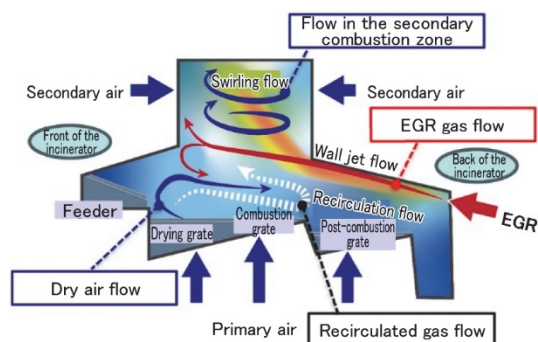


# Development of Ultra-Low NO<sub>x</sub> Combustion Technology for Stoker Incinerator



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From the viewpoint of minimizing environmental impact, waste incineration facilities are expected to reduce NO<sub>x</sub> emissions. In stoker incinerators, exhaust gas recirculation is combined with selective non-catalytic reduction to decrease NO<sub>x</sub> levels. With the aim of reducing the cost for the denitrifying agent, a low NO<sub>x</sub> combustion system using a novel gas injection method for exhaust gas recirculation has been developed. In this system, gas from exhaust gas recirculation is used to induce the flow of recirculation in the primary combustion zone, thereby expanding the area of reduction. A swirling flow is also formed in the secondary combustion zone to facilitate complete combustion, which decreases the total air ratio. This system produced half the NO<sub>x</sub> compared to that by conventional methods, and is summarized in this report.

## 1. Introduction

From the viewpoint of minimizing environmental impact, waste incineration facilities are required to reduce NO<sub>x</sub> emissions. Mitsubishi Heavy Industries Environmental & Chemical Engineering Co., Ltd. (hereinafter referred to as MHIEC) has delivered stoker incinerators that meet the needs of local governments. In these incinerators, technology to reduce NO<sub>x</sub> emissions (i.e. exhaust gas recirculation, EGR) is combined with NO<sub>x</sub> removal technology (i.e. selective catalytic reduction, SCR, or selective non-catalytic reduction, SNCR). In order to further reduce environmental impact and the cost of denitrifying agents, MHIEC has developed a low NO<sub>x</sub> combustion system using a novel EGR gas injection method.

This newly-developed low NO<sub>x</sub> combustion system is summarized in this report, and a demonstration test at an actual waste incineration plant is described.

## 2. Features of the new low NO<sub>x</sub> combustion system

Generally speaking, two-stage combustion is used to decrease fuel NO<sub>x</sub> derived from nitrogen (N) in waste. This combustion method lowers NO<sub>x</sub> emissions by allowing reducing combustion to occur in the primary combustion zone immediately above the waste layer, whereas oxidizing combustion occurs in the secondary combustion zone to complete combustion and prevent the emission of unburnt waste and dioxins.

This low NO<sub>x</sub> combustion system is characterized by improved efficiency of two-stage combustion, which is enabled by the formation of three flow paths that enhance the mixing of gases in the primary and secondary combustion zones using EGR. The schematic diagram is shown in **Figure 1**.

### (1) Formation of wall jet flow

In a conventional EGR system, multiple nozzles are attached in a row along the width of the incinerator below the secondary air. Jet streams from the nozzles are joined above the

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drying grate and combustion grate. In the new low  $\text{NO}_x$  combustion system, however, EGR nozzles with a large diameter are consolidated in one area, and are attached to the back of the incinerator, injecting jet streams at an angle so that they flow along the ceiling. The jet streams flatten out and form a sheet-like, wall jet flow. This helps prevent gas leakage between the nozzles and allows a greater amount of unburned gas - which contains volatile gases derived from nitrogen-containing components in the waste and which plays a role in the reduction of  $\text{NO}_x$  - to remain in the primary combustion zone, thereby promoting  $\text{NO}_x$  reduction.

(2) Formation of recirculation flow

The penetration force of the jet streams that are injected from the large-diameter EGR nozzles blocks the gas flowing upwards in the area above the drying grate, to create a recirculation flow within the incinerator. The volatile gases produced from pyrolysis of waste are entrained in this recirculation before being driven in the opposite direction by the flow of EGR gas toward the front of the incinerator. This creates an enlarged reduction atmosphere in the primary combustion zone. Especially air-derived  $\text{O}_2$ , which is injected into the drying grate, tends to remain unused in the front of the incinerator. Recirculation flow contributes to increased mixing of such excess  $\text{O}_2$  with volatile gases. Thus, reduction of  $\text{NO}_x$  production and decomposition by reduction reaction can be expected.

