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Numerical Study on the NO_x Control in Municipal Solid Waste Incinerator by Direct Spray of Food Wastewater

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ABSTRACT: *In this study, numerical study result of computational numerical simulation under the same condition of existing experiment result that researched NO_x reduction effect by substituting ammonia water required for SNCR process by food wastewater in MSW incinerator of C city was comparatively analyzed. Based on existing experiment result, 4 experiment conditions, that is, Case A in which NO_x was removed by using SNCR, Case B in which NO_x was removed by spraying food wastewater in secondary combustion chamber, Case C in which food wastewater was sprayed in primary combustion chamber (2ton/hr) and secondary chamber (4ton/hr) and Case D in which food wastewater was reversely sprayed in primary chamber (4ton/hr) and secondary chamber (2ton/hr) were established. In Case A, NO_x generation was predicted to be higher than that of experiment result by 5.4ppm and in Case B, it was predicted to be close to experiment result (29.0ppm). Case C & D also showed higher result than experiment result by app. 2ppm. When comparing Case A&B, a case of spraying food wastewater showed better NO_x reduction effect and when comparing Case C with D, Case C that sprayed much more food wastewater quantity in secondary combustion chamber showed better NO_x removal rate.*

KEYWORDS: *NO_X Control;SNCR;CFD;Food Wastewater;MSW Incinerator.*

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I. INTRODUCTION

Since 2005, as direct burial of food waste was prohibited in Korea, food waste has been made as resources (fodder, compost).

In washing, dehydration process, food waste leachate(food wastewater) that is organic by-product of high concentration has been generated in reality.

Since 2007, in order to convert to inland treatment of food wastewater as a result of prohibiting its ocean disposal, policies of converting existing treatment facility to inland treatment facility by the end of 2012 based on London Dumping Convention have been promoted by expanding inland treatment facility of food wastewater through promotion of general countermeasure for food wastewater inland treatment and making waste resource (biomass including food wastewater)as energy.

Since London Dumping Convention, ocean disposal of food wastewater was entirely prohibited from 2013 [1-4] .

Recently, as a method of inland treatment of food wastewater, a technology of spraying food wastewater and incinerating it in large incineration plant has been developed. As a part of this effort, in order to remove NO_x in a process of incinerating MSW of C city, a technology of spraying food wastewater instead of ammonia water that is reducing agent was developed and commercialized [5] .

In this study, based on existing experiment result [6] , numerical analysis was performed for NO_x generation amount, temperature being obtained from actual experiment by performing NO_x removal test through spray of food wastewater after predicting NO_x being generated at the time of incinerating wastes by progressing computer numerical simulation for MSW and food wastewater incineration process based on same experiment condition of CFD commercial code.

A principle of reducing NO_x by food wastewater ammonia component is as shown on below formula (1), (2):

$4NH_3+6NO \longrightarrow 5N_2+ 6H_2O$ (1)

$8NH_3+6NO_2 \longrightarrow 7N_2+ 2H_2O$ (2)

II. EXPERIMENTAL

2.1 Numerical analysis method

2.1.1 Analysis model

Incinerator applied for this study is continuous stoker type incinerator that incinerates MSW 200ton/day and in order to analyze actual incinerator shape (H×W×L=22.08m×10.31m×3.60m), it was implemented as 3D model. Major components are as follows.

(a) Fuel Inlet (b)Primary Combustion Air Inlet 1, 2, 3, 4, 5, 6(Primary combustion air inlet 1, 2, 3, 4, 5, 6) (c)Secondary Combustion Air Inlet(Secondary combustion air inlet) (d)Food Wastewater Inlet 1, 2, 3, 4(Food wastewater inlet 1, 2, 3, 4), (e)Outlet.

Shape and dimension of incinerator model are shown on Fig. 1. As shown on the Fig, in the bottom of boiler, fuel inlet is arranged between primary air inlets.

