NOx Emission Control Strategy for the Steel Mill Industry

Advances in Emission Control and Monitoring Technology for Industrial Sources
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Fuel Tech at a Glance

- Innovative Approaches to Enable Clean Efficient Energy
  - Air Pollution Control – Capital Projects
    - NO\textsubscript{x}OUT\textsuperscript{®} Products including SNCR, CASCADE, SCR, and ULTRA
  - FUEL CHEM\textsuperscript{®} Technology– Specialty Chemical Operating Programs
    - Boiler Efficiency and Availability Improvements
    - Slag and Corrosion Reduction
    - Controls SO\textsubscript{3} Emissions and Addresses Related Issues
  - Technology solutions based on Advanced Engineering Capabilities Including State of the Art Computer Visualization and CFD/CKM Modeling
Fuel Tech Air Pollution Control (APC) Technologies

Nitrogen Oxide Reduction
- NOxOUT® SNCR, NOxOUT® SCR, NOxOUT CASCADE®
- Customer Benefits
  - Effective: 20 - 90% Reduction
  - Low Capital Cost: $5 - 75 per kilowatt (compares to SCR at $250+ per kilowatt)
  - ROI Potential: NOx Allowances
  - Flexible: Staged Implementation
  - Easy to Retrofit: Modular Designs
- Over 480 Installations So Far

UREA to Ammonia Conversion
- NOxOUT ULTRA®
- Non-Hazardous Reagent for Selective Catalytic Reduction (SCR)
- Avoids Dangers of Anhydrous & Aqueous Ammonia
- Customer Benefits
  - Low Capital and Operating Cost
  - Safe (Non-Hazardous Materials Throughout)
  - Built on Proven Fuel Tech Technologies
- 15 Commercial Installations
Fuel Tech’s Global Activities

★ Office Locations: Warrenville, IL; Stamford, CT; Milan, Italy; Beijing, China

★ Countries where Fuel Tech does business: USA, Belgium, Canada, China, Columbia, Czech Republic, Denmark, Dominican Republic, Ecuador, France, Germany, Italy, Jamaica, Mexico, Poland, Portugal, Puerto Rico, Romania, South Korea, Spain, Taiwan, Turkey, United Kingdom, Venezuela
**Selective Non-Catalytic Reduction of NOx**

\[ 2\text{NO} + \text{CO(NH}_2\text{)}_2 + \frac{1}{2}\text{O}_2 \rightarrow 2\text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O} \]

NITROGEN OXIDE + UREA + OXYGEN $\Rightarrow$ NITROGEN + CARBON DIOXIDE + WATER

- Post Combustion
- Gas Phase Reaction
- Typical Combustion Products
- Furnace is the Reactor
- Widely Applicable
- Easily Installed
- Low Capital Cost

Goal: Distribute the Reagent at Specific Temperature Regime to Effect a Reducing Reaction.
<table>
<thead>
<tr>
<th>Electric Utilities</th>
<th>Refinery Process Furnaces</th>
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<tbody>
<tr>
<td>Wood-fired IPPs / CoGen Plants</td>
<td>CO Boilers</td>
</tr>
<tr>
<td>TDF Plants</td>
<td>Petrochemical Industry</td>
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<tr>
<td>Pulp &amp; Paper</td>
<td>CoGeneration Package Boilers</td>
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<tr>
<td>Grate-fired</td>
<td>Municipal Solid Waste</td>
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<td>Sludge Combustors</td>
<td>Process Units</td>
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<td>Recovery Boilers</td>
<td>Steel Mills</td>
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<tr>
<td>Wellons Boilers</td>
<td>Cement Kilns</td>
</tr>
<tr>
<td>Cyclones</td>
<td></td>
</tr>
</tbody>
</table>
Fuels

- Coal – Bituminous, PRB, Lignite
- Oil – #2 and #6
- Natural Gas
- Refinery Gases (High CO)
- Municipal Solid Waste
- Tire Derived Fuel
- Wood
- Sludge
Boiler Types

- Utility Boilers
  - T-fired, Wet Bottom, Front-wall Fired, Cyclone, Tower
- Circulating Fluidized Bed
- Bubbling Fluidized Bed
- Stoker, Grate Fired
- Incinerators
- Industrial
CRITICAL SNCR PROCESS PARAMETERS

