




Review

Reduction of NO_x Emission from the Cement Industry in South Korea: A Review

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Abstract: As climates change around the world, concern regarding environmental pollutants emitted into the atmosphere is increasing. The cement industry consistently produces more than 4000 million metric tons of cement per year. However, the problem of air pollutants being emitted from the calcination process is becoming more critical because their amount increases proportionally with cement production. Each country has established regulatory standards for pollutant emission. Accordingly, the cement industry is equipped with facilities to reduce air pollutants, one of which is the NO_x removal process. NO_x reduction processes under combustion conditions are modified to minimize NO_x generation, and the generated NO_x is removed through post-treatment. In terms of NO_x removal efficiency, the post-treatment process effectively changes the combustion conditions during calcination. Selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR) processes are post-treatment environmental facilities for NO_x reduction. Accordingly, considering the stringent NO_x emission standards in the cement industry, SNCR is essential, and SCR is selectively applied. Therefore, this paper introduces nitrogen oxide among air pollutants emitted from the South Korean cement industry and summarizes the technologies adapted to mitigate the emission of NO_x by cement companies in South Korea.

Keywords: environmental regulation; nitrogen oxide; cement industry; South Korea; reduction process



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1. Introduction

Cement is a binder in the form of fine powder that has been used for a long time in the building industry and is one of the most basic materials. Owing to its hardening properties when mixed with water, it is used as a building material by adding other aggregates or additives. This became the basis for the beginning of modern civilization and contributed greatly to urban development. Consequently, cement is continuously produced, and it is difficult to replace cement in the construction industry [1–3]. Looking at the amount of cement produced worldwide (Figure 1, red line and symbol), production has increased relative to 10 years ago and has been consistently maintained at over 4000 million metric tons over the last five years. The major cement producers, in decreasing order, are China, India, Vietnam, United States, Indonesia, Turkey, Iran, Brazil, Russia, Japan, Egypt, and South Korea, with Asia producing the largest amount of cement. The amount of cement produced in these 12 countries accounts for approximately 80% of the total cement produced worldwide, with China producing the largest amount (over 50%). Among them, Korea ranks 12th in cement production, accounting for only 1%. Cement demand (Figure 2) increased by approximately 24% in 2020 compared to 2017, and in terms of demand by region, the Asia Pacific, which produces the most cement, accounts for approximately

75% of the total demand. As such, satisfying the increase in the demand for cement is difficult [4–6].

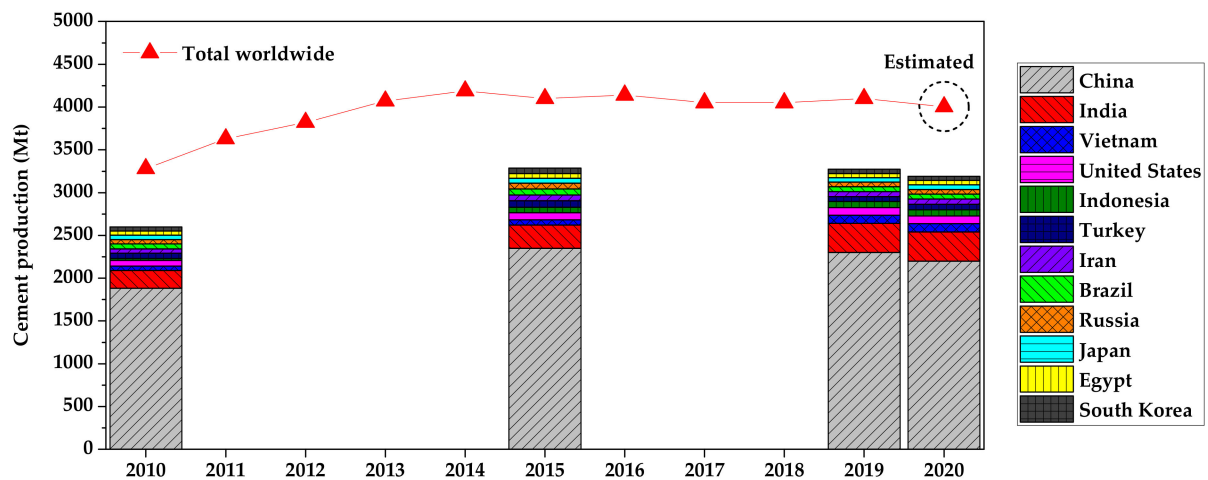


Figure 1. Annual cement production (data taken from [4,5]; [5] is based on IEA data from IEA (2020) Global cement production, 2010–2019, www.iea.org/data-and-statistics, accessed on 2 November 2021. All rights reserved; as modified by J. Kim, IAE).

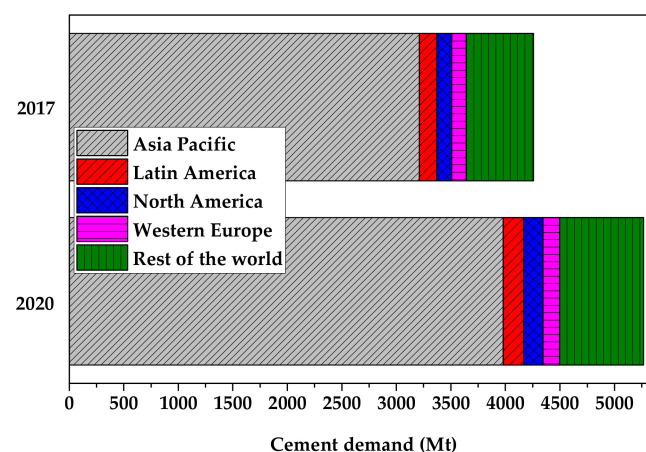


Figure 2. Cement consumption in 2017 and 2020 (data taken from [6]).

The scale of the cement production process, which produced approximately 4000 million metric tons in 2020, is bound to be large, and it has a proportional environmental impact. As seen from the life cycle of cement in Figure 3A, the input materials are raw materials, fuels, and energy, and a significant amount of waste is emitted as air pollutants and byproducts in the cement process. A large amount of coal is used as fuel to supply the high amount of heat required for the characteristics of the cement industry. However, as the amount of waste increases, the use of waste to supply heat is becoming a trend. As described above, eco-friendly management is being conducted from the viewpoint of recycling resources with waste treatment technology while using waste as fuel; however, because a significant amount of air pollutants are generated by calcination (Figure 3B), an air pollutant reduction facility is necessary for the cement production process. Air pollutants such as CO₂, CO, CH₄, sulfur oxide (SO_x), nitrogen oxide (NO_x), and particulate matter (PM), which are not only carcinogens but also cause global warming and acidification, are generated [1,7,8].

