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Study on the Incineration Process of Food Wastewater in the Demo-Scale Stoker System†

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The demo-scale stoker system is used at incineration facilities and the scheme on incineration treatment of the food wastewater emitted from food recycling facilities into municipal waste incinerators was investigated. The ammonia component in the food wastewater functions as the reductant in selective non-catalyst reduction. Remarkable reduction of nitrogen oxide is achieved by using food wastewater containing plenty of the NH_3 component. The 26 items of air pollution matter, that is, nitrogen oxide (NO_x), sulfur oxide (SO_x) and dioxin *etc*. are measured while incinerating food wastewater and it is found that they all are under the value of allowable exhausts, by allowable exhaust standards. In case of the food wastewater, it can be confirmed that the furnace wall is kept in the unsoiled condition of the refractory surface by a coating effect, according to the spray of the food wastewater. Furthermore, it is found that the fly ash is combusted completely and the outer wall of the water pipe is in a satisfactory state owing to keeping it at 870-950 ºC of the second combustion temperature in order to spray the food wastewater.

Key Words: Food wastewater, Incineration, Nitrogen oxide, Dioxin, Ammoniac nitrogen.

INTRODUCTION

In Korea, since the government prohibited landfill disposal of food waste in January 2005, the amount of ocean disposal has more than doubled during the last two years (700,000 m^3 in 2004, 1,660,000 m^3 in 2006) and the total amount has accounted for about 16.7 % (9,930,000 m^3) of food waste disposal[1-4]. The Ministry of Maritime Affairs and Fisheries has responded properly to international regulation on prevention of ocean pollution in accordance with the London Convention[5,6] and has restricted ocean disposal of food wastewater which are for reasons of preservation of the ocean ecosystem, et cetera[7,8]. According to the regulations of the Ministry of Maritime Affairs and Fisheries, the ocean disposal is allowed temporarily until it is prohibited completely in 2012. Since October 2007, however, it is allowed due to a more than 92 % water content in the food wastewater.

If the organic wastewater with high concentrations of waste, like food wastewater, is treated at general treatment plants for middle or low concentrations, there are some problems, that is, the economics and the efficiency in managing the food wastewater recycling plants fall due to enormous cost[9]. To effectively treat the food wastewater, it is desirable to be equipped with wastewater treatment in the recycling plants and to be linked with sewage treatment plants to treat below the optimum load[10]. In the present conditions, however, the technology which is able to treat food wastewater below optimum load is not enough. In addition, although biodegradation is more easily applied to food wastewater than industrial wastewater, for instance, there are a lot of troubles in operating the biological processes because the concentration of salinity and oil in the food wastewater is different.

The generally used treatment process of the food wastewater is ocean disposal, sewage treatment, landfill and incineration et cetera and the ocean disposal and the sewage treatment are given a lot of weight in Korea[11,12]. The policy of the Ministry of Maritime Affairs and Fisheries to decrease ocean disposal by tightening regulation gradually until 2012 has been already implemented. In the case of the sewage treatment, there are a lot of problems such as long treatment periods, high costs, malodor and sludge reprocessing et cetera. Furthermore, landfill needs to undergo pretreatment processes like weight reduction, which induces malodor and soil pollution. In the case of incineration, compared with these treatment processes,

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it reduces the cost and period of treatment as wastewater is directly sprayed into the incinerator. In addition, easy post-processing is the advantage of it.

However, the civil complaint is sued frequently due to noxious gas such as nitrogen oxide (NO_x), sulfur oxide (SO_x), dioxin, fly ash, phenol and benzene *etc*. which are generated from incineration of the food wastewater. To control these noxious gases, it is urgently needed to develop the incineration treatment technology of food wastewater using the demo-scale plant. The purpose of this study is to investigate a scheme on incineration treatment of the food wastewater, emitted from food recycling facilities, in municipal waste incinerators and to develop a control technology for noxious gases. Furthermore, the stability of incineration facilities is ensured and the permanent treatment of food wastewater which has troubles in inland treatment is induced.