(3) Formation of swirling flow

EGR gas is injected in such a way that its flow does not align with the central axis of the secondary combustion zone. This results in the formation of a swirling flow (see the flowlines in Figure 2(a) in the following chapter). This swirling flow facilitates the mixing of gases in the secondary combustion zone for thorough combustion even under lean air conditions. Thus, the total air ratio can be lowered, which decreases  $\text{NO}_x$  production in the secondary combustion zone to achieve low  $\text{NO}_x$ . As heat loss due to exhaust gas can also be reduced, improvement in power generation efficiency is expected.

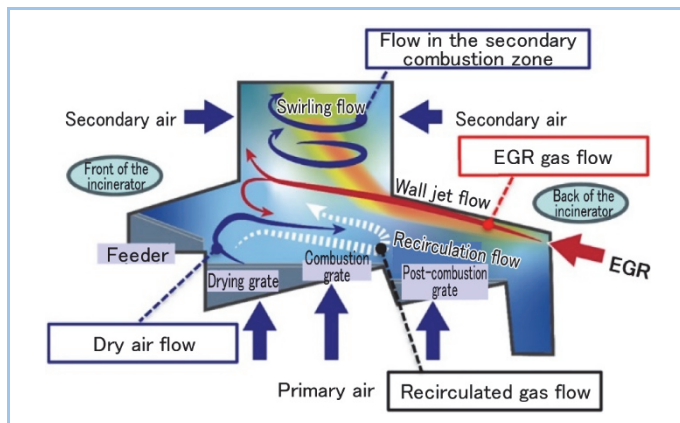


Figure 1 Schematic diagram of EGR gas flow

### 3. Assessment of combustion by computational fluid dynamics

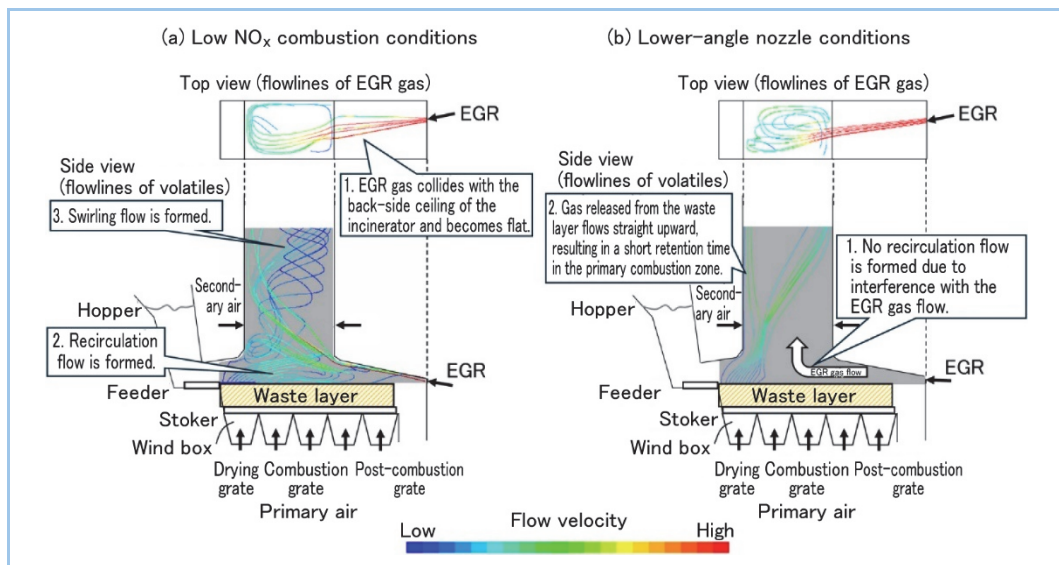
Assessment by computational fluid dynamics (CFD) was carried out before the verification test of the actual unit<sup>(1), (2)</sup>.

