Boiler NOx Emissions and Energy Efficiency

Prepared For:
Boiler Operators and Facility Managers

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Introduction

Boiler NOx Formation
  • Types of NOx
  • How NOx is Formed

NOx Reduction and Compliance Strategies
  • Control Combustion
  • Treat Exhaust After Combustion

Combining Energy Efficiency with NOx Reduction
  • Benefits
  • Example Energy Efficiency Upgrades

Summary
Enovity:

- Is an energy engineering and sustainability consulting firm
- Offers an array of services:
  - Utility Programs
  - Energy Services
  - Building Commissioning
  - Building Automation
  - Advanced Operations and Maintenance
  - Sustainability Services
- Has a team of 75+ mechanical and controls engineers, project managers, O&M, and admin staff
- Operates offices in San Francisco, Sacramento, Irvine, and Phoenix
BOILER NOx FORMATION
Key points:

• Boiler burners use combustion to produce heat to make steam or hot water

• NOx is:
  – A by-product of combustion
  – A pollutant that contributes to
    • Ozone
    • Particulate matter
    • Acid rain

• NOx has three sources:
  – Thermal NOx
  – Prompt NOx
  – Fuel-bound NOx (not typically a concern with natural gas)
Thermal NOx formation:

- Is the largest contributor to overall NOx emissions
- Occurs under high temperatures of combustion
  - Combustion: Fuel + Air \((O_2 + N_2)\) + Ignition
  - Ideal Natural Gas Combustion: \(CH_4 + O_2 + N_2 \rightarrow CO_2 + H_2O + N_2 + O_2 + \text{Heat}\)
  - Above 2600 F: \(N_2 + O_2 + \text{Heat} \rightarrow \text{NOx}\)
- Is an exponential function of flame temperature
THERMAL NOx
There are two basic strategies to reduce NOx emissions:

1. Reduce thermal NOx formation
   - Requires modifying or replacing the boiler burner
   - Can achieve emissions of 7 ppm or lower
   - Is typically less expensive than exhaust treatment
   - May decrease efficiency (depending on the burner type)

2. Treat the boiler exhaust to remove NOx after it is formed
   - Requires installing a Selective Catalytic Reduction (SCR) system
   - Uses ammonia and a catalyst to remove NOx from the exhaust
   - Can achieve emissions of 5 ppm or lower
   - Has less impact on efficiency
   - Is typically more expensive than burner retrofit/replacement
   - May not be applicable to boilers smaller than 30 MMBtu/hr
OVERVIEW OF STRATEGIES

- Ammonia Injection
- SCR
- Economizer
- Boiler
- Burner
- Fan
- Exhaust

NOx Reduction Strategy 1:
- Flue Gas Recirculation (FGR)

NOx Reduction Strategy 2:
- Steam or HW

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Techniques to reduce NOx formation:

• Include:
  – Adding flue gas recirculation (FGR)
  – Altering the fuel/air ratio and excess \( O_2 \)
  – Using staged fuel or air
  – Improving fuel/air distribution and mixing
  – Improving flame distribution to reduce hot spots
  – Using staged combustion (both fuel and air)

• Are typically focused on lowering the flame temperature
  – *The challenge: how to lower flame temperature without reducing efficiency and/or flame stability?*
    ▪ Increasing excess \( O_2 \) will decrease efficiency
    ▪ Using FGR has less impact on efficiency, but requires additional fan energy
<table>
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<tr>
<th>Excess (%)</th>
<th>Combustion Efficiency</th>
<th>Exhaust Stack Temperature minus Combustion Air Temperature (°F)</th>
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<tr>
<td>Air</td>
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LOW- AND ULTRA-LOW-NOx BURNERS

Low-NOx Burners (30 ppm):

- Use FGR
- Can maintain 3 to 5% excess O₂ with good controls
- Offer good turndown (> 8:1) and flame stability

Ultra-Low-NOx Burners (7 to 15 ppm):

- Use FGR, adjusted fuel/air ratios, and staging
- May have (in some designs):
  - Higher excess O₂ (anywhere from 5 to 9%)
  - Larger combustion air fans (15% to 50% increase in required HP)
  - Reduced turndown (3:1 or 4:1) and flame stability
- Are improving
  - Many now in the 5% to 7% O₂ range
Conventional designs:

- Utilize higher FGR and lean mixture designs
  - *Lean premix: Gas nozzles and metal fiber*
  - *Lean rapid mix: Gas nozzles*
  - *With or without secondary fuel staging*

Newer Designs:

- Are aimed at improving efficiency
- Use less excess air (3% to 5%), less FGR and therefore less fan energy
- May use staged combustion
  - *Fuel and air are combusted in multiple stages (rich and lean)*
  - *Low NOx in each stage of combustion*
- Remain unknown in terms of availability and performance
NOX FORMATION AND FUEL/AIR RATIO

- Rich Flammability Limit
- Stoichiometric Combustion
- Lean Flammability Limit

**Rich Premix Combustion**

**Lean Premix Combustion (excess air)**

Fuel Rich  →  Fuel Lean
(more excess air)
Selective Catalytic Reduction (SCR) systems:

