
PREVENTION OF NO_x POLLUTION IN AIR WITH SELECTIVE NON-CATALYTIC REDUCTION (SNCR) TECHNOLOGY FOR COAL BASED POWER PLANT

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ABSTRACT:

Coal-fired thermal power stations release nitrogen oxides (NO_x), which are important air pollutants that contribute to environmental problems like acid rain and photochemical smog. In compliance with Indian environmental standards, this research study evaluates Selective Non-Catalytic Reduction (SNCR) technology as a post-combustion technique to reduce NO_x emissions from pulverized coal boilers. Technical viability, operational details, performance metrics, environmental effects, economic considerations, and implementation challenges—particularly with regard to the emission standards established by the Ministry of Environment, Forest and Climate Change (MoEF&CC) under the Environment (Protection) Act, 1986—are important areas of assessment. A comprehensive technical examination and comparison with alternative techniques, such as Selective Catalytic Reduction (SCR), are included in the research, which concludes that SNCR provides an affordable way to achieve moderate NO_x reduction while maintaining operational

KEYWORDS: Selective Non-Catalytic Reduction, Nitrogen Oxides, Pulverized Coal Boilers, Ministry of Environment, Forest and Climate Change, Post-Combustion NO_x Control, Selective Catalytic Reduction, Coal-Fired Thermal Power Stations

INTRODUCTION

The Indian thermal power sector plays a crucial role in electricity generation, with coal-based capacity exceeding 205 GW. However, coal combustion results in significant nitrogen oxide (NO_x) emissions, contributing roughly 30% of total industrial NO_x emissions in India. These emissions adversely affect the environment and public health, involved in issues like ground-level ozone, acid rain, and respiratory diseases. NO_x is produced mainly from two mechanisms in pulverized coal combustion: thermal NO_x from atmospheric nitrogen at high temperatures, and fuel NO_x from chemically bound nitrogen in coal, with the latter accounting for over 80% of emissions. Regulatory measures from the Ministry of Environment, Forest and Climate Change mandate specific NO_x limits based on the commissioning date of plants, establishing a framework for stricter environmental governance and highlighting the need for urgent technology upgrades by the December 2022 deadline.

Nitrogen Oxide Formation Mechanisms in Pulverized Coal Combustion

The process of thermal NO_x formation occurs in high-temperature flame regions of pulverized coal boilers, primarily described by the Extended Zeldovich mechanism, which involves three sequential reactions. The formation process is notably affected by factors such as furnace temperature, residence time, and oxygen concentration. Significant thermal NO_x formation starts at approximately 1200°C and requires a sustained residence time of 50-500 milliseconds in flame zones. The rate of formation increases exponentially above 1400°C, highlighting the importance of effective temperature control in NO_x management strategies. On the other hand, fuel NO_x, which constitutes 80-90% of total NO_x emissions from pulverized coal combustion, arises from the oxidation of chemically bound nitrogen in coal macromolecules. This process involves complex heterogeneous reactions during precocious devolatilization at temperatures ranging from 800-1200°C, where coal nitrogen is released as volatile compounds like hydrogen cyanide (HCN) and ammonia (NH₃). In fuel-rich zones, these compounds form N₂ and intermediate products, whereas in fuel-lean zones, they yield NO. Additionally, nitrogen remaining in coal char contributes to fuel NO_x formation through oxidation in the secondary combustion zone. The conversion efficiency of coal nitrogen to N₂ rather than NO relies heavily on combustion staging, air distribution, and residence time conditions in the furnace.

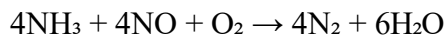
Selective Non-Catalytic Reduction (SNCR): Technology Overview

Process Description and Chemistry

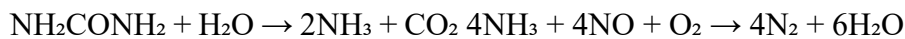
Selective Non-Catalytic Reduction represents a post-combustion emissions control technology based on chemical reduction of nitrogen oxide molecules through injection of ammonia-based reducing agents directly into the furnace flue gas stream. Unlike Selective Catalytic Reduction (SCR), SNCR operates without catalyst systems, relying instead on homogeneous gas-phase chemical reactions at high temperatures within a specific thermal window.

