

Industrial-Scale Field Demonstration of Integrated Removal of PM and NO_x Using Pleated SCR Pellet Catalyst Filter Bags in a Wood Waste Incineration Boiler

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ABSTRACT

The simultaneous removal of particulate matter (PM) and nitrogen oxides (NO_x) in biomass and waste incineration facilities remains challenging due to space limitations, fluctuating operating conditions, and the complexity of conventional multi-stage emission control systems. In previous pilot-scale tests, pleated filter bags incorporating SCR pellet catalyst cartridges demonstrated the technical feasibility of integrated PM filtration and NO_x reduction, exhibiting stable filtration behavior and effective DeNO_x performance under controlled conditions. Building upon these pilot-scale results, the present study extends the technology to an industrial-scale field demonstration under real plant operating conditions.

Following pilot validation, pleated SCR pellet catalyst filter bags were installed in a wood waste incineration boiler and operated as part of the plant's routine emission control system. The demonstration aimed to evaluate long-term operational stability, scalability, and reliability under fluctuating flue gas temperature, dust loading, and boiler load conditions typical of industrial biomass incineration. Key performance indicators included PM removal efficiency, NO_x conversion efficiency, pressure drop behavior, and ammonia injection characteristics.

The industrial-scale operation confirmed that the pleated configuration provided stable dust cake formation and controlled pressure drop during extended continuous operation. At the same time, the integrated SCR pellet catalyst cartridges maintained consistent NO_x reduction performance without adversely affecting filtration characteristics or causing abnormal pressure increases. No mechanical damage or catalyst-related operational issues were observed during the field demonstration period.

These results demonstrate a successful transition from pilot-scale validation to industrial field application, confirming that pleated SCR pellet catalyst filter bags represent an effective one-step technology for integrated removal of PM and NO_x in biomass and waste incineration facilities. A schematic diagram illustrating the structural concept of the pleated SCR pellet catalyst filter bag is also presented to clarify the integrated filtration and DeNO_x configuration.

Keywords: Pleated SCR catalyst filter bag; Catalytic bag filter; Industrial field demonstration; Integrated PM and NO_x removal; Biomass incineration

Introduction

Rapid industrialization and economic growth have significantly increased emissions of air pollutants from combustion sources such as coal-fired power plants, industrial boilers, and waste incinerators [1-4]. Among these pollutants, nitrogen oxides (NO_x) and particulate matter (PM) are considered major contributors to air pollution problems including acid rain, photochemical smog, and atmospheric ozone formation. Therefore, effective control of these pollutants has become an important environmental issue worldwide [5]. Nitrogen oxides (NO_x) cause serious air pollution problems, such as acid rain, photochemical smog, and ozone depletion [6]. The removal of nitrogen oxides has been an important issue.

Selective catalytic reduction (SCR) using ammonia (NH₃-SCR) is widely recognized as one of the most effective technologies for NO_x removal, achieving removal efficiencies exceeding 90% under suitable operating conditions [7]. However, the performance of SCR catalysts can be influenced by operating temperature and the presence of sulfur compounds in the flue gas. For example, SO₂ can be oxidized to SO₃, which subsequently reacts with NH₃ and water vapor to form ammonium bisulfate (ABS) or ammonium sulfate (AS). These compounds may deposit on the catalyst surface and cause reversible deactivation by blocking active sites and reducing the available surface area [8-13]. In conventional flue gas treatment systems, particulate removal and NO_x control are typically performed using separate units such as bag filters and downstream SCR reactors. Although effective, these multi-stage systems require large installation space, high capital investment, and complex operation and maintenance. Consequently, integrated flue gas treatment technologies capable of simultaneously removing multiple pollutants have recently attracted increasing attention. This approach may be more suitable for treating of multiple pollutants from combustion flue gas in small and medium industries. Among them, catalytic filter bags are particularly attractive for this purpose because of their unique characteristics, coupling SCR catalysts and particulate removal filter bags in one unit [14].