In the upper part of primary combustion chamber, 6 rows of secondary combustion air inlet are distributed and in inlet 1, 2, 3, 5, 6, 7 injection nozzles are provided in 1 row and in inlet 3, 4, 6 injection nozzles are provided. In central position, food wastewater spray nozzle 1, 2 are provided and in central part of secondary combustion chamber, food wastewater nozzle 3, 4 are provided at both sides. At secondary combustion chamber of left upper part of incinerator, outlet is located.

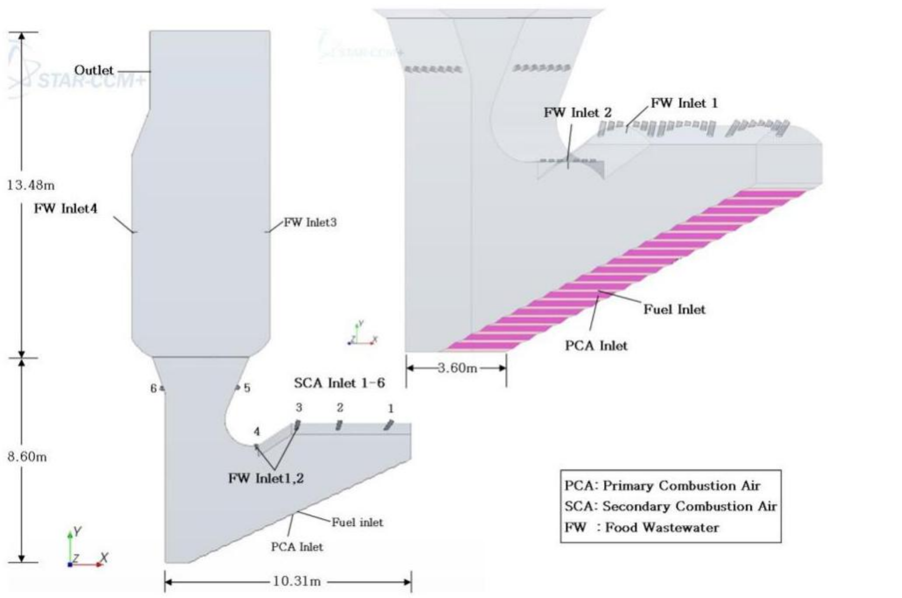

Fig.1 Schematic diagram of the incinerator

2.1.2 Physical model

(1) Operation data and input condition

In order to establish a physical model in progressing this study, 16 days' operation data [7] of MSW incinerator of C city was surveyed. Based on surveyed operation data, computational simulation of incinerator was performed.

In this study, quantity of fuel and air being injected into each inlet was shown on below Table 1 and temperature condition of injection air and wall was shown on Table 2.

Table 1 Flow conditions of fuel and air in simulation

Item			Velocity(m/s)
Fuel			0.000499
NH_3 liquid	case A	FW inlet 1, 2	0.08
	case B	FW inlet 1, 2	-
	case C	FW inlet 1, 2	-
	case D	FW inlet 1, 2	-
Food wastewater	case A	FW inlet 1, 2	-
		FW inlet 3, 4	-
	case B	FW inlet 1, 2	9.7

		FW inlet 3, 4	-
	case C	FW inlet 1, 2	11.11
		FW inlet 3, 4	22.22
	case D	FW inlet 1, 2	22.22
		FW inlet 3, 4	11.11
Primary Combustion Air			0.23
Secondary Combustion Air	1		3.63
	2		3.12
	3		2.65
	4		-
	5		1.41
	6		1.43

Table 2 Temperature conditions in simulation

Part	Temperature(K)
Fuel	873.15
Primary combustion air	873.15
Secondary air	773.15
Secondary combustion chamber wall	973.15

Considered reaction formula is as follows.

$C + O_2 = CO_2 (3)$

$C + 0.5O_2 = CO_2 (4)$

$H_2 + 0.5O_2 = H_2O (5)$

$NH_2 + NO + 0.25O_2 = N_2 + 1.5H_2O (6)$

Formula(3),(4),(5),(6) are reaction formula when waste combustion is progressed and formula(6) is reducing reaction when spraying food wastewater that plays a role of reducing agent.

