Reaction Characteristics of NO\textsubscript{x} and N\textsubscript{2}O in Selective Non-Catalytic Reduction Using Various Reducing Agents and Additives

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Abstract: Artificial nitrogen oxide (NO\textsubscript{x}) emissions due to the combustion of fossil fuels constitute more than 75% of the total NO\textsubscript{x} emissions. Given the continuous reinforcement of NO\textsubscript{x} emission standards worldwide, the development of environmentally and economically friendly NO\textsubscript{x} reduction techniques has attracted much attention. This study investigates the selective non-catalytic reduction (SNCR) of NO\textsubscript{x} by methane, ammonia, and urea in the presence of sodium carbonate and methanol and the concomitant generation of N\textsubscript{2}O. In addition, the SNCR mechanism is explored using a chemical modeling software (CHEMKIN III). Under optimal conditions, NO\textsubscript{x} reduction efficiencies of 80–85%, 66–68%, and 32–34% are achieved for ammonia, urea, and methane, respectively. The N\textsubscript{2}O levels generated using methane (18–21 ppm) were significantly lower than those generated using urea and ammonia. Addition of sodium carbonate and methanol increased the NO\textsubscript{x} reduction efficiency by methane to ≥40% and 60%, respectively. For the former, the N\textsubscript{2}O level and reaction temperature further decreased to 2–3 ppm and 850–900 °C, respectively. The experimental results were well consistent with simulations, and the minor discrepancies were attributed to microscopic variables. Thus, our work provides essential guidelines for selecting the best available NO\textsubscript{x} control technology.

Keywords: selective non-catalytic reduction; NO\textsubscript{x}; N\textsubscript{2}O; CHEMKIN III; greenhouse gas; chemical modeling

1. Introduction

Nitrogen oxides (NO\textsubscript{x}), along with sulfur oxides and dust, are representative air pollutants predominantly produced through the combustion of fossil fuels and are precursors of particulate matter [1,2]. Artificial NO\textsubscript{x} emissions due to fossil fuel combustion represent more than 75% of the total NO\textsubscript{x} emissions [3], which highlights the need for effective NO\textsubscript{x} abatement methods.

Among the NO\textsubscript{x} reduction technologies applied to various industrial processes involving combustion, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) are particularly noteworthy post-treatment prevention methods [4,5]. Although SCR processes are more efficient than SNCR processes [6], the latter offer the benefits of lower installation costs, convenience, and broad applicability, and are therefore more widely used in industry [7]. Given that SNCR has been used as the best available control technology and best available technique in numerous countries [6–8], many researchers have attempted to improve its NO\textsubscript{x} reduction efficiency by altering the reaction conditions, e.g., through the introduction of auxiliary agents and additives [9–11].

In SNCR, the choice of the reducing agent directly impacts the NO\textsubscript{x} reduction efficiency. Amines and cyanides are predominantly used as the reducing agents; ammonia and urea have also been used in general industrial processes [12]. Given the continuous
reinforcement of NO\textsubscript{x} emission standards worldwide and the issues associated with existing reducing agents, the development of environmentally and economically friendly NO\textsubscript{x} reduction methods has drawn much attention [13,14]. Although ammonia and urea are the most widely used reducing agents, ammonia slip caused by unreacted reducing agents adversely affects human health and corrodes process equipment [15]. In addition, ammonia is classified as a toxic chemical in South Korea, and this limits the use of high ammonia concentrations [16]. In view of its low cost, urea is widely used in small businesses instead of ammonia. However, large quantities of N\textsubscript{2}O, a potent greenhouse gas [17], are generated, often failing to meet the environmental standards because of its low NO\textsubscript{x} reduction effectiveness [18].

Herein, gas fuel (CH\textsubscript{4}) typically used in the combustion process was employed as a direct reducing agent to overcome the problems of high cost, ammonia slip, facility site problems, and greenhouse gas generation. The use of carbon-containing gases as reducing agents [19] and the injection of additional CH-based additives into existing reducing agents [19,20] during SNCR have been extensively investigated. Although CH-based reducing agents have lower efficiencies than existing reducing agents, no site is required in the former case, as fuels that are used in the combustion process are directly added as reducing agents and do not cause severe issues such as ammonia slip [20,21]. Most studies on NO\textsubscript{x} reduction technologies have primarily derived conclusions through the analysis of experimental results, whereas only few works have analyzed the SNCR mechanism.