The SNCR process utilizes either ammonia (NH_3) or urea (NH_2CONH_2) as reducing agents. These reagents undergo decomposition and reaction with NO_x molecules according to the following representative reactions:

With ammonia injection:



With urea injection (followed by hydrolysis):



The chemical reduction of NO to N_2 and H_2O represents the primary desired reaction pathway. However, alternative reaction pathways can produce undesired byproducts including nitrous oxide (N_2O), nitrogen dioxide (NO_2), and unreacted ammonia (NH_3 slip).

LITERATURE REVIEW

Nitrogen oxide (NO_x) emissions from coal-fired thermal power plants are a major environmental concern because they contribute to acid rain, smog formation, and respiratory diseases. To comply with stricter emission norms, researchers have explored several post-combustion technologies, among which Selective Non-Catalytic Reduction (SNCR) has emerged as a cost-effective solution for moderate NO_x reduction.

Gal et al. (2017) investigated the efficiency of SNCR systems under different combustion parameters and reported that temperature range, reagent injection location, and residence time significantly influence NO_x reduction performance. Their study concluded that SNCR can achieve satisfactory NO_x control when operating conditions are optimized.

Yang et al. (2009) examined the application of hybrid coal reburning and SNCR processes in coal-fired boilers. The researchers observed that combining reburning with SNCR improves

NO_x reduction efficiency compared to standalone SNCR systems. The study highlighted the importance of integrating multiple combustion modification techniques to enhance emission control.

Further research by Yang et al. (2011) focused on a hybrid SNCR-SCR system for utility boilers. The authors demonstrated that combining Selective Non-Catalytic Reduction with Selective Catalytic Reduction (SCR) offers improved NO_x removal efficiency while reducing operational costs compared to using SCR alone.

Kim et al. (2023) studied NO and N₂O emissions during SNCR and SCR processes in pulverized coal/ammonia co-fired boilers. Their findings revealed that SNCR technology can effectively reduce NO emissions; however, improper operating conditions may increase secondary pollutant formation such as nitrous oxide.

Yu et al. (2010) conducted a comparative evaluation of NO_x control technologies for coal-fired power plants using a fuzzy evaluation method. The study concluded that SNCR is economically attractive for developing countries because of its lower installation and maintenance costs, although its reduction efficiency is lower than SCR systems.

Daood et al. (2013) explored NO_x control through the integration of biomass co-firing, oxygen enrichment, and SNCR technology. Their results showed that combining SNCR with cleaner combustion approaches can significantly reduce overall emissions while improving combustion stability.

Modliński (2015) performed numerical simulations of SNCR processes in coal-fired grate boilers and emphasized the role of computational modeling in optimizing reagent injection and temperature distribution. The study demonstrated that simulation techniques can improve system efficiency and reduce ammonia slip.

Sahu and Sharma (2026) analyzed the economic and policy implications of implementing SCR and SNCR technologies in Indian coal-fired thermal power plants. Their research highlighted that SNCR provides a practical and affordable alternative for plants seeking compliance with the emission standards established by the Ministry of Environment, Forest and Climate Change (MoEF&CC).

Overall, the reviewed literature indicates that SNCR technology is an effective and economical NO_x reduction technique for coal-based thermal power plants. Although its efficiency is generally lower than SCR, SNCR offers advantages such as lower capital investment, easier installation, and reduced operational complexity, making it suitable for developing countries like India.

METHODOLOGY

Injection System Architecture

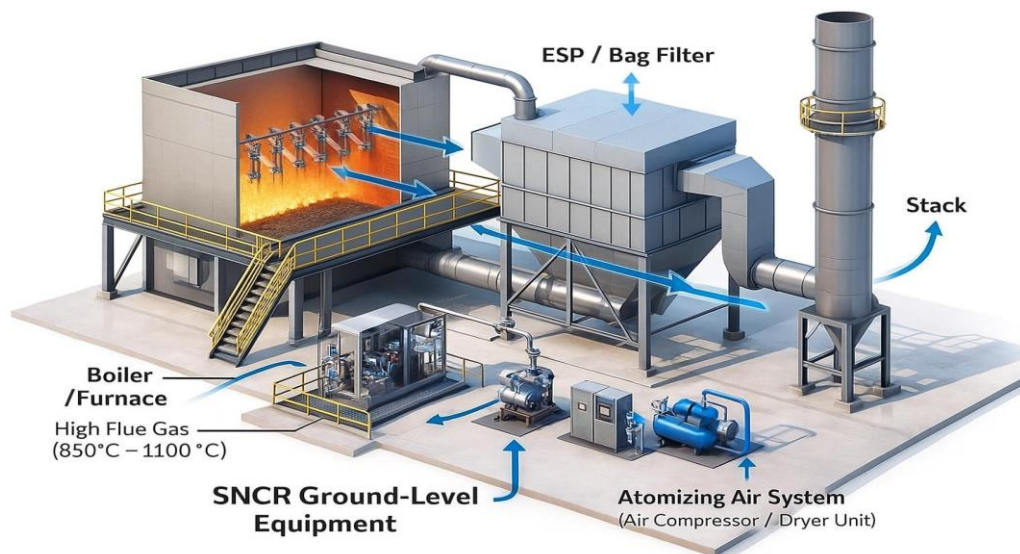
Effective SNCR system design fundamentally depends on precise spatial and temporal distribution of reducing agent across the furnace cross-section, maintaining injection within the optimal temperature window during all operating conditions. Modern SNCR installations typically employ multi-level, Multi injector configurations enabling independent control of individual injection lances.

