REDUCTION OF DIOXINS FROM A MUNICIPAL SOLID WASTE INCINERATOR BY NATURAL GAS REBURNING

Ryo Takeya 1, Yasumichi Kori, Takahisa Honjo 2 and Kazuya Kurimoto

[1] Energy and Environmental Technology Laboratory, Tokyo Gas Co., Ltd., 1-16-25, Shibaura, Minato-ku Tokyo 105-0023, JAPAN
[2] Industrial Sales Dept., Tokyo Gas Co., Ltd., 3-7-1, Nishi-shinjuku, Shinjuku-ku, Tokyo 163-1059, JAPAN

Introduction

Dioxins emitted from MSW (Municipal Solid Waste) incinerators have become serious social problem in Japan. The problem is likely to be more serious since more MSW incinerators are expected to be used, particularly, in densely populated urban areas like Tokyo that face stringent problems of landfill shortage. Currently governments all over the world are considering of enacting very strict regulations on Dioxins and other trace toxic species. Dioxins concentration in stacks have been regulated since 1997 in Japan as well. Further regulations are reportedly discussed, regulating the total emission of Dioxins discharged from the entire of the waste treatment process.

Natural gas reburning technology, which was originally invented to reduce NOx emissions from utility boilers (1-6) has been applied to the reduction of Dioxins emissions from MSW incinerators (7-13). Systematic investigations on natural gas reburning have been conducted in the existing full-scale MSW incinerator in Tokyo area with the capacity of 105 tons/day(14). The effect of natural gas reburning on the reduction of Dioxins has been carefully examined. Three phases of experimental campaigns were conducted in July 1998 (the 1st test), May 1999 (the 2nd test) and February 2000 (the 3rd test). Extensive and detailed analysis of the experimental results have successfully proven various positive effects of natural has reburning on the reduction of Dioxins.

Materials and Methods

Figure 1 shows the schematic of a stoker-fired MSW incinerator accommodating natural gas reburning. Natural gas is injected to create a sub-stoichiometric environment in the reburning zone to reduce NO generated by the combustion of wastes. The flow rate of natural gas is generally set at 5-20% of the wastes on heat value basis. Secondary air is injected into the downstream of the reburning zone to complete the oxidation of CO and possibly trace unburnt combustibles like dioxins and their precursors.

Figure 1 Reburning concept in a municipal solid waste incinerator

Figure 2 shows the schematic of the MSW incinerator retrofitted for the natural gas reburning. The combustion chamber was refractory lined. The exhaust gas from the combustion chamber was introduced into a water quenching chamber to be cooled down to about 300°C. After slaked lime injection for HCl removal, the exhaust gas was led to an ESP (electrostatic precipitator). Mixture of natural gas and re-circulated exhaust gas (EGR) was injected into the combustion
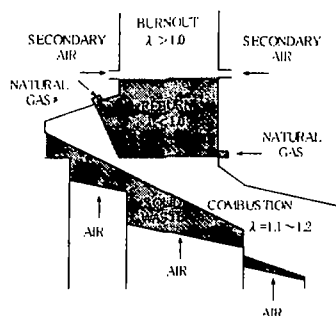
chamber. Since the injected natural gas flow rate was as small as only 1% of the flow rate of the primary combustion product generated from wastes, natural gas injected alone would not mix sufficiently with the primary combustion products. Exhaust gas was taken from either the inlet or outlet of the ESP and mixed with natural gas before being injected into the combustion chamber. Approximately 3-15% of the total exhaust gas was re-circulated. The combustion chamber had two different positions for the injection of the reburning gas, one from the front and the other from the rear. Secondary air was injected into the downstream of the reburning zone through the both sides of the incinerator.
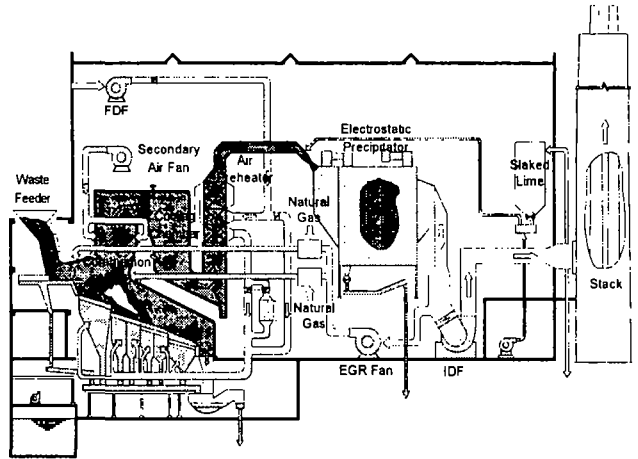

