SNCR Experience on Large Coal-Fired Boilers with Difficult Operating Conditions

Kelly Borgen, Engineer, Jeffrey Energy Center
JEFFREY ENERGY CENTER
ST. MARYS, KANSAS

- Three (3) eight-corner, tangentially-fired units designed for PRB coal
  - Units 1, 2, and 3 commissioned in 1978, 1980, & 1983, respectively
  - CE subcritical drum boilers – 5,050,000 lb/hr capacity
  - 800 MWg nameplate
- Dispatched as part of the Southwest Power Pool (SPP)
PROJECT OVERVIEW

• 2010 Consent Decree required JEC NOx emissions upgrades
  o Coordinated effort with the Environmental Protection Agency (EPA) and the State of Kansas
    ▪ SCR required to be installed on one unit at a minimum – selected Unit 1
    ▪ Option to build a second SCR or comply with a 0.10 lb/mmbtu site-wide NOx limit
  o Stacked technologies to achieve site-wide NOx limit without an additional SCR
    ▪ Neural network combustion and sootblowing optimizers on all three units
    ▪ Boiler modifications on Units 2 & 3
      – Additional elevation of over-fire air (tertiary over-fire air, TOFAs)
      – New low-NOx burners with horizontally biased combustion
    ▪ SNCRs on Units 2 & 3
PERFORMANCE OBJECTIVES & SCHEDULE

- Control NOx emissions over large load range (39-100% MCR)
  - Reduce NOx from ~0.17 to <0.125 lb/mmbtu with combustion modifications
  - Reduce NOx from 0.125 to <0.115 lb/mmbtu with SNCRs on Units 2 & 3
  - Reduce NOx from 0.17 to 0.04 lb/mmbtu with SCR on Unit 1
- Ammonia slip <10 ppm for SNCRs
- Maintain CO and other unit performance metrics

<table>
<thead>
<tr>
<th>Fall 2010</th>
<th>Spring 2011</th>
<th>Fall 2011</th>
<th>Spring 2012</th>
<th>Fall 2012</th>
<th>Spring 2014</th>
<th>Fall 2014</th>
<th>Spring 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Enter Consent Decree</td>
<td>• Research NOx reduction options</td>
<td>• Decide to proceed with boiler mods and SNCR on J3</td>
<td>• Install SNCR and boiler mods on J3</td>
<td>• Decide to proceed with boiler mods and SNCR on J2</td>
<td>• Install SNCR and boiler mods on J2</td>
<td>• SCR tie-in on Unit 1</td>
<td>• In compliance with 0.10 lb/mmbtu site-wide 30-day NOx average</td>
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30-day NOx average
DESIGN CHALLENGES

- Limited time
- High FEGT due to high net heat input per plan area and PRB coal
- Challenging SNCR reagent distribution due to large furnace cross-sectional area and superheat pendants in upper furnace
- Boiler combustion modifications completed simultaneously with SNCR install, resulting in:
  - Very low baseline NOx (~0.125 lb/mmbtu)
  - High CO concentration at the point of urea injection (~1600 ppm)
  - Even higher FEGT
  - Need for modeling of both the boiler modifications and the SNCR

\[
\text{Urea} + 2 \text{NO} + \frac{1}{2} \text{O}_2 \rightarrow 2 \text{N}_2 + \text{CO}_2 + \text{H}_2\text{O}
\]
HIGH UPPER FURNACE TEMPERATURE
FULL LOAD - CFD MODEL

Furnace Centerline Temperature

Superheater Platens Elevation 1464'

TOFA and Lower Windbox Elevations
DROPLET TRAJECTORIES AND NOX PROFILE
INJECTION MODELING

Full Load:
Wall Injectors and Multiple Nozzle Lances (MNLs)

Level 4: MNL
Level 3: HERT

NOx Profile

65% Load: Wall Injectors Only

Full Load:
Wall Injectors and Multiple Nozzle Lances (MNLs)
SYSTEM SUMMARY

- Fuel Tech’s injection strategy
  - Three (3) zones of wall injectors
    - One (1) zone of MNLs
  - Zones 1 and 2 consist of NOxOUT® wall injectors
  - Zone 3 consists of HERT™ wall injectors
  - Zone 4 consists of multiple nozzle lances (MNLs)
SOLUTIONIZING SYSTEM

• JEC has ability to receive both dry and aqueous urea
• Solutionizing system scope of supply
  o 3,100 ft³ dry urea silo
  o 10,000 gallon solutionizing tank w/ mixer, heaters, and load cells
  o Solutionizing module with density meter and strainer
  o Dehumidification unit
  o Redundancy in heating and mixing
  o Remote I/O panels controlled by DCS
  o Treated water system
• Significant reagent cost savings with dry urea solutionizing system vs. 50% aqueous urea delivery
PERFORMANCE TEST RESULTS

- Met or exceeded performance objectives
- Overall NOx performance on Unit 2 with SNCR in service is approximately 5%-7% better than Unit 3
  - Benefits include flexibility in compliance with site-wide NOx limit and annual urea cost savings

<table>
<thead>
<tr>
<th>Unit</th>
<th>Unit 3 (Load Condition)</th>
<th>Unit 2 (Load Condition)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Full Load</td>
<td>Mid Load</td>
</tr>
<tr>
<td>NOx after Combustion Mods (lb/mmbtu)</td>
<td>0.125</td>
<td>0.108</td>
</tr>
<tr>
<td>NOx with SNCR (lb/mmbtu)</td>
<td>0.112</td>
<td>0.101</td>
</tr>
<tr>
<td>NH3 slip (ppm)</td>
<td>8.8</td>
<td>6.9</td>
</tr>
</tbody>
</table>
JEC 2 AND 3 HOURLY NO$_X$
JEC 2 AND 3 SNCR CHEMICAL FLOW

SNCR Chemical Flow from October to December 2014

- Unit 3 SNCR Chemical Flow
- Unit 2 SNCR Chemical Flow

% Load

Total Chemical Flow (GPH)
BUMPS ALONG THE WAY & LESSONS LEARNED

• Short timeline resulted in oversights and rework.
  o Freeze protection
  o Water pretreatment system
  o Air compressors
• Simultaneous install of combustion modifications and SNCR produced challenges in predicting performance and establishing guarantees.
• Coordination among all involved parties was key.
• Learned from Unit 3 and made the most of the opportunity to improve on Unit 2.
PROJECT SUMMARY

- Jeffrey Energy Center is able to comply with the Consent Decree
  - Flexible emission compliance plan
  - Significant capital savings
  - Reduced consumption of urea from lower baseline NOx
  - Operating cost savings from SNCR operating at low loads
- Units control NOx emissions over wide load range offering operating flexibility
- Flexibility with reagent supply options
- SNCRs have been in normal operation since fall 2014
  - NOx remains well controlled