# $NO_x$ Control in a Reduced Load Environment

Presented by:

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# *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 $NO_x$ EMISSIONS IMPACTS*

- **Reduced Boiler Efficiency, Higher Net Heat Rate**
- **Increased Fuel Use per Megawatt of Electricity Generated**
- **Higher Excess Air or Operating $O_2$ 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 $NO_x$ Control at Full Load Lose Effectiveness at Reduced Loads**
- **$NO_x$ Emissions from Some Boiler Types are More Sensitive to Low-Load Operation**
- **Decisions Regarding When to Take Pulverizers Out-of-Service Can Impact $NO_x$ 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 $NO_x$ Controls or Any Post-Combustion $NO_x$ Controls**

- **Often Have Very Attractive Full-Load $NO_x$ Emission Rates but Unusually High Low-Load $NO_x$ 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 $NO_x$ 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**

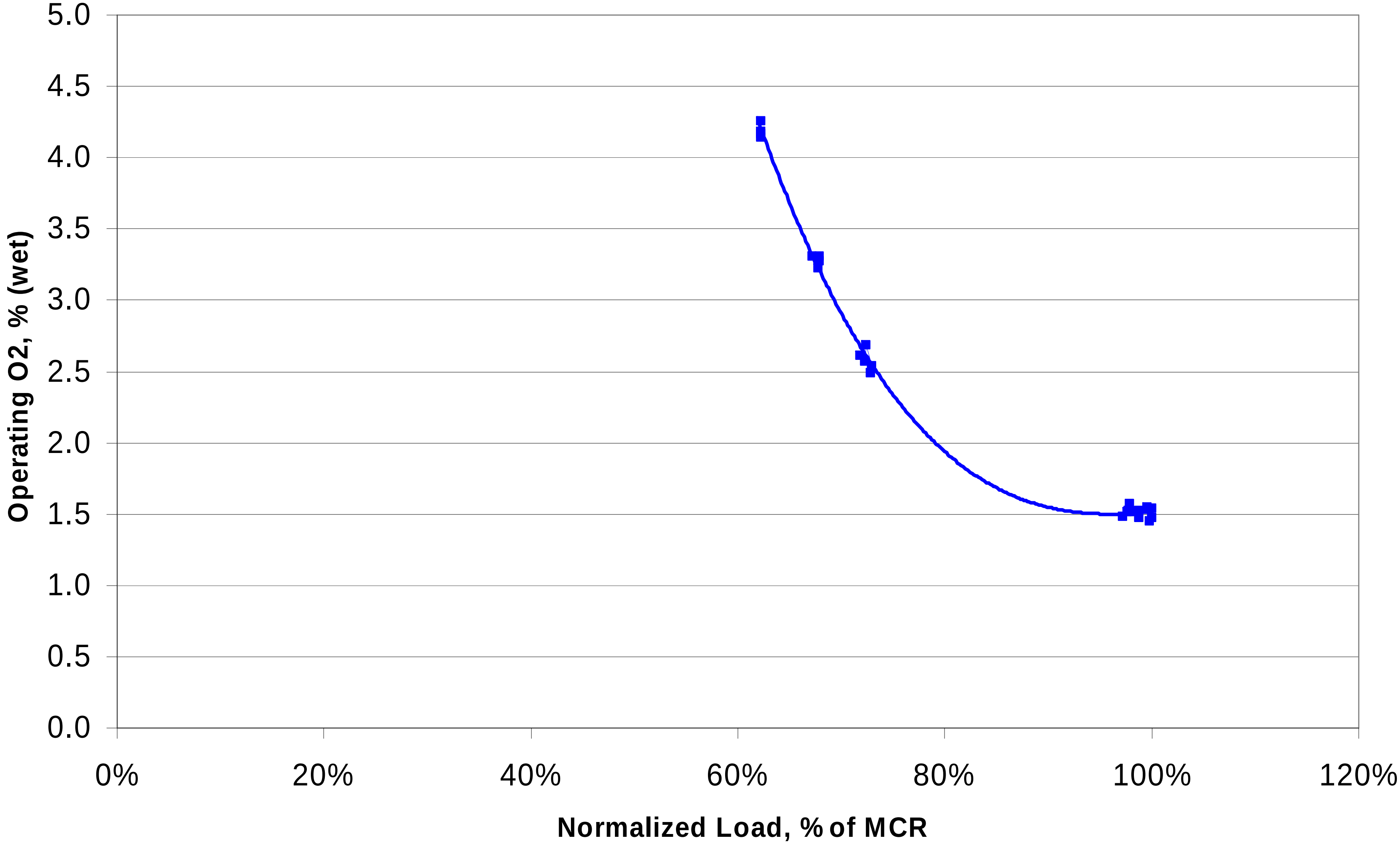
# *SMALL T-FIRED CASE HISTORY*

- **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**

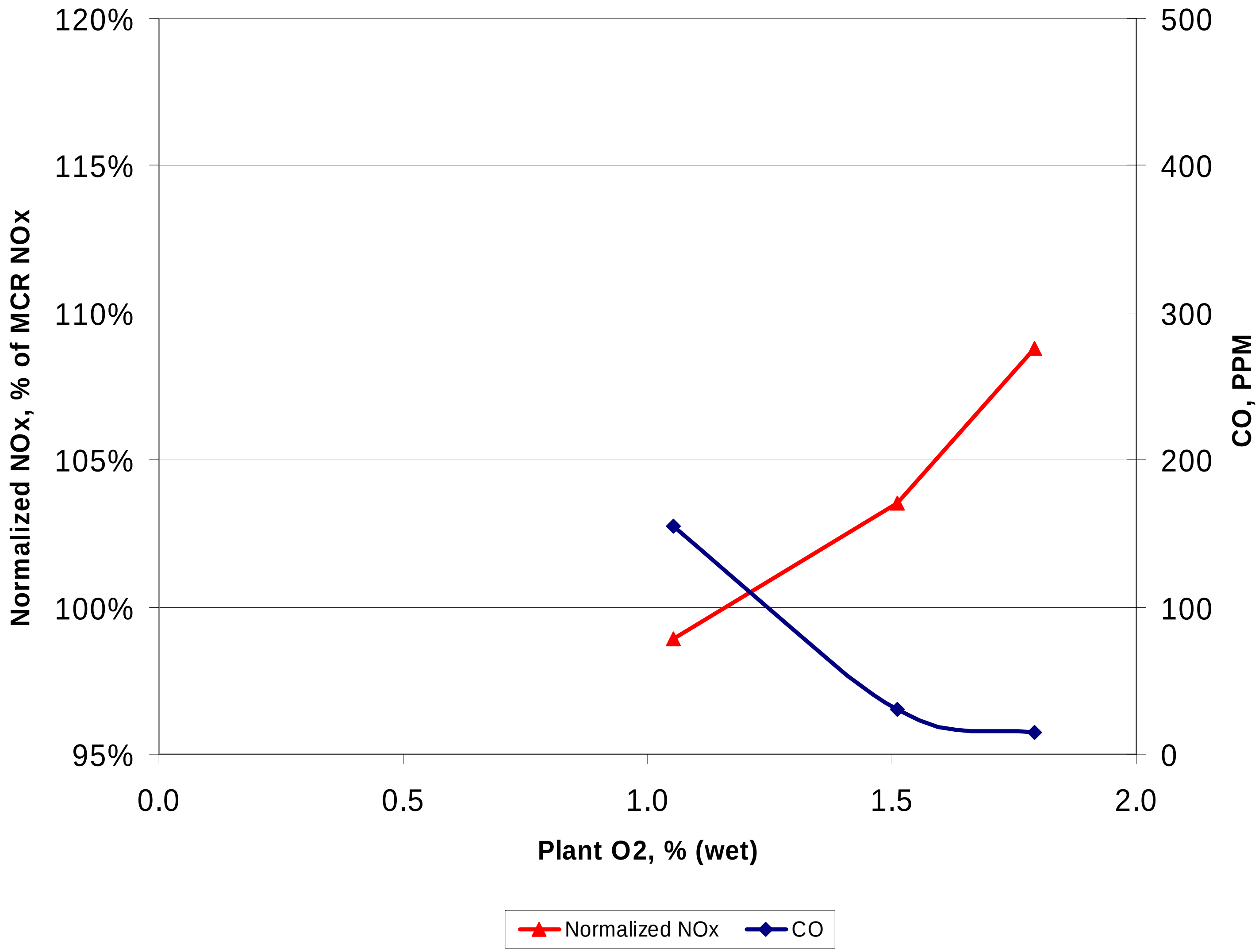
# *SMALL T-FIRED CASE HISTORIES (continued)*

- **Operating Constraints**
  - **Steam temperatures**
  - **CO emissions**
  - **Frequency of changing mill OOS**
  - **System load response requirements**
  - **Mill restarts**

