NOx Control Technologies for Stationary Engines

Advances in Emission Control and Monitoring Technology for Industrial Sources
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NO\textsubscript{x} CONTROL FOR STATIONARY ENGINES USING SCR & ADVANCED AMMONIA SLIP CATALYSTS

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Federal Emission NO$_x$ Standards for New Engines

- Tier 1 – 3, compliance met with engine design (mostly)
- Tier 4, further 90+\% reduction over Tier 1 – 3

**Tier 4 NO$_x$ Emission Standards**

<table>
<thead>
<tr>
<th>Category</th>
<th>Model Year</th>
<th>Emission Limit, g/bhp-hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 &lt; hp &lt; 750</td>
<td>2011+</td>
<td>0.30</td>
</tr>
<tr>
<td>Gensets &gt; 900 kW (1207 hp)</td>
<td>2011+</td>
<td>0.50</td>
</tr>
<tr>
<td>hp &gt; 750</td>
<td>2011+</td>
<td>2.6</td>
</tr>
<tr>
<td>(except gensets &gt; 900 kW)</td>
<td></td>
<td></td>
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</tbody>
</table>

*Districts in nonattainment areas (CA, Northeast, ATL) may impose more stringent standards for new and existing engines.*
CA Stationary Engine NO\textsubscript{x} Standards

- CARB 2007 DG Standard (> 50 bhp)
  - 0.07 lb/MW-hr (1.6 – 4.0 ppm @ 15% O\textsubscript{2})

- SCAQMD Proposed Changes to Rule 1110.2, future reduction to BACT levels
  - >500 bhp, 11 ppm NO\textsubscript{x} by 7/1/2010
  - <500 bhp, 11 ppm NO\textsubscript{x} by 7/1/2011
CT NO\textsubscript{X} Standards, Section 22a-174-22

- Existing DG sources, 1.3 g/bhp-hr
- New DG sources
  - 1/1/05, 0.2 g/bhp-hr
  - 5/1/08, 0.1 g/bhp-hr
  - 5/1/12, 0.05 g/bhp-hr
- Proposed General Permit for Demand Response engines – 90% NO\textsubscript{X} reduction
Compliance with stringent NO\textsubscript{x} emission standards requires exhaust after treatment

**SCR**

Proven Technology for NO\textsubscript{x} Control
SCR Process Basics

- **SCR = Selective Catalytic Reduction**
- Aftertreatment to reduce NO\(_x\) (NO & NO\(_2\)) from combustion exhaust
- Urea (NH\(_3\)) is injected into exhaust as reducing agent.
- NH\(_3\) reacts with NO\(_x\) on catalyst surface to form nitrogen and water

\[
\begin{align*}
4\text{NO} + 4\text{NH}_3 + \text{O}_2 & \xrightarrow{\text{Catalyst}} 4\text{N}_2 + 6\text{H}_2\text{O} \\
2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 & \xrightarrow{\text{Catalyst}} 3\text{N}_2 + 6\text{H}_2\text{O}
\end{align*}
\]
Extruded SCR Catalyst

- Homogeneously extruded ceramic
- Composition
  - >80% TiO$_2$, Titanium Dioxide
  - 10% WO$_3$, Tungsten Trioxide
  - 0 – 3% V$_2$O$_5$, Vanadium Pentoxide, active material
- Geometry, honeycomb monoliths
- 10 – 400 cpsi
- Blocks cut to length, 250 – 1000+ mm
- Operating temperature, 350 – 950°F
- High active surface area per unit volume
Coated Metal Monolith SCR Catalyst

- **NOTES:**
  - **BLOCK WEIGHT:** 50-75 LBS.
  - APPLICATION AND CELL DENSITY DEPENDANT
  - 304 STAINLESS STEEL FRAME.
  - (*) THIS DIMENSION MUST ALWAYS BE INSTALLED PARALLEL TO GRADE

- **STANDARD CATALYST WHOLE BLOCK**
  - 22 1/4 x 23 1/4 x 3 11/16

- **PROPERTY OF JOHNSON MATTHEY, NO REPRODUCTION PERMITTED EXCEPT BY WRITTEN AUTHORITY OF THE CORPORATION. UNAUTHORIZED REPRODUCTION IS PROHIBITED.**
Catalyst Performance vs T

1. SCR-Reaction
   \[ \text{NO}_x + \text{NH}_3 = \text{N}_2 + \ldots \]

   Side Reactions:
   2. NH\textsubscript{3} Oxidation
      \[ \text{NH}_3 + \text{O}_2 = \text{NO}_x + \ldots \]