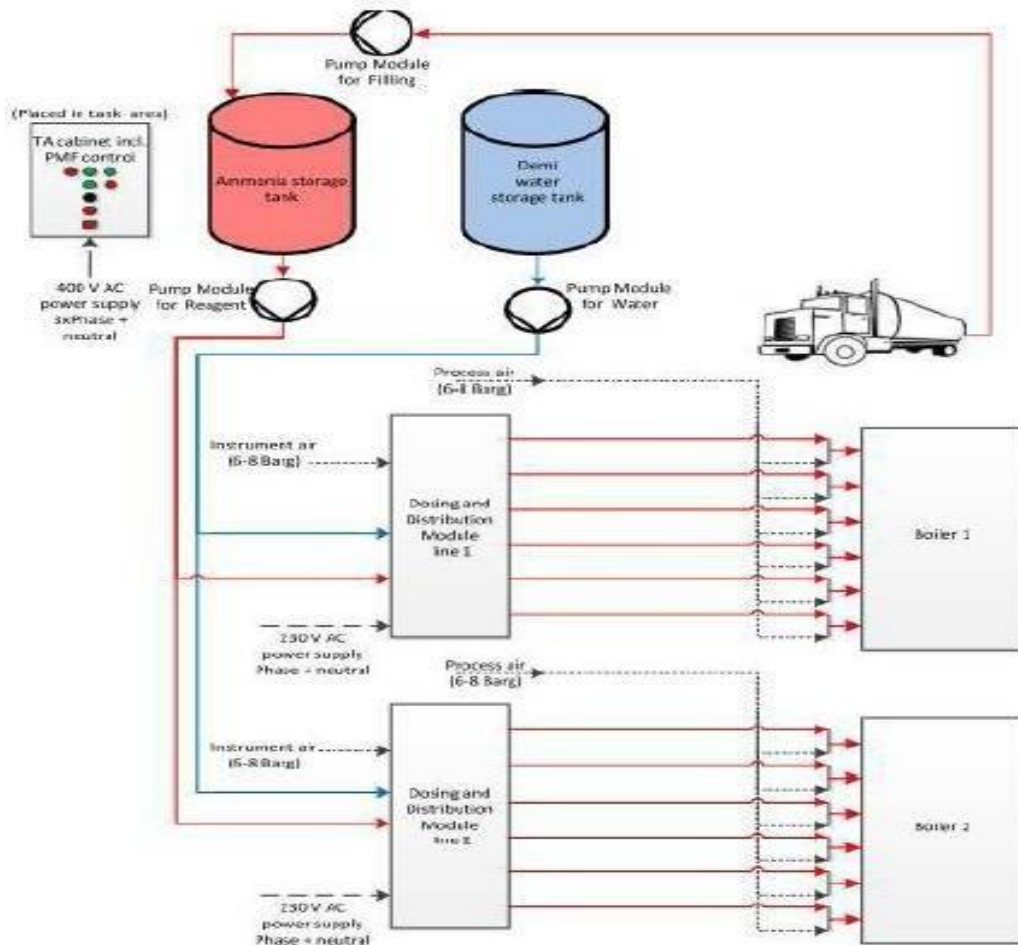
Reducing Agent Storage and Handling:

- Tanks for urea solution (18-20% aqueous solution) or anhydrous ammonia storage
- Pumping systems capable of delivering variable flow rates responding to NO_x concentration and boiler load
- Filtration and pre-treatment systems prevent injector blockage
- Safety systems include pressure relief, automatic shutoff, and leak detection

Injection Lance Configuration:

- Typically, 3-5 injection levels distributed vertically across the furnace
- 4-16 injection nozzles per level enabling cross-sectional coverage
- Lance penetration depths optimized through computational fluid dynamics (CFD) modeling to ensure adequate mixing with flue gas
- Nozzle design emphasizing appropriate droplet size distribution for complete evaporation and gas-phase mixing.