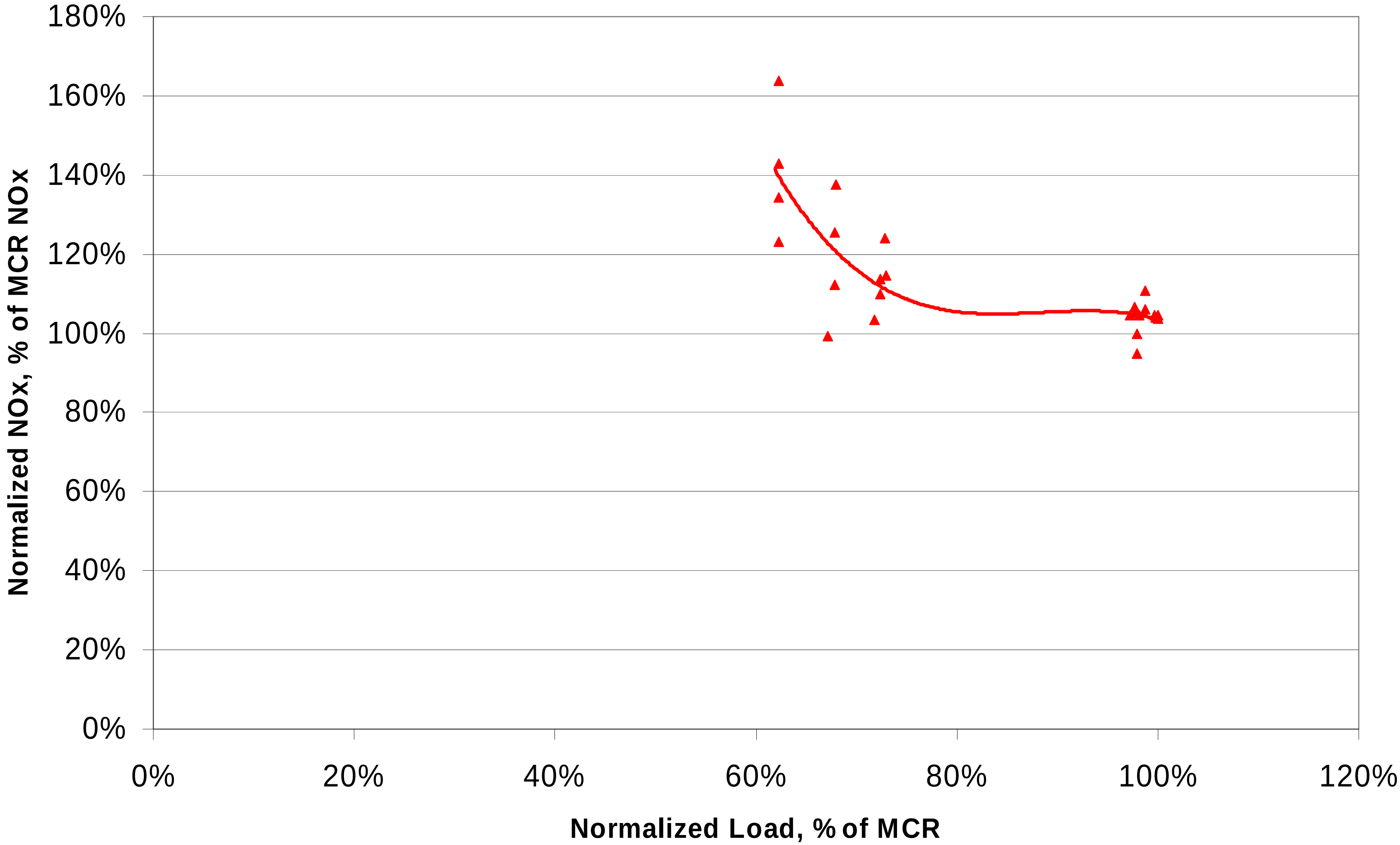
# *TYPICAL OPERATING $O_2$ VARIATION WITH LOAD*



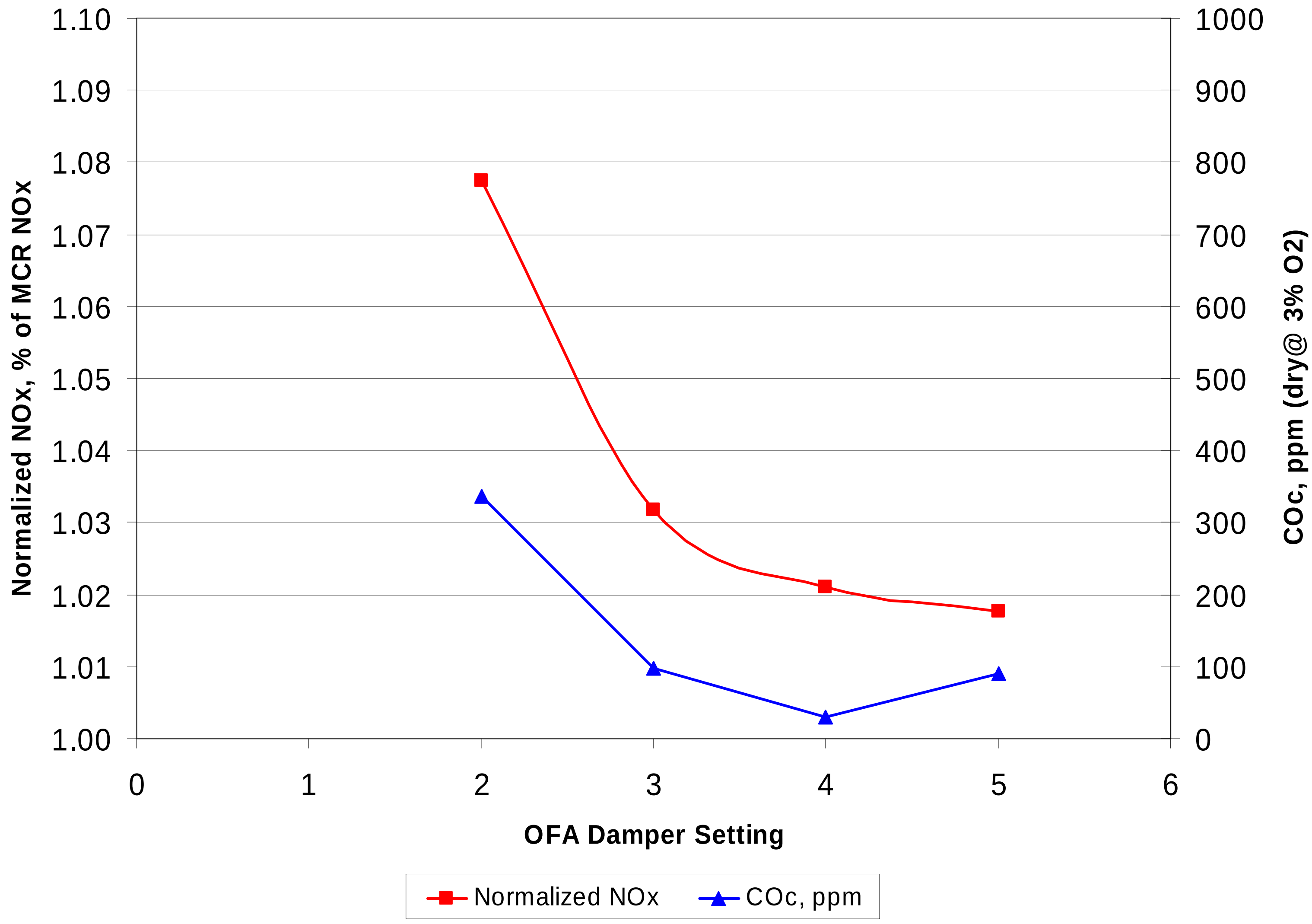
# *NORMALIZED $NO_x$ AND CO VS. PLANT SET POINT $O_2$ AT FULL-LOAD*



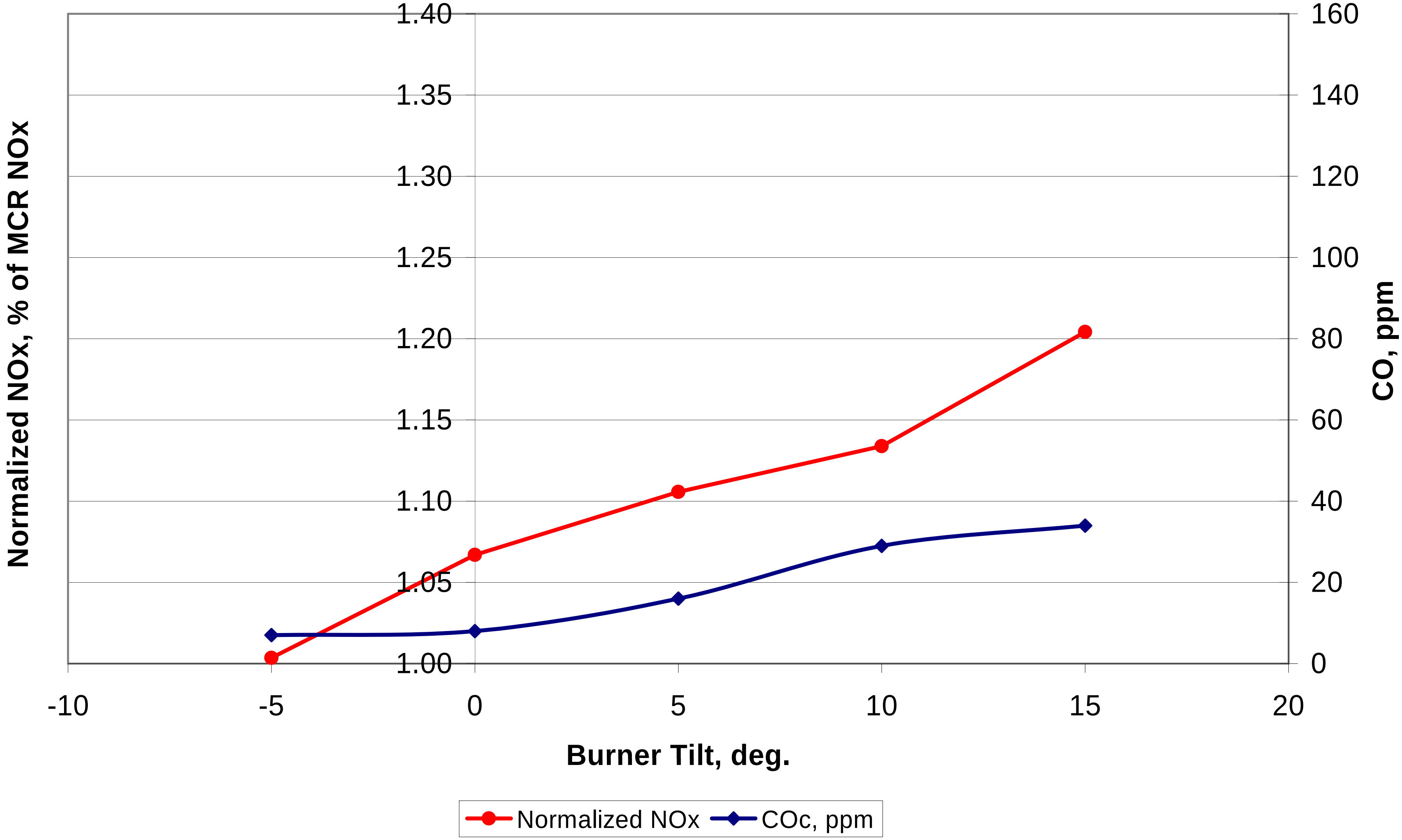
# $NO_x$ VS LOAD AT NORMAL $O_2$ – SMALL T-FIRED



