Boiler Emission Control - NOx

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NOx Generation During Combustion

During the combustion of fossil fuels, nitrogen oxides (NO and NO\textsubscript{2}) collectively referred to as “\textbf{NOx}”, are produced in and around the high temperature region by two primary reaction processes.

\textbf{THERMAL NOx} – formed through oxidation and combination of N\textsubscript{2} & O\textsubscript{2} in combustion air

20 – 40\% of the total NOx

\textbf{FUEL NOx} – formed from the organically bonded nitrogen contained in the fuel

60 – 80\% of the total NOx

\textbf{Prompt NOx} – ‘Near flame envelop’
Options for NOx Reduction

During Combustion (Prevent NOX Formation)
- Tangentially Fired
- Wall Fired

Post Combustion (Reduces the NOx)
- SNCR
- SCR
**NOx Control During Combustion (Prevent NOX Formation)**

**THERMAL NOx**
- Formation is very sensitive to both temperature and oxygen.
  - Increases exponentially with temperature.
  - Proportional to the square root of oxygen content.
- To reduce Thermal NOx:
  - Reduce the **Peak flame temperature**.
  - Reduce the **oxygen** concentration in the region of the maximum temperature zone.
  - Reduce the **residence time** of the combustion gases at the peak temperature.

**FUEL NOx**
- There is a weak correlation to fuel nitrogen.
  - Depends on fuel O$_2$ / Fuel N$_2$ ratios
  - Lower the ratio, lower will be the NOx produced
- **Fuel NOx** can be minimized by:
  - Controlling quantity of air permitted to mix with the fuel in the early stages of combustion.
Quantity of NOx generation

- Coal properties
- Fuel Oxygen /Nitrogen ratio
- Heat release rates in the furnace
- Furnace size and geometry
- Firing system Design
- Excess air
- Residence time
NOx Reduction During Combustion – LNCFS™

TFS 2000™

- Reduces available O2 during critical early phase of combustion in the main burner zone to maximize time at sub or near stoichiometric condition
  
  • Staging air to CCOFA and SOFA
  • CFS™ Secondary air nozzle tips
  • Flame attachment coal nozzle tips

- Also uses a finer coal grind that allows for more aggressive staging
  
  • < 1% on +50 mesh, > 75% - 200 mesh

Finer grind increase surface area

Allow less O2 in burner zone

- Helps control both Fuel & Thermal NOx
Advantages & Limitations

- Proven Technology since early 1980s
- Low Capex
- No Opex
- Low shut down time for implementation
- No additional Aux. power
- No impact on boiler operation
- No impact on boiler operating parameters

- Increase in UBC losses due to firing zone sub stoichiometric condition but can be addressed by improving the coal fineness by mill classifier re-design
- Limitations to reduce the NOx up to 50%
Post Combustion (Reduces the NOx by Chemical Reaction)

Basic Chemistry for Post Combustion NOx Reduction

\[ \text{NO}_x + \text{NH}_3 \rightarrow \text{N}_2 + \text{H}_2\text{O} \]

FURNACE ZONE
- High Temperature 850 Deg.C to 1100 Deg.C

SELECTIVE NON CATALYTIC REDUCTION (SNCR)

ECONOMIZER OUTLET
- Presence of Catalyst & Temperature 350 Deg.C to 450 Deg.C

SELECTIVE CATALYTIC REDUCTION (SCR)

\[ \text{NO}_x + \text{NH}_3 \rightarrow \text{N}_2 + \text{H}_2 \]
Types of SNCR

Traditional SNCR
- Uses lances to inject urea
- Limited effectiveness in boilers >400 MW because of jet penetration

GE Power Umbrella SNCR
- New Patented method of injecting Urea
- No limitation on boiler size
Umbrella SNCR