Food wastewater is composed of ammonia, water and other components but for an analysis, it was assumed to be composed of NH_3 and water that are actually participated in reaction. Volume fraction of NH_3 and H_2O was established as 0.1: 0.9.

2.2Case Set-up

Experiment condition of Table 3 was established by referring to existing experiment research result of Master's degree thesis of Lee, Young-Jin [6]in which experiment was progressed with same incinerator.

Table 3 Establish of case A, B, C, D

Item	SNCR (㎥/hr)		Food wastewater (ton/hr)		Temperature (℃)		Emission (ppm)	
	1st Combustion chamber (Inlet 1, 2)	2nd Combustion chamber (Inlet 3, 4)	1st Combustion chamber (Inlet 1, 2)	2nd Combustion chamber (Inlet 3, 4)	1st Combustion chamber (A, B)	2nd Combustion chamber (C, D)	NOx	CO
CaseA	-	25.7	-	-	1,254	948	41.1	-
Case B	-	-	-	3.5	1,210	935	29.4	-
Case C	-	-	2.0	4.0	1,257	930	18.0	30.0
Case D	-	-	4.0	2.0	1,243	932	26.0	10.0

Note) FW: Food Wastewater

2.3 Analysis method

In this study, turbulence model-standard $\kappa - \epsilon$ model that was most stable and widely verified together with excellent performance ability when solving industrial flow problem was used for calculation. Regarding combustion reaction being taken place in incinerator, fast eddy break-up model was used and NO_x model followed Zeldovich mechanism considering thermal NO_x only.

For an analysis, STAR-CCM+7.04.011 of CD-adapco that is universal commercialization code was used. Polyhedral mesh having app. 465,000 grids was used and the shape of dividing grid is as shown on Fig. 2.

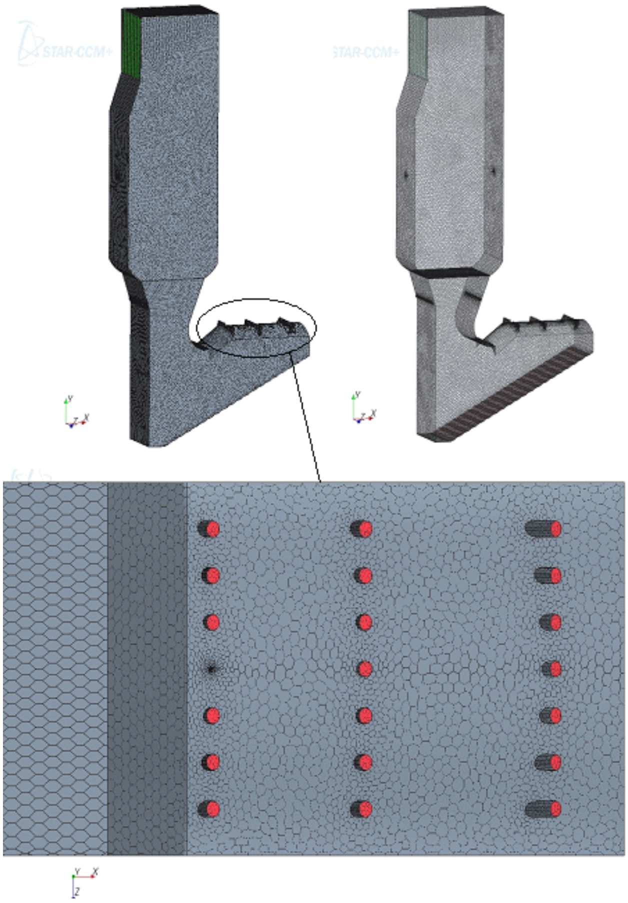

Fig.2 Grid system of geometry

III. RESULTS AND DISCUSSION

Comparative summary between analysis result of Case A, B, C, D and relevant experiment result was shown on below Table 4 and its graphic diagram is Fig. 3.