The flowline results of CFD analysis, under the following two conditions, (1) low  $\text{NO}_x$  combustion conditions expected to occur in MHI EC's new low  $\text{NO}_x$  combustion system, and (2) lower-angle nozzle conditions in which the angle of EGR nozzle is set nearly horizontal, are shown in Figure 2. The flowlines in Figure 2(a) agree with the aforementioned flow fields which are characteristic of low  $\text{NO}_x$  combustion conditions. In the case of lower-angle nozzle conditions in Figure 2(b), however, the flow of EGR gas interfered with the gas in front of the incinerator, and failed to induce recirculation. Therefore, an increase in retention time in the primary combustion zone was not possible. From these results, the importance of nozzle angle, i.e. setting the nozzle at an upward angle to form a wall jet flow, was shown.

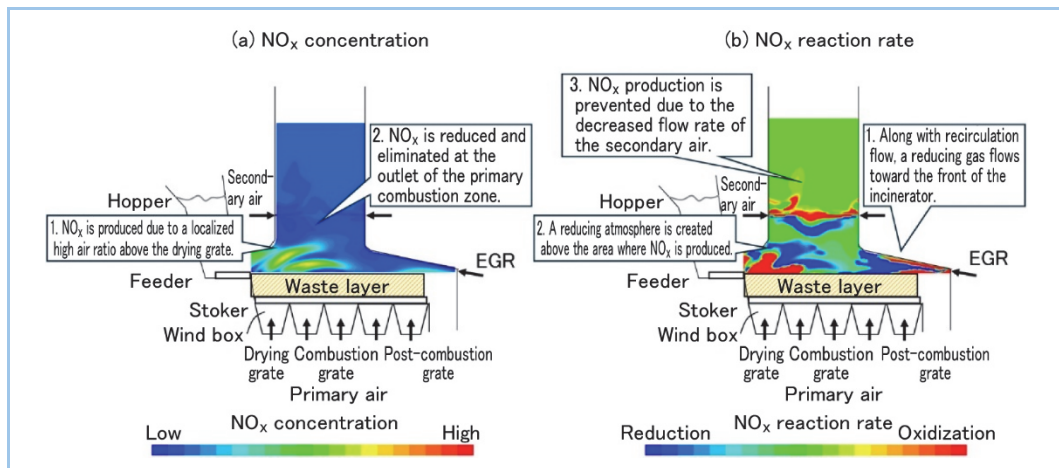
Distribution of  $\text{NO}_x$  concentration and  $\text{NO}_x$  reaction rate under the low  $\text{NO}_x$  combustion conditions obtained by the CFD analysis are shown in Figure 3. First, as there is more air than

volatile gas generated from pyrolysis of waste in the area above the drying grate,  $\text{NO}_x$  is produced by oxidation of N in the fuel. The resulting  $\text{NO}_x$  is then mixed with a reducing gas contained in the EGR gas flow, and is reduced downstream from where secondary air is injected. Lastly, mixing by the swirling flow facilitates the complete combustion of unburned gas. This enables the secondary air ratio to be reduced.  $\text{NO}_x$  is hardly produced in the secondary combustion zone. Due to these reasons, decrease in  $\text{NO}_x$  concentration at the outlet could be expected.

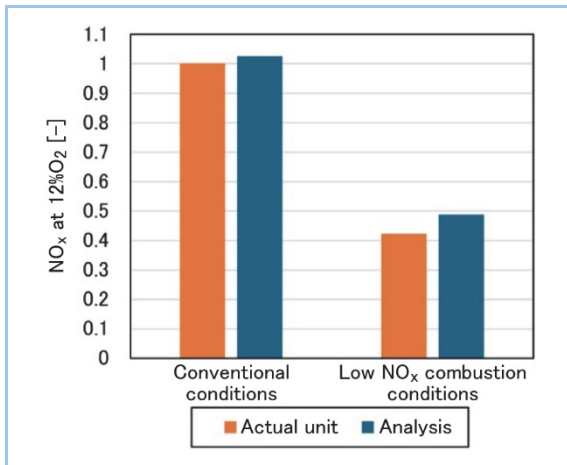
Comparison of the results of outlet  $\text{NO}_x$  levels between the CFD analysis and the verification test using the actual unit (described later). The y-axis is dimensionless, and is shown as a ratio relative to the results obtained from the actual unit in operation under conventional conditions. This baseline is the value of  $\text{NO}_x$  production calculated from the theoretical rate of  $\text{NO}_x$  removal by SNCR and is based solely on the consumption of denitrifying agent in the actual unit. As shown in **Figure 4**, the analysis results showed good agreement with those from the actual unit quantitatively, which demonstrates the validity of CFD prediction<sup>(3)</sup>.