EXPERIMENTAL

The facilities used in this study are able to incinerate the food wastewater by heat generated from municipal waste incinerators at low cost. Additionally, the economics of the incinerators are improved by reducing the use of NH_3 in selective non-catalyst reduction (SNCR) to eliminate NO_x in exhaust gases through the spray and incineration of the food wastewater containing ammoniacal nitrogen (NH_3-N).

The facilities are composed of transporter, incinerator, cooling apparatus of combustion gas and treatment apparatus of combustion gas. The schematic diagram of municipal waste facilities used in this study is illustrated in Fig. 1. The amount of waste picked up by a garbage truck is measured and is carried into the incinerator in order to incinerate after storage and mixture in the bunker. Then, the waste which is inputted into the incinerator by crane is transferred to fire grates and it becomes an ash after going through the process of drying, ignition, combustion and post combustion. The ash is dropped into an ash extractor and the combustion gas is emitted to a waste heat boiler. In the cooling apparatus, it refrigerates to under 200 ºC, suitable for the treatment process of high combustion gas generated from waste combustion and the recovered waste heat in this process is used to heat the incinerator by generating saturated vapour. The combustion gas, which is refrigerated to under 200 ºC at the cooling apparatus, includes dust and various types of harmful substances. Hence, it should be emitted into the atmosphere to reduce the presence of harmful substances, under the effluent limitations standards for environmental protection.

The treatment apparatus for the combustion gas is composed of two systems, that is, one is the elimination apparatus for dust, hydrogen chloride (HCl), SO_x, dioxin and another is the elimination apparatus for NO_x. The SDR (semi-dry reactor) and bag filter were used as elimination apparatus of dust, HCl, SO_x, dioxin and selective non-catalyst reduction (selective non-catalyst reduction) was used for NO_x. The sampling ports were installed in the stack to analyze exhaust gas composition. The flow rate, temperature and concentration of exhaust gases were monitored in real time at the central control room by a tele-monitoring system (TMS).

The detailed structure of the incinerator system for both municipal waste and food wastewater is shown in Fig. 2. This facility is able to incinerate 200 tons of waste (municipal waste: 180 tons, food wastewater: 80 tons) and the incineration process is the stoker system. The characteristic of this facility is the ability to automatically control the speed of the fire grate by automatic operation at the distributed control system (DCS) according to a change of the waste condition. Additionally, it is able to automatically supply a combustion to air ratio of within the 40-60 % range, according to the automation by the supply system of first and second combustion air. Since it is able to combust, which is close to complete combustion by high temperature incineration, to keep the first combustion temperature at 1,200-1,300 ºC and a residence time of 4.5 seconds, the O_2 and CO concentration in the exhaust gases are maintained low at 5-8 % and under 5 ppm. Since the second combustion temperature is adjusted to 870-950 ºC for the spray and incineration of food wastewater, it is able to improve the reaction efficiency of selective non-catalyst reduction and to prevent the clogging phenomenon in the boiler and to operate automatically with all chemicals in relation to treatment of exhaust gases by tele-monitoring system.

The composition and characteristics of municipal waste should be individually different because of various emission sources. Thus, an efficient and stable combustion is maintained