To bridge this gap, this study investigates the reduction of NO\textsubscript{x} by methane, ammonia, and urea and the concomitant generation of N\textsubscript{2}O. In addition, the SNCR mechanism is probed using a chemical modeling software (CHEMKIN III).

2. Materials and Methods
2.1. Experimental Setup

Lab-scale experiments were performed in a cylindrical stainless steel (304 3/4H SS) reactor with a width of 42.6 mm and a length of 850 mm inside a heating furnace operated at a maximum temperature of 1150 °C (Figure 1). The gaseous reactants were mixed in the mixing chamber and then introduced into the reactor through the preheater. The temperature of preheater was set to 750–800 °C. For efficient mixing, the mixing chamber utilized a tube of 20 mm in diameter and 5 m in length. Three thermocouples were installed inside the reactor to measure and adjust the reaction temperature. The injected reducing agent was sprayed at a set flow rate using a mass flow controller.

![Figure 1. Schematic of the experimental procedure and the lab-scale SNCR process.](image-url)

Among the gases emitted after SNCR, NO\textsubscript{x} and O\textsubscript{2} were quantified using a portable flue gas analyzer (GreenLineMK2, Il-Sang Co., Ltd., Korea) of the electrochemical electrode
cell type, whereas N\textsubscript{2}O was quantified using the instrument (Hymeth, Kinsco Co., Ltd., Seoul, Korea) employed in the NDIR method.

2.2. Experimental and Modeling Conditions

The reactor temperature ranged from 800 to 1150 °C and was varied in steps of 25 °C for a detailed analysis of temperature change effects. The concentration of the introduced NO\textsubscript{x} was fixed at 1000 ppm. To simulate the actual process, a mixture of NO (90 vol%) and NO\textsubscript{2} (10 vol%) was introduced into the system, where the O\textsubscript{2} level ranged from 0 to 10 vol%. The normalized stoichiometric ratio (NSR) of the reducing agents ranged from 1.0 to 2.0, and the NSR of the additionally injected additives relative to the reducing agents ranged from 0 to 0.3. The total reaction time was set to 1.0 s, and the flow velocity inside the reactor ranged from 21 to 27 L/min. The flow rate and flow velocity were adjusted in real time using MFC. CHEMKIN III modeling was performed to analyze the experimental results under conditions similar to those used in the experiments. CHEMKIN III is a software whose purpose is to facilitate the formation, solution, and interpretation of problems involving elementary gas-phase chemical kinetics. The thermodynamic data pertaining to substances related to each unit reaction were extracted from NASA CEA code [22,23] and GRI Mech 3.0 code [24,25] databases. Table 1 lists the experimental and modeling conditions.

Table 1. Experimental and modeling conditions.

| Carrier Gas | Ar          |
|-------------|-------------|
| Gas Conditions |           |
| NO          | 900 ppm     |
| NO\textsubscript{2} | 10 vol% of NO |
| O\textsubscript{2}    | 0, 3, 5, 7, 10 vol% |

Experimental and Modeling Conditions

| reducing agent (NH\textsubscript{2})\textsubscript{2}CO, CH\textsubscript{4}, NH\textsubscript{3} |
|---------------------------------------------------------------|
| NSR of reducing agent 1.0, 1.5, 2.0                          |
| Additive to reducing agent Na\textsubscript{2}CO\textsubscript{3}, CH\textsubscript{3}OH |
| NSR of additive 0.0, 0.2, 0.3 (0.1 interval)                 |
| Temperature 800, 825, ..., 1075, 1100 °C                      |
| Residence time 1.0 s                                         |
| Modeling database NASA CEA code, GRI Mech 3.0 code            |