# *NORMALIZED $NO_x$ AND CO VS OFA AT FULL-LOAD*



# *NORMALIZED $NO_x$ VS BURNER TILT – 72% LOAD*

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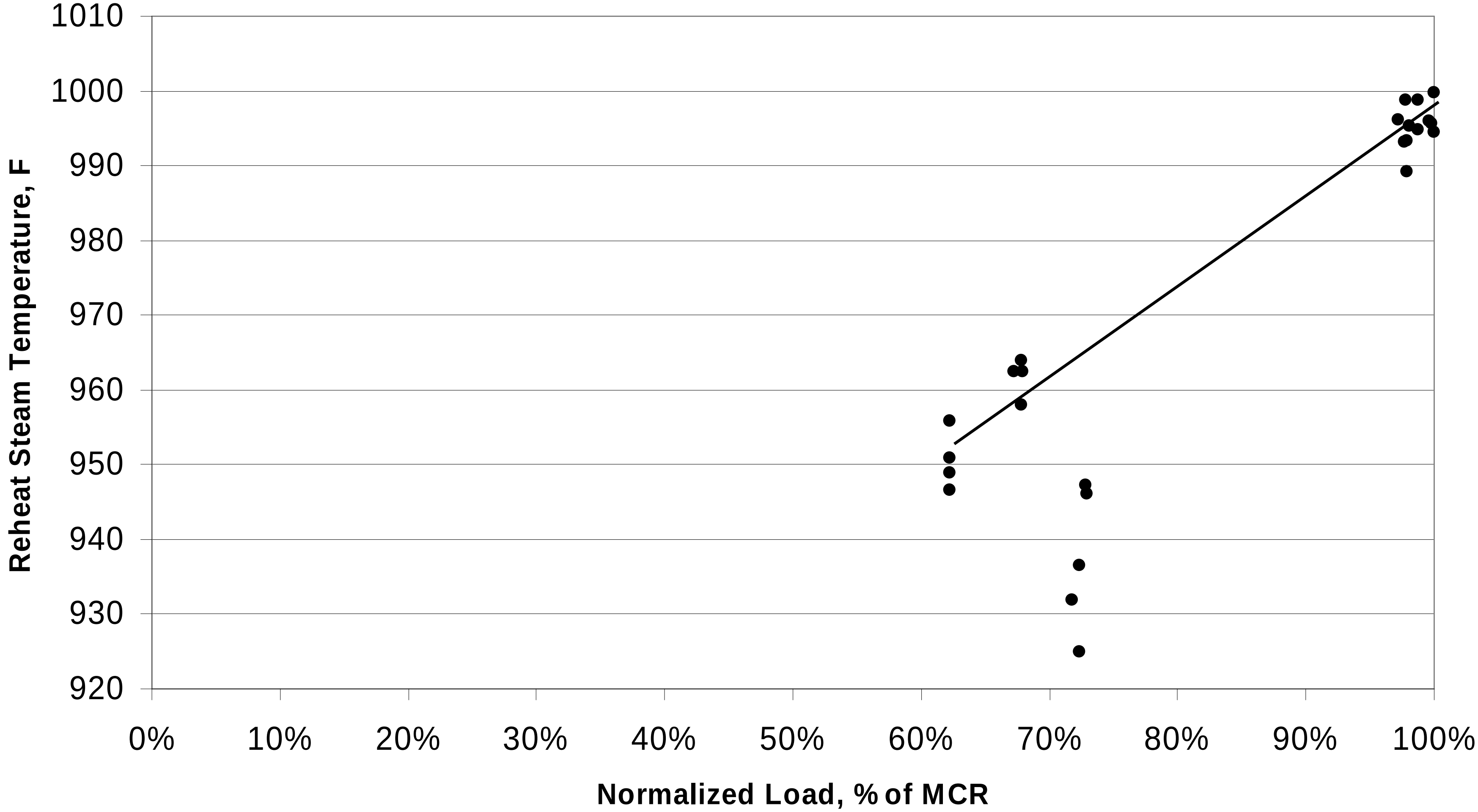
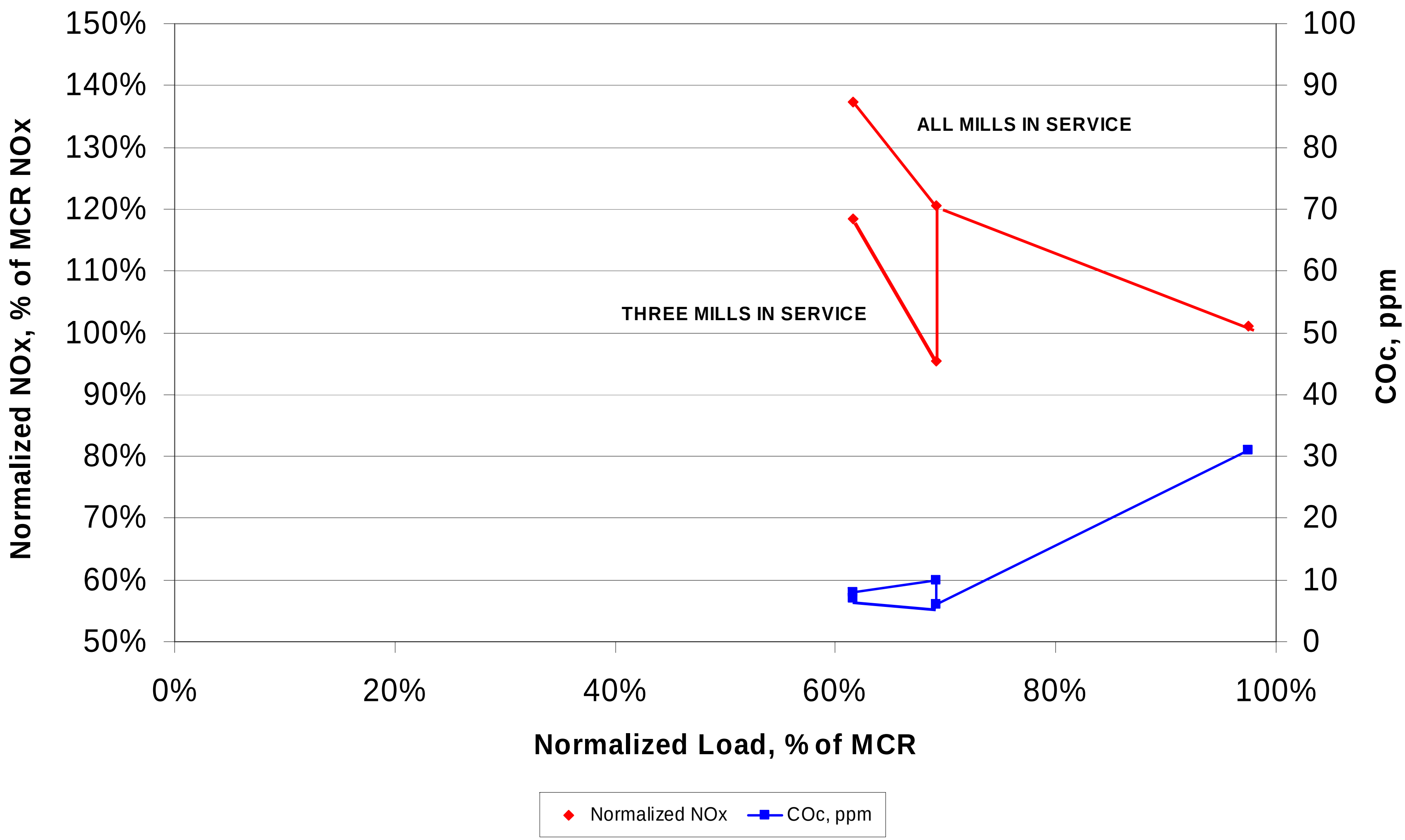
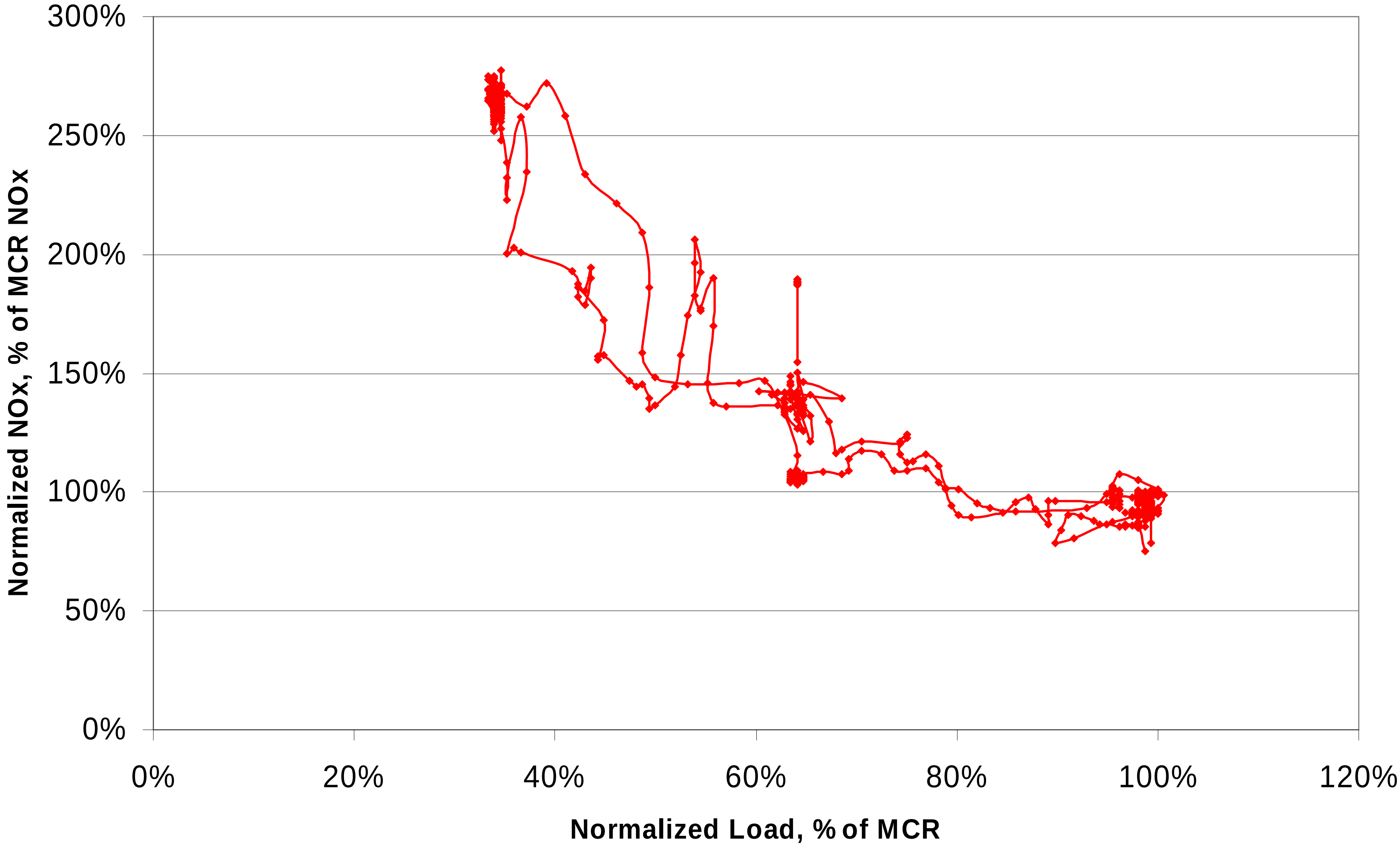
# *REHEAT STEAM TEMPERATURE VS LOAD*
# *MANUAL BURNER TILT AT 72% LOAD*



