NO$_x$ Control in a Reduced Load Environment

Presented by:
Richard E. Thompson
Fossil Energy Research Corp. (FERCo)
Laguna Hills, California
92653

Presented at:
2012 NOx-Combustion RoundTable
Columbus, Ohio
February 13-14, 2012
REASONS FOR REDUCED LOAD OPERATION

• Reduced Industrial Power Demand

• Economic Load Dispatch – Older, Smaller Units are Less Efficient, Higher Heat Rate

• Seasonal Variations and Weather

• Alternative Generation Sources
  ▪ Combined-cycle gas turbines (CCGT) burning cheap natural gas
  ▪ Wind farm power generation
  ▪ Solar power generation

• Independent System Operator (ISO) Dispatch Priorities
OPERATIONAL AND NO\textsubscript{x} EMISSIONS IMPACTS

• Reduced Boiler Efficiency, Higher Net Heat Rate

• Increased Fuel Use per Megawatt of Electricity Generated

• Higher Excess Air or Operating O\textsubscript{2} Levels Typically Required at Lower Loads

• Boiler Thermal Efficiency Impacted if Reheat and Superheat Steam Temperatures Drop Well Below Design Levels

• Boilers Relying on OFA for Deeply Staged Combustion NO\textsubscript{x} Control at Full Load Lose Effectiveness at Reduced Loads

• NO\textsubscript{x} Emissions from Some Boiler Types are More Sensitive to Low-Load Operation

• Decisions Regarding When to Take Pulverizers Out-of-Service Can Impact NO\textsubscript{x} Emissions
REASONS FOR EXCEEDING ANNUAL NO$_x$ EMISSIONS BUDGET

• Shift in Unit Load Profiles to Lower Loads and Higher NO$_x$ Emissions Rates

• Variability in Coal Quality or Coal Blend Consistency

• System Load Dispatch Based on Heat Rate Without Also Considering NO$_x$ Emissions Impacts

• Assigning Top Priority to Maintaining High Thermal Performance Without Considering NO$_x$ Emissions Tradeoffs

• Reluctance to Derate Units and Operate on 100% PRB During Weekends or Low Generation Seasonal Periods

• ISO Requests for Frequent Rapid Load Savings Due to Wide Variability in Wind Farm Generation
WHAT UNIT TYPES ARE OF GREATEST CONCERN?

- Older, Smaller Tangentially-Fired Legacy Units Without Advanced Combustion NO\textsubscript{x} Controls or Any Post-Combustion NO\textsubscript{x} Controls
  - Often Have Very Attractive Full-Load NO\textsubscript{x} Emission Rates but Unusually High Low-Load NO\textsubscript{x} Emissions
  - Typically Must Operate to Meet Spinning Reserve Requirements and/or to Maintain Geographical Power Balance in Remote Areas of the System
  - Not a Candidate for NO\textsubscript{x} Controls Upgrade Since Currently Scheduled for Retirement in 2015
  - Possible Equipment Performance and Maintenance Issues Because Large Units with Better Heat Rate Have Priority for Upgrade and Maintenance Budgets
FACTORS THAT AFFECT LOW-LOAD NO$_x$ EMISSIONS

- Operating O$_2$ Level
- Pulverizers In Service and Location
- Overfire Air Amount and Location (Overfire Air Tilt Position, If Controllable)
- CO Emissions
- Burner Tilt Position and Steam Temperatures (Reheat and Superheat)
- Coal Quality Variability
CASE HISTORY UNIT CATEGORIES

• Small T-fired Divided Furnaces
  - Size – 100 to 150 MWe
  - Burners – LNB, Manual Auxiliary Air Dampers
  - Overfire Air – Manual, One Level
  - Pulverizers - Four, Exhauster Type

• Medium-size T-fired Divided Furnaces
  - Size ~ 250 MWe
  - Burners – Advanced LNB with Auto FA/AA Dampers
  - Overfire Air – CCOFA (1), SOFA (1 – 5)
  - Pulverizers – Five Raymond Bowl Mill Type
CASE HISTORY UNIT CATEGORIES (continued)