Catalytic bag filters are primarily used for treating flue gas at low and medium operating temperature, as filter bag material has temperature resistance limitations and they are cost effective. Therefore, catalytic filter bags made of polyphenylene sulfide (PPS) [15-17], polyimide fiber (P84) [18], and polytetrafluoroethylene (PTFE) [19, 20] are the most promising candidates for the production of catalytic filter bags. These materials can enhance the dispersion of catalytic particles, leading to improved activity, and also help in reduce the cost of dust removal. However, the felt media results in a short contact time between the loaded catalysts and flue gas, and the low catalyst loading of the catalytic filter bags cannot achieve a satisfactory DeNO_x efficiency [21, 22]. Furthermore, the catalytic filter bags with high catalyst loading will inevitably increase the pressure drop and may blind the pores of the felt media, and shortening their service life [23]. Therefore, it is necessary to develop high catalyst loading technologies with excellent activity at high filtration velocity to achieve efficient DeNO_x efficiency and relatively low pressure drop for catalytic filter bags.

The PTFE membrane laminated filter bags are made of 100% PTFE fiber or polyimide fiber needle-punched that are covered with a layer microporous PTFE membrane on the surface. The membrane is formed through a hot melt bonding process using a professional filter material laminator. In addition to the characteristics of ordinary filter media, finished microporous PTFE membrane laminated felt filter material offers greater precision and higher

filtration efficiency, reaching up to 99.99%, nearly 100% with almost zero emissions. The microporous PTFE film laminated filter bags have the characteristics of being resistance to dew formation, having a smooth surface, and facilitating easy removal of particulate matter. After the PTFE membrane laminated filter bags are put into operation, the pressure drop does not increase due to the extended service life, resulting in a longer lifespan for the filter bag [24-26].

Catalysts are one of the most important components in a catalytic filter [27]. The Ti/V-oxide catalysts are often utilized in catalytic filters because of their satisfactory NO_x removal performance at lower temperatures (<250°C). This catalyst is applied in a DeNO_x system that converts NO_x in flue gases with ammonia over a catalyst to environmentally inert components, water, and nitrogen. The catalyst is a commercially manufactured extrudate consisting of a proprietary mix of titanium/vanadium components, and finally pelletized. This form allows for the easy diffusion of NO_x molecules to the large internal surface area, leading to a very high intrinsic activity. Consequently, it is possible to achieve very high NO_x removal efficiencies, even at relatively low operating temperatures, typically 150-350°C [28].

In this study, a commercial-scale pleated SCR pellet catalyst filter bag with capable of increasing catalyst loading was developed for the simultaneous removal of fine particulate matter and NO_x. It was tested for NO_x and particulate matter removal performance by simulating waste incineration flue gas conditions in a pilot-scale experimental device. Based on the results of the pilot-scale experiment, the design specifications of the commercial-scale pleated SCR pellet catalyst filter bag to be applied in industrial settings were determined. In the industrial field application research of development products, a commercial-scale pleated SCR pellet catalyst filter bag was applied to a wood waste incineration flue gas treatment process and long-term demonstration operation was conducted. Through long-term operation, the study aimed to confirm the changing trends of pressure drop, particulate matter collection efficiency, and NO_x removal performance of the pleated SCR pellet catalyst filter bags.

Structure of pleated SCR pellet catalyst filter bag

The structural configuration of the pleated SCR pellet catalyst filter bag is illustrated in Fig. 1. The system consists of a pleated filter bag fabricated from polyimide needle-punched felt laminated with a microporous PTFE membrane, together with an internal SCR pellet catalyst cartridge. The pleated filter bag has a diameter of 156 mm and a length of 1,500 mm, with 40 pleats and a pleat height of 25 mm. The catalyst cartridge consists of a spiral perforated stainless-steel outer cage and an inner perforated cage that supports the SCR pellet catalyst.

The outer cage has a diameter of 120 mm and a length of 1,480 mm, while the inner cage has a diameter of 76 mm and a length of 1,480 mm. A venturi is installed at the upper part of the cartridge to enhance gas distribution during filtration. In addition, a preliminary catalyst filling layer is provided in the upper section of the cartridge to compensate for catalyst settling that may occur during long-term pulse-jet cleaning operation. The configuration of the catalyst cartridge and the assembly process of the pleated SCR pellet catalyst filter bag are shown in Fig. 2 and Fig. 3, respectively.

