Principal of Operation for Selective catalytic reduction (SCR) for NOx control

Comprehensive Guide

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MANAGING NITROGEN OXIDES

Understanding Emissions, Regulations, and Reduction Technologies

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01. THE NATURE OF NOx

What are Nitrogen Oxides?

NOx emissions are the inevitable byproduct of air-fed combustion processes. While Nitric Oxide (NO) and Nitrogen Dioxide (NO2) are products of high-temperature combustion, it is NO2 that is largely responsible for the visible orange-to-brown haze associated with smog.

Primary Sources:

- Power Plants & Industrial Boilers
- Automobiles & Transportation
- Solid Waste Disposal
- Industrial Manufacturing Processes

Environmental Impact

NOx emissions contribute directly & indirectly to atmospheric degradation, resulting in:

- **Acid Rain:** Formation of nitric acid in the atmosphere.
- **Vegetation Decline:** Damage to forests and crops.
- **Ozone Depletion:** Alterations to the protective ozone layer.

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02. REGULATORY LANDSCAPE

The Clean Air Act & Compliance

The EPA has established stringent guidelines to regulate NOx, carbon monoxide, and unburned hydrocarbons. Compliance is managed at state and local levels based on air quality standards.

- **Attainment vs. Non-Attainment:** Area’s meeting standards are "Attainment" areas. "Non-attainment" areas face stricter controls; new NOx generating sources cannot be installed without equal reductions elsewhere (net-zero increase).
- **Emission Reduction Credits (ERCs):** Facilities that reduce emissions below required levels earn ERCs. These can be monetized and sold to other facilities that cannot economically or technically meet standards.
- **Reduction Goals:** The 22 State Ozone Transport Rule targets an 80% overall reduction in NOx, pushing the industry toward high-efficiency reduction technologies.

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03. REDUCTION TECHNOLOGY: SCR

Selective Catalytic Reduction (SCR)

The SCR process involves injecting a reducing agent (Ammonia) into flue gas in the presence of a catalyst. This triggers a chemical reaction converting NOx into harmless free nitrogen and water vapor.

The Chemistry of Reduction

- Reaction for NO:

  $4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$

- Reaction for NO2:

  $4NO_2 + 8NH_3 + 2O_2 \longrightarrow 6N_2 + 12H_2O$

Operational Parameters

- **Efficiency:** SCR systems can achieve NOx reductions of **80-90%**.
- **Temperature Window:** Ideal de-nitrification occurs between **392°F and 1022°F**.
  - *Below 400°F:* Risk of ammonia salt formation.
  - *Above 850°F:* Risk of reverse reaction (Ammonia converting back to NOx).
- **Control Logic:** The process utilizes online feedback from Continuous Emission Monitoring Systems (CEMS) to map injection. Precise control is vital to prevent **"Ammonia Slip"** (over-injection).

Catalyst Technology

Catalysts typically utilize Titanium Oxide or Iron Oxide bases. In coal-fired plants, a mixture of Vanadium (active) and Titanium (support) is common. Geometries vary between:

- **Plate Type:** Higher resistance to erosion and deposition (preferred in German markets).
- **Honeycomb:** High surface area.
- **Moving Bed:** Used for granular activated carbon.

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04. SELECTING A REDUCING AGENT

Choosing the right reagent balances cost, safety, and system complexity.

Option A: Anhydrous Ammonia/NH3 (100% Concentration)

The most efficient and cost-effective reducing agent.

- **Properties:** A colorless gas that boils at -28°F. Stored as a liquid under pressure.
- **Pros:** Lowest cost per ton of Nitrogen; simple delivery system.
- **Cons:** Classified as a Toxic Substance by the EPA. Requires strict Process Safety Management (PSM) and Risk Management Programs (RMP).

Option B: Ammonium Hydroxide (Aqua Ammonia)

Ammonia dissolved in water (NH_4OH).

- **Concentrations:** Commercially available in 19% or 29% (26-Degree Baumé) solutions.
- **Pros:** 19% solution avoids many stringent EPA toxic substance regulations; excellent acid neutralizer.

- **Cons:** Higher freight costs (shipping water); requires larger storage tanks and containment areas; corrosive to copper and aluminum alloys.

Option C: Urea

A solid or liquid fertilizer-grade chemical converted to ammonia for SCR use.

- Process: Urea ($CO(NH_2)_2$) is thermally decomposed/hydrolyzed to form ammonia.

$$2NH_3 + CO_2 \longrightarrow NH_2COONH_4 \longrightarrow CO(NH_2)_2 + H_2O$$

- **Pros:** Safest to handle; minimal regulatory burden.
- **Cons:** Highest complexity and cost. Requires on-site conversion equipment (hydrolysis) and de-mineralized water. System failure leads to immediate SCR shutdown due to lack of ammonia inventory.

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05. MARKET ANALYSIS

Comparative Costs & Transport

Product	Market Reference	Freight Range	Delivered Price	Equiv. Ammonia %
Anhydrous Ammonia	New Orleans (NOLA)	\$50 - \$60	NOLA + \$60-70	**100%**
Ammonium Hydroxide (29%)	Baltimore	Included	\$280 - \$310	**29%**
Ammonium Hydroxide (19%)	Baltimore	Included	\$310 - \$340	**19%**
Urea Prill	New Orleans (NOLA)	\$65 - \$75	NOLA + \$65-75	**56%**
Urea Liquor (50%)	Baltimore	Included	\$250 - \$260	**28%**

Note: While Urea and Aqua Ammonia offer safety advantages, Anhydrous Ammonia remains the standard for industrial efficiency, supported by its massive supply chain in agriculture (80% of US production).

For Engineering Support & Application Specifics

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