- Large T-fired Single Furnaces
  - Size ~ 630 MWe
  - Burners – Advanced LNB, Auto Dampers
  - Overfire Air – SOFA (two levels, divided)
  - Pulverizers – Six Bowl Mill Type
SMALL T-FIRED CASE HISTORY

• Key Low-Load Operating Variables
  ▪ Operating $O_2$ level (steep variation with load)
  ▪ Firing configuration – pulverizers out-of-service and location
  ▪ Overfire air flow (damper settings for CCOFA)
  ▪ Burner tilt position
SMALL T-FIRED CASE HISTORIES (continued)

- Operating Constraints
  - Steam temperatures
  - CO emissions
  - Frequency of changing mill OOS
  - System load response requirements
  - Mill restarts
TYPICAL OPERATING O₂ VARIATION WITH LOAD

Normalized Load, % of MCR

Operating O₂, % (wet)
NORMALIZED NO\textsubscript{x} AND CO VS. PLANT SET POINT O\textsubscript{2} AT FULL-LOAD

![Graph showing normalized NO\textsubscript{x} and CO versus plant set point O\textsubscript{2} at full-load.](image)

- X-axis: Plant O\textsubscript{2}, % (wet)
- Y-axis 1: Normalized NO\textsubscript{x}, % of MCR NO\textsubscript{x}
- Y-axis 2: CO, PPM

Legend:
- Red: Normalized NO\textsubscript{x}
- Blue: CO
$NO_x$ VS LOAD AT NORMAL $O_2$ – SMALL T-FIRED
NORMALIZED NOₓ AND CO VS OFA AT FULL-LOAD

![Graph showing Normalized NOx and CO vs OFA Damper Setting]

- **Normalized NOx, % of MCR NOx**
- **COc, ppm** (dry@ 3% O2)

OFA Damper Setting

- Red squares represent Normalized NOx,
- Blue triangles represent COc, ppm
NORMALIZED NO$_x$ VS BURNER TILT – 72% LOAD

The graph illustrates the relationship between normalized NO$_x$, % of MCR NO$_x$, and COc, ppm, as a function of burner tilt, degree. The graph shows how normalized NO$_x$ and COc ppm change with increasing burner tilt degree.
REHEAT STEAM TEMPERATURE VS LOAD
MANUAL BURNER TILT AT 72% LOAD

Normalized Load, % of MCR vs Reheat Steam Temperature, °F
NORMALIZED NO$_x$ AND CO VS LOAD – SMALL T-FIRED

- Normalized NO$_x$, % of MCR
- Normalized Load, % of MCR
- COc, ppm

ALL MILLS IN SERVICE
THREE MILLS IN SERVICE

Normalized NO$_x$ and COc in relation to the normalized load, expressed as a percentage of MCR.
NORMALIZED NO\textsubscript{x} VS LOAD – SMALL T-FIRED
KEY RESULTS – SMALL T-FIRED CASE HISTORY

• Older Legacy Units with Few Mills and Limited NO$_x$ Controls Often Operate at High O$_2$ at Low Loads

• NO$_x$ Formation is Very Sensitive to O$_2$ at Any Load

• Even Close-Coupled OFA (CCOFA) Helps NO$_x$ and CO Burnout at Reduced Loads

• Constraining Burner Tilt Position to Less than Horizontal Reduces NO$_x$ but Impacts Reheat Steam Temperature

• Operation with a Mill OOS gives Lower NO$_x$ Than All Mills In Service, Lightly Loaded

• Taking a Mill Out-of-Service May Be Constrained by System Load Response Requirements and Mill Restart Limitations
KEY RESULTS – SMALL T-FIRED CASE HISTORY
(continued)

• Unconstrained NO\textsubscript{x} Emissions at 60% MCR Can Exceed Full-Load MCR NO\textsubscript{x} by 65% or More but it Can be Reduced to Only 18%

• Operation with One Mill Out-of-Service, 80% Open OFA Damper, Low O\textsubscript{2}, and -10° Burner Tilt Position Minimized Low Load NO\textsubscript{x} for this Unit