• **Temperature** – 1600°F to 2200°F (Process Dependent)

• **Residence Time** – 0.2 Seconds to 2.0 Seconds

• **Background Gas Composition** – CO, O₂, NOx

• **NOx Reduction** – Baseline and Target

• **Reagent Distribution** – Access and Penetration
“RIGHT SIDE OF THE SLOPE” INJECTION

Low Temperatures
- Slow Droplet Evaporation
- Slow Kinetics
- Ammonia Slip

High Temperatures
- Rapid Droplet Evaporation
- Fast Kinetics
- NOx Generation
Computational Fluid Dynamics (CFD)
Used to Define Effective Boundaries of Critical Process Parameters, Test Effectiveness of Distribution Strategies, Identify/Locate/Define Gas Species Concentrations – Physical Unit and Field Testing Input

Chemical Kinetics Model (CKM)
Used to Calculate Each Specific Time/Temperature Reduction Reaction

Process Know-how and Commercial Experience
Combined with Modeling to Validate Process
Urea Injection Modeling

Furnace Injection
3D VISUALIZATION – Urea Injection Sprays
NOxOUT SNCR for GALVANIZING FURNACE
0.5 Seconds of Residence Time

- Heat Input = 63.1 MMBTU/hr
- Estimated Flue Gas Flow = 13,956 SCFM
- Baseline NOx = 242 ppmd@4.3% O2
- Baseline NOx = 0.32 lb/MMBTU, 20.3 lb/hr
- Controlled NOx = 0.209 lb/MMBTU
- NOx Reduction = 35%
- Ammonia Slip = 10 ppm
- Required Injection Temperature = 1,750 - 1,850 °F
- Injection CO Limit = 100 ppm
- NOxOUT® LT Reagent Consumption = 5 GPH
**NOxOUT SNCR for GALVANIZING FURNACE**

**1.0 Seconds of Residence Time**

- Heat Input = 63.1 MMBTU/hr
- Estimated Flue Gas Flow = 13,956 SCFM
- Baseline NOx = 242 ppmd@4.3% O₂
- Baseline NOx = 0.32 lb/MMBTU, 20.3 lb/hr
- Controlled NOx = 0.161 lb/MMBTU
- NOx Reduction = 50%
- Ammonia Slip = 20 ppm
- Required Injection Temperature = 1,750 - 1,850 °F
- Injection CO Limit = 100 ppm
- NOxOUT® LT Reagent Consumption = 7 GPH
NOxOUT SNCR for GALVANIZING FURNACE
1.5 Seconds of Residence Time

- Heat Input = 63.1 MMBTU/hr
- Estimated Flue Gas Flow = 13,956 SCFM
- Baseline NOx = 242 ppmd@4.3% O₂
- Baseline NOx = 0.32 lb/MMBTU, 20.3 lb/hr
- Controlled NOx = 0.097 lb/MMBTU
- NOx Reduction = 70%
- Ammonia Slip = 30 ppm
- Required Injection Temperature = 1,750 - 1,850 °F
- Injection CO Limit = 100 ppm
- NOxOUT® LT Reagent Consumption = 10 GPH
SELECTIVE CATALYTIC REDUCTION (SCR)

- Capable of High Efficiencies (85+\%)
- Efficient Reagent Utilization
- Susceptible to Non-ideal Inlet Conditions and Catalyst Deactivation – Moisture, Arsenic, Abrasive Ash, Other Fuel-bound Contaminants
- SO$_2$ to SO$_3$ Conversion
- Sensitivity to NH$_3$/NO$_x$ Deviations
SCR CATALYST DESIGN PARAMETERS

- Flue Gas Flow Rate
- Flue Gas Temperature at Catalyst
  - Conventional Catalyst - 800F
  - Zeolite Based Catalyst – 1000F
- Composition
  - NOx, SO2, O2, and Particulate Loading
- NOx Conversion Requirement
- Ammonia Slip Limit
- Pressure Drop Constraints
NOxOUT® SELECTIVE CATALYTIC REDUCTION (SCR) SYSTEM