SNCR System Design and Components

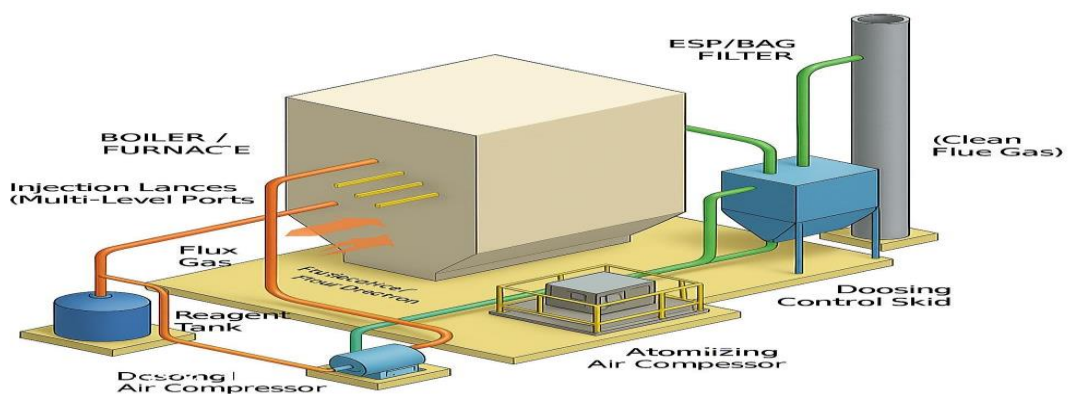


Figure 1-2-3.

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SNCR PERFORMANCE CHARACTERISTICS AND EFFICIENCY PARAMETERS

Normalized Stoichiometric Ratio (NSR) and Performance Relationships

The Normalized Stoichiometric Ratio (NSR) represents a fundamental design and operational parameter determining SNCR performance. NSR is defined as the actual molar ratio of reducing agent (ammonia equivalent) to inlet NO_x divided by the stoichiometric molar ratio required for complete NO_x reduction:

$$\text{NSR} = (\text{Actual NH}_3/\text{NO molar ratio}) / (\text{Stoichiometric NH}_3/\text{NO molar ratio})$$

Optimization of NSR value represents a critical design consideration balancing competing performance objectives:

NSR Effects on NO_x Reduction:

- NSR values below 1.0: Insufficient reducing agent; incomplete NO_x reduction with efficiency increasing proportionally to NSR
- NSR 1.0-1.25: Optimal performance range; maximum NO_x reduction efficiency with minimal ammonia slip
- NSR above 1.25: Diminishing NO_x reduction returns; excess reducing agent oxidizes to NO_x rather than further reducing inlet NO_x; ammonia slip increases sharply

Research optimization studies demonstrate that NSR values of 1.25 yield denitrification efficiencies of 81-82% with ammonia escape of 1.76-2.08 mg/s for large utility boilers. Maintaining NSR strictly within the narrow optimal window requires sophisticated control systems responding dynamically to furnace conditions.

NO_x Reduction Efficiency and Performance Ranges

SNCR efficiency varies substantially based on boiler design, fuel characteristics, and operational conditions:

Typical SNCR Performance:

- Small industrial boilers (<50-200 MW): 40-75% NO_x reduction
- Large utility boilers (200-600 MW): 20-50% NO_x reduction
- Very large utility boilers (>600 MW): <40% NO_x reduction (mixing limitations)

Load-Dependent Performance:

- Full load operation: Maximum efficiency due to optimal temperature window availability.
- Partial load operation (50-75%): Reduced efficiency due to furnace temperature variations and suboptimal flame characteristics.
- Very low load operation (<40%): Substantial efficiency reduction and elevated ammonia slip risk.