3. Results and Discussion

3.1. Reactor Temperature Profile

Prior to experiments, a temperature profile test was conducted to confirm the uniformity of the temperature distribution inside the reactor. As temperature conditions significantly influence chemical reactions occurring during the SNCR, a uniform setting is required [26]. When the temperature distribution was examined at the same temperature setting by selecting three measurement points inside the reactor and two measurement points outside the reactor, points 2, 3, and 4 inside the reactor exhibited differences of 30, 10, and 20 °C, respectively. These temperature variations were attributed to a discrepancy between the temperature of the gas at the point of introduction (point 1) and that of the mixture at point 2. Moreover, the “end effect” [27], which was observed at both ends of the reactor, and the “wall effect”, which occurred on the reactor wall for points 3 and 4, may have contributed to the observed temperature discrepancies [28]. “End effect” and “wall effect” are phenomena in which the temperature decreases at the beginning and end of the reactor due to movement of fluid inside the reactor and the reactor temperature. These effects were accounted for, and the temperatures at the three points were suitably altered for the experiment. Figure 2 shows the data measured at each temperature.
3.2. NO\textsubscript{x} Reduction Performances of Ammonia, Urea, and Methane

NO\textsubscript{x} reduction efficiencies were analyzed for reductant (ammonia, urea, and methane) NSRs of 1.0–3.0 (Figure 3). The NO\textsubscript{x} reduction efficiency equaled 80–85% for ammonia at an NSR of 1.5, 66–68% for urea at an NSR of 1.5, and 32–34% for methane at an NSR of 2. Moreover, the primary reactions affecting NO\textsubscript{x} reduction in the reactor during reducing agent injection were identified as reactions (1) and (2) for ammonia and urea and as reactions (3) and (4) for methane [29,30]:

\begin{align}
\text{(1)} & \quad \text{NH}_3 + \text{NO} + 0.25\text{O}_2 \rightarrow \text{N}_2 + 1.5\text{H}_2\text{O} \\
\text{(2)} & \quad (\text{NH}_2)_2\text{CO} + 2\text{NO} + 0.5\text{O}_2 \rightarrow 2\text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O} \\
\text{(3)} & \quad \text{CH}_4 + 4\text{NO}_2 \rightarrow 4\text{NO} + \text{CO}_2 + 2\text{H}_2\text{O} \\
\text{(4)} & \quad \text{CH}_4 + 4\text{NO} \rightarrow 2\text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O}
\end{align}

Figure 3. Effects of temperature on the levels of (a) NO\textsubscript{x} and (b) N\textsubscript{2}O obtained under optimal conditions (NO = 900 ppm, NO\textsubscript{2} = 100 ppm, O\textsubscript{2} = 7%, NH\textsubscript{3} and (NH\textsubscript{2})\textsubscript{2}CO NSR = 1.5, CH\textsubscript{4} NSR = 2) for (NH\textsubscript{2})\textsubscript{2}CO, NH\textsubscript{3}, and CH\textsubscript{4} as reducing agents.
The N$_2$O levels generated using methane (18–21 ppm) were significantly lower than those generated using urea (157 ppm) and ammonia (51 ppm). In addition, the range of activation temperatures for methane (875–925 °C) was 50–80 °C lower than those for ammonia and urea.

Methane exhibited a lower NO$_x$ reduction efficiency than ammonia and urea but generated a significantly smaller amount of N$_2$O and offered the benefit of a lower (by ~80 °C) reaction temperature range. Considering that N$_2$O is a potent greenhouse gas, it is necessary to develop methods of increasing the NO$_x$ reduction efficiency, such as for the injection of additives to reducing agents and the adjustment of operating variables [31–33]. These methods are expected to be used as alternatives for existing reducing agents.

3.3. CH$_4$-SNCR in the Presence of Additives (Na$_2$CO$_3$ and CH$_3$OH)

Numerous studies have attempted to reduce the range of activation temperatures and increase the NO$_x$ reduction efficiency by injecting supplementary additives into the primary reducing agents used in the SNCR process, namely ammonia and urea [10,11]. In this section, methane, which exhibited a low NO$_x$ reduction efficiency compared to urea and ammonia, was used as a direct reducing agent in the presence of sodium carbonate and methanol as additives, and the effects of these additives were analyzed (Figure 4).