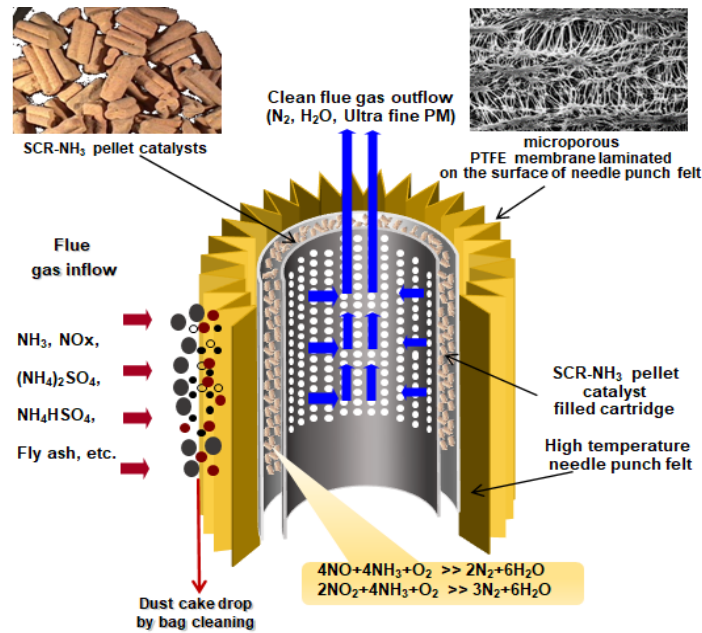


Fig.1. Structural configuration of the pleated SCR pellet catalyst filter bag developed in this study. The system consists of a pleated PTFE-membrane laminated polyimide filter bag and an internal SCR pellet catalyst cartridge, enabling simultaneous particulate filtration and catalytic NO_x reduction within a single filtration unit.

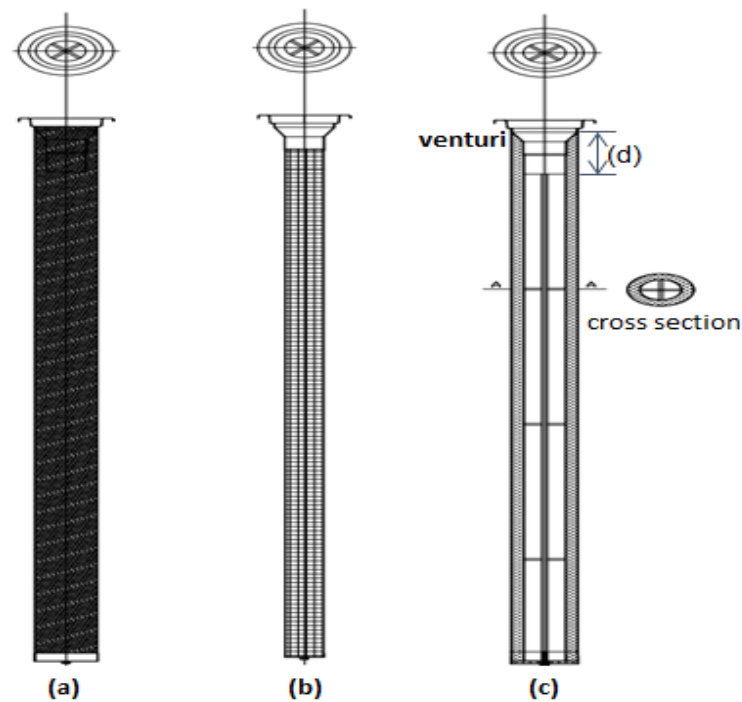


Fig.2. Structural components of the SCR pellet catalyst cartridge: (a) outer perforated stainless-steel cage, (b) inner perforated cage, (c) assembled catalyst cartridge filled with SCR pellet catalyst, and (d) preliminary catalyst filling layer designed to compensate catalyst settling during long-term pulse-jet cleaning operation.