- Use ammonia injection and a catalyst to remove NOx from exhaust
- Are engineered solutions
- Require sufficient space and proper design, installation, and control
- Need fairly high exhaust temperatures (350 F or higher)
- Have some potential issues
  - Excessive boiler cycling
  - Ammonia slip and/or leakage
- Are recommended (instead of burner upgrade) for large water-tube boilers
- May soon be available for fire-tube boilers
  - Stack temperature and cost are issues
Options for reducing NOx emissions include:

1. Retrofit or modify the existing burner
   - From 15 ppm to 9 ppm
   - From 9 ppm to 7 ppm (only available for some burners)

2. Replace the burner
   - To meet 30 ppm, 15 ppm, or 9 ppm limits
   - Perhaps to meet 7 ppm (availability?)

3. Replace the boiler
   - Cost vs. efficiency improvement

4. Install SCR system
   - Good option for water-tubes, but for fire-tubes?

5. De-rate boiler below threshold of regulation

6. Pay an annual emission fee (only in San Joaquin Valley APCD)
When deciding on a compliance strategy:

• Evaluate site-specific options and proposals
  – *Address design or installation issues*
  – *Evaluate experience and expertise of contractors and suppliers*
  – *Look at condition of existing equipment (retrofit vs. replace)*
  – *Obtain actual (as opposed to design) performance data for a site-specific installation*
  – *Ask for a performance guarantee!*
  – *Consider that regulations may change again in the future*
  – *Assess impact on energy efficiency and other spending activities*

• Evaluate total operating cost
  – *Energy*
  – *Operations*
  – *Compliance*
COMBINING ENERGY EFFICIENCY WITH BOILER NOx UPGRADES
WHY INCLUDE ENERGY EFFICIENCY?

Reasons to include energy efficiency with NOx upgrades include:

• Mitigating efficiency decrease and/or operating cost increase from NOx reduction
• Energy and utility cost savings
• Some advantages of implementing as a single project:
  – Downtime is limited
  – Upgrades may be more cost-effective
  – Project will generate a return
• Greenhouse gas emission reductions
• Taking advantage of rebates available for energy efficiency upgrades
• Increasing boiler capacity
• Improving operations and maintenance
• Replacing aged equipment
Combine energy efficiency with burner upgrades by:

- Installing a variable frequency drive (VFD) on the burner fan
  - Cost-effective for larger fans and longer operating hours
- Installing a SCR system and replacing an existing ultra-low-NOx burner
  - If using an older, high-excess air ULN burner, replace with a high-efficiency 30 ppm burner
  - Applicable for boilers larger than 30 MMBtu/hr
  - Can save both natural gas and electricity
When replacing a boiler, consider:

- High-efficiency boilers
- Condensing boilers
- Direct-contact water heaters
- Steam generators
- Switching from steam to hot water
HIGHLIGHT: CONDENSING BOILERS

Inlet Water Temperature (F) vs. Combustion Efficiency (%)

- Combustion Efficiency decreases as the Inlet Water Temperature increases.
- At an Inlet Water Temperature of 60°F, Combustion Efficiency is approximately 98%.
- At an Inlet Water Temperature of 140°F, Combustion Efficiency is approximately 86%.
HEAT RECOVERY OPPORTUNITIES

- Pipe, tank, and other heated surface insulation
- Exhaust stack economizers (feedwater or condensing)
- Blowdown heat recovery
- Condensate recovery
- Mechanical vapor recompression or other custom efficiency upgrades for evaporators
- Flash steam recovery
- Thermosorber heat pump
- Process heat recovery
HIGHLIGHT: CONDENSING ECONOMIZERS

- Applicable to larger boilers with nearby low-temperature water demand (domestic hot water, process water, clean-in-place)
- Preheats water up to 140°F to reduce steam consumption
- Most efficient when combined with a first-stage feedwater economizer
VARIABLE FREQUENCY DRIVES

- Boiler burner combustion air fan
- Feedwater pumps
- Condensate return pumps
- Process water pumps
EXAMPLE BURNER FAN VFD RESULTS

Boiler Part-Load (%) vs. Burner Fan kW

Pre-installation Fan kW vs. Post-installation VFD Fan kW

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• Replace old or failed steam traps
• Repair/replace control linkage
• Repair/replace failed blowdown controls or reduce excessive blowdown
• Reduce or eliminate boiler cycling

• Repair/replace dirty heat exchanger or boiler economizer
• Replace boiler refractory
• Reduce boiler steam pressure or hot water supply temperature set points
• Repair/replace failed VFD
• Reverse osmosis water treatment systems (for reduced boiler blowdown)
• High-efficiency boiler burners
• Electronic parallel positioning fuel-air controls (with or without oxygen trim)
  – Only for burners ≥ 30 ppm NOx
Key points to review:

• New regulations may require boiler upgrades
• Evaluate your options for compliance
• Combine energy efficiency with NOx-related upgrades
  – *Save energy, reduce operating cost and greenhouse gas emissions*
  – *Create a payback*
  – *Make the most of down time*
• Take advantage of utility energy efficiency rebates and no-cost technical services
Providing commissioning, energy engineering, sustainable design and building operations and maintenance services to the construction and property management industry.