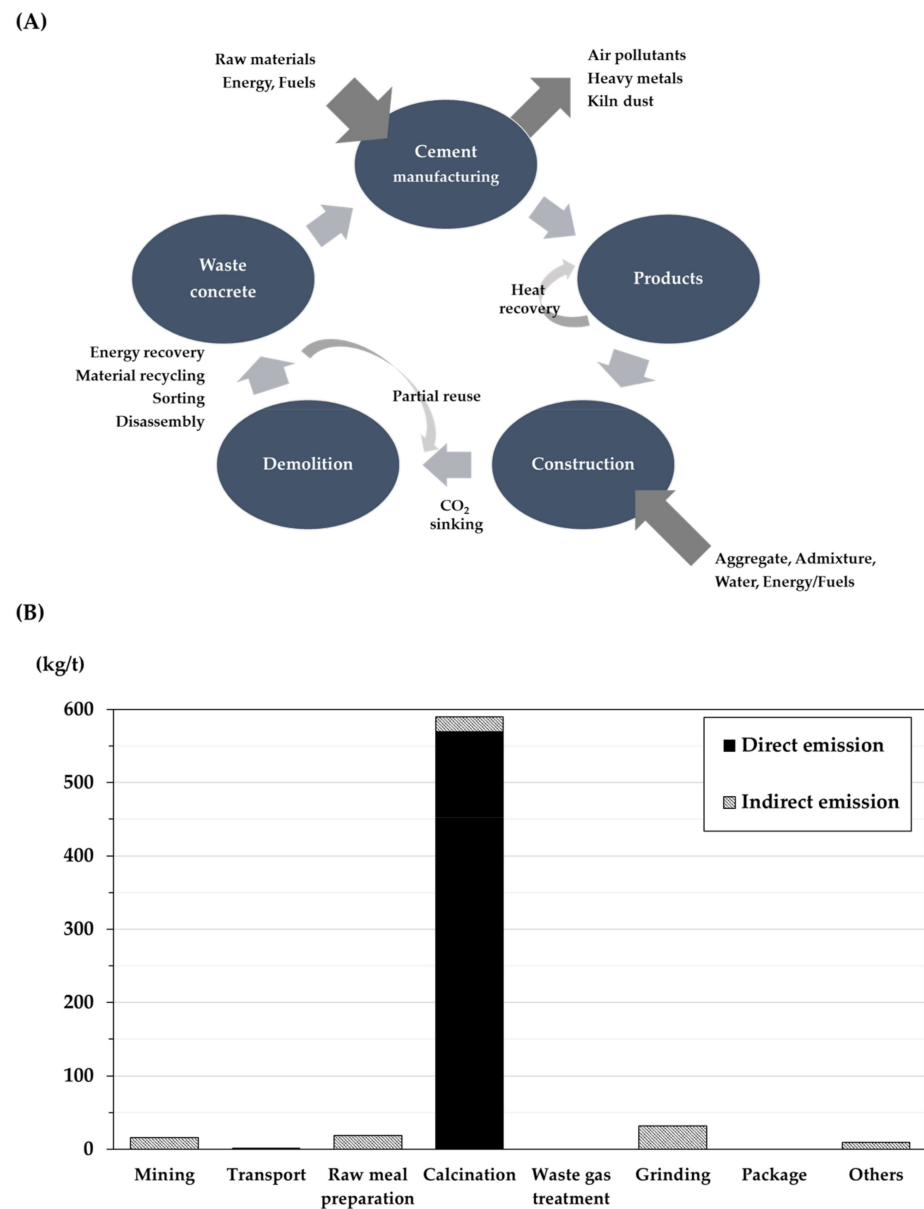


Figure 3. Life cycle (A) and greenhouse gas emissions by process (B) of cement production (data taken from [7]).

The annual air pollutant emissions of CO_2 , SO_x , and NO_x are steadily increasing (red dotted line in Figure 4) in China, accounting for more than 50% of the global cement production. When comparing air pollutants as of 2015, it can be seen that they occur mostly in the order of CO_2 , CO, and NO_x , which are substances produced by combustion [9]. As such, because significant amounts of air pollutants are emitted from the cement industry, the climate change caused by this cannot be ignored, and environmental problems have been pointed out.

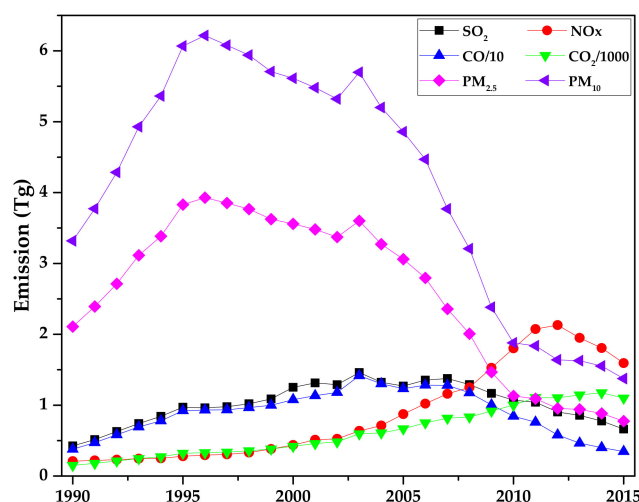


Figure 4. Air pollution emissions trend from China's cement industry for the period 1990–2015 (data taken from [9]).

Each country manages the measurement system at the national level to measure the air pollutants emitted from the cement process. According to the data published by Global Cement [10], different emission standards (SO_2 , NO_x , Hg, PM) of air pollutants from the cement industry are applied in each country. In most countries, regulations are imposed based on the date of establishment of cement factories, and in the case of newly established cement factories, the regulations are tighter than those of existing factories as emission standards are gradually becoming stringent [10]. In the case of South Korea, the Korea Environment Corporation (K-eco) manages the emission status through the telemonitoring system (TMS) of the place of business. Air pollutants measured by TMS include dust (total suspended particles (TSP)), SO_x , NO_x , hydrogen chloride (HCl), hydrogen fluoride (HF), ammonia (NH_3), and carbon monoxide (CO). To measure air pollutants, measuring devices are attached to several outlets, and the results are obtained by measuring the average concentration in 30-min increments. By providing measured values of various substances as mentioned above, business sites are encouraged to voluntarily reduce air pollutants.