• It May be Necessary to Sacrifice Boiler Thermal Performance (Reheat Steam Temperatures as Low as 930°F) for Minimum NO\textsubscript{x}

• Test Engineers Can Define Low NO\textsubscript{x} Firing Options but Plant Operations and Management Must Decide When and How Low to Go
MEDIUM SIZED T-FIRED CASE HISTORY

• Reduced Load Operating Variables

  ▪ Firing configuration – pulverizers out-of-service and location (five elevations, more options)

  ▪ Overfire air flow (dampers percent open)

  ▪ Overfire air position (one CCOFA and 5 SOFA)

  ▪ Burner tilt position (auto) and SOFA tilt (manual)
MEDIUM SIZED T-FIRED CASE HISTORY (continued)

• Operating Constraints
  ▪ Steam temperatures
  ▪ CO emissions
  ▪ Windbox pressure
  ▪ Furnace water wall corrosion
  ▪ Instrumentation
ORIGINAl O₂ VARIATION WITH LOAD

![Graph showing the variation of plant O₂, % (wet) with normalized load, % of MCR. The graph indicates a decreasing trend as load increases.](image-url)

**Normalized Load, % of MCR**

**Plant O₂, % (wet)**
RANGE OF O₂ AND NOₓ EMISSIONS DURING PARAMETRIC TESTS

![Graph showing the range of O₂ and NOₓ emissions during parametric tests.](image-url)
OFA TUNING INVOLVES MANY OPTIONS

![Graph showing OFA tuning options](image-url)
### MEDIUM T-FIRED – RECOMMENDED INTERIM FIRING PRACTICE

<table>
<thead>
<tr>
<th>Load</th>
<th>Mills OOS</th>
<th>Operating $O_2$, %</th>
<th>Burner Tilts, deg</th>
<th>OFA Damper, % Open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CCOFA</td>
</tr>
<tr>
<td>100%</td>
<td>None</td>
<td>3.2</td>
<td>-5</td>
<td>25</td>
</tr>
<tr>
<td>80%</td>
<td>One</td>
<td>3.2</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>60%</td>
<td>Two</td>
<td>4.1</td>
<td>+5</td>
<td>25</td>
</tr>
<tr>
<td>40%</td>
<td>Two</td>
<td>5.8</td>
<td>+3</td>
<td>25</td>
</tr>
</tbody>
</table>

SOFA Tilts = +10 deg manual
**SUMMARY OF NO\textsubscript{x} REDUCTION POTENTIAL – MEDIUM SIZE T-FIRED**

<table>
<thead>
<tr>
<th>Load, % MCR</th>
<th>Baseline Normalized NO\textsubscript{x}</th>
<th>Post-Tuning Normalized NO\textsubscript{x}</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>100%</td>
<td>92%</td>
<td>-8%</td>
</tr>
<tr>
<td>80%</td>
<td>170%</td>
<td>78%</td>
<td>-92%</td>
</tr>
<tr>
<td>60%</td>
<td>193% to 285%</td>
<td>98%</td>
<td>-95% to -185%</td>
</tr>
<tr>
<td>40%</td>
<td>297%</td>
<td>219%</td>
<td>-78%</td>
</tr>
</tbody>
</table>

Normalized NO\textsubscript{x} = NO\textsubscript{x} as % of MCR NO\textsubscript{x}
KEY RESULTS – MEDIUM SIZED T-FIRED CASE HISTORY

- Dropping Mills from Service During Load Reductions Gives Lower NO\(_x\) Than Lightly Loaded Mills
- NO\(_x\) Formation is Sensitive to Operating O\(_2\) at Any Load
- Manual Control of the Burner Tilt Position Can Significantly Reduce NO\(_x\) at the Expense of Reheat Steam Temperature
- OFA Tuning Provides Many Options for Flow and Separation Distance Above the Fireball
- Windbox Pressure Can be a Significant OFA Constraint at Low Loads
- Advanced OFA Instrumentation Must be Maintained to Facilitate Periodic Boiler Tune-Ups
LARGE T-FIRED CASE HISTORY