- Utilizes a aqueous urea solution to form ammonia which will react with a catalyst to reduce NOx under the appropriate conditions to produce nitrogen and water.
- The dominant SCR reactions are described as follows:

\[
\begin{align*}
4\text{NO} + 4\text{NH}_3 + \text{O}_2 & \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \quad \text{(dominant)} \\
\text{NO} + \text{NO}_2 + 2\text{NH}_3 & \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O} \\
\text{Nitrogen Oxide(s)} + \text{Ammonia} + \text{Oxygen} & \rightarrow \text{Nitrogen} + \text{Water}
\end{align*}
\]

- The optimum temperature range for the NOxOUT LT® urea injection is 850 – 1,200° F
- Urea allows a single, safe reagent at the site for combined technologies
NOxOUT Industrial SCR
Gas Fired Commercial System No. 1

- Heat Input, MMBTU/hr = 99.0
- Estimated Flue Gas Flow = 173,977 lb/hr (39,500 SCFM, wet)
- Baseline NOx = 547 ppmd@3% Oxygen
- Controlled NOx = 55 ppmd@3% Oxygen
- NOx Reduction = 90%
- Ammonia Slip = 15 ppm
- Required Injection Temperature = > 850 °F
- Required Catalyst Temperature = 600 - 720°F
- NOxOUT® LT Reagent Consumption = 16 GPH
NOxOUT Industrial SCR
Gas Fired Commercial System No. 2

- Maximum Heat Input, MMBTU/hr = 117
- Flue Gas Flow Rate = 137,000 lb/hr (30,900 SCFM, wet)
- Uncontrolled NOx = 223 ppmd@7.37%O₂
- Controlled NOx = 22.3 ppmd@7.37%O₂
- NOx Reduction Guaranteed = 90%
- Ammonia Slip at Stack, < 15 ppm
- Temperature at Point of Injection = > 850 °F
- Temperature at Catalyst Face = 600 - 750 °F
- NOxOUT® LT Consumption = 12.0 GPH
INDUSTRIAL SCR REACTOR HOUSING
System Description

The Combination of In-Furnace SNCR with Downstream Selective Catalytic Reduction (SCR) to Extend the NOx Reduction Capability of SNCR, Improve Overall SNCR Reagent Utilization and Mitigate Downstream Balance of Plant Impacts.
A **Redesigned** SNCR system with SCR
- Higher NO\textsubscript{x} reduction and chemical utilization than SNCR
- Lower capital costs than full-scale SCR
- Greater operational flexibility
  - Seasonal NO\textsubscript{x} emission limits
  - Seasonal and daily load variations
“RIGHT ON THE SLOPE”

Low Temperatures
- Slow Droplet Evaporation
- Slow Kinetics
- Ammonia Slip

High Temperatures
- Rapid Droplet Evaporation
- Fast Kinetics
- NOx Generation

CASCADE
- Small Droplets
- Ideal Kinetics
- Limited NH3

Low Temperatures: 1290 1470 1650 1830 2010 2190 2370
SENSITIVITY TO $NH_3 / NO_x$ DEVIATIONS

- Based on control of local ammonia slip to 5 ppm
• Furnace Heat Input = 48 MMBTU/hr
• Flue Gas Flowrate @ SNCR = 48,725 lb/hr (11,126 SCFM, Wet)
• Flue Gas Flowrate @ SCR = 117,600 lb/hr (26,610 SCFM, wet)
• NOx Baseline = 0.30 lb/MMBtu, 87 ppmd@15 % O₂
• Controlled NOx = 0.043 lb/MMBtu, 13 ppmd@15% O₂
- SNCR NOx Reduction = 75%
- SCR Reduction = 41% Reduction
- Overall Cascade Reduction = 85%
- Chemical Consumption = 9 GPH
- Catalyst Size = 1.0 Cubic Meter
- Temperature at Point of Injection = 1,650 °F
- Temperature at Catalyst Face = 650 - 700 °F
Urea Reagent Storage and Circulation Module
w/Building
Reagent Circulation Module
SLP3 Independent Level Control Metering Module
Three-Position Distribution Module
Urea Injector with Automatic Retract Mechanism
Urea Injector Inside Boiler
## Fuel Tech Steel Industry Experience