When methanol was injected at a ratio of 0.3, the NO$_x$ reduction efficiency marginally increased to 60%, and the reaction temperature range decreased by 25 °C compared to that observed in the methane-only scenario. The N$_2$O concentration (16 ppm) obtained in the presence of methanol was also lower than that obtained without methanol (21 ppm). The following primary reactions occurred in the presence of methanol [34]:

\[
\begin{align*}
    \text{CH}_3\text{OH} + O & \rightarrow \text{CH}_3 + O_2 + H \quad (5) \\
    \text{CH}_3 + \text{NO} & \rightarrow \text{HCN} + \text{H}_2\text{O} \quad (6) \\
    \text{HCN} + \text{OH} & \rightarrow \text{HNCO} + \text{H} \quad (7) \\
    \text{HNCO} + \text{OH} & \rightarrow \text{NCO} + \text{H}_2\text{O} \quad (8) \\
    \text{NCO} + \text{NO} & \rightarrow \text{N}_2 + \text{CO}_2 \quad (9) \\
    \text{NCO} + \text{NO} & \rightarrow \text{N}_2\text{O} + \text{CO} \quad (10) \\
    \text{HCN} + O & \rightarrow \text{CN} + \text{OH} \quad (11)
\end{align*}
\]
NO$_x$ reduction was affected by reaction (6), which involves the separation of CH$_3$ from methanol [34]. The increase in the N$_2$O reduction efficiency was relatively minor compared to the significant increase in the NO$_x$ reduction efficiency, which was attributed to the simultaneous occurrence of N$_2$O generation in reaction (10) and its reduction in reaction (12). As simultaneous reactions are affected by reaction conditions, our results suggest that N$_2$O can be further generated depending on the reaction conditions. CH compounds as reducing agents are known to increase the reaction efficiency and induce reactions at low temperatures by accelerating the reactions of OH radicals [35].

Na-containing additives are known to accelerate the generation of hydrogen, hydrogen peroxide, hydrocarbons, and alcohols, and induce NO$_x$ reduction [36,37]. In particular, the addition of Na-based additives to reducing agents lowers the reaction temperature and extends the range of the activation temperature [37]. In the present method, the injection of sodium carbonate (additive/CH$_4$ = 0.2) increased the NO$_x$ reduction efficiency by ~40%. Moreover, this agent efficiently promoted N$_2$O reduction, generating only 2–3 ppm of N$_2$O. This increased efficiency was attributed to reaction (19), in which Na generated by the decomposition of sodium carbonate combines with N$_2$O to generate NaO and N$_2$. However, significantly lower quantities of N$_2$O were generated at temperatures of 900 $^\circ$C and higher. The primary reactions occurring in the SNCR reactor during the injection of sodium carbonate were identified as follows [36,37]:

$$\text{Na}_2\text{CO}_3 \rightarrow \text{Na}_2\text{O} + \text{CO}_2$$ (13)

$$\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH}$$ (14)

$$\text{NaOH} + \text{O}_2 \rightarrow \text{NaO}_2 + \text{OH}$$ (15)

$$\text{NaOH} + \text{M} \rightarrow \text{Na} + \text{OH} + \text{M}$$ (16)

$$\text{NaOH} + \text{H} \rightarrow \text{Na} + \text{H}_2\text{O}$$ (17)

$$\text{NaO}_2 + \text{M} \rightarrow \text{Na} + \text{O}_2 + \text{M}$$ (18)

$$\text{Na} + \text{N}_2\text{O} \rightarrow \text{NaO} + \text{N}_2$$ (19)

$$\text{Na} + \text{NO}_2 \rightarrow \text{NaO} + \text{NO}$$ (20)

$$\text{NaO} + \text{H}_2\text{O} \rightarrow \text{NaOH} + \text{OH}$$ (21)

$$\text{NaO} + \text{NH}_3 + \text{M} \rightarrow \text{NaOH} + \text{NH}_2 + \text{M}$$ (22)

### 3.4. Reaction Modeling

CHEMKIN III was used for the theoretical analysis of experimental results. Among the reaction models available in CHEMKIN III, the SENKIN reaction model uses the thermodynamic properties (entropy, enthalpy, and heat capacity) of chemical species participating in reactions and the reaction mechanisms composed of unit reactions. Moreover, the SENKIN model derives experimental results in advance, enabling the examination of chemical changes with reaction time [38,39]. In this section, after the optimal efficiency response in the experiment was compared with the modeling results, reaction pathways were constructed using the Fortran (Ver. 95, IBM, ISO/IEC 1539-1:1997) program based on sensitivity analysis to investigate the reducing agents and additive reactions.