# *NORMALIZED $NO_x$ AND CO VS LOAD – SMALL T-FIRED*



# *NORMALIZED $NO_x$ 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 $NO_x$ Emissions at 60% MCR Can Exceed Full-Load MCR $NO_x$ by 65% or More but it Can be Reduced to Only 18%**
- **Operation with One Mill Out-of-Service, 80% Open OFA Damper, Low $O_2$, and -10° Burner Tilt Position Minimized Low Load $NO_x$ for this Unit**
- **It May be Necessary to Sacrifice Boiler Thermal Performance (Reheat Steam Temperatures as Low as 930°F) for Minimum $NO_x$**
- **Test Engineers Can Define Low $NO_x$ Firing Options but Plant Operations and Management Must Decide When and How Low to Go**

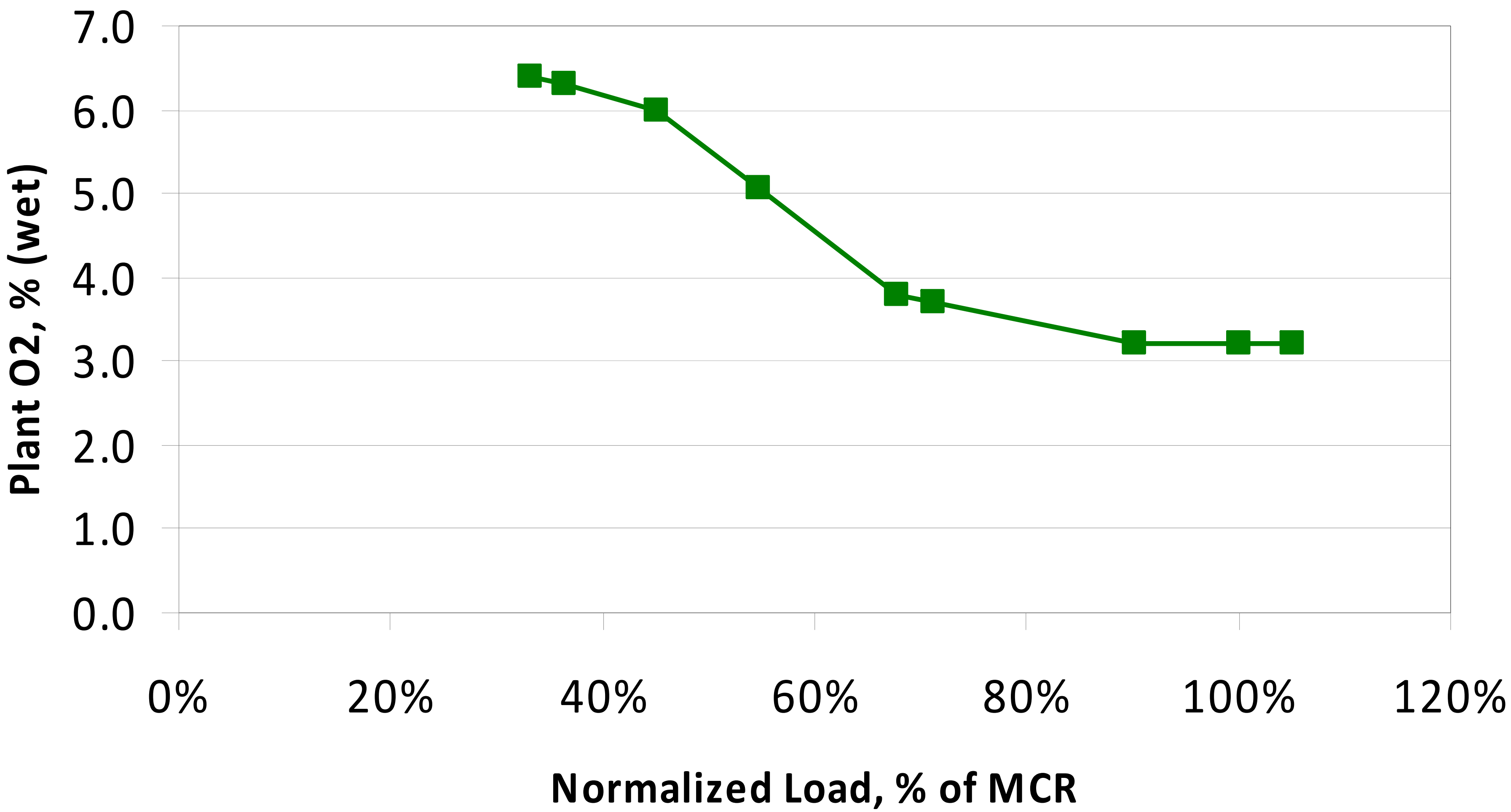
# *MEDIUM SIZED T-FIRED CASE HISTORY*

- **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)**

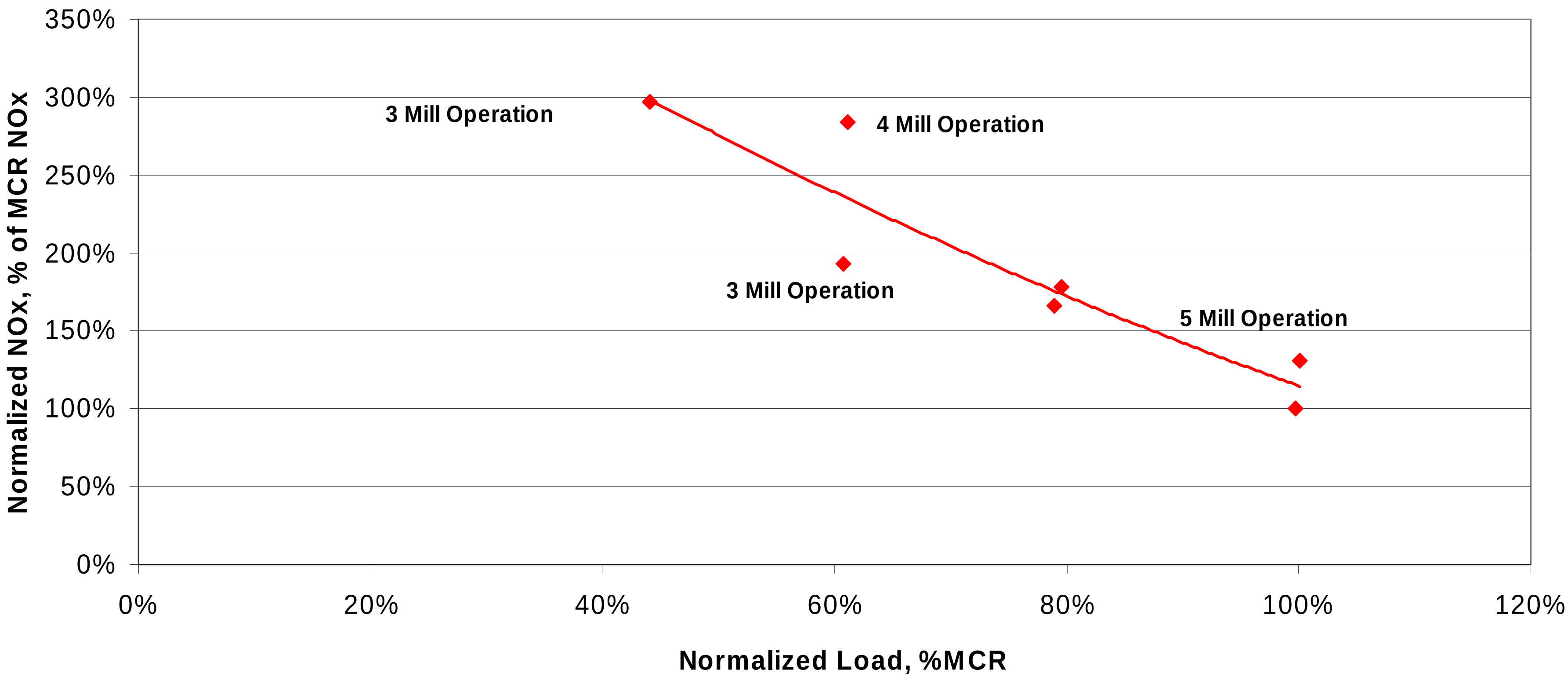
# *MEDIUM SIZED T-FIRED CASE HISTORY (continued)*

- **Operating Constraints**
  - **Steam temperatures**
  - **CO emissions**
  - **Windbox pressure**
  - **Furnace water wall corrosion**
  - **Instrumentation**