NO_x emission concentration at Case A outlet in case of removing NO_x by relying on SNCR only was 46.5ppmthat was higher than experiment result of 41.1ppm by 5.4ppm. In case of Case B that sprays food wastewater at the speed of 3.5ton/hr at secondary combustion chamber without using SNCR, NO_x emission volume at outlet was 29.0ppm and this result was almost close to experiment result of 29.4ppm (less than the latter by 0.4ppm).

Table 4 Comparison of the modeling & experimental result

Items	SNCR (NH_3 Feed rate) (m^3/hr) combustion chamber		Food wastewater (ton/hr) combustion chamber		Temperature (℃) combustion chamber				NO_x Emission (ppm)	
					1st		2nd			
	1st	2nd	1st	2nd	Modeling	Experiment	Modeling	Experiment	Modeling	Experiment
CaseA	-	25.7	-	-	1,230	1,254	906	948	46.5	41.1
CaseB	-	-	-	3.5	1,200	1,210	903	935	29.0	29.4
CaseC	-	-	2.0	4.0	1,130	1,257	902	930	29.0	18.0
CaseD	-	-	4.0	2.0	1,100	1,243	903	932	28.9	26.0

In case of Case C & D in which food wastewater spray volume in primary, secondary combustion chamber was established to be controlled, when speed is 4ton/hr where food wastewater volume sprayed in secondary combustion chamber is much plenty than that of primary combustion chamber, NO_x emission volume of 20.0ppm that showed same pattern as experiment result in which NO_x emission volume at outlet was reduced from 26.0ppm to 18.0ppm was represented and 29.0ppm and 28.4ppm that were a result close to Case B were represented.

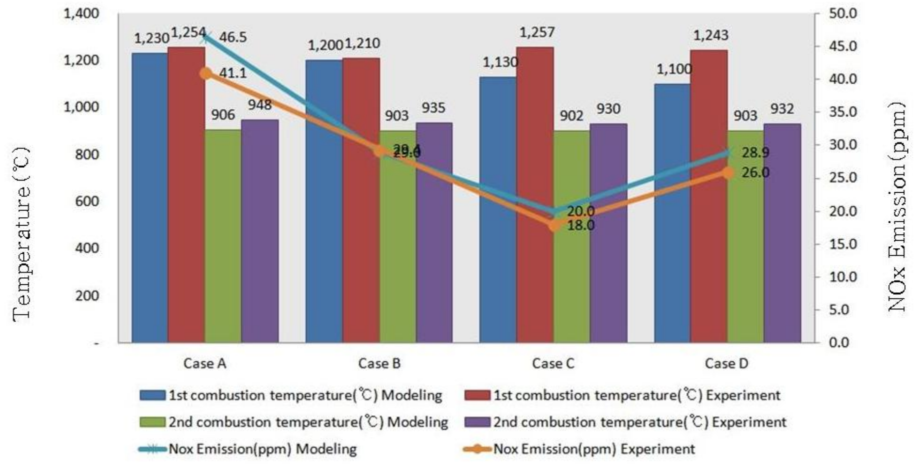

Fig.3 Comparison of the modeling & experimental result

3.1 Velocity field

Residence time in SNCR process is residence time of reducing agent in minimum temperature range and scale of reaction time. In order to achieve complete NO_x removal reaction in most of the systems, residence time of at least 0.2-0.5 seconds is required and generally, in pilot scale experiment, effective NO_x reduction could be obtained by enough residence time of app. 1 second[7-8]. Therefore, velocity of combustion gas in combustion chamber significantly affects reduction.

When observing from Fig. 4, as velocity of combustion gas in secondary combustion chamber is the fastest (3.2m/s), it is considered that its reaction time is enough after reducing agent is injected.
Flow streamline was shown on Fig. 5 by taking Case C as a typical case where combustion air, fuel and food wastewater flow are provided as a whole.