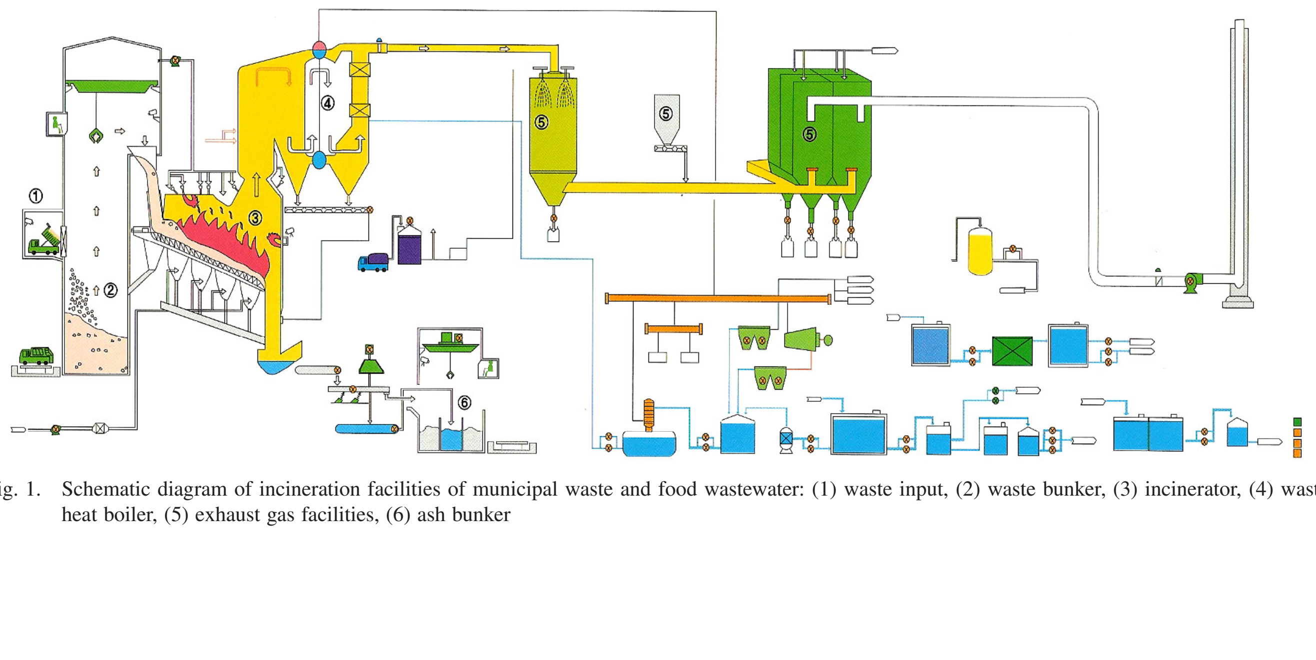

Fig. 1. Schematic diagram of incineration facilities of municipal waste and food wastewater: (1) waste input, (2) waste bunker, (3) incinerator, (4) waste heat boiler, (5) exhaust gas facilities, (6) ash bunker