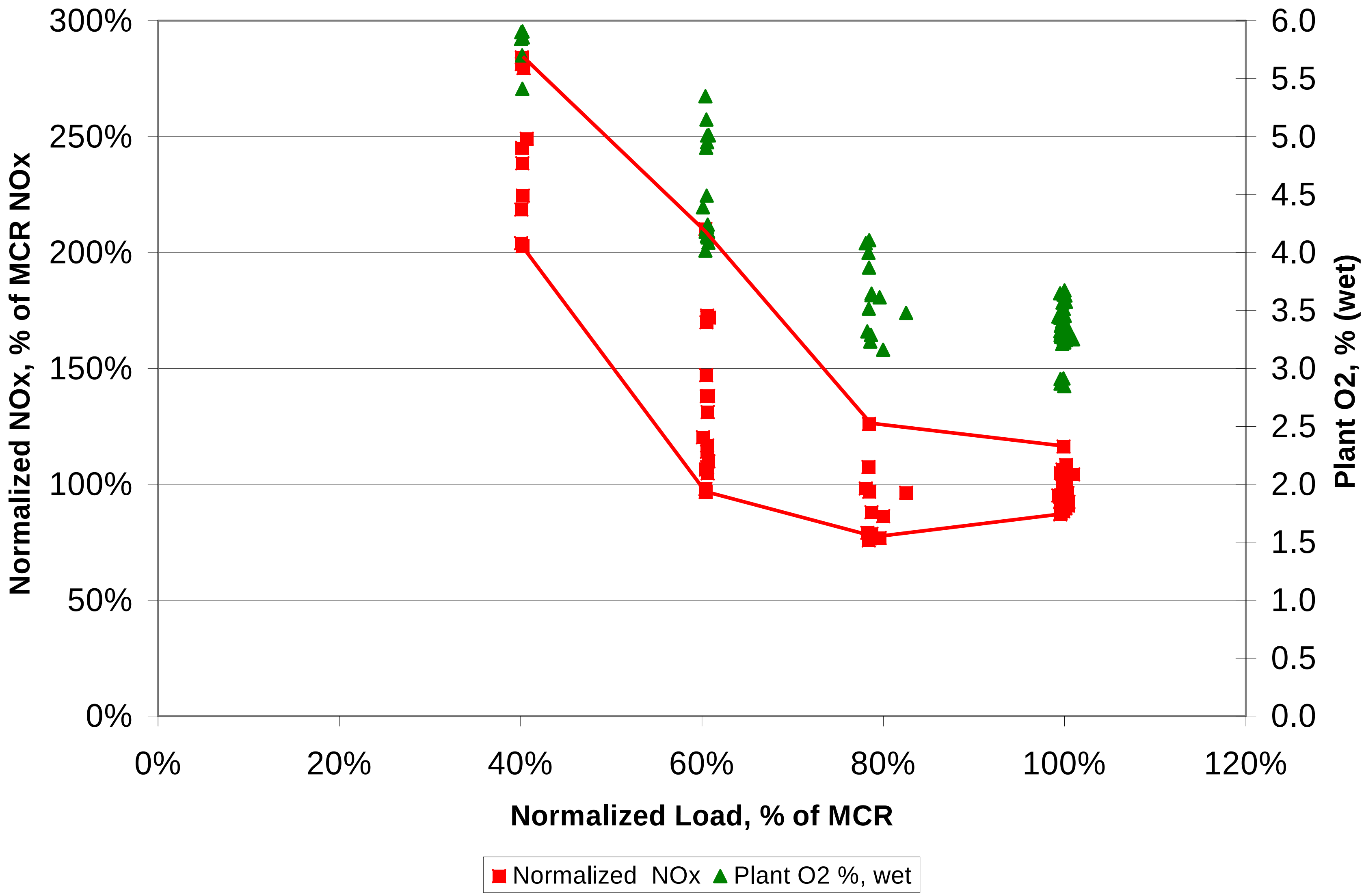
# *ORIGINAL $O_2$ VARIATION WITH LOAD*



# *BASELINE $NO_x$ EMISSIONS VARIATION WITH LOAD*



# *RANGE OF $O_2$ AND $NO_x$ EMISSIONS DURING PARAMETRIC TESTS*

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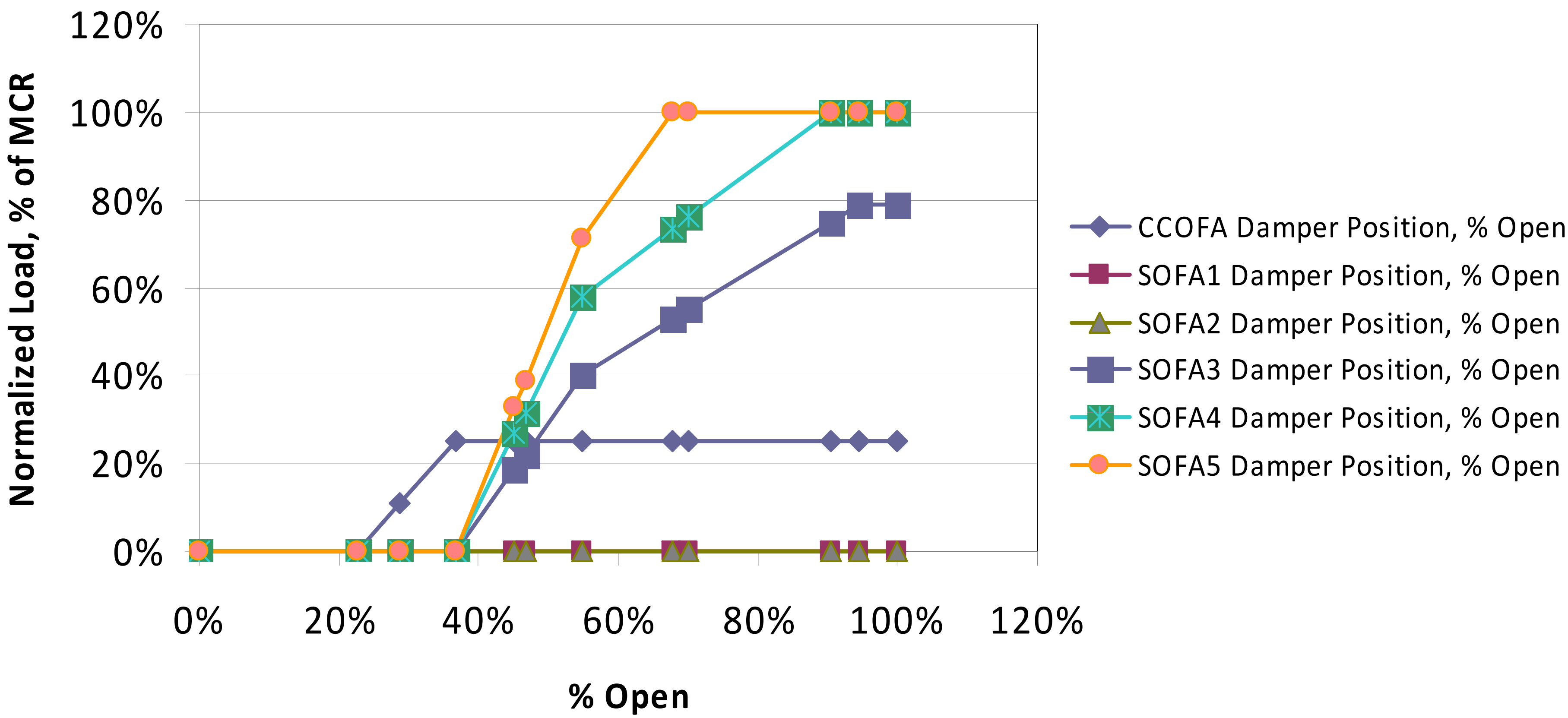
# *OFA TUNING INVOLVES MANY OPTIONS*