• Low-Load Operating Variables
  ▪ Firing configuration – pulverizers out-of-service and location
  ▪ Overfire air flow (dampers percent open)
  ▪ Overfire air position (two SOFA levels, two dampers per level)

• Operating Constraints
  ▪ Steam temperatures
  ▪ CO emissions
  ▪ Slagging and fouling
TYPICAL OPERATING $O_2$ VARIATION WITH LOAD

Normalized Load, % of MCR

Operating $O_2$, % (wet)
VARIATION IN NO$_x$ EMISSIONS WITH OFA – 50% LOAD

![Graph showing variation in NO$_x$ emissions with OFA at 50% load.](image)

**Normalized NO$_x$, % of MCR**

- **Level H**
  - AF: 4, 4, 10, 20, 29, 20, 30, 30, 40
  - OFA Damper Position, % open: 200%
- **Level G**
  - AF: 26, 34, 11, 11, 11, 20, 30, 30, 40
  - OFA Damper Position, % open: 200%

- **Level H**
  - AF: 10, 10, 10, 10, 20, 30, 39, 31, 40
  - OFA Damper Position, % open: 200%
- **Level G**
  - AF: 10, 20, 30, 39, 10, 10, 10, 31, 40
  - OFA Damper Position, % open: 200%
STEAM TEMPERATURE VARIATIONS WITH FIRING CONFIGURATION – 50% LOAD

![Graph showing steam temperatures with different firing configurations.](image-url)

**E & F OOS**

**A & F OOS**

---

**Ferco**

35
KEY RESULTS – LARGE T-FIRED CASE HISTORY

50% Load

- Opening Both OFA Dampers to 40% Dropped the Normalized NO\textsubscript{x} from 162% to 77% of Baseline, Full-Load NO\textsubscript{x}

- Lowest Low-Load NO\textsubscript{x} Emissions Obtained with Top Two Mills Out-of-Service

- NO\textsubscript{x} Emissions with a Top and Bottom Mill Out-of-Service Dropped from 191% to 106% of Baseline Full-Load NO\textsubscript{x}
50% Load

• Operation with 40% Open OFA Damper, E & F OOS, Increased Superheat Steam Temperature from 980°F to 1005°F. Reheat Temperature from 911°F to 954°F

• Operation with 40% Open OFA Dampers Had Minimal Impact on Superheat and Reheat Temperatures with A & F Mills OOS
VARIATION IN NO$_x$ EMISSIONS WITH OFA – 67% LOAD

**E & F OOS**

Normalized NO$_x$, % of MCR

<table>
<thead>
<tr>
<th>Level H</th>
<th>AF</th>
<th>40</th>
<th>40</th>
<th>40</th>
<th>40</th>
<th>60</th>
<th>70</th>
<th>79</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level G</td>
<td>AF</td>
<td>40</td>
<td>61</td>
<td>71</td>
<td>79</td>
<td>41</td>
<td>40</td>
<td>41</td>
<td>60</td>
</tr>
</tbody>
</table>

OFA Damper Position, % open

**A & F OOS**

Normalized NO$_x$, % of MCR

<table>
<thead>
<tr>
<th>Level H</th>
<th>AF</th>
<th>39</th>
<th>40</th>
<th>60</th>
<th>79</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level G</td>
<td>AF</td>
<td>41</td>
<td>79</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>
STEAM TEMPERATURE VARIATIONS WITH FIRING CONFIGURATION – 67% LOAD

![Graph showing steam temperatures and OFA damper positions for E & F OOS and A & F OOS configurations.](image)
KEY RESULTS – LARGE T-FIRED CASE HISTORY

67% Load

- Opening Both OFA Dampers to 60% Dropped the Normalized NO\textsubscript{x} from 149% to 75% of Baseline Full-Load NO\textsubscript{x}

- Lowest Low-Load NO\textsubscript{x} Emissions Obtained with Top Two Mills Out-of-Service

- NO\textsubscript{x} Emissions with a Top and Bottom Mill Out-of-Service Dropped from 175% to 95% of Baseline Full-Load NO\textsubscript{x}

- Operation with 60% Open OFA Damper, E & F OOS, Increased Superheat Steam Temperature from 980°F to 1005°F. Reheat Temperature Increased from 946°F to 980°F
67% Load

• Operation with 60% Open OFA Dampers Produced a 10 to 25 Degree Improvement in Superheat and Reheat Temperatures with A & F Mills OOS
AS-FOUND VS. TUNED NO\textsubscript{x} EMISSIONS VARIATION WITH LOAD – LARGE T-FIRED

[Graph showing normalized NO\textsubscript{x} emissions variation with load for as-found and tuned conditions.]