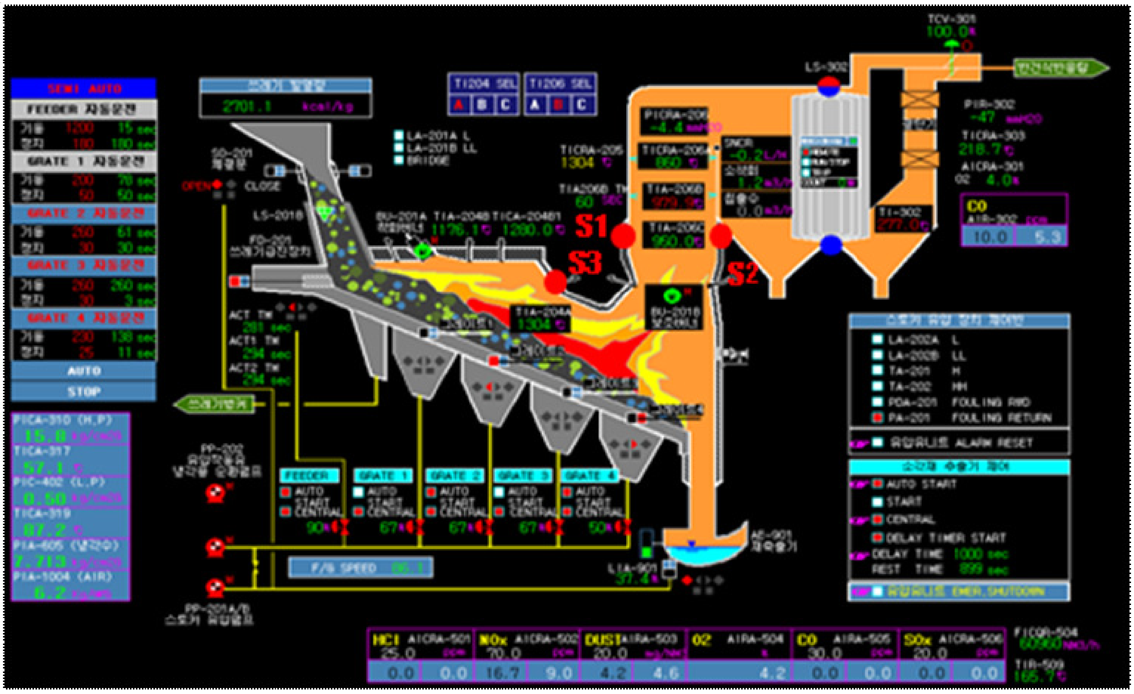

Fig. 2. Detail of incinerator and incineration system (spray position of food wastewater: S1, S2 and S3)

by mixing fully in the bunker before inputting into the incinerator. The amount to incinerate is inputted in accordance with the optimum load at regular intervals, by crane. The supplied air for combustion is separated into first and second air. The first air is supplied to the waste layer through the lower part of the fire grate in the incinerator and the air amount of each fire grate is manually set by the operator or automatically set by automatic combustion control. The partition rate of the first air supplied into the fire grates is set by waste composition at distributed control system of the central control room. The second air is supplied above the waste layer, which has the highest flame temperature, in order to promote the complete combustion of unburned gas in the flue gas and refrigerate the gas temperature in the combustion room. The total amount of second air is controlled from automatic combustion control by the combustion room temperature and the oxygen concentration. The partition rate of second air supplied to each nozzle is set by the fixing load and the waste composition at distributed control system.

There are three nozzles for spraying food wastewater. Two nozzles are installed in the lower part of selective non-catalyst reduction for control of the second combustion temperature and one nozzle is installed in the upper part of the incinerator for control of the first combustion temperature. Since the food wastewater of high turbidity, compared to water, has to spray at a constant amount (3.2 ton/h), the nozzle was changed from a honeycomb style to a straight style so that the food wastewater, which is high suspended solid (SS) and containing foreign substances, is sprayed without any problems. Furthermore, the temperature of the second combustion exit is maintained at 870-950 ºC which is connecting the nozzle with the apparatus of the waste supply. Therefore, the operation time is lengthened and the incineration efficiency is increased owing to a decrease of adhesion of fly ash on the outer wall of the water pipe in the waste heat recovery boiler. When the temperature at the second combustion exit is above 950 ºC there is adhesion of fly ash in the flue gas. In the case of the fly ash being emitted as it is, it is attached on the outer wall of the water pipe in the waste heat recovery boiler. As a result, the flow of flue gas is disturbed, the operation time of the incineration apparatus is shortened and the efficiency of the heat exchange declines. Furthermore, the temperature of the second combustion exit in the incinerator ought to be kept above 850 ºC, the legal standard temperature, to prevent dioxin generation. The amount of food wastewater spray is set automatically to a standard that keeps temperatures at 870-950 ºC at the second combustion exit, in order to fulfill these criteria.

To solve the problems associated with the transfer and spray of food wastewater of high suspended solid concentration, the solid-liquid separator (4-5 ton/h) of screw rotation type is installed between the reservoir tank of food wastewater and the reservoir tank of treated food wastewater. A pump is changed to a multistage centrifugal style of horizontal type from a screw type because of a continuous transfer of food wastewater. To allow an inner pressure at the nozzle of 3-4 kg/cm^2, the pressure of the pump exit is kept above 7-10 kg/cm^2. For such a method, the problem of dropping efficiency due to high concentration and foreign matter are solved.

