NOx Reduction: Flue Gas Recirculation vs Selective Catalytic Reduction

Presented by Jason Jacobi
October 28, 2015
Agenda

- NOx Regulations
- What is NOx?
- NOx types
- How to control NOx?
- What is FGR?
- What is SCR?
- Pros/Cons
- CAPEX/OPEX
NOx Regulations

Federal Government
- EPA (US)
- CCME (Canada)

State/Provincial Government
- California (US)
- Alberta (Canada)

Local Jurisdictions
- San Joaquin Valley (US)
- Alberta Environment (Canada)
BACT – Best Achievable Control Technology
BMACT – Boiler Maximum Achievable Control Technology

California & NOx Tolerance:

- 2 – 5 mmbtu  30 ppm
- 6 – 20 mmbtu  15 ppm
- 21 – 75 mmbtu  9 ppm
- 76+ mmbtu  5 ppm

San Joaquin Valley, CA

- 20+ mmbtu  5 ppm
CCME – Canadian Council of Ministers of the Environment

Canada & NOx Tolerance:
- 40.0 g/GJ (76 ppm) current
- 13.0 g/GJ (25 ppm) proposed

Alberta Environment
Natural Gas (NG)
- 26.0 g/GJ (50 ppm) proposed limit
- 7.9 g/GJ (15 ppm) proposed target

Alternate Gaseous Fuel (AGF)
- 40.0 g/GJ (76 ppm) proposed limit
- 15.8 g/GJ (30 ppm) proposed target
What Is NOx?
Combustion

Fuel

- Mixing
- Turbulence
- Temperature
- Contact Time

Air

Some Fuels

C\textsubscript{2}H\textsubscript{2}O\textsubscript{2}N\textsubscript{2}

S, N\textsubscript{2}
Combustion

Fuel

- Mixing
- Turbulence
- Temperature
- Contact
Time

Air

S N\textsubscript{2} Some
Fuels

C H\textsubscript{2}

Heat

O\textsubscript{2} N\textsubscript{2}

CO\textsubscript{2} H\textsubscript{2}O CO

NO NO\textsubscript{2} SO\textsubscript{2}
Emission
Gases
(sometimes)

Some
Fuels

C H\textsubscript{2} O 2 N\textsubscript{2} 8
Mono-Nitrogen Oxides, NO & NO\textsubscript{2}

- NO (Nitric Oxide)
- NO\textsubscript{2} (Nitrogen Dioxide)
- Ambient = Equilibrium
- Heat = Endothermic Reaction
- NO = 80 – 90%
NOx: A Precursor to Photochemical Smog
Acid Rain

How acid rain is formed

Chemical transformation pan
- NO₂ → HNO₃
- SO₂ → H₂SO₄

Hydrocarbons NOₓ, SO₂
Emissions to the atmosphere

Photo-oxidation
Acid pollutants

Dry deposition
- Particulates
- Gases

Wet deposition: acid rain and snow
- H₂SO₄
- HNO₃

Nitric Acid, HNO₃

Industry
Transport
Domestic
Electricity generation
Three Types of NOx

- Fuel Bound
- Prompt
- Thermal
NOx Formation

Temperature

Duration
Result is Total NOx

Natural Gas:
• Approx. 120 ppm

#2 Oil:
• Approx. 180 ppm
• (Fuel Bound Nitrogen .015%)

#6 Oil:
• Approx. 425 ppm
• (Fuel Bound Nitrogen 0.300%)

Values are based on industrial watertube boilers >100 mmbtu/hr input
Smaller commercial boilers may be capable of lower values
• **Forms at lower temperatures (2200 – 2500°F)**

• **Reacts with radicals such as Carbon (C) or Methylene (CH₂)**

• **Minor contributor to overall NOx production**
Thermal NOx

- 2900°F...Nitrogen Oxides forming (NO & NO₂).
- Temperature and residence time.
- Major contributor to NOx production
Natural Gas

Primarily Methane CH₄

- Hydrocarbons
- Carbon Dioxide
- Nitrogen
- Hydrogen Sulfide
How is it reduced?
• Low NOx Burners

• Flue Gas Recirculation (FGR)

• Selective Catalytic Reduction (SCR)
Low-NOx Burners

- 120 - 80 ppm
- 80 - 9 ppm
- > 9 ppm
Fitting the Burner to the Furnace
Furnace Geometry

- Provide the most generous volume possible for combustion
- Promote more uniform flame temperature
- Elimination of refractory that re-radiates heat back into furnace

Modern Industrial Watertube Furnace
CFD- Furnace Temperature Profiling
Gas Injection
Flue Gas Recirculation

- 120 - 80 ppm
- 80 - 9 ppm
- > 9 ppm
This is the most popular and efficient method of utilizing flue gas recirculation for NOx reduction.