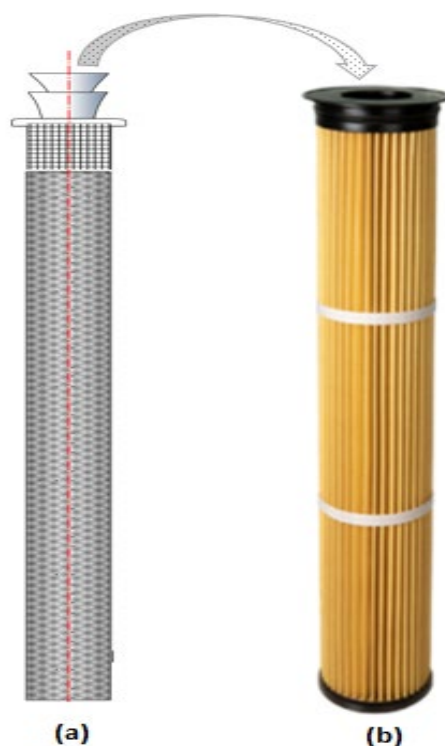


Fig.3. Assembly process of the pleated SCR pellet catalyst filter bag. The catalyst cartridge is inserted into the center of the pleated filter bag and supported by a cage structure to maintain stable catalyst distribution and filtration performance.

Industrial site set-up

Fig.4 shows the improved flue gas treatment process applied to the wood waste incineration boiler for the industrial demonstration. In this system, the existing multi-cyclone was removed and replaced with an ammonia vaporizer to supply gaseous NH_3 for the SCR reaction. The pleated SCR catalyst filter bags were installed in the existing bag filter chambers, enabling integrated particulate filtration and catalytic NO_x reduction in a single unit. The operating conditions listed in Table 1.

Fig.5 presents the installation status of the pleated SCR pellet catalyst filter bags in the existing bag filter system. The SCR catalyst cartridge is inserted into the pleated filter bag and supported by a cage structure. In addition, low-pressure high-volume pulse injection valves were installed to ensure effective off-line cleaning of the pleated filter bags.

Specification wood waste incineration boiler :
 Steam generation rate : 5.0 ~ 8.0 ton/h, 10 kg/cm²
 Incineration rate : 1.25 ~ 2.0 ton/h
 Flue gas flow rate : 20,000 ~ 35,000Nm³/h