Typical Ammonia Slip Values:

Well-optimized SNCR systems: 2-5 ppm

Poorly controlled systems: 10-30 ppm

COMPARATIVE TECHNOLOGY EVALUATION: SNCR VERSUS SCR

Performance Efficiency Comparison

Parameter	SNCR	SCR
NO_x Reduction Efficiency	30-70% (typical: 40-50%)	80-95% (typical: 90%)
Catalyst Requirement	None	Metal oxide catalyst (TiO ₂ -based)
Operating Temperature Window	850-1050°C (furnace)	300-430°C (duct)
Ammonia Slip	2-10 ppm (typical)	<2 ppm (well-optimized)
Byproduct Formation	N ₂ O (particularly with urea)	Minimal N ₂ O

SCR achieves substantially higher NO_x reduction efficiency through catalyst-assisted reactions occurring at lower flue gas temperatures, enabling complete NO_x oxidation to N₂ and H₂O with minimal ammonia slip. The lower operating temperature reduces thermal sensitivity compared to SNCR's narrow temperature window, providing more stable performance across varying boiler loads and conditions.

Capital Cost and Economic Comparison

Cost Category	SNCR	SCR	Cost Ratio
Equipment & Installation	Low	5-10× higher	1:5-10
Ductwork Modifications	Minimal	Extensive	1:3-5
Space Requirements	200-300 m ³	500-1000 m ³	1:2-5
Installation Timeline	12-18 months	24-36 months	1:2
Boiler Downtime	4-8 weeks	12-16 weeks	1:2-4

NCR's substantially lower capital requirement makes it attractive for plants with limited capital availability or facing aggressive compliance deadlines. The simpler system architecture requires minimal ductwork modifications and accommodates existing flue gas treatment trains with limited integration complexity.

TECHNOLOGY SUITABILITY FOR INDIAN COAL-FIRED PLANTS

Indian coal-fired plants face unique challenges influencing technology selection:

High-Ash Coal Characteristics:

Indian coals typically contain 30-40% ash content with complex silica-rich compositions

SCR catalyst fouling and degradation accelerated by ash deposition

SNCR avoids catalyst-related ash interaction issues

European experiences with high-ash coal-fired SCR demonstrate technical feasibility but with increased maintenance requirements.

Existing Plant Infrastructure:

- Most Indian plants designed without SCR accommodations requiring substantial retrofitting
- SNCR retrofits require minimal modifications to existing boiler and flue gas treatment systems
- Limited capital and engineering resources favor simpler SNCR approaches

Regulatory Compliance Requirements:

- 100 mg/Nm³ NOx limit for new plants may require SCR or combined technologies
- 300-450 mg/Nm³ limits achievable through SNCR combinations with combustion modifications
- Staged implementation approaches beginning with SNCR and progressing to SCR remain

viable for existing plants

NTPC Pilot Projects and Performance Results

The National Thermal Power Corporation Limited (NTPC), India's largest power generation company, conducted pilot demonstrations of both SNCR and SCR technologies on coal-fired units to evaluate suitability for Indian plant conditions. These pilot programs, conducted at selected NTPC facilities between 2018-2019, provided crucial data informing technology selection decisions for compliance with 2015 emission standards.

Regulatory and Compliance Challenges

Compliance Deadline Pressure:

- Challenge: Limited time for extended engineering, procurement, and installation cycles.
- Mitigation: Parallel procurement and engineering activities; expedited vendor selection.
- Risk Management: Penalty reduction through phased compliance approaches.

Continuous Emissions Monitoring Requirements:

- Challenge: CEMS installation and calibration adds cost and operational complexity.
- Mitigation: Selection of certified CEMS providers; integration with plant instrumentation.
- Compliance Strategy: Redundant monitoring systems for regulatory verification.

CONCLUSION

Selective Non-Catalytic Reduction (SNCR) is a cost-effective post-combustion NO_x control approach for Indian coal-fired thermal power plants. It offers advantages for plants facing NO_x emission standards, particularly those commissioned between 2003-2016. SNCR's lower capital cost, operational flexibility, and proven performance in Indian coal combustion conditions make it the primary technology for achieving mid-range NO_x reductions across India's existing coal-fired generation fleet. Integration with primary combustion modification measures enables achievement of 200-250 mg/Nm³ emission targets for large plant categories with manageable capital investment. Successful deployment requires careful attention to boiler-specific design considerations, commissioning procedures, and sophisticated automatic control systems. The regulatory compliance pathway established through the Environment (Protection) Rules, 1986 provides clear targets and timelines for SNCR deployment. Strategic deployment of SNCR technology will contribute to improved air quality, public health protection, and sustainable coal-based power generation.

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