Consists of “inducing” flue gases using the suction pressure at the inlet of the combustion air fan.
Flue Gas Recirculation

Air

FD Fan

Burner

Economizer

Boiler

Stack
Flue Gas Recirculation

- Air
- Mixing Box
- FD Fan
- Burner
- Cold FGR
- Economizer
- Boiler
- Stack
Flue Gas Recirculation

Air
Mixing Box
FD Fan
Burner
Cold FGR
Hot FGR
OR
Economizer
Stack
Boiler
**Ductwork**
- From stack to fan suction

**Damper**
- To control % of flue gas recirculation

**Air Inlet Mixing Box**
- To provide a chamber for fresh air to mix with flue gases prior to burner

**Larger Fan**
- To handle increased mass flow and higher mixture temperature

**Control Upgrade**
- Additional programming, instrumentation (FGR flow), I/O
The mixing of cooled flue gases with combustion air effectively reduces combustion temperature thus reducing thermal NOx. Using conventional burner technology, reductions of up to 80% are possible.

Using a 100 MMBTU/hr natural gas register burner as a reference, typical emissions are as follows:

- Uncontrolled: 120 ppm NOx
- Using FGR: 20-30 ppm NOx
Sub 20 ppm NOx are possible using induced FGR, but to reach these levels, the formation of prompt NOx must also be addressed. This can be accomplished by premixing the fuel and air/FGR mixture prior to ignition thus minimizing fuel rich zones which are susceptible to forming prompt NOx.

Using high FGR rates and premixing of fuel and air/FGR, NOx reductions of 90% are possible thus allowing to reach 9ppm NOx levels.

These are commonly called “Ultra Low-NOx” burners.
As Excess Air Increases, Efficiency Decreases
Ultra Low NOx
Selective Catalytic Reduction

- 120 - 80 ppm
- 80 - 9 ppm
- > 9 ppm
Post Combustion NOx Reduction

\[ \text{NH}_3 + \text{NOx} = \text{N}_2 + \text{H}_2\text{O} \]

**SNCR – Selective Non-Catalytic Reduction**
- Spontaneous @ approx. 1800° F.
- Ammonia injected directly into furnace
- Large furnace, adequate residence time
- Not practical for packaged boilers

**SCR – Selective Catalytic Reduction**
- Lower temperatures @ 600-800° F
- Ammonia injected at boiler flue gas outlet
- Catalyst required
- Common on packaged boilers
Source testing measurements of NOx & NH₃ slip

Usually 90-93% NOx reduction is achieved on units firing NG and #2 oil.

“Rule of Thumb” : NOx after the Catalyst will be 10% of the upstream NOx

Ammonia slip is measure at the stack and corresponds to the amount of NH₃ that didn’t react with NOx.

Typically NH₃ slip levels are of 5 ppm or 10 ppm.
NH₃ + NOₓ = N₂ + H₂O

SCR Reagent Types

**Anhydrous NH₃**
- Pure Ammonia liquefied under pressure
- Low capital & operating cost
- Perceived as high risk
- Can be difficult to permit

**Aqueous NH₃**
- Ammonia in 20-30% water
- Higher capital & operating cost
- Perceived as low risk
- Permit normally easy to obtain

**Urea**
- Highest capital & operating cost
- Perceived as minimal risk
- Permit easy to obtain
SCR System Components

- **Reagent Processing Skid**
  - Anhydrous Ammonia – Anhydrous Bottles For Storage, AFCU
  - Aqueous Ammonia – Ammonia Storage Tank, Forwarding Pump Skid, AFCU c/w Vaporizors
  - Urea – Urea Storage Tank, Urea Conversion Skid, AFCU