The selective non-catalyst reduction reduces the NO_x concentration to generate a denitrification reaction with NH_3, without a catalyst unlike selective catalyst reduction and is advantageous because the initial equipment expense and maintenance expense is lower compared to selective catalyst reduction. The NH_3 sprayed from the selective non-catalyst reduction reacts to the NO_x in the flue gas and is deoxidized into harmless N_2 and H_2O. Thus, the economics of the municipal waste incinerator is further enhanced by the reduction in the amount of NH_3 used and the waste consignment cost is reduced to spray the organic food wastewater which is able to generate NH_3.

RESULTS AND DISCUSSION

Component analysis of food wastewater: In the spray and incineration of food wastewater at the municipal waste incinerator, some phenomena arise. It is impossible to maintain continuous high pressure with a high suspended solid concentration. It also causes a nozzle clogging phenomenon due to a sticky mucilage state and dioxin is increased by the salt content in food wastewater, resulting in corrosion.

Thus, the suspended solid concentration of food wastewater is investigated. The result which is compared with untreated food wastewater and treated food wastewater is shown in Fig. 3. Here, untreated food wastewater means wastewater before treatment by the solid-liquid separator and treated food wastewater means wastewater after treating. The result is averaged, which is measured a total of six times and it is found that the suspended solid concentration is decreased to about half from 140,000-72,000 ppm.

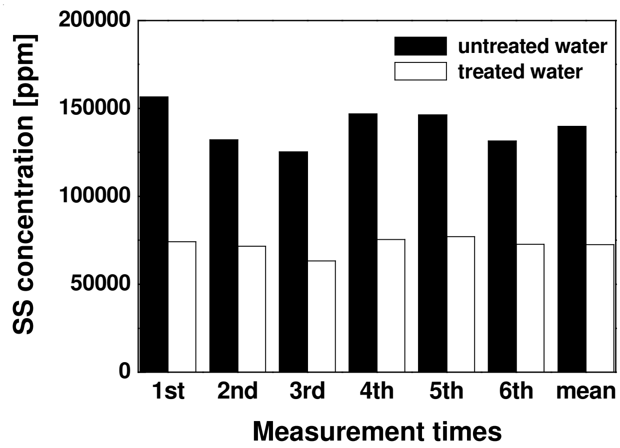

Fig. 3. Comparison of suspended solid concentration (SS) in untreated and treated food wastewater

Table-1 shows the result of component analysis after a passing of a number of generation days in untreated and treated food wastewater. It is found that the ammonia nitrogen (NH_3-N) concentration is increased with the passing of generation days and the highest NH_3-N concentration is after 10 days. Total nitrogen in the wastewater goes through the nitrification[13,14] in the order of organic matter ($C_5H_7O_2N$), ammonia nitrogen (NH_3-N), nitrite nitrogen (NO_2-N) and nitrate nitrogen (NO_3^--N). Here, the NH_3-N is the nitrogen which is able to generate the ammonium (NH_4^+) in wastewater. In the case of spray and incineration of the NH_3-N contained in wastewater, the NH_3-N performs the function of enhancing the removal efficiency and the stabilization of NO_x. Therefore, we will attempt to enhance the removal efficiency of NO_x and to reduce the amount of ammonia used at selective non-catalyst reduction by using the food wastewater which contains a high ammonia component.

NO_x reduction: Fig. 4 shows the NO_x emissions from incineration of food wastewater and the pump output and the flow rate of NH_3 at selective non-catalyst reduction. The left result of a vertical axis in Fig. 4 shows the NO_x emissions, the pump output and the flow rate of NH_3 for the case of spray of food wastewater and the right result shows the case without spray of food wastewater. In the case of spray of food wastewater, the NO_x emissions, the pump output and the flow rate of NH_3 are low and show the regular distribution. However, the NO_x emission without spray of food wastewater is increased gradually and the feed rate of NH_3 is rapidly increased at the same time and shows the irregular distribution.