**Figure 2** Flowline results of CFD analysis



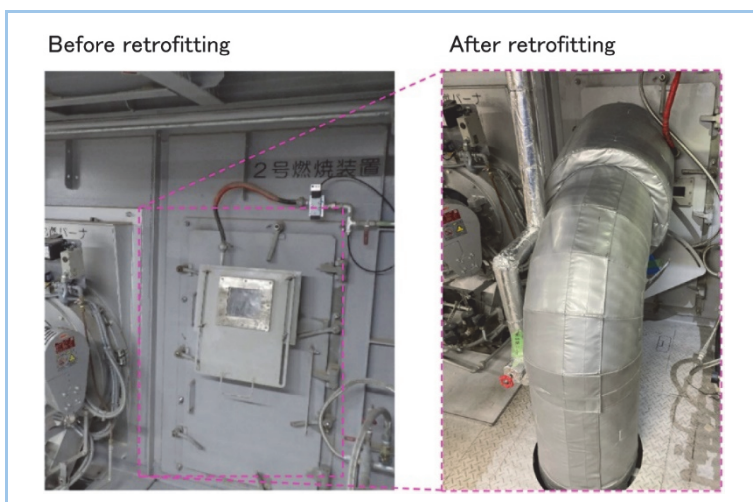
**Figure 3** CFD analysis results for  $\text{NO}_x$  concentration and  $\text{NO}_x$  reaction rate



**Figure 4** Quantitative comparison of the analysis results and the data obtained from the actual unit

#### 4. Retrofitting of the actual unit and verification

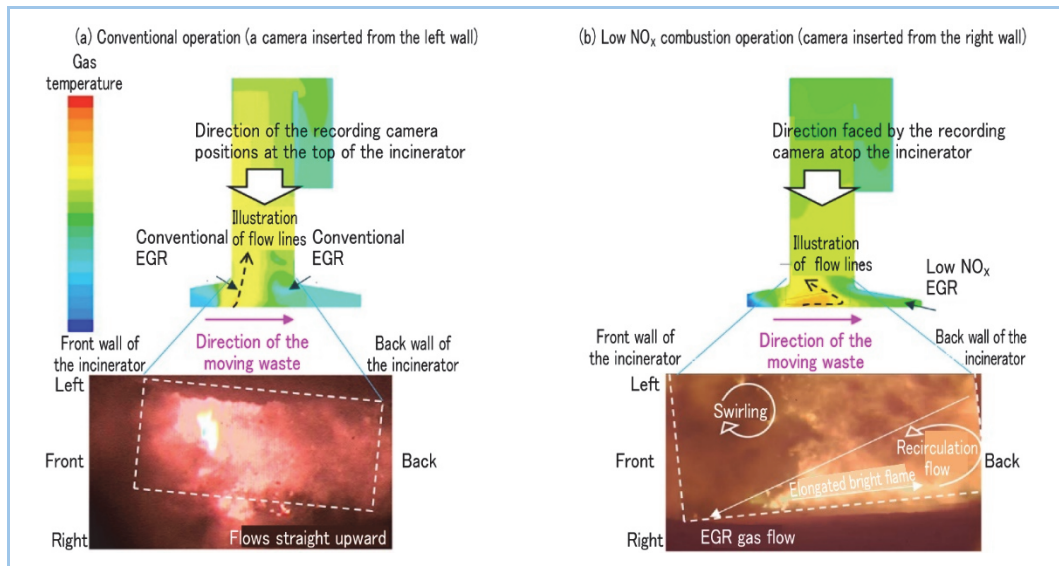
In the demonstration test using an actual unit, EGR piping and nozzles were added to the back of an existing incinerator (**Figure 5**). When retrofitting the piping, the duct route was designed and duct pressure loss etc. were evaluated. The final design of piping was determined after considering the plant's spatial limitations and the pipe diameter that was estimated to ensure a flow rate that could sufficiently achieve low NO<sub>x</sub> combustion conditions in the CFD analysis assessment. A flowmeter and a damper were installed in the additional EGR piping. Changes in the flow rate could be checked from the central control room using the control system and the damper could be opened/closed remotely and automatically.