In this study, we target NO_x , which is a carcinogen among air pollutants, and summarize the NO_x generation pathway in the cement industry, the amount of NO_x generated in the Korean cement industry, and Korean regulatory standards imposed to regulate this. In addition, the NO_x reduction process (DeNO_x) conducted by cement manufacturers in Korea to reduce NO_x emissions is summarized.

2. NO_x Emission and Regulation in the Cement Industry

NO_x generally includes NO and NO_2 , and it causes serious problems not only in the environment but also in the human body owing to chemical reactions in the atmosphere. Typically, it causes adverse environmental effects such as photochemical smog, acid rain, global warming, fine dust, and soil contamination due to nitrate, which in turn can cause diseases in the respiratory tract and heart due to lung damage [11,12]. NO_x is mainly generated from (1) nitrogen present in the air during cement production under high-temperature combustion conditions and also when the nitrogen contained in the fuel is oxidized. (2) In addition, the nitrogen present in the feed material combusts, or pre-existing free radicals react with the nitrogen in the air. Moreover, in recent years, there have been cases where waste is used as a raw material for combustion, and the concentration of NO_x generated varies depending on the type of waste [13]. However, NO_x generated under combustion conditions has a large difference in NO_x concentration caused by temperature, as shown in Figure 5; consequently, NO_x generation during the manufacture of cement with a firing process is a problem that must be solved [14].

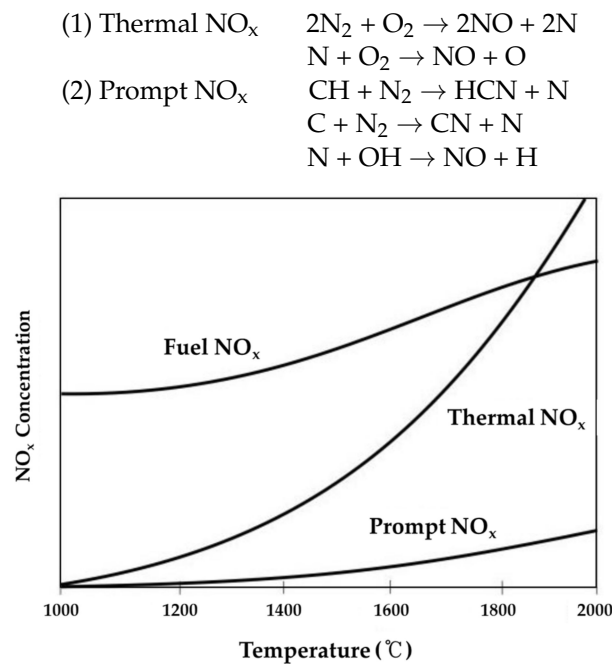


Figure 5. NO_x concentration by temperature (Reproduced with permission from [14] with permission from UNESCO-Encyclopedia of Life Support Systems (EOLSS)).

2.1. NO_x Emission Regulation of Each Country

According to the NO_x standard data of each country published in 2014 [10], most countries set the limit within the range of approximately 195–400 ppm, and a minimum and maximum of about 98 and 1220 ppm, respectively, of the emission limit of NO_x are allowed. In China and India, which are the largest producers of cement (Table 1), environmental regulations are being more rigid, and government authorities are demanding lower NO_x emission limits. This regulated value corresponds to recently built cement plants, and as countries do not regulate or discuss introducing the NO_x limit, NO_x emission regulation is becoming a severe concern worldwide.

Table 1. NO_x emission standard in each country (data taken from [10]).

Country	NO _x Emission Standard (ppm)	Note
China	≤390	2008 regs.
	≤195	2013 regs. (Existing plants)
	≤195	2013 regs. (New plants)
India	≤585 (≤390)	Proposed by industry
	≤488 (≤293)	Proposed by authorities
Lebanon	≤1220	Old plant standards
EU	≤98	—
Germany	≤98	—

2.2. NO_x Emission Regulation of South Korea

In South Korea, the NO_x concentrations emitted by nine cement manufacturers (A to H) can be confirmed through the TMS measurement results implemented by the Korea Environment Corporation. The annual NO_x emissions by each manufacturer are shown in the graph (Line and symbol) on the right axis of Figure 6, and the total NO_x emissions from cement plants in Korea are shown (gray column) on the left. As can be seen, there has been a general trend of decreasing NO_x over the past five years [15]. When compared (Figure 7A), a similar trend can be observed in reducing clinker and cement production [16]. In addition, NO_x emissions from cement manufacturers in Korea are on the rise if we observe the

contribution of the cement industry to NO_x emission sources measured by TMS in Korea (Figure 7B). In particular, as of 2020, NO_x emitted from Korean cement manufacturers is 52,427 tons/year, which accounts for 36% of the total NO_x emissions (145,934 ton/year) in Korea—the highest in the past 5 years, as measured by TMS [15]. In Figure 7, although the amount of NO_x emitted by cement manufacturers in Korea has decreased, the ratio of NO_x emitted by cement manufacturers to total NO_x emissions has increased. It can be indirectly inferred that while more efficient NO_x reduction technologies are being applied to businesses that emit NO_x , for observing tightened NO_x emission standards in Korea, they are not yet applied or prioritized for application to the cement industry.