Figure 5 shows the comparative data results of experiments and modeling. When methane was used as the reducing agent, the experimental and simulated trends in the NO$_x$ reduction efficiency, N$_2$O generation, temperatures for improved efficiency, and reaction time agreed with each other. However, the experimental efficiencies were lower than the simulated ones by about 4.21% (optimal efficiency condition). This discrepancy was attributed to the action of microscopic variables in the experiment and agreed with other studies, wherein modeling and experiments were performed simultaneously [40,41].
Figure 5. (a,c) Experimental and (b,d) simulated (identical conditions) effects of temperature and additives on the levels of (a,b) NO\textsubscript{x} and (c,d) N\textsubscript{2}O.

3.4.1. Sensitivity Analysis Using CHEMKIN III

Sensitivity analysis is a good method of obtaining chemically essential reactions from target reactions and has been used for process design, effect analysis, and device improvement [42]. Herein, sensitivity analysis was conducted for 645 reactions used in modeling to identify the reactions with the minimal effect on N\textsubscript{2}O generation and NO\textsubscript{x} reduction in the case of methane. The effect of the rate constant of each reaction on NO\textsubscript{x} and N\textsubscript{2}O concentrations was examined using the following equation [43,44]:

\[
S_{j,i} = \frac{\Delta Z_j}{\Delta k_i}
\]

Here, \(Z_j\) is the concentration under condition \(j\), \(k_i\) is the rate constant of reaction \(i\), and \(S_{j,i}\) is the sensitivity [42]. A negative result of sensitivity analysis represents a reduction in NO\textsubscript{x} and N\textsubscript{2}O concentrations, whereas a positive result represents an increase in these concentrations. When methane was used in the absence of additives, the primary reactions were identified as follows:

\[
\begin{align*}
CH_4 + O_2 &\rightarrow CH_3 + HO_2 & (23) \\
CH_4 + OH &\rightarrow CH_3 + H_2O & (24) \\
CH_3 + O_2 &\rightarrow CH_2O + OH & (25) \\
CH_3 + CH_3(M) &\rightarrow C_2H_6(M) & (26) \\
CH_3 + O_2 &\rightarrow CH_3O + O & (27)
\end{align*}
\]

Reactions (25)–(27) exhibited high sensitivity to NO\textsubscript{x} generation, NO\textsubscript{x} reduction and N\textsubscript{2}O generation, and N\textsubscript{2}O reduction, respectively. In particular, reaction (26) significantly affected both NO\textsubscript{x} reduction and N\textsubscript{2}O generation. This suggests that nitrogen and NO\textsubscript{x}, which were separated during NO\textsubscript{x} decomposition by the reducing agent, were converted into N\textsubscript{2}O, which resulted in simultaneous NO\textsubscript{x} reduction and N\textsubscript{2}O generation. As simultaneous reactions are significantly affected by external reaction conditions such as temperature,
oxygen concentration, and reaction time, we decided to comprehensively examine the external conditions when CH-based reducing agents were used for N₂O reduction.

Sensitivity analysis for NO and N₂O reactions showed that the most important reactions could be selected as CH₃ + O₂ = CH₂O + OH, CH₃ + CH₃(M) = C₂H₆(M), and CH₃ + O₂ = CH₃O + O used only CH₄ in 645 reactions (Figure 6).

Figure 6. Sensitivity coefficients of (a) NOₓ and (b) N₂O in CH₄ SNCR reactions (NO = 900 ppm, NO₂ = 100 ppm, O₂ = 7 vol%, CH₄ NSR = 2).

3.4.2. Identification of CH₄-SNCR Reaction Pathways Using Fortran

Reaction pathways were constructed by integrating the results derived from CHEMKIN III using Fortran (Ver. 95, IBM, ISO/IEC 1539-1:1997). Overall, an integral reaction flow analysis was constructed using methane as the reducing agent, and methane oxidation and NOₓ removal reactions were simulated separately. Finally, the major reaction pathways were constructed by applying the sensitivity constants obtained in Section 3.4.1 and compared with those determined for urea.

The oxidation reactions of methane to CH₂O and HCO are the primary reactions occurring during methane oxidation. Subsequently, HCO is decomposed into HCN and HCCO, converted into NCO via reactions with N and C, and finally generates CO₂ and N₂, thereby reducing NOₓ. Figure 7 shows the CH₄ oxidation reaction, NOₓ reduction reaction, and the total reaction flow for CH₄ as a reducing agent.