**Figure 5** Exterior view of the additional EGR nozzles

In order to verify the formation of flow fields as indicated by the CFD analysis of the actual unit, a heat-resistant borescope camera was used to observe flames over the waste layer by recording a video from above. Images of flames during conventional operation and during low NO<sub>x</sub> combustion operation are shown in **Figure 6**. The dotted white lines roughly indicate where the ceiling of the primary combustion zone meets the front/back walls of the secondary combustion zone (i.e. approximate reference of the outlet from the primary combustion zone). In **Figure 6(a)**, when the waste layer was viewed from above, a bright flame (i.e. high-intensity area) remained within a limited area in the waste-moving direction during conventional operation. During low NO<sub>x</sub> combustion operation in **Figure 6(b)**, however, the bright flame was elongated in the direction the waste was moving, and inside the dotted white lines was brighter overall. This occurs because, in low NO<sub>x</sub> combustion operation, the recirculation flow is induced by the EGR gas flow, creating a layer of recirculated combustion gas above the flames on the surface of the waste layer. Although it is difficult to see in the image in **Figure 6(b)**, the recorded video shows a circulating movement in

the light yellow area in the upper left corner of the image. This confirms the formation of a swirling flow. Thus, formation of the flow fields predicted by the CFD analysis could be verified.



**Figure 6** Combustion conditions inside the incinerator

Results of long-term (approximately 6 months) verification test operation under the conventional conditions and low NO<sub>x</sub> combustion conditions are shown in **Table 1** and **Figure 7**. The NO<sub>x</sub> concentration occurring during conventional operation includes the amount of NO<sub>x</sub> estimated from SNCR using a denitrifying agent. On the other hand, in the case of low NO<sub>x</sub> combustion operation without SNCR, NO<sub>x</sub> concentration obtained at the stack inlet is considered to be the amount of NO<sub>x</sub> produced solely by combustion.

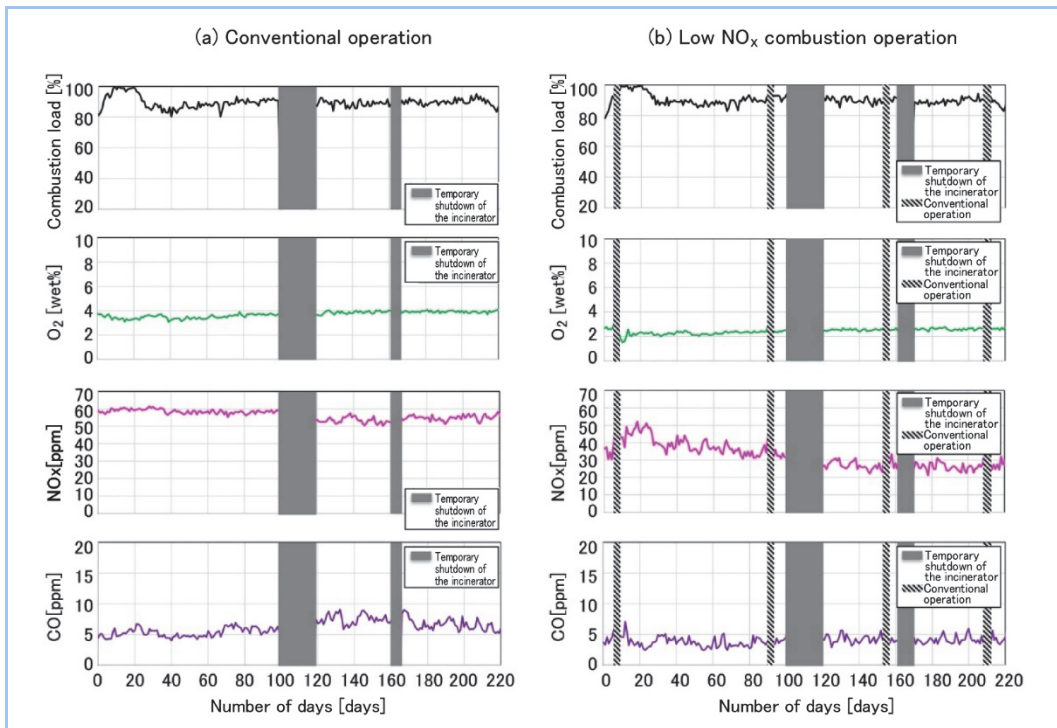
As shown in Table 1, operation under low NO<sub>x</sub> combustion conditions continued while maintaining production of NO<sub>x</sub> in the 30 ppm range with a CO level equal to or less than that under conventional conditions. As the NO<sub>x</sub> removal rate by SNCR in conventional operation is considered to be approximately 20%, NO<sub>x</sub> production was confirmed to successfully be reduced by half, as predicted by CFD analysis. In the low NO<sub>x</sub> combustion system, recirculation flow and swirling flow, both of which are induced by the EGR gas flow, could improve the degree of gas mixing inside the incinerator, leading to increased combustion stability. The number of manual interventions (which are made by on-site operators when combustion becomes unstable) was reduced to nearly half of that during conventional operation. Moreover, the lowered total air ratio enabled a decrease in power consumption of the fan by approximately 5% compared to that of conventional operation.