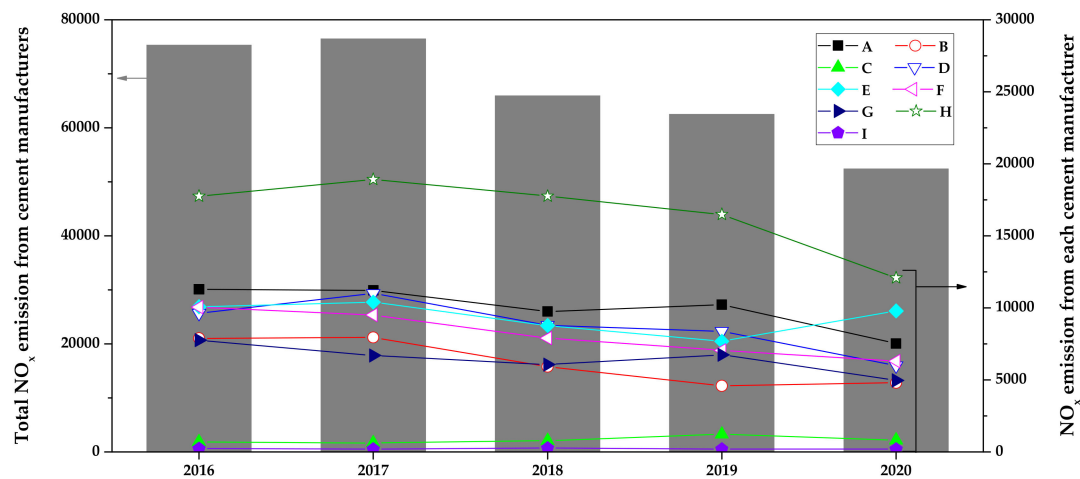


Figure 6. NO_x emissions of Korean cement manufacturers for the period 2016–2020 (Units: tons/year) (data taken from [15]).

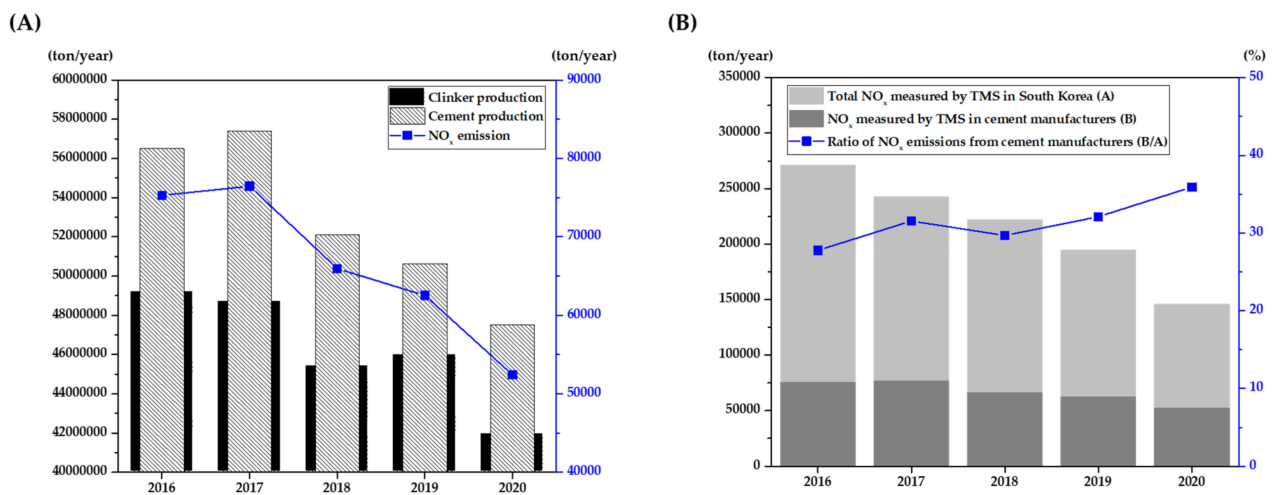


Figure 7. (A) NO_x emissions according to clinker and cement production in South Korea; (B) Ratios of NO_x emission from Korean cement manufacturers (Units: ton/year, %) (data taken from [15,16]).

The NO_x emission standard specified for Korean cement manufacturers is 270 ppm or less for kilns installed before 31 January 2007, as shown in Table 2. For kilns installed between 1 February 2007 and 31 December 2014, it is 200 ppm or less, and for those installed after 1 January 2015, it is 80 ppm or less.

Table 2. NO_x emission standards for cement industry kilns in South Korea (data taken from [17]).

Installation Period	NO _x Emission Standard (ppm)
Before 31 January 2007	≤270
1 February 2007–31 December 2014	≤200
After 1 January 2015	≤80

In addition, to impose an emission charge, the Enforcement Decree of the Air Environment Conservation Act was amended in 2018, which was earlier imposed only on dust, sulfur oxides, and nitrogen oxides. Based on the NO_x emission standards in Table 2, the enforcement time was 1 January 2020, and the emission charge was calculated to be 1.81 dollars per 1 kg. In this regard, a step-by-step application plan was prepared to minimize the burden on emission sites and stably establish a system with the detailed standards shown in Table 3.

Table 3. NO_x emission charge on business entities in South Korea (data taken from [18]).

	Min. Emission Concentration ¹ (%)	Emission Charge ² (\$/kg)
Before 31 December 2019	—	—
1 January 2020–31 December 2020	70	1.26
1 January 2021–31 December 2021	50	1.54
After 1 January 2022	30	1.81

¹ Appropriate percentage of the permissible emission levels. ² Converted based on the 21 December 2021 exchange rate.

Most cement factories are being maintained by facility renovation because a cement factory that is established with a new kiln has to strictly abide by the NO_x emission limit of approximately 3.4 times that of the existing value (before 2007). Ultimately, even though the NO_x limit has grown stricter, the standards imposed on cement factories are practically meaningless because they are imposed based on the date of factory establishment. As a result, residents and civic groups with cement factories are demanding that the NO_x emission standard in the cement industry be revised to follow that of the existing Air Environment Conservation Act. Specifically, the environmental regulations must be imposed such that the standard is based not on the kiln installation date but on the enforcement date of the law, which is the current standard of 80 ppm or less. They argue that the emission standards of kilns installed before 2015 must be urgently amended. In advanced countries, high-efficiency DeNO_x facilities are already installed to actively reduce NO_x emissions, and in Germany, approximately 77 ppm is imposed and followed. Accordingly, it is necessary to respond in advance by introducing a process that can effectively reduce NO_x when the Air Environment Conservation Act is amended in Korea. In this regard, the Ministry of Environment and the cement industry have set up an activity group, called the “Cement Nitrogen Oxide Reduction Council”, to prepare goals and measures to reduce NO_x emissions from the cement industry. Currently, SNCR is applied and operated in cement plants in Korea to reduce NO_x, but the NO_x removal efficiency is approximately 40–60%, and they plan to build a high-efficiency reduction facility. In addition, a method for upgrading the existing DeNO_x process is being investigated for improving the cement manufacturing process. As such, Korean cement manufacturers have agreed with the Ministry of Environment to reduce NO_x emissions to solve the associated environmental problems. Accordingly, the Korea Environmental Industry and Technology Institute (Seoul, Korea) has invested approximately 3 million dollars in research and development (2020–2021) for SNCR and SCR technologies to secure DeNO_x technology [19,20].