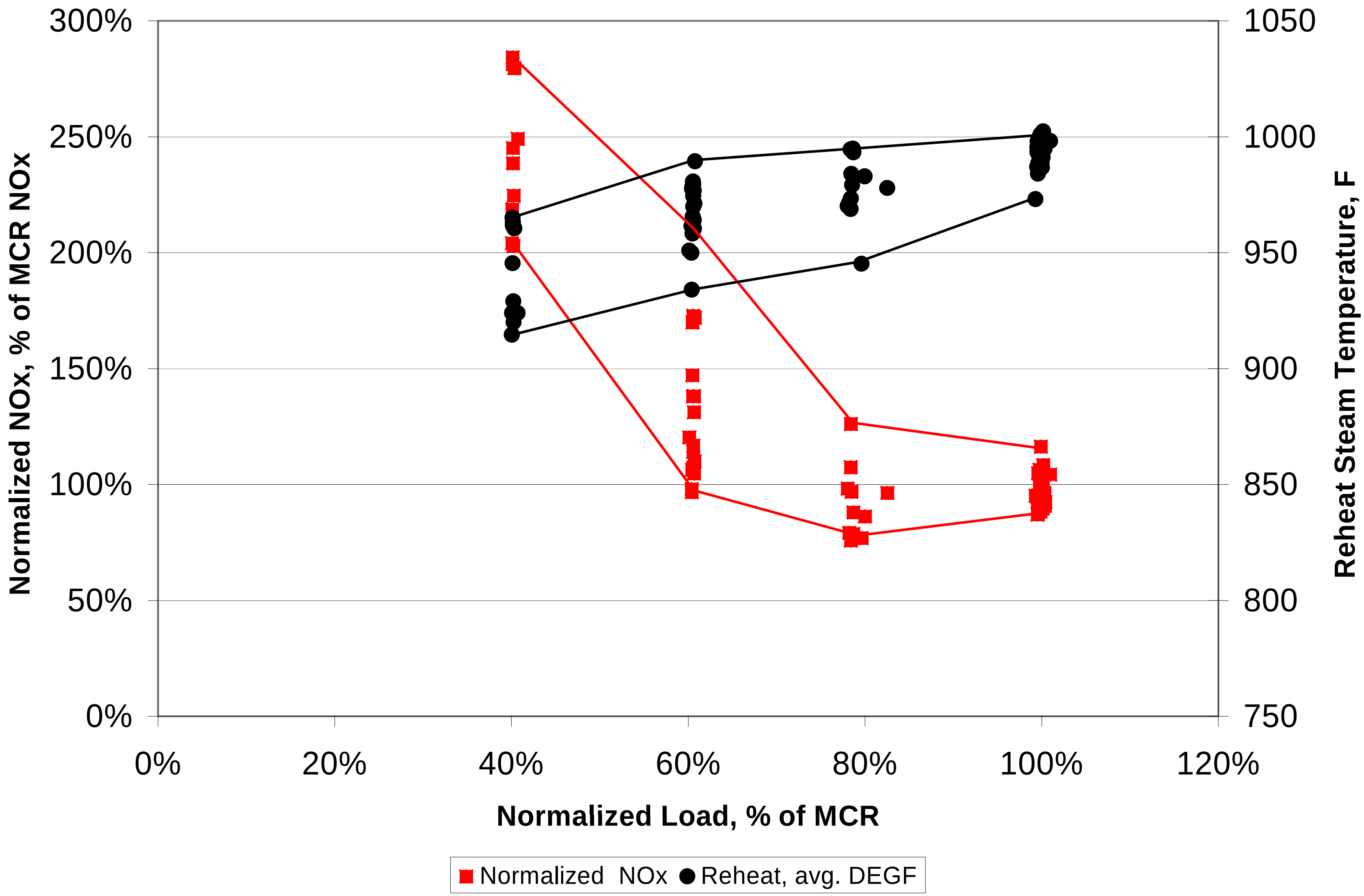


# *MEDIUM T-FIRED – RECOMMENDED INTERIM FIRING PRACTICE*

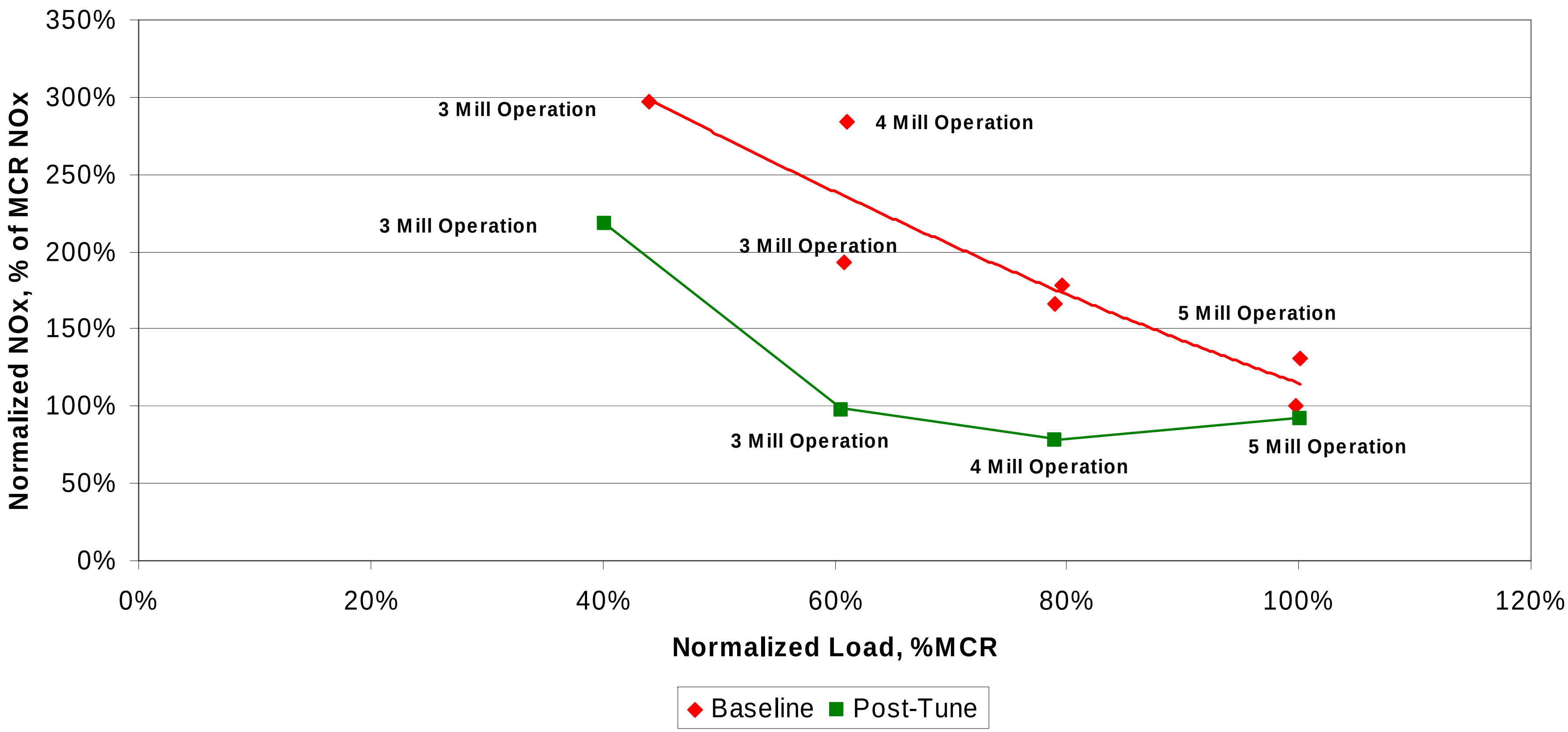
| Load | Mills OOS | Operating $O_2$, % | Burner Tilts, deg | OFA Damper, % Open | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | CCOFA | SOFA 1 | SOFA 2 | SOFA 3 | SOFA 4 | SOFA 5 |
| 100% | None | 3.2 | -5 | 25 | 0 | 0 | 75 | 100 | 100 |
| 80% | One | 3.2 | 0 | 25 | 0 | 0 | 55 | 78 | 100 |
| 60% | Two | 4.1 | +5 | 25 | 0 | 0 | 40 | 58 | 71 |
| 40% | Two | 5.8 | +3 | 25 | 0 | 0 | 0 | 0 | 0 |

**SOFA Tilts = +10 deg manual**

# $NO_x$ EMISSIONS AND REHEAT STEAM TEMPERATURE RELATIONSHIPS



# COMPARISON OF BASELINE AND POST-TUNE $NO_x$ EMISSIONS



# *SUMMARY OF $NO_x$ REDUCTION POTENTIAL – MEDIUM SIZE T-FIRED*

| Load, % MCR | Baseline Normalized $NO_x$ | Post-Tuning Normalized $NO_x$ | Improvement |
|---|---|---|---|
| **100%** | **100%** | **92%** | **-8%** |
| **80%** | **170%** | **78%** | **-92%** |
| **60%** | **193% to 285%** | **98%** | **-95% to -185%** |
| **40%** | **297%** | **219%** | **-78%** |

Normalized $NO_x$ = $NO_x$ as % of MCR $NO_x$

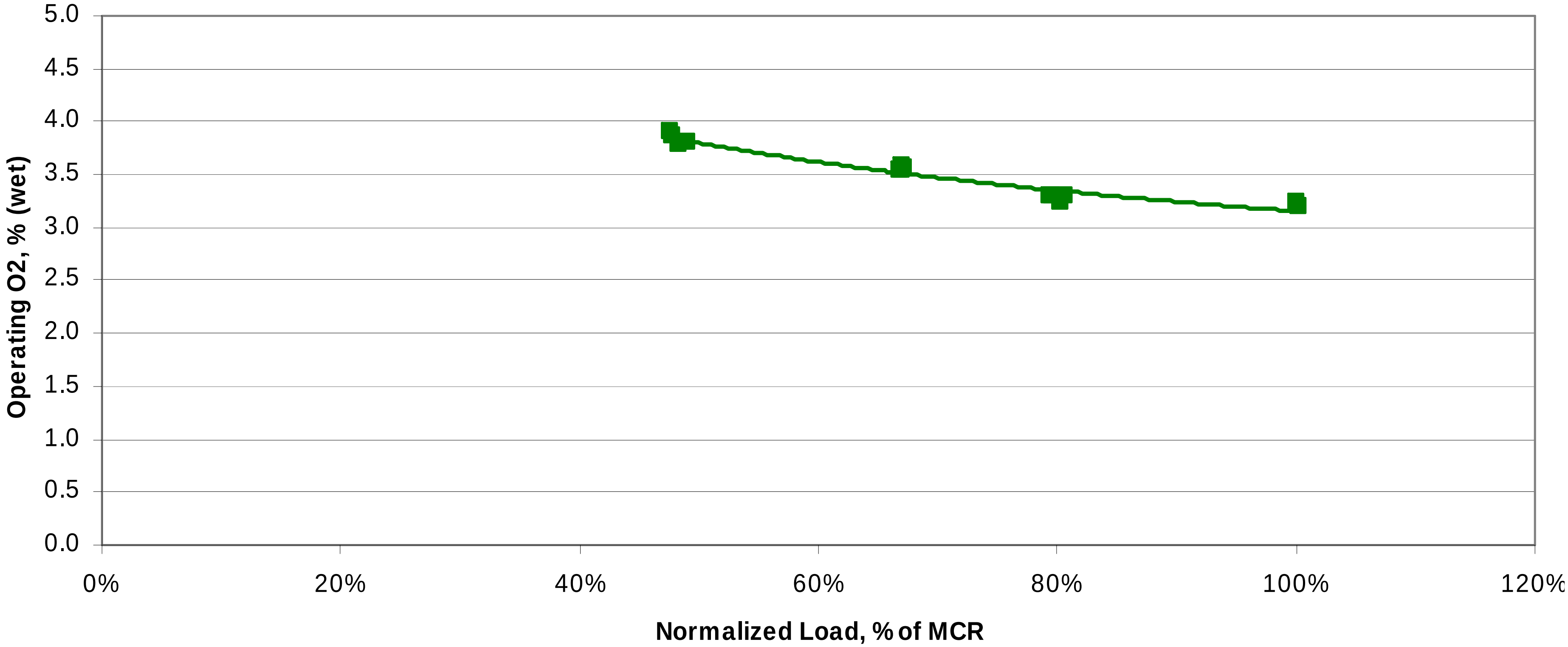
# *KEY RESULTS – MEDIUM SIZED T-FIRED CASE HISTORY*