- The Umbrella SNCR is a new application of the SNCR process.
- The Umbrella SNCR has been successfully demonstrated in multiple power plants in Europe. NOx reduction up to 60%
- Superior to other SNCRs:
  - Better gas mixing from top
  - Larger droplets allows high gas temperatures
  - No need for real time temperature mapping
  - Easier and more flexible installation
  - Applicable at large boilers
USNCR™ (Umbrella SNCR)
Urea Nozzle Locations Comparison

Conventional SNCR - >60 Spray Nozzles
Umbrella SNCR - 4 Spray Nozzles

Furnace opening
Urea spray dome
Nozzle

Less Nozzles and Penetrations
Lower Installation and Capital Cost
Umbrella SNCR
Lance assembly
Advantages & Limitations - SNCR

- Proven Technology
- Low to moderate Capex
- Very Low shut down time for implementation
- No impact on boiler operation
- No impact on boiler operating parameters

- Requires reagents like Ammonia or Urea
- Water Consumption
- Auxiliary power (very low)
- Limitations to reduce the NOx up to 50%
NOx Reduction - SCR

Selective Catalytic Reduction - SCR

- NOx reduction achieved with chemical reaction between NOx and ammonia as flue gases pass through a catalyst in a reactor
- 85% to 90+% NOx removal

SCR system basic chemical reaction process

Basic reaction formula:
- $4\text{ NO} + 4\text{ NH}_3 + \text{ O}_2 \rightarrow 4\text{ N}_2 + 6\text{ H}_2\text{O}$
- $6\text{ NO}_x + 8\text{ NH}_3 \rightarrow 7\text{ N}_2 + 12\text{ H}_2\text{O}$

Side effect formula:
- $\text{SO}_2 + \frac{1}{2}\text{ O}_2 \rightarrow \text{SO}_3$
- $\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4\text{HSO}_3$

Tank Urea/Ammonia
Advantages & Limitations - SCR

- Proven Technology Globally
- Very High NOx reduction (upto95%)

- Very High Capex
- Long Shut down for retrofit (Civil & Structural work)
- Requires reagents like Ammonia or Urea
- Auxiliary power due to ID Fan loading
- Periodic Replacement of costly Catalyst
- Performance of Catalyst yet to be proven for high ash erosive Indian coals
- Difficult to retrofit in existing boilers due to space constraints
- Limitation during boiler low load operations
## Boiler Emissions Norms

<table>
<thead>
<tr>
<th>Installation Date</th>
<th>NOX (mg/Nm³)</th>
<th>SOx (mg/Nm³)</th>
<th>Particulate (mg/Nm³)</th>
<th>Mercury (mg/Nm³)</th>
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</thead>
<tbody>
<tr>
<td>TPP’s installed before Dec 31, 2003</td>
<td>600</td>
<td>600 (units &lt; 500 MW)</td>
<td>100</td>
<td>Nil (units &lt; 500 MW)</td>
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<tr>
<td></td>
<td></td>
<td>200 (units ≥ 500 MW)</td>
<td></td>
<td>0.03 (units ≥ 500 MW)</td>
</tr>
<tr>
<td>TPP’s installed after Dec 31, 2003 – Dec 31, 2016</td>
<td>300</td>
<td>200 (units ≥ 500 MW)</td>
<td>50</td>
<td>0.03</td>
</tr>
<tr>
<td>TPP’s installed from 1st Jan, 2017</td>
<td>100</td>
<td>100</td>
<td>30</td>
<td>0.03</td>
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</tbody>
</table>
Options for NOx Reduction

Which one is Best?

- Boiler
- SNCR
- SCR
## Selection Of Technology

<table>
<thead>
<tr>
<th>Installation Date</th>
<th>NOX (mg/Nm³)</th>
<th>Recommended Technology</th>
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</thead>
<tbody>
<tr>
<td>TPP’s installed before Dec 31, 2003</td>
<td>600</td>
<td>Low NOx Firing System only</td>
</tr>
<tr>
<td>TPP’s installed after Dec 31, 2003 – Dec 31, 2016</td>
<td>300</td>
<td>Low NOx Firing System + USNCR</td>
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<tr>
<td>TPP’s installed from 1st Jan, 2017</td>
<td>100</td>
<td></td>
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</table>
Advanced Controls for Boiler efficiency and NOx reduction
GE / NeuCo BoilerOpt®