3. DeNO_x Process in Cement Industry

Methods for reducing NO_x generated in the cement production process (Figure 8) can be largely divided into primary control (combustion step) and post-control (after

combustion) processes. Based on the combustion stage, primary control is a method of minimizing NO_x generation by changing the combustion conditions, and the post-control method is a method of removal of NO_x generated through a chemical reaction. The primary control to change the combustion conditions suppresses N_2 oxidation by lowering the oxygen concentration and flame temperature in cement; however, if high-temperature combustion conditions are used, the reducing atmosphere is optimized. The presence of substances such as C, CO, HCN, CH^* (hydrocarbon intermediate), NH_3 , and $(\text{NH}_2)_2\text{CO}$ enables NO_x removal. However, in the case of primary NO_x treatment (Figure 9A), another air pollutant, CO or CO_2 , is generated; therefore, this method is undesirable. In addition, although the primary control method optimizes the process to change the conditions of the existing process, burner change, and combustion condition control, there is a limit to NO_x generation; thus, it has a maximum reduction efficiency of 60%. To efficiently remove the generated NO_x , a separate reducing agent (NH_3 , $(\text{NH}_2)_2\text{CO}$) is supplied to perform the post- NO_x treatment (Figure 9B). In this process, NO_x reduction of up to 95% can be achieved by using a reducing agent (NH_3 or urea) in the SNCR or SCR process [12,20–25].

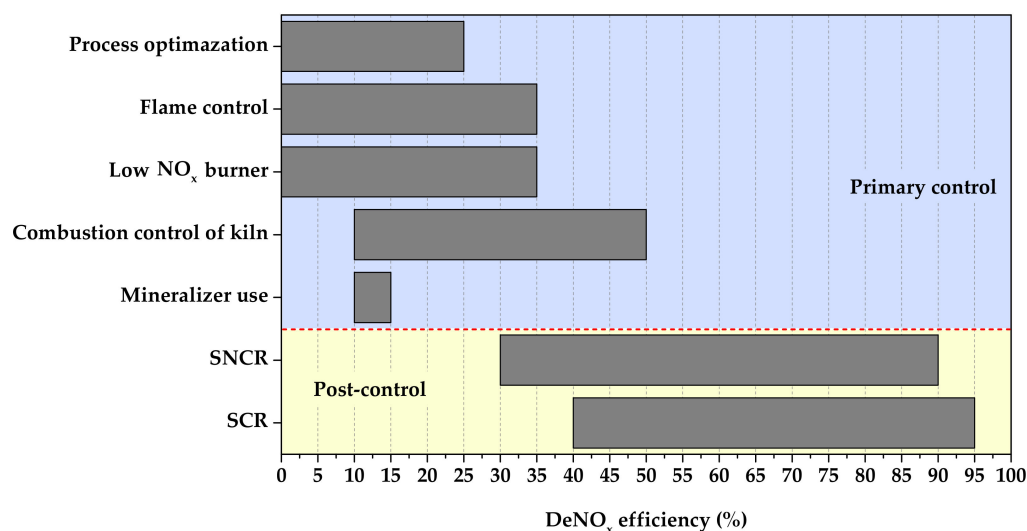


Figure 8. DeNO_x solutions in cement production (data taken from [22]).

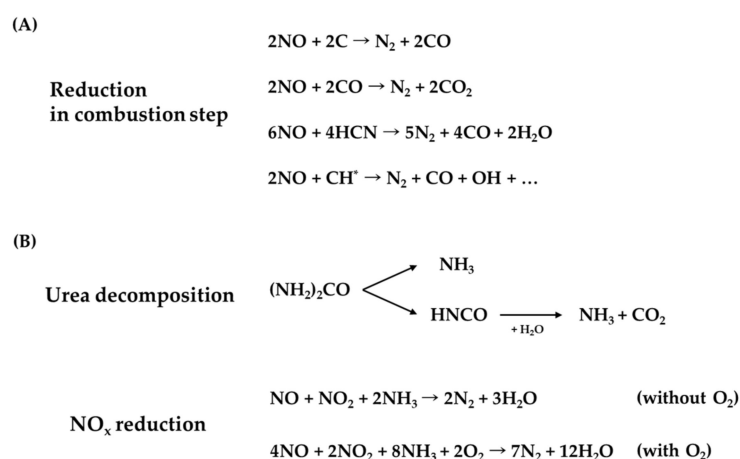


Figure 9. NO_x reduction pathway ((A) primary control, (B) post-control) with reducing agents.

In the SNCR and SCR processes, the amount of reducing agent injected is directly proportional to the DeNO_x efficiency. However, NH_3 slip occurs because unreacted NH_3 increases as the amount of injected reducing agents increases. Excessive NH_3 slip can lead to economic losses along with environmental issues and process downtime due to process

pipe corrosion and clogging due to ammonium formation. Therefore, it is necessary to optimize the process conditions to significantly reduce NO_x while minimizing the amount of NH_3 slip.

In the NO_x reduction process established in cement factories, a low NO_x burner is used as the primary control method for a single process, and SNCR, a method for reducing NO_x by supplying a reducing agent at high temperature, is most commonly used in the post-control method. Therefore, for more efficient reduction, a complex process that can reduce more NO_x by the post-control method after reducing some NO_x through the primary control method is sometimes applied [22].

3.1. De NO_x Process for Primary Control

The primary control method for removing NO_x from the cement manufacturing process is to control it by adjusting the combustion conditions in general. For example, it includes multi-stage combustion, gas reburning, and low NO_x burner use. In the case of Korean cement manufacturers, Seo et al. stated that NO_x generation is suppressed depending on the presence or absence of a pre-calciner. Primary controls classified according to the presence or absence of a pre-calciner are (1) a suspension preheater consisting of a rotary kiln and a multi-stage cyclone-type preheater and (2) a new suspension preheater (NSP) with a pre-calciner added. In addition, NSP is classified into the air through (AT) and air separate (AS) according to the form in which air is additionally supplied to the calciner. It has also been stated that an NSP to which a pre-calciner is added is more effective in suppressing NO_x generation than suspension preheater (SP) by reducing the combustion step. As seen in Figure 10, most of the kilns operated by nine Korean cement manufacturers are of the NSP type equipped with a preheater [20,26]. In addition, there are primary control methods to reduce NO_x by changing the combustion conditions in various ways; although a low NO_x burner is applied, the NO_x reduction rate is low; consequently, it is inevitably limited in its capability to meet the stringent NO_x emission standards.