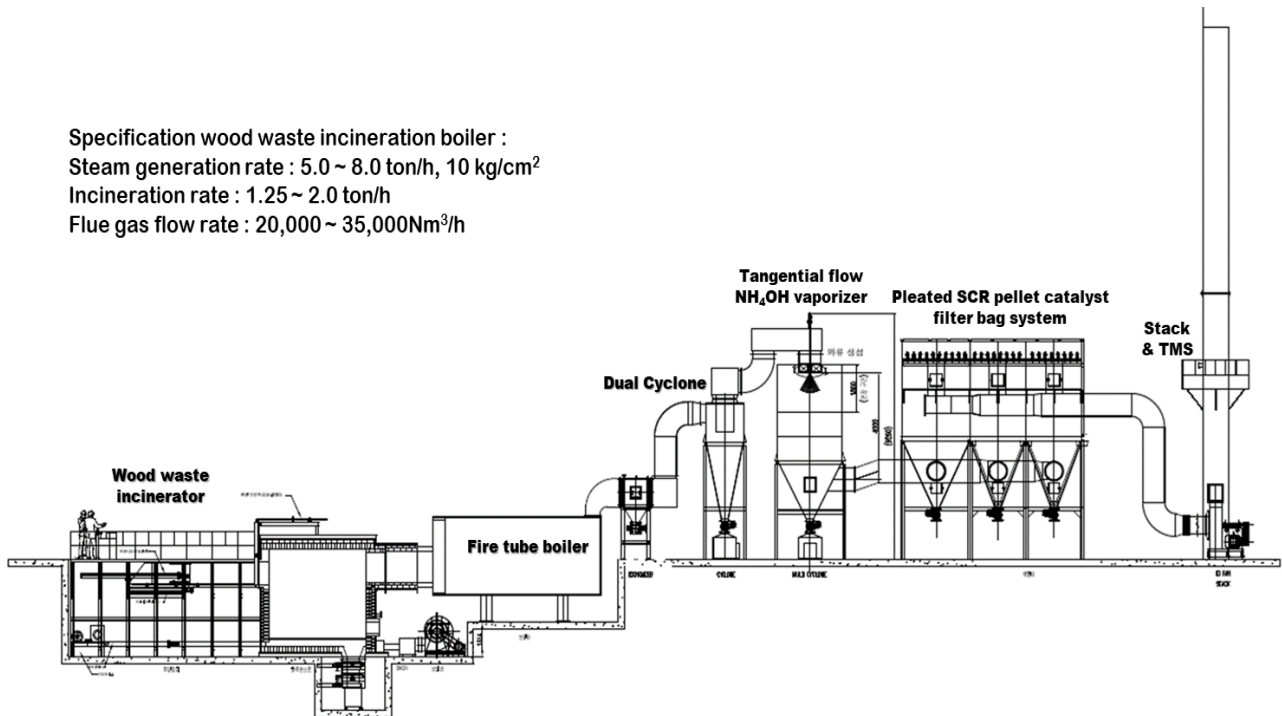


Fig.4. Improved flue gas treatment process for the wood waste incineration boiler used in the industrial demonstration. The existing multi-cyclone was removed and replaced by an ammonia vaporizer to supply NH₃ for the SCR reaction. Pleated SCR catalyst filter bags were installed in the existing bag filter chambers, enabling integrated PM filtration and catalytic NO_x reduction.



Fig.5. Industrial installation of the pleated SCR pellet catalyst filter bag system: (a) SCR pellet catalyst-filled cartridge, (b) bag filter chamber equipped with pleated SCR catalyst filter bags, and (c) low-pressure high-volume pulse injection valve bundles for off-line bag cleaning.

Table 1. Operating conditions.

Filter bags	Pleated SCR pellet catalyst filter bag
Dimension filter bag, mm (Filtration area,m ²)	D165,L1,500 (3.3)
Number bags, No.	312
Gas flow rate, Nm ³ /h	20,000 ~ 35,000
Inlet gas temperature, oC	170 ~ 180
Inflow dust concentration, mg/Nm ³	550 ~ 700
Inflow NOx concentration, ppm	80 ~ 160
Inflow SO ₂ concentration, ppm	50
Total wt. of SCR pellet catalyst, kg	2,340 (7.5 kg/bag)
GHSV(Space velocity), h ⁻¹	7,700 ~ 13,500
H ₂ O content, vol. %	6.5
O ₂ content, %	11.0
NH ₃ /NO molar ratio,-	0.9
Bag cleaning air pressure, kg/cm ²	3.0
Bag cleaning begins pressure drop, mmH ₂ O	70 ~ 90

Real-time monitoring of air pollutants (such as dust, NOx, O₂, SO₂, moisture, etc.) being emitted during standby in the stack of the improved exhaust gas treatment process, along with measurements of exhaust gas flow rate and temperature, are stored in the control room and transmitted to the environmental agency (averaged over 30 minutes) using the In-Suite combustion exhaust gas measurement system (Dong Woo Optron) installed. The concentration of air pollutants is measured in real-time. A photo of the installation of the In-Suite fuel combustion exhaust gas measurement system on the stack and the method of measuring air pollutants with the measurement system are shown in Fig.6.