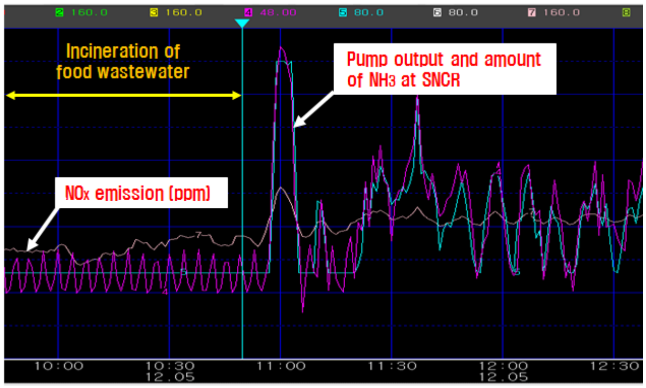

Fig. 4. Operating result of nitrogen oxide (NO_x) emission, pump output and ammonia (NH_3) amount at selective non-catalyst reduction for the incineration of leachate and food wastewater

Fig. 5 shows the compared results of the NO_x emissions and the amount of NH_3 used in selective non-catalyst reduction, while the leachate and the food wastewater is sprayed. The NO_x emission is shown to decrease by 29 ppm, while the food wastewater is 14.8 ppm compared with 43.8 ppm of leachate. In addition, it is found that the amount of NH_3 used at selective non-catalyst reduction diminishes by about half to 123 L/day from 228 L/day.

To further investigate this result, the NH_3 component in leachate and food wastewater is analyzed. Table-2 shows the analysis result of the NH_3 component. From the result, it is

TABLE-1
COMPONENT ANALYSIS IN UNTREATED AND TREATED FOOD WASTEWATER:
(a) UNTREATED FOOD WASTEWATER, (b) TREATED FOOD WASTEWATER

Generation day	pH	COD	SS	VSS	T-N	T-P	NH_3-N	NO_2-N	NO_3-N
(a) Untreated food wastewater									
3 days	4.48	45,000	156,500	125,200	3,552	832	417	0.60	4.80
6 days	4.61	42,300	167,800	133,568	3,705	809	522	0.76	5.30
10 days	4.57	39,800	170,200	133,436	3,755	886	956	0.82	6.00
13 days	4.63	40,500	169,800	128,878	3,890	920	978	0.78	5.80
(b) Treated food wastewater									
3 days	4.37	37,000	73,000	56,900	2,676	492	475	0.20	3.70
6 days	4.41	35,600	75,900	60,700	2,436	468	498	0.44	3.70
10 days	4.39	36,200	76,400	59,500	3,432	658	835	0.43	5.00
13 days	4.50	38,600	77,100	62,451	2,988	588	510	0.22	3.60

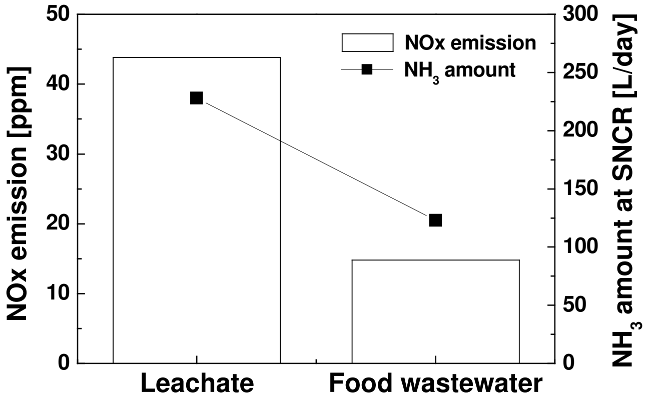

Fig. 5. Nitrogen oxide (NO_x) emission and ammonia (NH_3) amount for the incineration of leachate and food wastewater