- **Normalized Load % of MCR**
  - 40%
  - 50%
  - 60%
  - 70%
  - 80%
  - 90%
  - 100%

- **Normalized NO\textsubscript{x}, % of MCR NO\textsubscript{x}**
  - 0%
  - 50%
  - 100%
  - 150%
  - 200%
  - 250%

- As-found
- Tuned
## SUMMARY OF NO\textsubscript{x} REDUCTION POTENTIAL – LARGE T-FIRED

<table>
<thead>
<tr>
<th>Load, % MCR</th>
<th>Baseline Normalized NO\textsubscript{x}</th>
<th>Post-Tuning Normalized NO\textsubscript{x}</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>100%</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>80%</td>
<td>120% to 123%</td>
<td>88% to 90%</td>
<td>-32% to -33%</td>
</tr>
<tr>
<td>60%</td>
<td>149% to 170%</td>
<td>75%</td>
<td>-74% to -95%</td>
</tr>
<tr>
<td>40%</td>
<td>162% to 191%</td>
<td>77% to 106%</td>
<td>-85%</td>
</tr>
</tbody>
</table>

Normalized NO\textsubscript{x} = NO\textsubscript{x} as % of MCR NO\textsubscript{x}
CONCLUSIONS

• Boiler Tuning to Achieve Efficient Uniform Low $O_2$ Combustion is the First Step in NO$_x$ Control

• Tangentially-Fired Boilers Often Have High $O_2$ Levels at Reduced Loads (below 70% MCR)

• More Frequent Reduced Load Operation has Forced Utilities to Examine and Tune for Lower NO$_x$ Emissions

• Boiler Tuning to Optimize NO$_x$ Emissions Previously Was Not Allowed to Impact Boiler Thermal Performance but that Might be Changing

• Operation with Fewer Mills In Service Gives Lower NO$_x$ than Operation with More Lightly Loaded Mills
CONCLUSIONS (continued)

- Some Medium and Large T-Fired Units Can Have Baseline Low Load Normalized NO\textsubscript{x} Emissions that are 200\% to 300\% of MCR NO\textsubscript{x}

- Reduced Load Boiler Tuning Can Reduce NO\textsubscript{x} Emissions by 90\% to 185\% of MCR NO\textsubscript{x} at Loads Below 70\%

- The Increased Use of OFA at Low Loads Can Reduce NO\textsubscript{x}, Improve Steam Temperatures and Reduce CO Emissions

- Windbox Pressure Constraints Limit OFA Use at Low Loads on Some Units

- Manual Constraint of Burner Tilt Position Can Significantly Reduce NO\textsubscript{x} Emissions, Even on Small Units with Limited OFA
• The Decision to Take a Mill Out-of-Service May be Dictated by the ISO and Other System Generation Sources

• Frequent Nightly Load Swings May Exceed the Number of Allowable Mill Restarts

• Variability in Coal Quality and Coal Blend Consistency Must be Considered (Post-Tuning NO\textsubscript{x} May Not Hold)

• Test Engineers Can Define Low NO\textsubscript{x} Firing Options but Plant Operations, Engineering, and Management Must Decide When and How Low to Go

• Every Unit, Even Sister Units, Often Operate Differently
CONCLUSIONS (continued)

- No “Cookie Cutter” Strategy for Reduced Load NO\textsubscript{x} Control Can be Universally Applied

- Every Boiler Has to be Custom Tuned to Take Maximum Advantage of its NO\textsubscript{x} Reduction Capability

- Maintenance of Plant Process Instrumentation is CRITICAL