- **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**

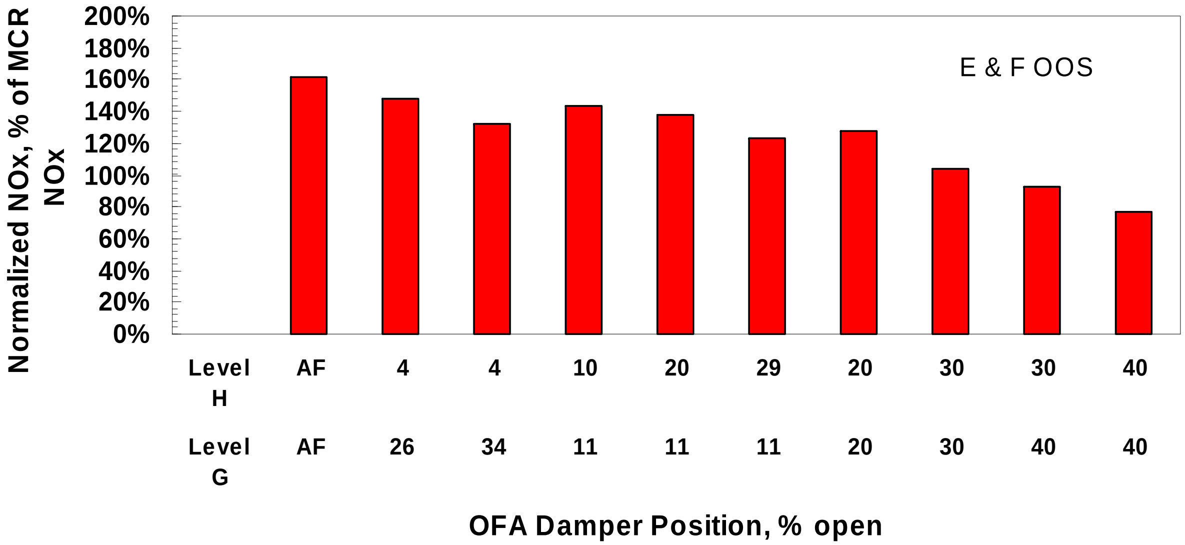
# *LARGE T-FIRED CASE HISTORY*

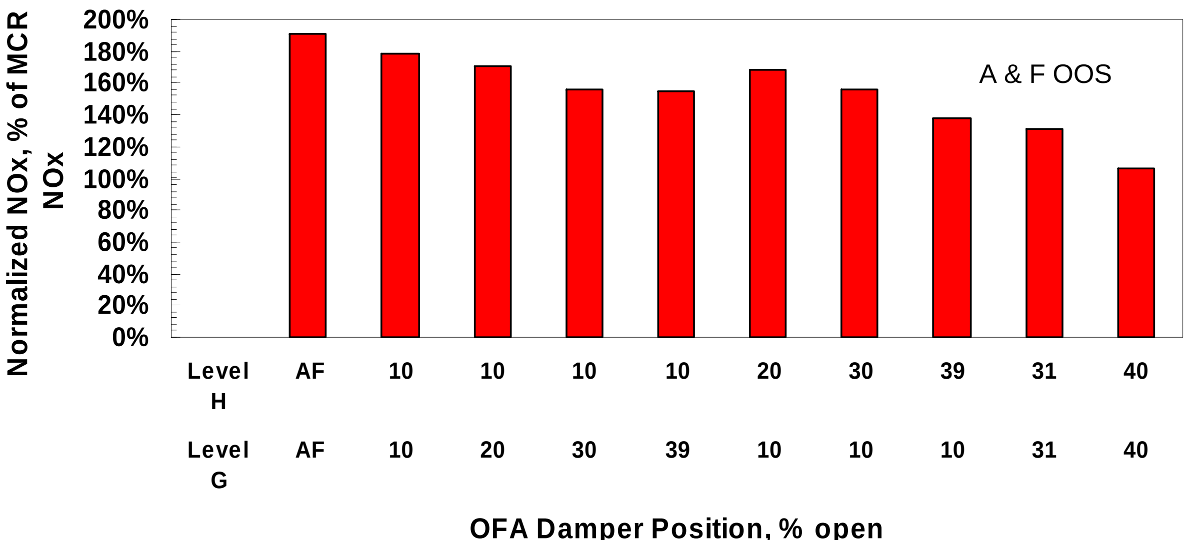
- **Low-Load Operating Variables**
  - **Firing configuration – pulverizers out-of-service and location**
  - **Overfire air flow (dampers percent open)**
  - **Overfire air position (two SOFA levels, two dampers per level)**
- **Operating Constraints**
  - **Steam temperatures**
  - **CO emissions**
  - **Slagging and fouling**

# *TYPICAL OPERATING $O_2$ VARIATION WITH LOAD*



# VARIATION IN $NO_x$ EMISSIONS WITH OFA – 50% LOAD

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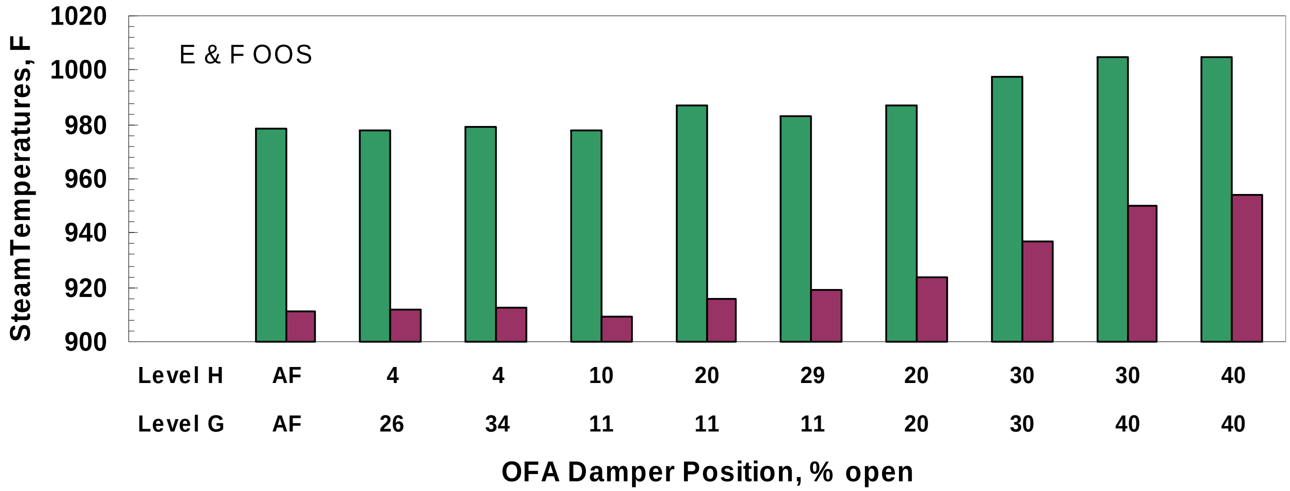
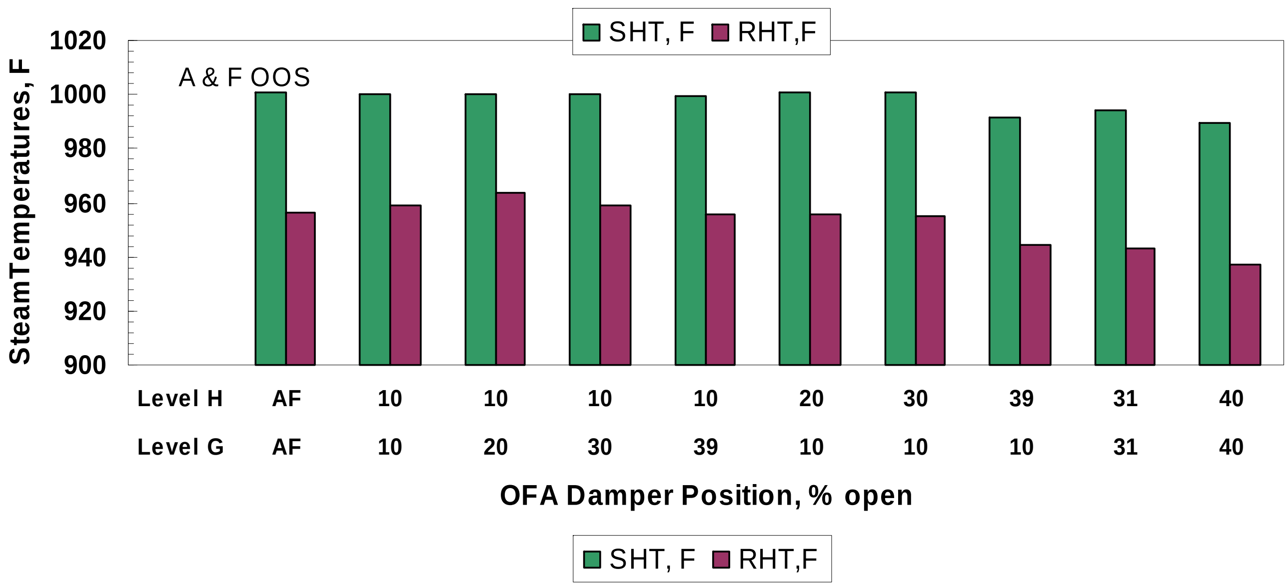
# *STEAM TEMPERATURE VARIATIONS WITH FIRING CONFIGURATION – 50% LOAD*

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# *KEY RESULTS – LARGE T-FIRED CASE HISTORY*

**50% Load**

- **Opening Both OFA Dampers to 40% Dropped the Normalized $NO_x$ from 162% to 77% of Baseline, Full-Load $NO_x$**
- **Lowest Low-Load $NO_x$ Emissions Obtained with Top Two Mills Out-of-Service**
- **$NO_x$ Emissions with a Top and Bottom Mill Out-of-Service Dropped from 191% to 106% of Baseline Full-Load $NO_x$**

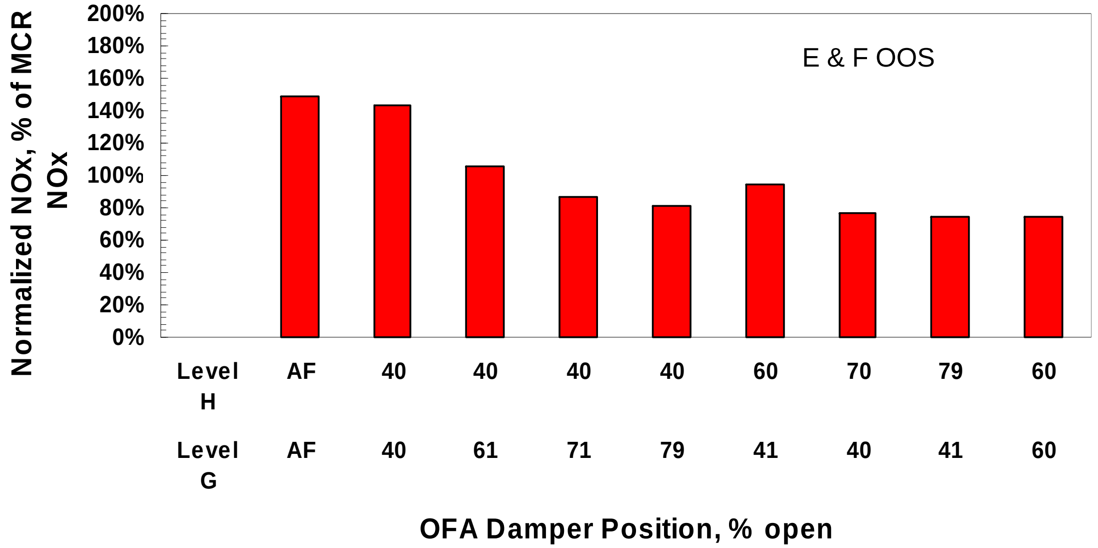
# *KEY RESULTS – LARGE T-FIRED CASE HISTORY (continued)*