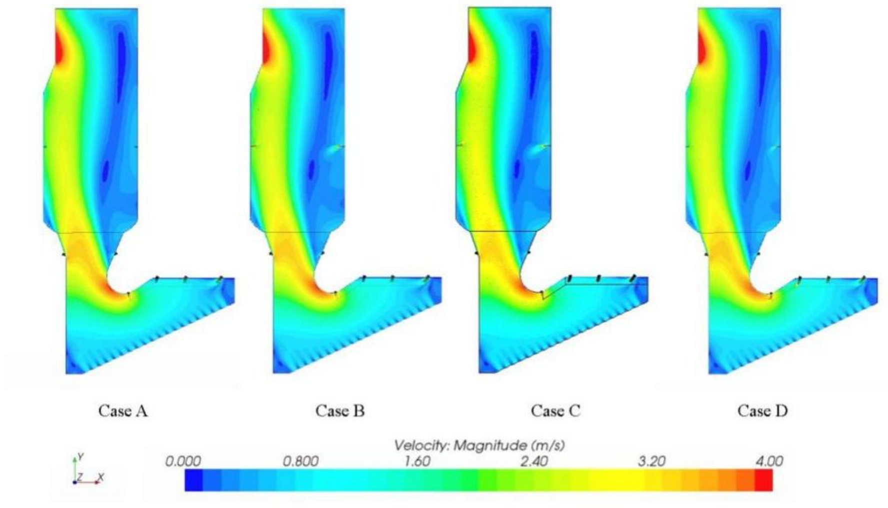

Fig.4 Result of simulation of velocity distribution

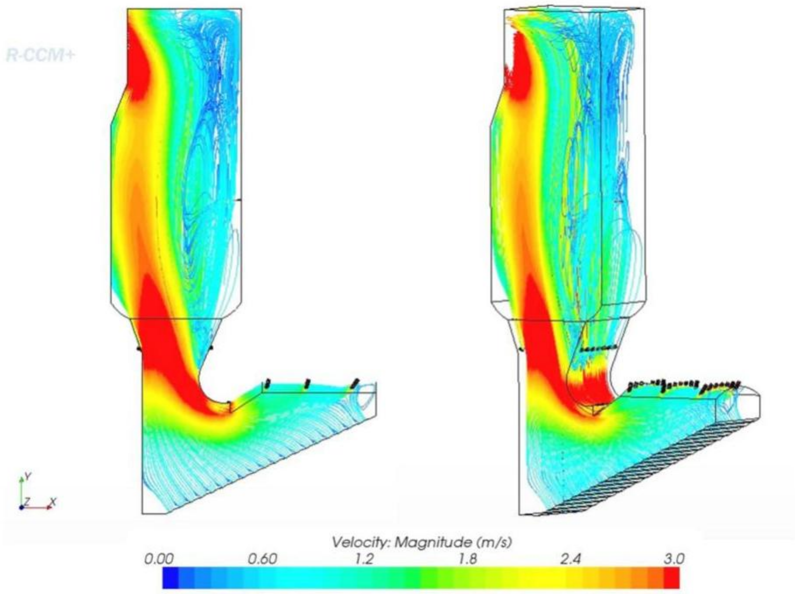

Fig.5 The streamline of Case C

3.2 Temperature field

In NO_x occurrence, temperature exerts a significant influence. In order to suppress NO_x, NO_x generation itself is required to be reduced and for already generated NO_x, post-treatment shall be performed by using reducing agent.

Already generated NO_x is unable to be controlled by temperature but in order to suppress NO_x generation itself, temperature of combustion gas is required to be lowered and generation of local high temperature section should be avoided. Where, temperature of overall incinerator section rather than that of combustion gas itself is also included.

Temperature distribution in overall primary, secondary combustion chamber of incinerator was shown on Fig. 6 by each case. It could be seen that overall temperature in combustion chamber is distributed below 1,100^{o}C and temperature in primary combustion chamber showed distribution over 1,100^{o}C in every case and in Case B, C, D where food wastewater was sprayed, Case C and D that sprayed food wastewater in primary, secondary combustion chamber showed lower distribution than Case B that sprayed in secondary combustion chamber only.