TMS system at the stack

Measuring items	Measuring methods
SO ₂ , NO _x , O ₂	UV Absorption(DGA-XP)
Dust	Light Transmittance (LCD-80) Laser Diode Light Source Red visible light wavelength : 645 – 660nm
Flue gas velocity	Pitot-tube(PGA-91)



UV Absorption Type (DGA-XP)



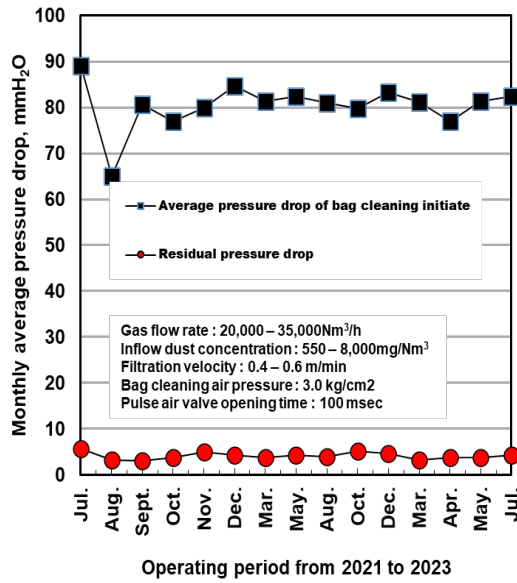
Dust concentration measuring system set(LCD-80)

Fig.6. In-situ emission monitoring system installed in the stack of the demonstration plant. The system measures real-time concentrations of gaseous pollutants (NO_x, SO₂, O₂) and dust emissions, and continuously transmits data to the plant control room and environmental monitoring authority.

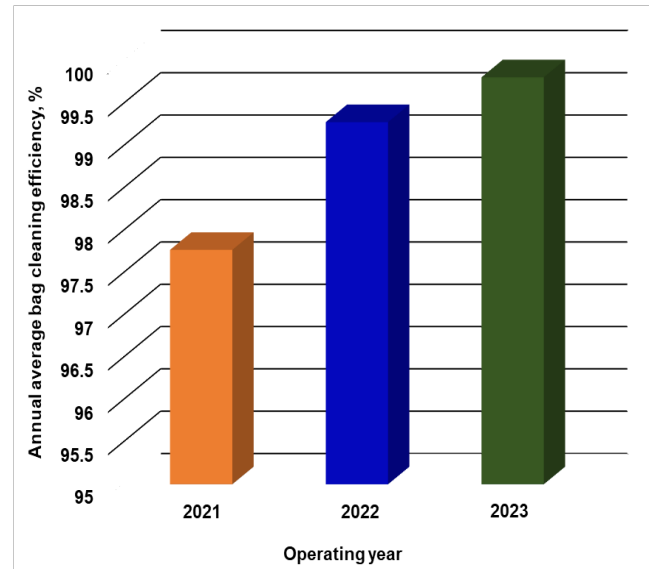
Results and Discussions

Fig.7 shows the long-term variation of pressure drop characteristics during industrial demonstration operation. The results indicate that stable cleaning initiation pressure drop and residual pressure drop were maintained during the three-year operation period, confirming that the pleated structure and catalyst cartridge configuration did not cause abnormal pressure build-up.

To remove the dust layer deposited on the surface of the pleated SCR pellet catalyst filter bag, off-line bag cleaning operation was performed while maintaining an average pressure drop range of 79.4mmH₂O, starting bag cleaning operation. The residual pressure drop after bag cleaning was maintained at an average of 4.2mmH₂O within a range of 3.0mmH₂O to 5.7mmH₂O. In the on-site demonstration operation of the industrial plant, the pressure of compressed air for bag cleaning was maintained at 3.0kg/cm², and under off-line cleaning conditions, it was confirmed that the bag cleaning efficiency of the pleated SCR pellet catalyst filter bag was maintained at 97% or higher.



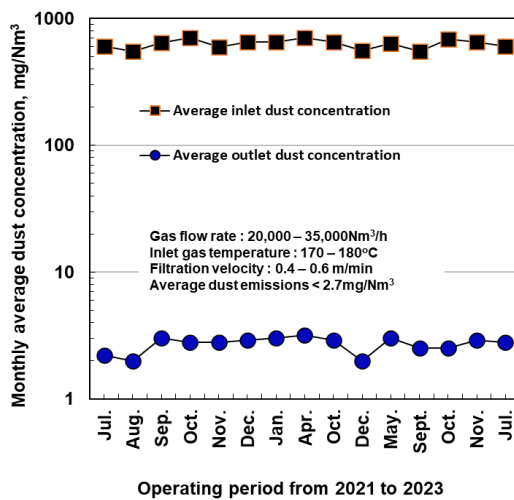
(a)