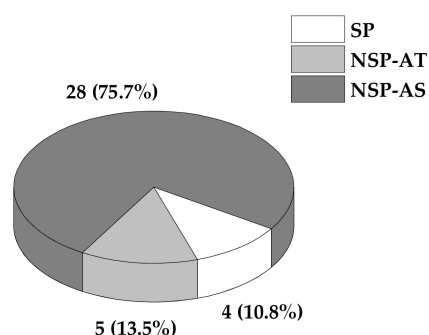


Figure 10. Cement production process facility types in South Korea.

3.2. Selective Non-Catalytic Reduction (SNCR)

The SNCR process is a method of reducing NO_x in exhaust gas at high temperatures without a catalyst by supplying a reducing agent. The SNCR process in the cement production process occurs before the preheater, as shown in Figure 11. This allows it to utilize the process temperature as the kiln temperature is high (850–1050 °C). SNCR is the most widely used reduction method for reducing NO_x in the cement production process because NO_x can be removed simply by supplying a general reducing agent (e.g., urea or NH_3) without a catalyst. The De NO_x efficiency is influenced by many factors, such as reaction temperature, reducing agent to NO_x/NH_3 ratio, residence time, oxygen concentration, and additives, as it utilizes the temperature of the kiln section without a catalyst to reduce NO_x present in the process gas [22,27–29].

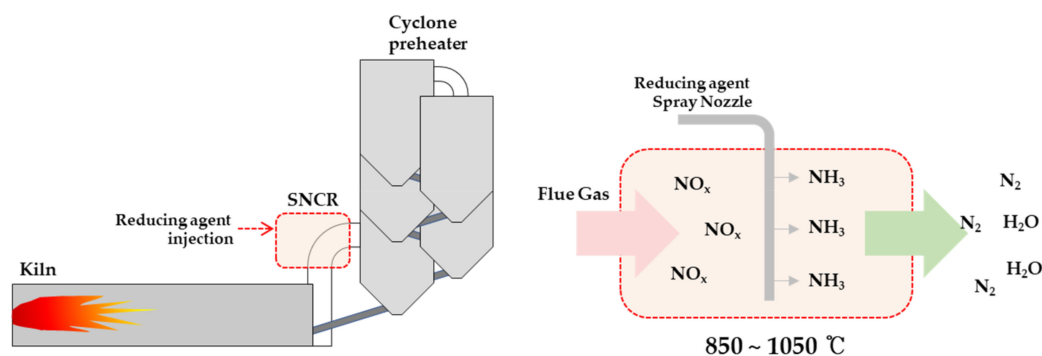


Figure 11. SNCR location and mechanism in the cement production process for DeNO_x.

This SNCR process was operated by Korean cement manufacturers in 2004 to reduce the amount of NO_x emitted. At this time, the SNCR between the preheater and the kiln complies with Korea's NO_x emission limit of 270 ppm (based on the installation date of the kiln) and the DeNO_x efficiency of SNCR is in the range of 10–40%. Accordingly, a plan such as the application of adaptive SNCR (ANCR) to maximize the NO_x reduction efficiency, which improves the performance of the existing SNCR, has been implemented. Unlike the existing SNCR process, the ANCR process is controlled by multiple stages arranged by the reducing agent spray nozzles. The reducing agent is continuously measured at the location where it is sprayed so that it is automatically adjusted to each temperature (NH₃: 820–950 °C, urea: 900–1020 °C). This not only significantly increases the NO_x reduction efficiency but also prevents NH₃ from slipping through the minimum injection of the reducing agent and reduces economic cost. Despite these improvements, there is a large difference in the DeNO_x efficiency due to a different processing condition of each manufacturer owing to the characteristics of the cement process. In addition, there is a limit to reducing NO_x by the SNCR process because the process gas and raw material are mixed at the point where the reducing agent is supplied [26,29,30]. In practice, in the cement process, a significant amount of ash and other minerals, as well as NO_x, are formed. Therefore, unlike the reaction formula in Figure 9B, in the actual cement process, the NH₃/NO_x ratio is generally supplied at 1.5–2.0 for NO_x removal efficiency and NH₃ slip minimization.

Recently, our research team conducted an SNCR demonstration operation according to the changes in NH₃/NO_x using an actual 650,000 Nm³/h flue gas. The results of minimizing NH₃ slip and NO_x removal rate are shown in Table 4. The results show that the NH₃/NO_x ratio was in the range of 1.0–1.71. The lowest NH₃ slip (approximately 20 ppm) and the highest NO_x removal efficiency was observed at the NH₃/NO_x ratio of 1.04. However, the DeNO_x efficiency was 55%, which limited the elimination of NO_x in the SNCR process.

Table 4. NO_x removal efficiency according to the NH₃/NO_x ratio in the SNCR process of Korean cement manufacturer G (13% with O₂ base).

Urea Concentration (%)	NO _x (ppm)		DeNO _x Efficiency (%)	NH ₃ /NO _x Ratio
	Before	After		
15	282	125	55.7	1.04
20	233	94	59.7	1.71

3.3. Selective Catalytic Reduction (SCR)

The SCR process using a catalyst is the most efficient process for reducing NO_x and is widely applied in industries (combustion or production process, transportation, etc.) corresponding to the NO_x emission source. The catalyst used is based on the already commercialized composition (V₂O₅-WO₃(or MoO₃)/TiO₂), and depending on the process

conditions (temperature, space velocity, etc.) to which SCR is applied, honeycomb, plate, and corrugated types are selectively used. As NO_x is reduced through a catalytic reaction at an appropriate reaction temperature (300–400 °C), NO_x removal efficiencies of up to 90% or more are achieved [12]. This SCR process can remove NO_x more efficiently by applying different catalyst types depending on the exhaust gas and overall process conditions. Accordingly, SCR is applied to thermal power plants or mobile pollution sources (ships, automobiles), which are sources of NO_x in Korea, to remove NO_x ; however, the SCR process has not been applied in cement factories. Therefore, to prepare for the stringent NO_x regulations and emission charges, recent attempts to introduce them into the Korean cement industry have been made.