The primary reaction pathways (Figure 8) were used to analyze the mechanism of NOₓ reduction by methane and urea. Urea generated ammonia and HNCO, and the former afforded NH₂ and an O or OH radical. NH₂ is an essential element of SNCR, as it reacts with NO to generate N₂ [45]. In addition, HNCO reacts with the H radical to furnish NH₂ or NCO, and NCO is finally converted into N₂O or N₂ to achieve the reduction of NOₓ.
Figure 7. Reactions occurring during SNCR with CH$_4$ as the reducing agent (NO = 900 ppm, NO$_2$ = 100 ppm, O$_2$ = 7 vol%, CH$_4$ NSR = 2, temperature = 900 °C). (a) CH$_4$ oxidation reactions, (b) NO$_x$ reactions, (c) overall pathways.

The primary reaction pathways (Figure 8) were used to analyze the mechanism of NO$_x$ reduction by methane and urea. Urea generated ammonia and HNCO, and the former afforded NH$_2$ and an O or OH radical. NH$_2$ is an essential element of SNCR, as it reacts with NO to generate N$_2$ [45]. In addition, HNCO reacts with the H radical to furnish NH$_2$ or NCO, and NCO is finally converted into N$_2$O or N$_2$ to achieve the reduction of NO$_x$.

Figure 8. Comparison of (a) CH$_4$ and (b) (NH$_2$)$_2$CO primary pathways (NO = 900 ppm, NO$_2$ = 100 ppm, O$_2$ = 7 vol%, CH$_4$ NSR = 2, temperature = 900 °C).

Unlike those obtained for urea, the modeling results obtained for methane as a reducing agent indicated only one primary reaction path, according to which CH$_4$ is converted...
into HCN through reactions ((26)–(31)), and the generated NCO reacts with an O radical to afford NO, N₂, and N₂O.

\[
\begin{align*}
\text{CH}_4 + O & \rightarrow \text{CH}_3 + \text{OH} \quad (28) \\
\text{CH}_3 + \text{OH} & \rightarrow \text{CH}_2 + \text{H}_2\text{O} \quad (29) \\
\text{CH}_3 + \text{O}_2 & \rightarrow \text{CH}_2\text{O} + \text{OH} \quad (30) \\
\text{CH}_2 + O & \rightarrow \text{HCO} + \text{H} \quad (31) \\
\text{CH}_2\text{O} + O & \rightarrow \text{HCO} + \text{OH} \quad (32) \\
\text{HCO} + N & \rightarrow \text{HCN} + \text{O} \quad (33)
\end{align*}
\]

4. Conclusions
The effects of reducing agents (ammonia, urea, and methane) on the SNCR process were determined experimentally and simulated using modeling software. In addition, the NOₓ reduction and N₂O generation characteristics were analyzed in the presence of sodium carbonate and methanol as supplementary additives.

NOₓ reduction efficiencies of 80–85%, 76–78%, and 32–34% were obtained for ammonia, urea, and methane, respectively. Although methane exhibited the lowest NOₓ reduction efficiency, its reaction temperature range (850–950 °C) was approximately 80 °C lower than that of the other reducing agents. Moreover, the N₂O level (21 ppm) observed in the case of methane was four times lower than that observed for ammonia and more than 15 times lower than that observed for urea. When additives were injected (CH₄ NSR = 0.2) to improve the NOₓ reduction efficiency of CH₄, the use of methanol increased this efficiency to ≥60%, while the use of sodium carbonate increased the efficiency to 40%. Moreover, the addition of methanol significantly reduced N₂O emissions. Chemical modeling revealed that N₂O reduction was caused by the chain reaction of Na. The reaction tree constructed for the use of methanol revealed that CH₂O and HCN were generated as intermediates and were eventually converted into NCO, which, in turn, reduced NOₓ and generated N₂O.

This study comprehensively analyzed various reducing agents and additives used in the SNCR process. The CH₄-SNCR process cannot be defined as the NOₓ reduction technology with the highest efficiency. However, considering the constantly changing technology and the diverse conditions at various industrial combustion facilities, we believe that our findings will serve as guidelines for selecting the best available control technology toward reducing air pollution, including NOₓ pollution.

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