- **Catalyst**
  - NOx Catalyst

- **Ammonia Injection Grid (AIG)**
  - To inject ammonia

- **Reactor Housing**
  - Contains precious metal catalyst to assist reaction

- **System Control Upgrade**
  - Additional programming, instrumentation, I/O
System Components

- Catalyst Bed
- AIG (ammonia injection grid)
- Ammonia metering and dilution skid (anhydrous shown)
Selective Catalytic Reduction (SCR)
Selective Catalytic Reduction (SCR)

Ammonia Injection Grid
Selective Catalytic Reduction (SCR)

SCR Reactor Housing
Inside the reactor, catalyst elements are stacked to form the catalyst bed.
Selective Catalytic Reduction (SCR)

NOx Catalyst

CO Catalyst
Selective Catalytic Reduction (SCR)

Anhydrous Ammonia Metering & Dilution Air Skid
Selective Catalytic Reduction (SCR)

Aqueous Forwarding Pump Skid
Selective Catalytic Reduction (SCR)

Aqueous Ammonia Vaporization Skid
Ultra Low-NOx Burners

PROS
• On-site storage of ammonia is NOT required
• No SCR equipment and associated maintenance

CONS
• Technology is limited to < 200 mmbtu/hr in a single burner
• Burner cost is higher than standard units
• Large furnace volumes are required, often resulting in costly modularized or field-erected boilers at larger heat inputs
• Burner turndown is limited (typical 6:1)
• High excess air reduces thermal efficiency
• High FGR rates increase fan size and power consumption
• Complex metered combustion control systems are required
• Burner ramp rates are slower than standard systems
• Inlet air preheat temps are limited (reduced efficiency)
Selective Catalytic Reduction

PROS

• Single-digit NOx levels can be achieved
• Low cost standard burners can be utilized
• Boiler furnace sizing is unaffected
• No impact on burner turndown (10:1 typical)
• Low excess air does not reduce efficiency
• No significant impact on FD Fan power consumption
• Burner ramp rates are in excess of 20% / minute
• High-temp inlet air preheat systems increase efficiency
• More forgiving of fuels with changing compositions

CONS

• On-site ammonia storage required.
• Increased footprint or height for ductwork
• Additional pressure drop across catalyst increases fan hp, but not significant when compared to ultra low-NOx burners
• Catalyst maintenance/replacement required every 3-5 years
**80,000 lb/hr watertube @ 9 ppm NOx**

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<th>SCR</th>
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<td>$960,000</td>
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<tr>
<td>Add FGR</td>
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<td></td>
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<td></td>
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<td>$/lb steam</td>
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33%
80,000 lb/hr watertube @ 9 ppm NOx

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SCR costs additional 30%, so FGR is most economical
425,000 lb/hr watertube @ 9 ppm NOx

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<td>Add FGR</td>
<td>$395,000</td>
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<td>Add SCR</td>
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<td>$675,000</td>
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<td>$/lb steam</td>
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5%
425,000 lb/hr watertube @ 9 ppm NOx

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This is interesting.
Cost of FGR vs. SCR is very close.
FGR is $280,000 less.
425,000 lb/hr watertube @ 9 ppm NOx

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We need to take a closer look at OPEX.

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425,000 lb/hr watertube @ 9 ppm NOx

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<td>Increase Fan HP</td>
<td>$315,539.10</td>
<td>$18,254.33</td>
<td></td>
</tr>
<tr>
<td>Increase NG</td>
<td>$322,599.70</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Add ammonia</td>
<td></td>
<td>$235,872.00</td>
<td>$/yr</td>
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<td><strong>TOTAL</strong></td>
<td>$638,138.81</td>
<td>$254,126.33</td>
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$USD Assumptions:
Electricity: 5¢/kWh
Fuel Gas: $3/mmbtu
Ammonia: $3/lb (anhydrous)
### 425,000 lb/hr watertube @ 9 ppm NOx

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**SCR clearly costs less to operate than FGR.**

* $384,000 savings per year!
1. Our environment is finite and fragile…
2. Fuels we burn also finite
3. Efficiency are compromised for ultra low-NOx levels with FGR
4. KWh may also be impacted along with turndown with FGR
5. SCR will not normally impact fuel efficiency
6. Consider ALL options for NOx reduction.
Contact Us

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