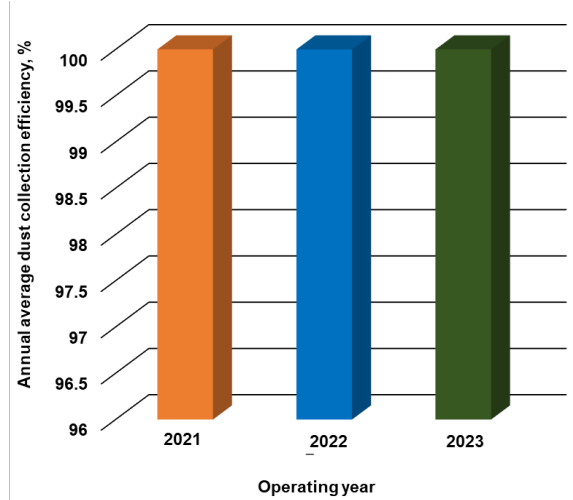
(b)

Fig.7. Long-term variation of pressure drop characteristics during industrial demonstration operation from July 2021 to June 2023: (a) monthly average pressure drop at bag cleaning initiation and residual pressure drop after cleaning, and (b) annual average bag cleaning efficiency.

Fig.8 shows the inlet and outlet dust concentration during industrial operation. Despite significant fluctuations in inlet dust concentration due to variations in boiler load and fuel composition, the outlet dust concentration remained consistently low, demonstrating the high filtration performance of the pleated SCR catalyst filter bags.



(a)



(b)

Fig.8. Dust removal performance of the pleated SCR pellet catalyst filter bags during industrial operation: (a) monthly average inlet and outlet dust concentrations, and (b) annual average particulate collection efficiency.

In Fig. 8 (b), the annual average collection efficiency of the pleated SCR pellet catalyst filter bag in the existing bag filter system at the industrial site was shown as an average value from July 2021 to June 2023 through on-site demonstration operation. The annual average particulate collection efficiency was consistently maintained above 99.9% throughout the industrial demonstration period.

The industrial bag filter system under verification operation is installed in an incinerator that operates according to the fluctuation in steam usage at a paper making process, causing the amount of fuel incinerated in the incinerator to vary, resulting in a fluctuation in the concentration of dust particles contained in the incineration flue gas from 550mg/Nm³ to 700mg/Nm³. The average inlet dust concentration from July 2021 to June 2023 was calculated to be around 622mg/Nm³. As a result, the concentration of dust particles discharged from the stack into the atmosphere fluctuated from 2.0mg/Nm³ to 4.2mg/Nm³, and the average dust concentration discharged into the atmosphere from July 2021 to July 2023 was calculated to be around 2.7mg/Nm³. It was confirmed that the actual dust emission concentration into the atmosphere is maintained at a lower level than the guaranteed dust emission concentration of 5.0mg/Nm³ in the industrial site application operation of the pleated SCR pellet catalyst cartridge filter bag.

Fig.9 presents the NO_x removal performance during the industrial demonstration period. Even under fluctuating NO_x concentrations and varying flue gas temperatures, the integrated SCR catalyst cartridges maintained stable NO_x reduction performance.

The pleated SCR-NH₃ pellet catalyst filter bag was installed in three chambers of the existing bag filter system, and from July 2021 to June 2023, the trend of changes in outlet NO_x concentration during industrial on-site demonstration operation was shown in Fig. 9 (a) as monthly average values. The target industrial site for the demonstration was a waste wood incineration boiler, and the amount of incinerated waste wood for fuel varied according to the increasing steam usage in a paper making process, resulting in fluctuations in the incineration flue gas flow. During the demonstration operation period, the NO_x concentration in the incineration exhaust gas fluctuated in the range of 80ppm to 140ppm. Also flue gas temperature fluctuated in the range of 150°C to 170°C. As a result, the NO_x concentration emitted from the stack into the atmosphere fluctuated in the range of 18.4ppm to 26.6ppm, and the monthly average NO_x concentration emitted into the atmosphere from July 2021 to June 2023 was calculated to be around 21.0ppm. The measured NO_x concentration at the stack outlet remained significantly lower than the guaranteed emission limit.