The capability of maintaining low NO<sub>x</sub> combustion was demonstrated regardless of seasonal variations in waste quality and changes in load due to the incinerator operation schedule of the facility during the long-term verification test operation period (Figure 7)<sup>(4)</sup>.

**Table 1 Results of the long-term verification test operation**

		Conventional operation	Low NO <sub>x</sub> combustion operation
Number of days of operation	[day]	196	180
Amount of evaporation <sup>*1</sup>	[t/h]	8.0	8.4
Combustion load rate	[%]	80-100	78-100
Lower heating value	[MJ/kg]	8.7-11.0	9.0-11.0
Boiler outlet O <sub>2</sub> concentration <sup>*1</sup>	[wet%]	3.7	2.4
Designed value of total air ratio <sup>*2</sup>	[-]	1.33	1.20
Stack inlet NO <sub>x</sub> <sup>*3</sup>	[ppm-dry]	56	33
Stack inlet CO <sup>*3</sup>	[ppm-dry]	6.1	3.9
Denitrifying agent flow rate <sup>*1</sup>	[L/min]	17.6	0.0
Manual intervention ratio (low NO <sub>x</sub> combustion operation vs conventional operation)	[-]	-	0.46
Fan power consumption ratio (low NO <sub>x</sub> combustion operation vs conventional operation)	[-]	-	0.94

<sup>\*1</sup> Average per operation day, <sup>\*2</sup> Assuming a moisture content in exhaust gas of 30%, <sup>\*3</sup> Converted to 12% oxygen

**Figure 7 Long-term trend data (daily average)**

## 5. Conclusion

A novel low NO<sub>x</sub> combustion system has been developed, which decreases both NO<sub>x</sub> and CO concentrations in a stable manner. In this system, EGR gas is injected from the back of the stoker incinerator to induce both recirculation flow and swirling flow within the incinerator. The following results were obtained using the new system.

- The NO<sub>x</sub> production was in the 30 ppm range (half of that of conventional operation).
- Long-term (180 days) operation data indicate that low NO<sub>x</sub> combustion can be maintained regardless of seasonal variations in waste quality and changes in incinerator load.
- The enhanced degree of gas mixing within the incinerator successfully contributed to combustion stability. The number of manual interventions was nearly half of that of conventional operation.

Looking forward, MHIEC will actively promote continued development to achieve further improvements in the reduction of manpower, power consumption and environmental impact by incorporating automatic operating systems into this new system.

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## References

- (1) S. Yokoi et al., Development of Low NO<sub>x</sub> Combustion Technology for Small and Medium Sized Stoker Furnace Using Exhaust Gas Recirculation (in Japanese), The 36<sup>th</sup> Annual Conf. of JSMCWM (2025) D2-5-0
- (2) S. Yokoi et al., Development of Low NO<sub>x</sub> Combustion System for Stoker Incinerator Utilizing Recirculation Flow and Swirling Flow (in Japanese), The 63<sup>rd</sup> Proceedings of the Japanese Symposium on Combustion (2025) D112
- (3) S. Yokoi et al., Introduction of CAE application cases for Incinerator to reduce NO<sub>x</sub> emissions (in Japanese), The 47<sup>th</sup> Proceedings of the Annual Conference of the Japan Waste Management Association (2026) II-4-94
- (4) H. Momose et al., Development of Low NO<sub>x</sub> Combustion Technology in Stoker Furnace Using Exhaust Gas Recirculation (in Japanese), The 47<sup>th</sup> Proceedings of the Annual Conference of the Japan Waste Management Association (2026) II-4-92