The commercial SCR process, which is usually applied to other industries, has the optimum DeNO_x efficiency at a temperature of 300–350 °C, but the efficiency in the cement production process is lowered because the temperature of the process gas, at the end of the bag filter, after removing dust is lower than approximately 150 °C. In addition, it is difficult to secure an installation space to build an SCR facility within the existing cement manufacturing process. Consequently, only a few manufacturers around the world, as shown in Table 5, operate the SCR process, and the largest number of SCR devices are being built and operated in Germany. China, which produces the largest amount of cement, also introduced SCR process facilities [26,30–32].

Table 5. Examples of cement manufacturers with an SCR process.

Installation Year	Cement Manufacturer	SCR Type	DeNO_x Efficiency (%)
2000	Solnhofen	—	63
2006	Monselice	High Dust SCR	43–95
2010	Mergelstettn	High Dust SCR	83
2011	Rohrdorf	Tail End SCR	76
2012	Mannersdorf	Semi Dust SCR	81

In the case of Germany’s Solnhofen (Figure 12), which introduced SCR for the first time, the SCR facility with the highest reduction efficiency in the cement process was installed on the right side of the preheater for a pilot test. It consisted of three honeycomb catalyst layers and an empty layer between the catalyst layers. In the case of a honeycomb catalyst, compressed air is used to wash the dust accumulated, in the cement process, on the catalyst to increase the pitch size and minimize the clogging of the catalyst, and an SCR system suitable for the cement process is utilized [33].

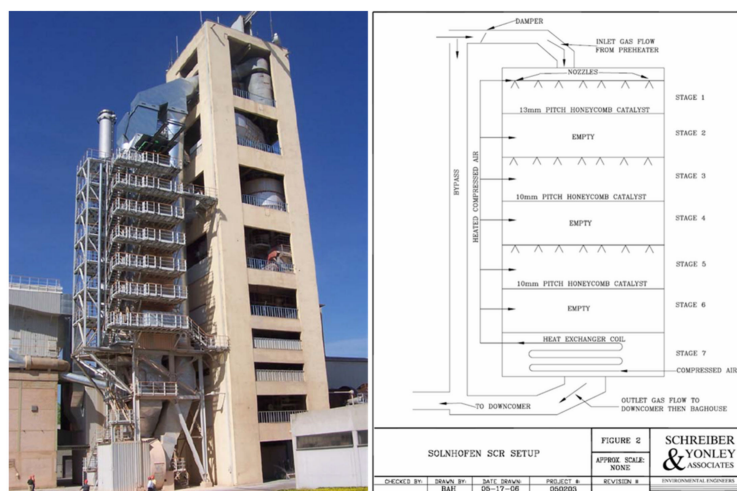


Figure 12. SCR Reactor in Solnhofen (reprinted from [33] under the Creative Commons Attribution 4.0 License).

To install the SCR process in a cement plant in Korea, it is necessary to secure a space in the existing plant site and develop a Korean-type SCR suitable for the Korean cement manufacturing process. Currently, a research project is in progress from 2020 to 2021, with the support of the Environmental Industry and Technology Institute. This project is currently being completed by our researchers in cooperation with the Korean cement manufacturer G and SOOM Environment. Tech. with SCR technology, as shown in Figure 13.

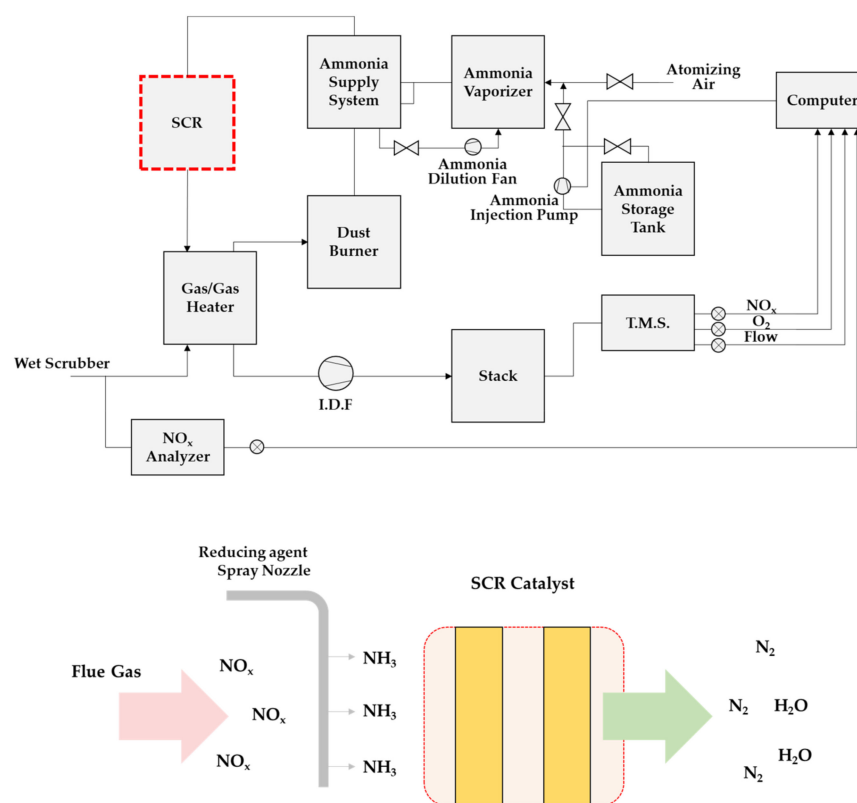


Figure 13. SCR system design and mechanism of SOOM Environ. Tech. (data taken from [34]).

Figure 14 show the pilot-scale SCR process with 4000 Nm³/h of exhaust gas as slipstream after the SNCR process. More than 65% of the dust contained in the slipstream exhaust gas is removed through the cyclone installed before the SCR process; subsequently, the exhaust gas is supplied to the SCR process for an ideal catalytic reaction. The SCR process was performed at approximately 270 °C with a commercial catalyst (volume 21.7 m³). As shown in Table 6, 70% of DeNO_x efficiency was observed at an NH₃/NO_x ratio of ≥0.8, including 20 ppm of NH₃ slip in SNCR. At this time, the NH₃ slip was measured to be as low as 4.8 ppm. Thus, the possibility of the simultaneous operation of the SNCR/SCR process was confirmed.