TABLE-2
COMPARISON OF AMMONIA (NH_3) CONTENT IN THE LEACHATE AND THE FOOD WASTEWATER

	NH_3 content (ppm)	NH_3 amount at SNCR (L/day)
Leachate	8.7	228
Food wastewater	530	123

found that food wastewater contains sixtyfold NH_3 as compared with leachate. The NH_3 of the reductant is sprayed at the rear of the second combustor to reduce the NO_x in these facilities and the NO_x is separated and emitted as N_2 and H_2O through the following reaction[15,16].

$$4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O \quad (1)$$
$$8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O \quad (2)$$

It is considered that the NH_3 component in the food wastewater is to function as the reductant and is able to reduce the NO_x remarkably as use of the food wastewater contains plenty of the NH_3 component, as compared with leachate. Thus, it can be said that the NH_3 component in the food wastewater affected the NO_x reduction. Furthermore, it is considered that it has the effect of reducing expenses for the use of chemicals to reduce NO_x.

Measurement of dioxin and air pollution: The dioxin becomes most important because the food wastewater contains plenty of salinity, which causes trouble for the operation of the incineration facilities due to exhaust gas instability and so on. Thus, the 26 items of air pollution, that is, nitrogen oxide (NO_x), sulfur oxide (SO_x) and dioxin *etc*. are measured during incineration of the food wastewater. The result is shown the Table-3. From the result, it is found that the 26 items of air pollution are under the value permitted by the allowable exhaust standard and dioxin is scarcely detected: 0.00-0.01 ng-TEG/Sm^3. Furthermore, it is considered that the dioxin is not detected by the absorption of the heavy metal which is the catalyst part of dioxin resynthesis and by removal of the particulated dioxin, which is kept under 200 ºC (actual temperature of operation: 150 ºC) of the inflow gas temperature.

Evaluation of incinerator stability: The other problem from incineration of food wastewater is the shortening of the continual operation period by a clinker phenomenon on the refractory surface in the furnace and by an adhesion of fly ash on the outer wall of the water pipe in the heat recovery steam generator. Since the first combustor is operated to 1200-1300 ºC because of a quality change of waste, the clinker phenomenon is generated by means of the high temperature in the second combustor (1000-1100 ºC). The incinerator stability regarding the clinker phenomenon on the surface of the refractory in the furnace and regarding the clogging phenomenon on the outer wall of the water pipe is evaluated. Fig. 6 shows the result regarding the clinker phenomenon on the surface of the refractory in the furnace with spraying of leachate and food wastewater. In the case of leachate, the clinker is generated on the furnace wall by the different melting point in spite of keeping the first combustion temperature high at 1,200-1,300 ºC. In the case of the food wastewater, however, it can be confirmed that the furnace wall is kept in the unsoiled condition of the refractory surface by the coating effect according to the spray of the food wastewater.

TABLE-3
MEASUREMENT RESULT OF AIR POLLUTION MATTERS (26 ITEMS)

	Dust (mg/Sm^3)	SO_X (ppm)	NO_X (ppm)	CO (ppm)	HCl (ppm)	Cl_2 (ppm)	H_2S (ppm)	HCN (ppm)	F^- (ppm)	Zn (ppm)
Leachate	3.8	1.30	49.3	N.D	1.36	0.38	0.10	0.011	0.489	N.D
Food wastewater	4.1	0.94	15.4	2.9	0.93	0.14	0.07	0.008	0.505	N.D
	Ash (mg/S)	Phenol (ppm)	NH_3 (ppm)	Ni (ppm)	Cd (ppm)	Pb (ppm)	Cr (ppm)	Cu (ppm)	HCHO (ppm)	Br_2 (ppm)
Leachate	0.15	N.D	0.88	N.D	N.D	0.004	N.D	N.D	0.007	0.009
Food wastewater	0.14	N.D	0.43	N.D	N.D	0.006	N.D	N.D	0.004	0.020
	CS_2 (ppm)	Smoke	Benzen (ppm)	Hg (ppm)	As (ppm)	Dioxin (ng-TEQ/Sm^3)				
Leachate	N.D	0	N.D	N.D	N.D	0.00-0.01				
Food wastewater	N.D	0	N.D	N.D	N.D	0.00-0.01				

*N.D: Not detect.