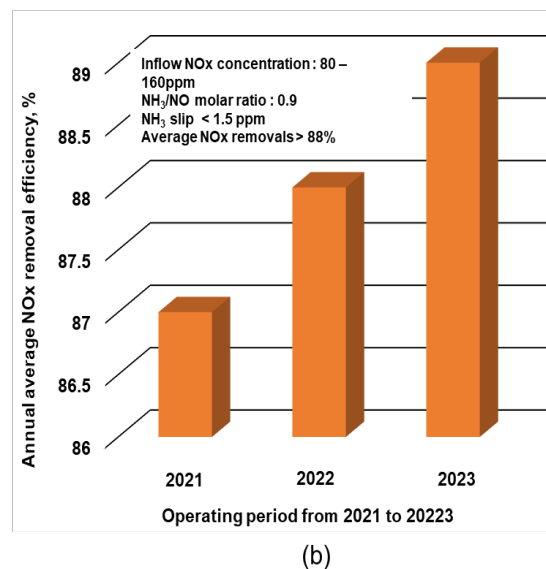
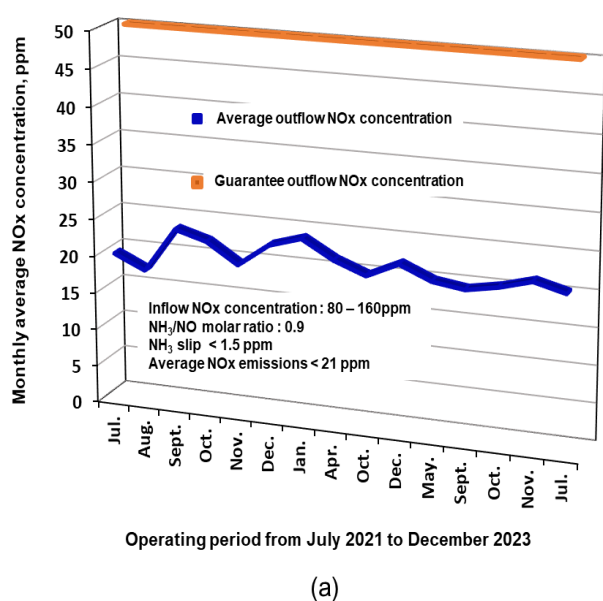


Fig.9. NO_x removal performance during industrial demonstration operation: (a) monthly average outlet NO_x concentration compared with guaranteed emission levels, and (b) annual average NO_x removal efficiency.

Conclusions

This study demonstrated the industrial applicability of pleated SCR pellet catalyst filter bags for the integrated removal of particulate matter and nitrogen oxides in a wood waste incineration boiler. Based on pilot-scale validation, commercial-scale pleated SCR pellet catalyst filter bags were installed in three chambers of an existing bag filter system and operated continuously for approximately three years under real plant conditions.

The long-term demonstration results showed stable filtration and bag cleaning performance. The pressure drop at the initiation of bag cleaning averaged approximately 79.4mmH₂O, while the residual pressure drop after cleaning remained around 4.2mmH₂O, indicating efficient dust removal and stable operation of the filtration system. The outlet dust concentration was maintained at an average level of approximately 2.7mg/Nm³, corresponding to particulate collection efficiencies exceeding 99.9%.

In addition, the integrated SCR catalyst cartridges enabled effective NO_x reduction under fluctuating boiler operating conditions. The outlet NO_x concentration was maintained at

approximately 21ppm, with annual average NO_x removal efficiencies ranging from approximately 86% to 89%.

These results confirm that pleated SCR pellet catalyst filter bags provide a reliable one-step technology for simultaneous removal of PM and NO_x. The technology offers a compact and cost-effective alternative to conventional multi-stage emission control systems and shows strong potential for application in biomass and waste-to-energy facilities.

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