Table 6. NO_x removal efficiency of pilot-scale SCR process operation in Korean cement manufacturer G (13% with O₂ base).

NH ₃ Water Concentration (%)	NO _x (ppm)		DeNO _x Efficiency (%)	NH ₃ /NO _x Ratio
	Before	After		
9	207	61.3	70.4	0.8

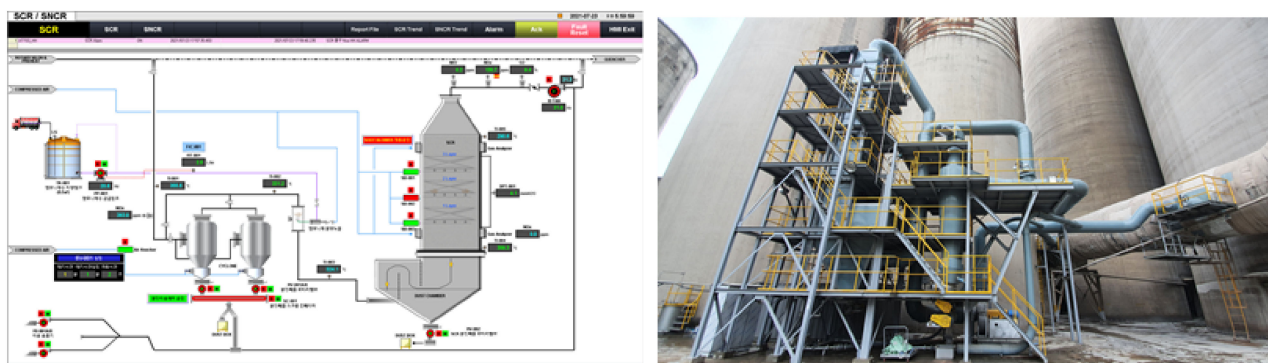


Figure 14. Pilot-scale SCR process operation screen and installation in Korean cement manufacturer G.

Owing to the flow conditions, high dust levels, and low temperature range in the cement production process, it is difficult to apply the existing SCR process from other industries directly. Therefore, SCR technology tailored for the cement production process must be actively developed through pilot tests. Comparison and analysis of the economic feasibility of a newly introduced low-temperature SCR process in an application scenario have shown that the cost can be reduced to approximately one fifth as compared to that where denitrification facilities are not introduced and about half compared to that where the general SCR process is applied [35]. Considering these aspects, the development and application of a catalyst with efficient SCR performance in the low-temperature region would be economically and environmentally advantageous. However, in the case of low-temperature SCR, it is necessary to overcome the problems caused by SO_x in flue gas (deactivation and poisoning by ammonium bisulfate), as well as the decrease in activity due to temperature [36,37].

The Korea Institute of Energy Research (KIER) has demonstrated in Figure 15 that the SCR reaction activity at low temperatures is related to the formation rate of monomeric VO_x structural species, and as the efficiency increases, the Lewis NH_3 acid site and oxygen mobility become closely related. This catalyst exhibits a DeNO_x efficiency of 80% or more even at 180–300 °C and also exhibits the anti-oxidation of sulfur oxides. Therefore, it is expected that it will be successfully applied to commercial plant facilities for effectively reducing NO_x in the cement industry [38,39].

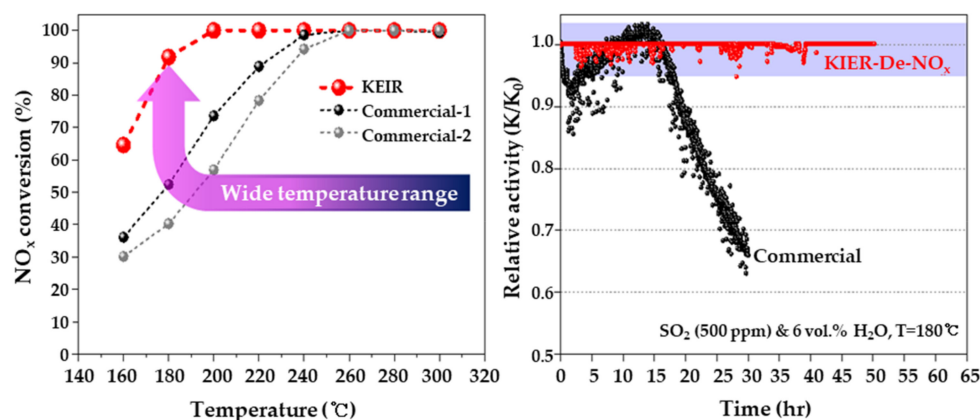


Figure 15. KIER catalytic activity and SO_x resistance over a wide temperature range (reprinted from [39] under the Creative Commons Attribution 4.0 License).

4. Conclusions

To reduce air pollution, new climate agreements are being concluded worldwide, and each country's regulations on pollutants are being amended. Accordingly, Korea is also tightening its environmental regulations and continuing to apply reduction technologies.

However, the cement industry in Korea, which emits a relatively large amount of NO_x , is still below the levels deemed acceptable regarding initiatives imposed by emission regulations. The technology currently applied to the cement industry in Korea suppresses NO_x generation by changing the process conditions or applying a low NO_x burner in the combustion stage and reducing NO_x generated through the SNCR process. However, because these two methods have limitations in terms of DeNO_x efficiency, a more efficient method must be urgently applied. In the case of the Korean cement production process, the operation of the DeNO_x process is determined depending on the production schedule and raw materials used (coal, waste plastic, waste rubber, and waste oil). In addition, since the cement industry generates a large amount of dust, it has a negative effect on NO_x reduction. Therefore, even if the ideal NH_3/NO_x ratio (SNCR: 1.04–1.76, SCR: 0.8–1.0) is supplied for NO_x reduction in the cement industry, the DeNO_x performance of 55–60% is obtained in SNCR and 70% in SCR, and the NH_3 slip obtained during the operation is less than 30 ppm (NH_3 emission limit in Korea). The primary control method and SNCR are currently employed in Korea to reduce NO_x , and the application of the SCR process is being considered for increasing the efficiency of the DeNO_x process. Therefore, it can be concluded that pilot-scale or further research is required in Korea to stabilize the SCR process in the cement production process.

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