   3. SO\textsubscript{2} Oxidation
      \[ \text{SO}_2 + \text{O}_2 = \text{SO}_3 + \ldots \]

All 3 reactions catalysed by V\textsubscript{2}O\textsubscript{5}
DeNOx Activity = f(T, V_{2}O_{5})

Activity vs Catalyst Formulation
SCR Applications

- Waste to Energy
- Heavy Duty Diesel
- Coal-Fired Generation
- Marine Engines
- Greenhouses
- Gas-Fired Generation
- Wood-Fired Boilers
- Stationary Engines
- SCR Applications

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Stationary Engine with SCR System
SCR Design Considerations

- Engine model, power
- Fuel
- Exhaust characteristics
  - Flow rate
  - Temperature
  - $O_2$, $H_2O$ concentration
  - Untreated NO$_x$ emissions
- Required NO$_x$ reduction
- Allowable pressure drop

Achievable Performance
- >95% DeNO$_x$
- <5 ppm NH$_3$ slip
- <0.05 g/bhp-hr outlet NO$_x$
- Low pressure drop
- Wide operating temperature range
Mixing and Flow Distribution

- Critical for
  - High DeNO$_x$ rates (>95%)
  - Low emission rates (<0.05 g/bhp-hr)
  - Low NH$_3$ slip

- Patented static mixers designed for
  - Complete NH$_3$/NO$_x$ mixing
  - Uniform NH$_3$/NO$_x$ distribution across duct
Static Mixers in Duct
Reactors with Catalyst
Design Considerations Continued

- **High Sulfur Fuels**
  - SCR catalyst converts SO\(_2\) to SO\(_3\)
  - SO\(_3\) + NH\(_3\) form ammonium bisulfate (ABS)
  - Adjust catalyst formulation to minimize SO\(_2\) oxidation
  - Restrict low temp operation of SCR

- **Catalyst Poisons**
  - Phosphorus
  - Na, K
  - Catalyst deactivation – lower catalyst life, increased reagent demand for high NO\(_x\) reduction
Stationary Engine SCR Examples
LIPA Metro Power
LIPA - Details

- 48 Cummins QSK60-G3 Engines (60.2 L)
- Backup generating capacity only
- Untreated exhaust NO$_x$, 6.9 g/bhp-hr
- 90% NO$_x$ reduction to 0.69 g/bhp-hr
- Integrated DPF and Oxidation catalyst
Plains End Generation Station-Colorado
Plains End - Details

- 20 Wärtsilä 18V34SG engines (5940 kW)
- Primary fuel is NG
- Baseload operation
- Untreated exhaust NO$_x$ $\sim$ 1.0 g/bhp-hr
- 95% NO$_x$ reduction to 0.05 g/bhp-hr
Advanced Ammonia Slip Catalysts, ASC
ASC Purpose – Convert NH$_3$ to N$_2$

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

SOx Catalyst

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

Trace NO$_x$

Trace NH$_3$

Ammonia Destruction Catalyst

\[ \text{N}_2 + \text{H}_2\text{O} \]

O$_2$

NH$_3$

NO$_x$

O$_2$

NH$_3$

NO$_x$
ASC Driver and Benefits

Driver:
- Compliance with 2010 onroad diesel truck NO\textsubscript{x} emission standard will require SCR and ASC to achieve

Benefits:
- Technology can also be applied to nonroad engines
- Extend life of SCR catalyst
  - As SCR deactivates NH\textsubscript{3} demand increases
  - NH\textsubscript{3} slip increases
  - Increased NH\textsubscript{3} slip reduced by ASC
- Increase NO\textsubscript{x} reduction
Conversion of NH₃

- **Ideal Conversion**
  \[2 \text{NH}_3 + 3/2 \text{O}_2 = \text{N}_2 + 3 \text{H}_2\text{O}\]

- **Undesired Conversion**
  \[2 \text{NH}_3 + 2 \text{O}_2 = \text{N}_2\text{O} + 3 \text{H}_2\text{O}\]

\[2 \text{NH}_3 + 5/2 \text{O}_2 = 2 \text{NO} + 3 \text{H}_2\text{O}\]
\[(\text{NO} + 1/2 \text{O}_2 = \text{NO}_2)\]
Oxidation Catalyst vs ASC

- **Catalyst A** – typical oxidation catalyst
  - High NH₃ conversion
  - Low N₂ selectivity

- **Catalysts B & C** – advanced ASCs
  - High NH₃ conversion
  - High N₂ selectivity
ASCs – Summary

- Under lab testing conditions
  - High NH$_3$ conversion
  - High N$_2$ selectivity
  - Exhibit thermal durability

- Field testing is required
  - to verify long-term thermal durability
  - to assess long-term durability against poisons
Thank You!

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