**Typical Results**

Optimal Control of Boiler through Load range. Allows a 0.5% to 1.5% improvement in heat rate (saving fuel)

Reduces steam for sootblowing by up to 1/3, resulting in fewer outages for tube failures caused by sootblower erosion

Reduces Steam temperature variations

- Close control of superheat and reheat to achieve full or increased power output without subjecting tubes to over temperature and creep damage

Controls fuel / air ratio and soot blowers to minimize Particulate, NOx and CO emissions. Typical reduction of 5-15%

Optimizes the Ammonia flow in SNCR and SCR
Impact on NH₃ Usage

WITHOUT Optimization, 400-600 klb/hr NH₃ flow needed to meet NOx target

WITH Optimization, 300-400 klb/hr NH₃ flow needed to meet NOx target
CombustionOpt Ammonia Reduction

Ozone Ammonia Flow - 2005

Ozone Ammonia Flow - 2006
## Spruce 1 BoilerOpt KPI Summary

<table>
<thead>
<tr>
<th>KPI</th>
<th>Units</th>
<th>OFF</th>
<th>ON</th>
<th>Delta (ON - OFF)</th>
<th>Delta (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross MW</td>
<td>MW</td>
<td>571.15</td>
<td>564.57</td>
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<tr>
<td>Heat Rate</td>
<td>Btu/kWh</td>
<td>9661.32</td>
<td>9556.74</td>
<td>-104.58</td>
<td>-1.08%</td>
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<tr>
<td>Blr Eff</td>
<td>%</td>
<td>83.99</td>
<td>84.77</td>
<td>0.78</td>
<td>0.93%</td>
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<tr>
<td>NOx</td>
<td>#/MMBtu</td>
<td>0.127</td>
<td>0.121</td>
<td>-0.006</td>
<td>-4.72%</td>
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<tr>
<td>CO</td>
<td>ppm</td>
<td>107.06</td>
<td>123.06</td>
<td>16</td>
<td>14.94%</td>
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<tr>
<td>O2 Avg</td>
<td>%</td>
<td>2.277</td>
<td>1.912</td>
<td>-0.365</td>
<td>-16.03%</td>
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<tr>
<td>RH Temp E</td>
<td>degF</td>
<td>1003.64</td>
<td>1003.88</td>
<td>0.24</td>
<td>0.02%</td>
</tr>
<tr>
<td>RH Temp W</td>
<td>degF</td>
<td>1002.96</td>
<td>1003.33</td>
<td>0.37</td>
<td>0.04%</td>
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<tr>
<td>RH Spray</td>
<td>klb/h</td>
<td>91.43</td>
<td>87.54</td>
<td>-3.89</td>
<td>-4.25%</td>
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<tr>
<td>SH Temp E</td>
<td>degF</td>
<td>1003.26</td>
<td>1004.12</td>
<td>0.86</td>
<td>0.09%</td>
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<tr>
<td>SH Temp W</td>
<td>degF</td>
<td>1000.16</td>
<td>1003.84</td>
<td>3.68</td>
<td>0.37%</td>
</tr>
<tr>
<td>SH Spray</td>
<td>klb/h</td>
<td>14.9</td>
<td>21.89</td>
<td>6.99</td>
<td>46.91%</td>
</tr>
</tbody>
</table>
Summary

Required NOx can be reduced by limiting NOx production during combustion and/or by post combustion equipment.

Cost and complexity rises with increased removal requirements:

- 600 mg limit achievable in most boilers with Low NOx firing system.
- 300 mg limit achievable in most boilers with Low NOx firing system and in some cases SNCR.
- 100 mg limit achievable with Low NOx firing system with SNCR+ SCR.

GE equipment for firing systems, and post combustion technologies in operation at hundreds of power plants globally.
Questions ?
Thanks