When observing Case C & D, primary combustion chamber temperature of Case D that sprayed a lot of volume in primary combustion chamber showed temperature lower than that of Case C by 30^{o}C. From this result, it could be realized that combustion temperature of primary combustion chamber was also lowered as all the food wastewater was sprayed from primary combustion chamber as well.

In case of Case A that simulated a case of removing NO_x by entirely relying on SNCR of Case A, it generally showed slightly high temperature distribution than other case of denitrification by relying on food wastewater. When comparing with primary combustion room temperature of experiment result, similar result was represented and both two results showed same changing pattern even though slight difference was evident.

Outlet temperature of incinerator secondary combustion room is required to be maintained over 850^{o}C and when observing outlet temperature of secondary combustion chamber of flue gas in Fig. 6, it is shown to be distributed to 906^{o}C and 902^{o}C that is early stage of 900^{o}C. When comparing with actual operation data of 900^{o}C, it is proper temperature. However, there is a difference of app. 30^{o}C than outlet temperature of secondary combustion chamber being distributed in the range of 930-950^{o}C that is experiment result.

The result of analyzing a cause of difference by comparing experiment result with numerical analysis result is as follows.

In computer numerical simulation, actual situation is unable to be completely reproduced but various assumptions close to reality are bound to be introduced. Plausible assumption is considered to be most important in computer numerical simulation but notwithstanding plausible assumption, difference with actual experiment result would be inevitably represented.

In this study, at the time of computer numerical simulation, it was assumed that combustible components of MSW would be burnt in incinerator without considering moisture contained in wastes. It was assumed that combustible components as a fuel being composed of C(s), CO, H_2 would be evaporated.

Food wastewater is also actually composed of water and sludge as well as ammonia component but it was assumed as ammonia solution (10%) of which concentration is lower than ammonia solution (25%) being used as reducing agent in SNCR process without considering other components.

There would be an activity of reducing NO_x by reduction of ammonia component when incinerating food wastewater by spraying it to combustion chamber in order to actually remove its NO_x and other activity of suppressing NO_x generation itself by lowering temperature of combustion chamber while food wastewater under room temperature is sprayed.

Moreover, as combustible components in sludge are burnt, outlet temperature of combustion chamber would be increased. Outlet temperature difference of 30-40^{o}C between experiment result and numerical simulation is considered to be taken place by this cause.

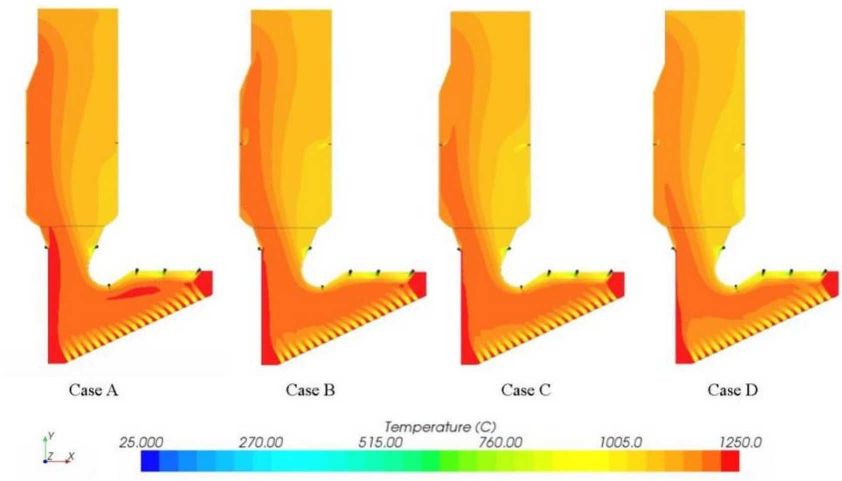

Fig.6 Result of simulation of temperature distribution

Local high temperature section could be seen in primary combustion chamber and front section is actually inlet of MSW fuel of incinerator and high temperature section under secondary combustion chamber is outlet where not combusted ash of waste fuel is dropped. At the time of performing computer numerical simulation, high temperature section is considered to be appeared as dead zone is formed by simulating this section as blocked place.