<table>
<thead>
<tr>
<th>INDUSTRY</th>
<th>PRODUCT TYPE</th>
<th>COUNTRY</th>
<th># of UNIT</th>
<th>UNIT TYPE</th>
<th>SIZE (MMBtu/hr)</th>
<th>FUEL</th>
<th>NOx BASELINE (ppm, * lb/MMBtu)</th>
<th>REDUCTION %</th>
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<tbody>
<tr>
<td>Steel</td>
<td>Urea SCR</td>
<td>USA</td>
<td>1</td>
<td>Radiant Tube Furnace</td>
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<td>Natural Gas</td>
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<td>Radiant Tube Annealing Furnace</td>
<td>117</td>
<td>Natural Gas</td>
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<td>CE T-Fired w/CCOFA</td>
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<td>410 mg/Nm³ @ 11% O₂</td>
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<td>Steel</td>
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<td>Italy</td>
<td>1</td>
<td>Coke Oven Incinerator</td>
<td>6200 Nm³/hr</td>
<td>Coke Oven OFF Gas</td>
<td>1200 mg/Nm³ @ 11% O₂</td>
<td>70</td>
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</tbody>
</table>
Previous List Includes Nucor Steel Experience

Multiple Plant Locations
- Berkeley, South Carolina
- Crawfordsville, Indiana
- Hickman, Arkansas

Paper from Previous ICAC Conference in 2002
Potential NOx Control Strategies

- Meet Specific Requirements
  - NSPS Standards
  - State or Regional
  - Clean Air Visibility Rule

- Cap and Trade Environment
  - Buy Allowances
  - Overcontrol and Sell Allowances
  - Install Low Capital Cost Controls
  - Partial Controls / Buy Allowances
Factors Affecting Allowance Pricing

- GDP
- Weather
- Natural Gas Supply Prices
- Fuel Transportation
- Transmission Congestion
- Utility Trading Behavior
- State Rules
- Ratemaking Policy
Cost Analysis System Parameters

- Data from over 40 recent Fuel Tech Industrial Installations
  - NOxOUT® SNCR, NOxOUT® SCR, NOxOUT CASCADE ®
- Annualized Costs for Overall Comparison
- Capital Costs are Based on Total Installed Costs
  - No Added Costs for Compressors, CEMS, or other misc items
- Capital Recovery Factor = 0.125
- Reagent and Maintenance Costs included in Annualized Total
- Average $/ton of NOx removed on an Annual Basis
  - Total for All Types of Systems < $2,000/ton
  - Steel Applications average $2,800/ton with one SNCR only data point
Annualized Costs to Control are less than Predictions of Totalized Allowance Prices

May help meet CAVR Requirement for Cost Effective Control

Turnaround Project Turnaround Time of 6-9 Months

Safe Urea Reagent

– SNCR, SCR or NOxOUT CASCADE
Reagent Alternatives for SCR Systems

- Anhydrous Ammonia
  - Highest Risk Reagent
  - Decrease in US Ammonia Production
  - Future Availability Questions – Rail Issue
  - Homeland Security Chemical of Interest

- Aqueous Ammonia
  - 19% Concentration
  - 29% Concentration - limited availability
  - Availability and price affected by anhydrous

- Urea
  - Direct Usage or On-Site Ammonia Generation Process
  - Significant Safety Advantages
  - Worldwide Availability of Urea
Anhydrous Ammonia – Safety Considerations

- Ammonia Storage
  - On-site tanks – homeland security issue as potential targets

- Transportation
  - Department of Transportation Restrictions
  - State and local restrictions on shipping and routing

- Safety Risks
  - EPA Worst Case Release Analysis – Toxic Endpoint for 60,000 Gallon Release Covers a Radius of 7 to 10 Miles

Aqueous Ammonia – Safety Considerations

- **Ammonia Storage**
  - Containment for possible liquid leaks/spills

- **Transportation**
  - 29% Aqueous ammonia is restricted by Department of Transportation in many areas
  - State and local restrictions on shipping and routing

- **Safety Risks**
  - Increased transportation risk due to more shipments of dilute chemical
  - Much higher unloading frequency at plant site raises potential incident probability
  - Toxic endpoint radius of 1 to 2 miles
Summary

- NOxOUT SNCR, NOxOUT SCR and NOxOUT Cascade have been demonstrated to provide safe, cost effective NOx control for steel mill applications
- Urea reagent minimizes safety related issues
- Questions?