Operating Below MOT on High Sulfur Unit

- 500 MW unit wall fired
- Bituminous coal with 3% sulfur
- Full load performance test
  - Guaranteed NO\textsubscript{x} removal exceeded
  - Ammonia slip not detectable
  - NO\textsubscript{x} outlet distribution +/- 10 PPM
Operating Below MOT on High Sulfur Unit

- Low load first performance test
  - As full load test
- Low load second performance test
  - Guaranteed NO\textsubscript{x} removal exceeded
  - Ammonia slip 2 PPM
  - NO\textsubscript{x} outlet distribution +/- 20 PPM
- Low load third performance test
  - Guaranteed NO\textsubscript{x} removal exceeded
  - Ammonia slip 10 PPM
  - NO\textsubscript{x} outlet distribution +/- 50 PPM
Bio Mass Unit

- SCR clean side arrangement (444°F) - downstream of baghouse and DSI.
- Most catalyst poisons have condensed on ash and removed in bag house.
- DSI removes 70-90% of SO$_x$
- Minimum operating temperature of 423°F based on design SO$_2$ / SO$_3$ values at baghouse outlet.
- Additional design constraints:
  - Ammonia Slip <5ppmv @ 7% O$_2$
  - 2 year initial lifetime guarantee
  - Catalyst pressure drop <1.2” wg
Bio Mass Unit

- Boiler first fire July 7, 2013
- SCR Baseline testing began on November 19, 2013.
- NO\textsubscript{x} removal set point target set at 0.078 lb/MMBTU and met.
- Ammonia slip testing done at a set point of 0.045 lb/MMBTU. Set point was met and no ammonia slip excursions found.
- Initial compliance emissions testing results, November 2013:
  - NO\textsubscript{x}: 0.052 lb/MMBtu
  - Ammonia slip: 0.7 ppmvd @ 7% O\textsubscript{2}

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Bio Mass Unit

Current Operation

• $\text{NO}_x$ Inlet 0.138 - 0.155 lb/MMBTU
• $\text{NO}_x$ Outlet 0.032 - 0.075 lb/MMBTU
• Temperature 375°F - 423°F
• Pressure Drop (SCR) less than 2” Wg
Operation Below MOT

![Graph showing local SCR inlet temperature changes from 11/16/13 to 11/21/13. The temperature fluctuates between 370°F and 420°F with peaks on 11/17/13 and 11/20/13.]
Bio Mass Unit

- Testing done at 4,000 and 8,000 hours
Economizer Gas Side Bypass
Economizer Gas Side Bypass

Economizer Temperatures

Temperature (°F) vs. Load (MW)

- Blue line: Economizer Outlet
- Red line: Economizer Inlet
Economizer Gas Side Bypass

Current SCR Inlet Temperature

Note: Economizer Bypass Must Remain Open if Load is Under 495 MW
Economizer Bypass is Insufficient for Loads Under 380 MW
Economizer Gas Side Bypass

Temperature (°F)

Thermocouples (West to East)

- Full Load (610 MW)
- 350 MW (Bypass Closed)
- 325 MW Bypass Open
- Low Load (250 MW)
Economizer Gas Side Bypass
Economizer Gas Side Bypass
Economizer Gas Side Bypass
Possible Solution
Economizer Water Side Bypass

- Pro: No flue gas mixing issues
- Con: Many times difficult to retrofit
- No flow water flow through part of the economizer
SO$_3$ Reduction With Targeted In-Furnace Injection TIFI

- Mg(OH)$_2$ calcines to high surface area MgO
- Direct Reaction with MgO
  - MgO + SO$_3$ => MgSO$_4$
  - MgO + NH$_4$HSO$_4$ => MgSO$_4$ + NH$_3$ + H$_2$O
- Lower Furnace Temperature
  - Decreased Oxidation Rate
- More Balanced Furnace
  - Reduced Excess Oxygen
- Reduced Slag and Iron Deposits
  - Less Catalytic SO$_2$ Oxidation
600 MW Wall Fired.
Illinois Basin Coal.
Need for Greater Low Load Flexibility.
New Low Load Operations began Aug 2013 and continues through present.
Original Low Load 430 MW – reduced to 275 MW
SO$_3$ Reduction With Targeted In-Furnace Injection TIFI
SO$_3$ Reduction With Targeted In-Furnace Injection TIFI

- **Lower furnace injection** (zones 1 – 4) is optimal for slag/fouling control
  - MgO reacts with ash to modify ash fusion temperature
  - MgO captures SO$_3$
- **Zone 5 injection** is more efficient for SO$_3$ control and still provides slag & fouling control at the horizontal superheats, reheats, economizer, SCR & air heater
  - MgO does not readily react with fly ash at T < 2000°F
  - Less sintering of MgO = more available surface area for SO$_3$
Optimized Mg(OH)$_2$ Injection for SO$_3$ Control

![Graph showing SO$_3$ removal based on Mg/S ratio and injection/reactor temperature.]