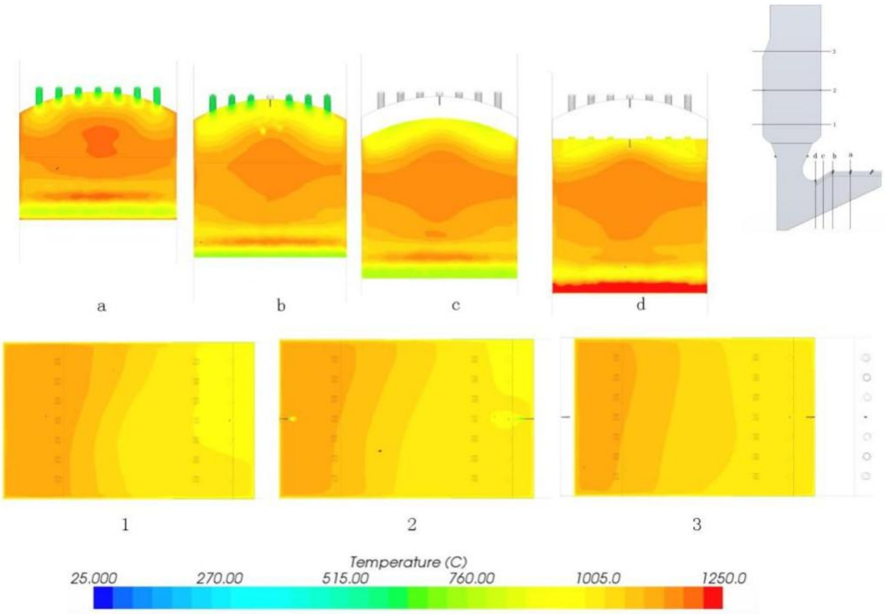

Fig.7 Temperatures of section a, b, c, d, and section 1, 2, 3

3.3 NO_xemission

In this study, predicting NO_x generation is most important in order to achieve research objective of verifying an effect of reducing NO_x by spraying food wastewater.

Generally, when observing NO_x emission volume, an effect of reducing NO_x by spraying food wastewater rather than by relying on ammonia solution using SNCR process was bigger by app. 17ppm and it could be confirmed through Fig. 9, 10. In case of Case C & D that spray food wastewater in primary, secondary combustion chamber, Case C that sprayed extensively in secondary combustion chamber (4ton/hr) while spraying less in primary combustion chamber (2ton/hr) emitted less NO_x than Case D by 8ppm.

When comparing computer numerical simulation with experiment result, experiment result and Case A & B are considered to be almost coincided.

However, when changing food wastewater quantity being combusted in primary, secondary combustion chamber represented in Case C & D, change of NO_x emission was almost marginal.

In experiment result, it could not be confirmed that NO_x emission at outlet was reduced from 28ppm to 18ppm when spraying food wastewater at 2ton/hr in primary combustion chamber and 4ton/hr in secondary combustion chamber rather than when spraying food wastewater reversely and NO_x of same quantity was emitted.

A mode of spraying reducing agent in secondary combustion chamber for NO_x reduction in general incinerator is frequently used but a mode of spraying in primary combustion chamber is not frequently used. In view of experiment result, NO_x reducing activity of food wastewater sprayed from primary combustion chamber is more effective for reducing NO_x by lowering temperature of combustion chamber rather than by chemical reaction.

When comparing with NO_x emission of experiment result, generally same changing pattern was represented.

Fig. 8 shows NO_x emission in overall section of incinerator and Fig. 10 shows NO_x emission at outlet.