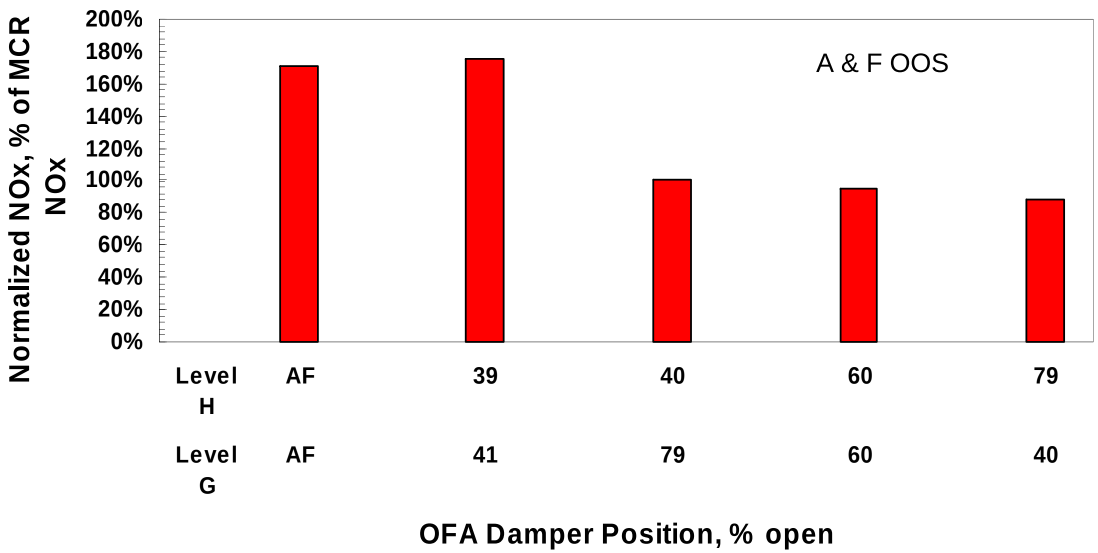
**50% Load**

- **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*

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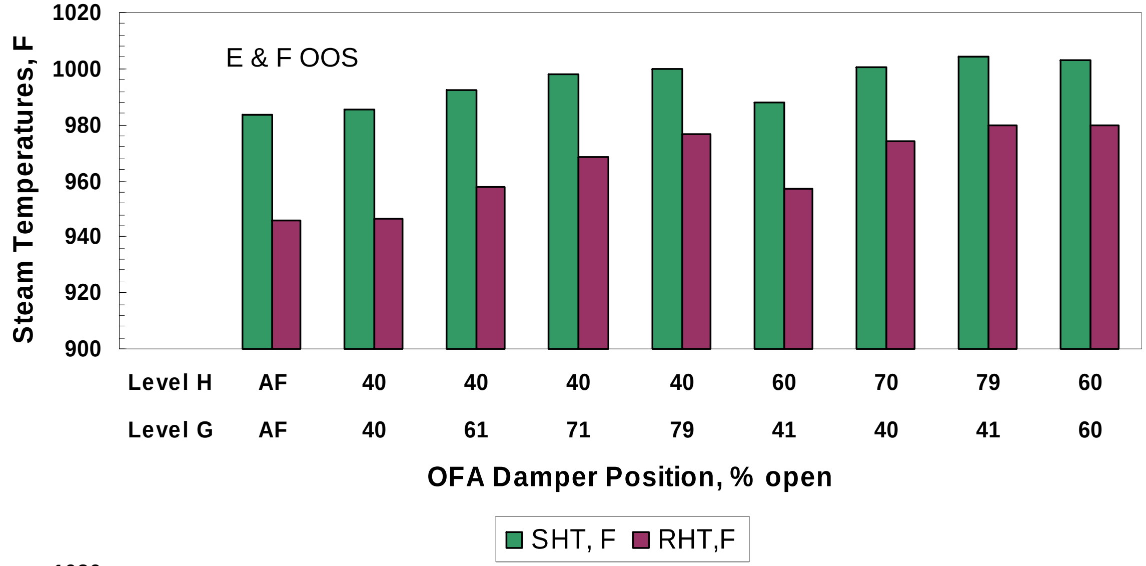
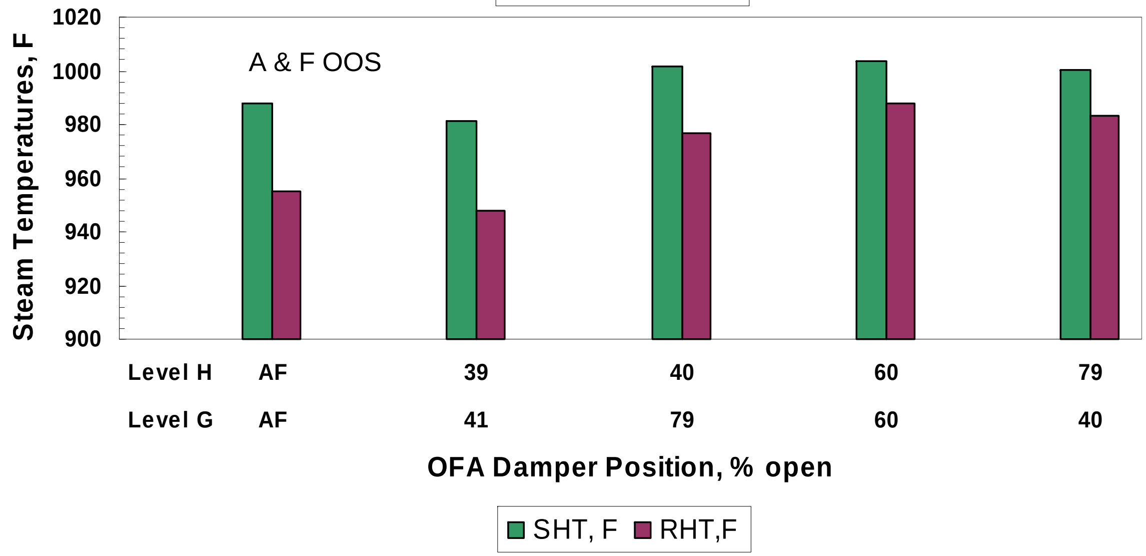
# *STEAM TEMPERATURE VARIATIONS WITH FIRING CONFIGURATION – 67% LOAD*

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# *KEY RESULTS – LARGE T-FIRED CASE HISTORY*

**67% Load**

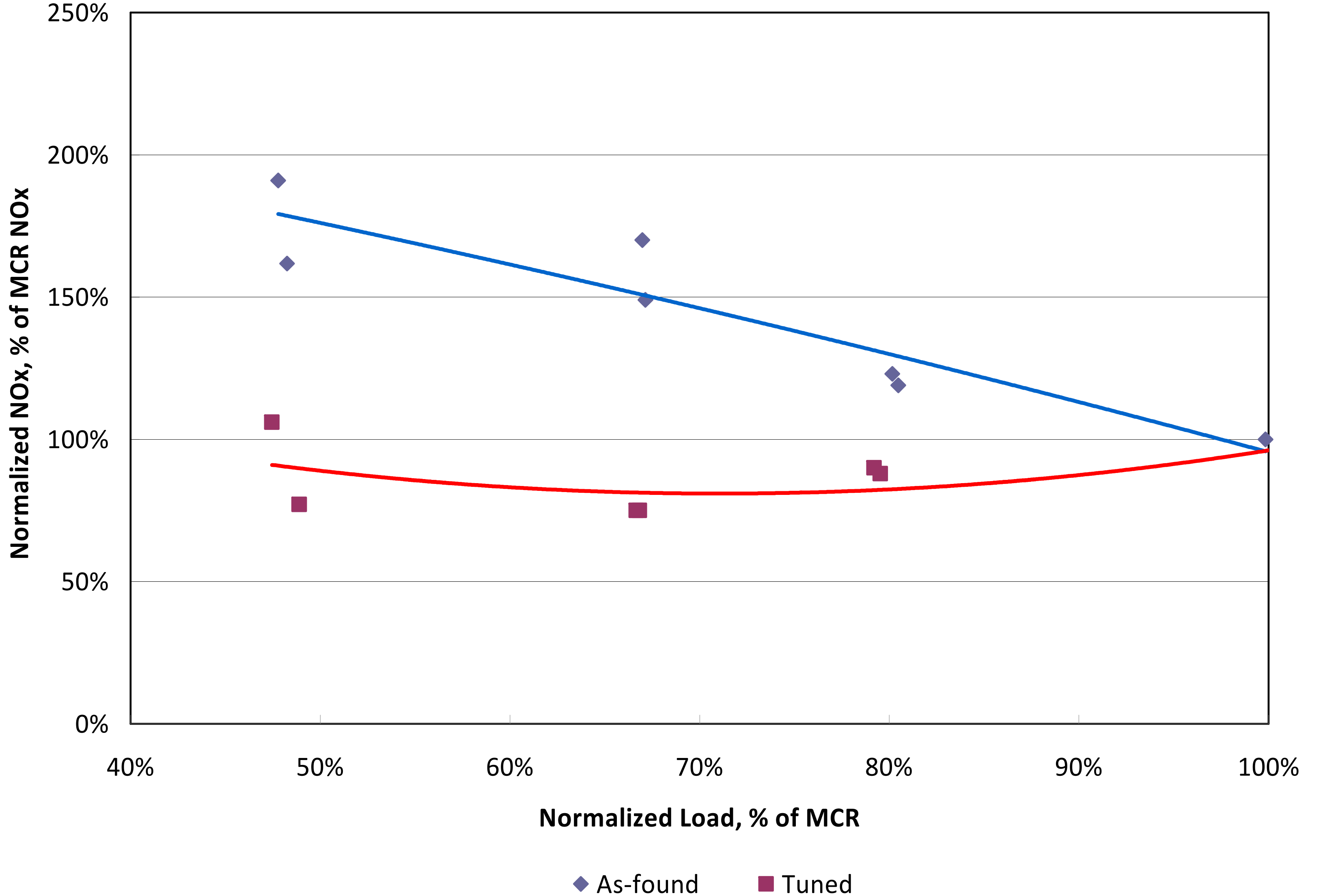
- **Opening Both OFA Dampers to 60% Dropped the Normalized $NO_x$ from 149% to 75% of Baseline Full-Load $NO_x$**
- **Lowest Low-Load $NO_x$ Emissions Obtained with Top Two Mills Out-of-Service**
- **$NO_x$ Emissions with a Top and Bottom Mill Out-of-Service Dropped from 175% to 95% of Baseline Full-Load $NO_x$**
- **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**

# *KEY RESULTS – LARGE T-FIRED CASE HISTORY (continued)*

**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 $NO_x$ EMISSIONS VARIATION WITH LOAD – LARGE T-FIRED*



# *SUMMARY OF $NO_x$ REDUCTION POTENTIAL – LARGE T-FIRED*

| Load, % MCR | Baseline Normalized $NO_x$ | Post-Tuning Normalized $NO_x$ | Improvement |
|---|---|---|---|
| 100% | 100% | --- | --- |
| 80% | 120% to 123% | 88% to 90% | -32% to -33% |
| 60% | 149% to 170% | 75% | -74% to -95% |
| 40% | 162% to 191% | 77% to 106% | -85% |

Normalized $NO_x$ = $NO_x$ as % of MCR $NO_x$

# *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 $NO_x$ Emissions that are 200% to 300% of MCR $NO_x$**
- **Reduced Load Boiler Tuning Can Reduce $NO_x$ Emissions by 90% to 185% of MCR $NO_x$ at Loads Below 70%**
- **The Increased Use of OFA at Low Loads Can Reduce $NO_x$, 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 $NO_x$ Emissions, Even on Small Units with Limited OFA**

# *CONCLUSIONS (continued)*

- **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 $NO_x$ May Not Hold)**
- **Test Engineers Can Define Low $NO_x$ 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 $NO_x$ Control Can be Universally Applied**
- **Every Boiler Has to be Custom Tuned to Take Maximum Advantage of its $NO_x$ Reduction Capability**
- **Maintenance of Plant Process Instrumentation is CRITICAL**