Fig. 6. Clinker phenomenon on refractory surface in furnace: (a) case of leachate, (b) case of food wastewater

The clogging phenomenon on the outer wall of the water pipe from the generation of fly ash by salinity in the food wastewater is shown in Fig. 7. The fly ash in the exhaust gas has absorbing properties when the exit temperature at the second combustor is over 950 ºC. Unchanged fly ash absorbs onto the outer wall of the water pipe in the heat recovery steam generator. Thus, the flow of exhaust gases is disturbed, the continual operation period of the incinerator is shortened and the efficiency of heat exchange is decreased. From the results, it is found that the fly ash is combusted completely and the outer wall of the water pipe is in a satisfactory state owing to keeping it at 870-950 ºC of the second combustion temperature in order to spray the food wastewater.

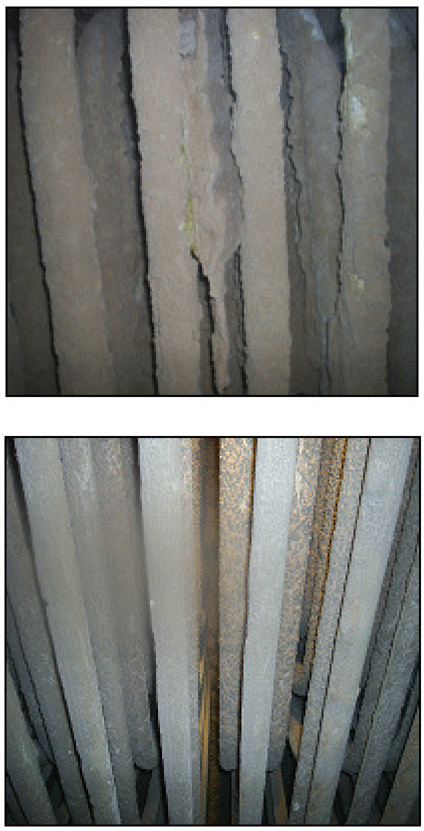

Fig. 7. Clogging phenomenon on outer wall of water pipe: (a) case of leachate, (b) case of food wastewater

Conclusion

The scheme on incineration treatment of the food wastewater, emitted from food recycling facilities, in municipal waste incinerators was investigated and the control technology on noxious gases was examined. The main results obtained in this study can be summarized as follows. The NH_3 component in the food wastewater functions as the reductant in the selective non-catalyst reduction and the NO_x is able to reduce remarkably as using the food wastewater contained plenty of NH_3. Furthermore, it has the effect of reducing expenses for chemicals used to reduce the NO_x. The 26 items of air pollution matter, that is, NO_x, SO_x and dioxin *etc*. are measured during incineration of the food wastewater and it is found that the total concentrations are under the permitted values of the allowable exhaust standard. As a result, it is considered that, the dioxin is destroyed sufficiently by the high temperatures (the first combustion temperature: 1200-1300 ºC, the second combustion temperature: 870-950 ºC). In the case of leachate, the clinker is generated on the furnace wall by a different component of combustion of the melting point in spite of keeping the first combustion temperature high at 1,200-1,300 ºC. In the case of the food wastewater, however, it can be confirmed that the furnace wall is kept in the unsoiled condition of the refractory surface by a coating effect according to the spray of the food wastewater. Furthermore, it is found that the fly ash is combusted completely and the outer wall of the water pipe is in a satisfactory state owing to keeping it at 870-950 ºC of the second combustion temperature in order to spray the food wastewater.

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