Figure 2 Schematic of a MSW incinerator with natural gas reburning

Results and Discussion

Table 1 shows Dioxins concentrations in exhaust gas at cooling chamber exit and ESP exit measured in the 1st (1998) and the 2nd (1999) reburning tests. For the baseline operations Dioxins

Table 1 Dioxins in flue gas of the 1st (1998) and 2nd (1999)

1st Reburning Tests		Baseline	Baseline with Low Primary Air		Reburning			
					Reburn 1-1	Reburn 1-2	Reburn 1-3	
Dioxins in Flue Gas ng-TEQ/Nm3 @12%O2	Cooling Chamber Exit	1.1	1.1		0.44	0.22	0.11	
	ESP Exit	1.2	1.6		0.85	0.41		
2nd Reburning Tests		Baseline	EGR only		Reburning					
			EGR 2-1	EGR 2-2	Reburn 2-1	Reburn 2-2	Reburn 2-3	Reburn 2-4	Reburn 2-5
Dioxins in Flue Gas ng-TEQ/Nm3 @12%O2	Cooling Chamber Exit	0.42	–	0.59	0.53	0.67	0.42	–	0.26
	ESP Exit	0.65	0.97	0.89	0.69	0.68	0.43	0.54	0.32

concentration at the cooling chamber exit varies between 0.42 and 1.1 ng I-TEQ/Nm3. Reburning operations show promising results, with dioxins concentrations at the cooling chamber exit being reduced down to 0.11-0.67 ng I-TEQ/Nm3. The results clearly demonstrate positive effects of reburning on the reduction of Dioxins in the cooling chamber exit.

Figure 3 shows the relationship between the Dioxins levels at the gas cooling chamber exit and the product of temperature and exhaust gas residence time in the combustion chamber. Strong correlation between flue gas temperature and residence time in the combustion chamber and dioxins concentrations is observed.

The following chemical kinetic reaction rate of Dioxins is assumed:

$$\frac{dDXN}{dt} = -A_{DXN} \cdot \exp(\frac{E_{DXN}}{R \cdot T}) \cdot [DXN_{int}]$$

i.e.

$$dDXN = -A_{DXN} \cdot \exp(\frac{E_{DXN}}{R \cdot T}) \cdot [DXN_{int}] \cdot dt$$

where A_{DXN} and E_{DXN} are constants, R is gas constant, T is temperature and DXN_{int} is initial Dioxins concentration. This equation empirically relates the destruction rate of Dioxins with temperature, initial Dioxins concentration
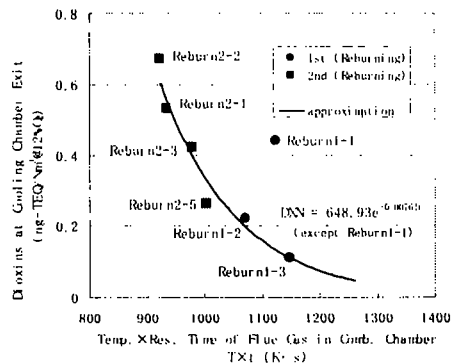

Figure 3 Relation between Dioxins and Temp. * Residence time (the 1st and 2nd tests)

and residence time.

Mixing between the combustion products and the reburning gas is widely believed to be another crucial factor that controls Dioxins destruction rate in a combustion chamber. The effect of mixing can be expressed by the

$$\sigma_T = \sqrt{\frac{1}{2}\sum_{i=1}^{3}(T_i - T_{ave.})^2}$$

degree of temperature distribution in combustion chamber as:

where T_1, T_2 and T_3 are measured temperature at the front, center and rear side in the combustion chamber respectively.

Using the above two controlling equations, Dioxins concentration can be expressed as:

$$DXN_{reburn} = a \cdot f(T_{reburn} \cdot t_{res}) + b \cdot \sigma_T + c$$

where DXN_{reburn} is Dioxins concentration in flue gas, T_{reburn} is temperature in reburning zone, t_{res} is residence time of flue gas in combustion chamber and a, b and c are constants.

By analyzing the experimental results from the 1st and 2nd reburning tests shown in Figure 3, constants a, b and c have been determined, yielding Dioxins concentration in combustion chamber as:

$$DXN_{reburn} = 0.9449 \times 648.93^{-0.00767 T_{reburn} \cdot t_{res}} + 0.1023\sigma_T + 0.0450$$

This equation indicates that lower Dioxins concentration can be obtained under higher temperature, longer residence time and better mixing conditions.