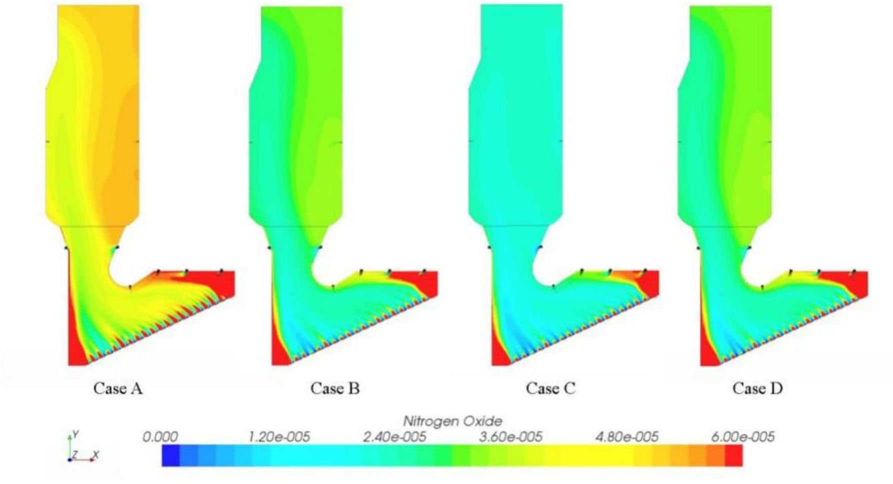

Fig.8 Result of simulation of NO_x emission

IV. CONCLUSIONS

In this study, numerical analysis result being obtained by performing computer numerical simulation under the same condition as existing experiment result that researched on NO_x reduction effect by substituting ammonia water required for SNCR process by food wastewater in MSW incinerator of C city was comparatively analyzed.

As a result of numerical analysis, temperature of primary combustion chamber was represented over 1,100^{o}C and as changing pattern, temperature of SNCR process that uses ammonia water as reducing agent was the highest as 1,230^{o}C and comparing with this, temperature of Case B was represented as 1,200^{o}C and Case C & D where food wastewater was sprayed both in primary and secondary combustion chamber showed 1,130 and 1,100^{o}C, respectively. When comparing this result with temperature of primary combustion chamber of experiment result, Case A & B showed slight change but Case C & D showed difference as much as app. 130^{o}C.

However, experiment result and numerical analysis result showed same changing pattern and in case of Case D that sprayed much plenty food wastewater in primary combustion chamber among Case C & D, it showed lower temperature than Case C that sprayed much plenty food wastewater in secondary combustion chamber by app. 30^{o}C. From this result, it could be seen that when increasingly spraying room temperature food wastewater in primary combustion chamber, it has a tendency of further decreasing combustion temperature.

Temperature of secondary combustion chamber showed early 900^{o}C in all the Cases and this result means difference lower than actual outlet temperature by 30-40^{o}C. The reason of this result is that while simulating food wastewater numerically, as combustion heating value of solid waste in food wastewater was not reflected in numerical analysis while considering just ammonia and water component in food wastewater, combustion temperature was low and actual experiment value was represented to be high while solid combustible component was burnt.

NO_x emission of Case A was predicted as 46.5ppm that is higher than actual experiment result by 5.4ppm and that of Case B was predicted to be very close to numerical analysis result and experiment result as 29.0ppm and this value was lower than experiment result by 0.4ppm.

Case C & D also showed higher difference than experiment result by app. 2ppm. When comparing Case A with B, Case B that sprayed food wastewater in secondary combustion chamber showed less NO_x emission and from this result, it could be seen that food wastewater induces better NO_x reducing effect.

When comparing Case C with D, Case C that sprayed less food wastewater in primary combustion chamber and more in secondary chamber emitted NO_x of 18ppm that is less than Case D that sprayed food wastewater reversely.

When considering this result based on temperature, food wastewater sprayed in primary combustion chamber is more active in lowering temperature of combustion chamber rather than in reducing NO_x as reducing agent and that sprayed in secondary combustion chamber is more active in reducing NO_x by creating reduction and this result was obtained through analysis of temperature and NO_x emission of Case C & D.

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