**Mg/S Ratio = 3.0**

**Inject here**

**ESP inlet**

**dopece floor**

**APH$_{in}$**

**SCR**

**Injection/Reaction Temperature, °C**

**SO$_3$ Removal, % (Baseline = 26ppmv)**
Predictive Performance Model for SO$_3$ Control
Predictive Performance Model for SO$_3$ Control

![Graph showing the performance of Mg(OH)$_2$ and Ca(OH)$_2$ for SO$_3$ reduction. The graph includes curves for Mg(OH)$_2$ and Ca(OH)$_2$ feed rates versus SO$_3$ reduction. Key points:
- Mg(OH)$_2$, $[SO_3] = 325$ ppm, 380% coverage.
- Ca(OH)$_2$, EPRI, $[SO_3] = 25$ ppm, 80% coverage.
- Ca(OH)$_2$, EPRI, $[SO_3] = 25$ ppm, 100% coverage.
]
SO$_3$ Tests

- Modified EPA Method 8A Controlled Condensate
- Single train sampling
  - Preliminary tests conducted to understand cause (dose) and effect (reduction) relationship
  - One SO$_3$ train measured AH inlet at low load, ramp period and full load
- Six train full test protocol
- SO$_3$ measurement locations (both sides):
  - Economizer outlet
  - SCR outlet
  - APH outlet
- Unit configuration during measurements:
  - Low load
  - Ramp
  - High load
- Determined critical data on SO$_2$/SO$_3$ conversion rates, sorbent performance as a function of temperature during each unit configuration
Results at Low Load (< 400 MWg)

- Uncontrolled $\text{SO}_3$ concentration is $51 - 63 \text{ ppm}_{\text{vdc}}$ (at 3.0% $\text{O}_2$)
- $\text{SO}_2$ concentration during this period averaged $3.66 \pm 0.24 \text{ lbs/MBTum}$
  - Corresponds to $\text{SO}_2 = 1926 \pm 125 \text{ ppm}_{\text{vdc}}$ at 3.0% $\text{O}_2$
- Side B total conversion rate 2.6% -- 3.5%
  - Side B $\text{O}_2$’s are approximately 1 -- 2% lower than Side A
  - Therefore Side A conversion is expected to be greater than Side B
Results During Ramp

- As unit ramps, the catalyst releases stored SO$_3$.
- Increasing Mg(OH)$_2$ feed rate in zone 5 during ramp decreases severity of “burn off”.
- Dance floor injection (zones 5) is 20% -- 30% more efficient than furnace injection for SO$_3$ control.
Results at Full Load

Full Load (> 580 MW) - Airheater Inlet (B side)

\[ \text{[SO}_3\text{]} \text{(ppm \text{v}, 3\% O}_2\text{)} \]

Total Dose (Zone 1-4 + Zone 5)
Low Load Results

Low Load - A side

Measurement Location

Low Load - B side

Measurement Location

[SO3] ppmvdc (3% O2)

% of SO2

Measurement Location
Ramp Results

Ramp - A side

Ramp - B side

Measurement Location

Measurement Location

[SO3] ppmvdc (3% O2)

% of SO2

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Full Load Results

**Full Load - A side**

- 3/2a
- 3/2b
- 3/2c
- 3/2d

**Full Load - B side**

- 3/2a
- 3/2b
- 3/2c
- 3/2d

Measurement Location

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New Minimum Loads

- New limiting load factor – combustion stability
- Wider operating range may pay for all day chemical consumption
Additional Solutions

- Duct burner to raise the temperature
  - Pro: Provides the entire load range
  - Con: Economics
- Gas co-firing
  - Reduces SO$_3$ and NO$_x$ concentration in the flue gas
- Burner improvements to reduce the NO$_x$ concentration
- SNCR to reduce the NO$_x$ concentration
Conclusions

• Several options are available to broaden the SCR operating range.
• Precise definition of low load operating conditions is mandatory.
• Operation below MOT can be detrimental if there is no mechanism to preclude ABS formation in the air pre heater.
• Economic evaluation important for optimized solution.
• TIFI is a solution especially for high sulfur applications to reduce SO$_3$ and broaden the operating range.
Thank You

Questions?