By using the Dioxins destruction equation resulting from the 1st and 2nd tests, experimental conditions for the 3rd reburning test were carefully determined. Compared with the previous two tests, relatively low flow rate of EGR was employed to maintain high temperature and long residence time of combustion products in combustion chamber. The number of reburning gas nozzles was reduced to keep high injection velocity and effect of mixing. Table 2 shows Dioxins concentrations in exhaust gas at combustion chamber exit, cooling chamber exit and ESP inlet and exit in the 3rd (2000) reburning tests. Reburning operations show promising results, with Dioxins concentrations at ESP exit being reduced down to 0.11 ng I-TEQ/Nm3 at the optimized condition

Table 2 Dioxins in flue gas of the 3rd (2000) reburning

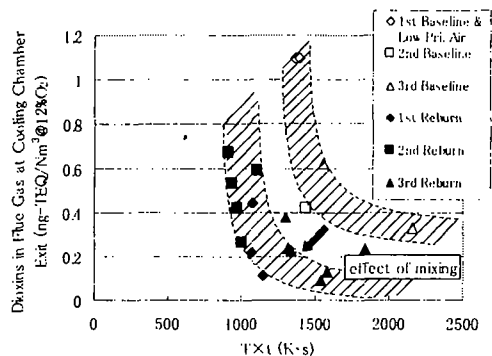| Conditions		Baseline 3-1	Reburning						Baseline 3-2
			Reburn 3-1	Reburn 3-2	Reburn 3-3	Reburn 3-4	Reburn 3-5	Reburn 3-6	
Dioxins in Flue Gas ng-TEQ/Nm³ @12%O₂	Combustion Chamber Exit	0.41	0.19	0.44	1.6	0.13	3.51	0.18	11.7
	Cooling Chamber Exit	0.33	0.38	0.23	0.13	0.24	0.09	0.24	0.62
	ESP Inlet	0.35	0.59	0.34	0.23	0.28	0.28	0.31	0.38
	ESP Exit	0.17	0.13	0.21	0.11	0.19	0.20	0.23	0.20

Figure 4 Relation between Dioxins and Temperature * Residence time (all tests)

The findings suggest the importance of maintaining high temperature and ensuring longer residence time as well as promoting the mixing of combustion gas to reduce dioxin emissions. Figure 4 shows the relationship between the Dioxins levels at the gas cooling chamber exit and the product of temperature and exhaust gas residence time in the combustion chamber. Generally speaking,

higher temperature and/or longer residence time in the chamber is likely to lower Dioxins at the exit. The product of temperature and residence time should be large to achieve lower Dioxins. Figure 4 clearly indicates that to obtain same level of Dioxins, the reburning requires smaller levels of the products of temperature and residence time than the baseline operations. This identifies another important effect of reburning, that is the enhancement and promotion of the mixing in the combustion chamber.

Figure 5 shows total amount of Dioxins in flue gas and ESP ash in the 2nd (1999) and the 3rd (2000) tests. For the reburning operations, Dioxins concentrations in ESP ashes are also reduced under both conditions of ESP temperature 260C and 230C. This indicates that reburning can reduce total amount of Dioxins from MSW incinerators.
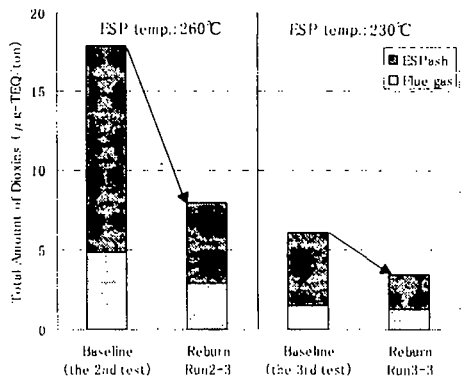

Figure 5 Total amount of Dioxins of the 2nd (1999) and 3rd (2000) tests

The following conclusions have been drawn from the results:
- Natural Gas Reburning technology is capable of reducing Dioxins from MSW incinerator by creating high temperature reburning zone with better mixing in the combustion chamber.
-Under optimized reburning condition, i.e., creating high temperature reburning zone with better mixing in combustion chamber, Dioxins from an existing incinerator can be reduced down to the regulations on Dioxins for newly built incinerators in Japan, i.e., 0.1 ng I-TEQ/Nm3.
-Natural Gas Reburning can reduce total amount of Dioxins from MSW incinerators.

Acknowledgments

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