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Hyper 21 Stoker System —Demonstrative Test at Numanohata Clean Center—[†]

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Abstract:

JFE Engineering's advanced stoker-type incinerator the "Hyper 21 Stoker System" is the first municipal solid waste incinerator which has adopted the new technology called "high-temperature air combustion technology." With this technology, the system realizes stable combustion under low excess air condition, which results in reduction of NOx, dioxins and flue gas flow rate. The system also treats waste from combustion to ash melting with high efficiency and low pollutant emissions. The Hyper 21 Stoker System described in this paper demonstrated excellent operational stability and easy operating features, while also minimizing environmental pollutants, improving heat (energy) recovery rate, and reducing operational costs.

1. Introduction

With increasing social awareness of the problems associated with the environment and energy, the roles required of waste incineration treatment are becoming more sophisticated and various every year. In particular, the reduction in the concentration of the emissions of hazardous pollutants such as dioxins and NOx, the enhanced efficiency in energy utilization, and the reduction of life cycle costs are very important issues and various technological endeavors are ongoing in these fields. In Japan, stoker-type incinerators, which have high reliability account for more than 80% of the municipal solid waste (MSW) incineration facilities in terms of treatment capacity. JFE Engineering has been developing an advanced stoker-type incinerator due to settlement of the problems mentioned above[1–2]. The development aimed at the reduction in the concentration of the emissions of environmental pollutants and the improvement in heat recovery rate through establishing two key technologies. One is to realize stable combustion at a low excess air ratio and the other was to integrate waste incineration with ash treatment. As partly reported previously, a low excess air ratio combustion and integrated ash treatment were tested at the 105 t/d capacity plant of Numanohata Clean Center in Tomakomai City[2]. This paper reports the latest operating.

2. Experiment

2.1 Facility

The experiment was performed at Numanohata Clean Center in Tomakomai City. This plant was constructed by JFE Engineering under a contract with Tomakomai City and started up in 1999. The specifications and schematic flow of this commercial plant are as shown in **Table 1** and **Fig. 1**, respectively. This plant was originally composed of a conventional stoker-type incinerator with a waste treatment capacity of 105 t/d (two-way gas flow type incinerator, approximately 3.2 m wide, 8.0 m long, and 6.2 m high), a heat recovery boiler, a cooling tower, a bag house, an induced draft fan, an ash extractor, etc. The original plant was modified to an advanced stoker-type incinerator by adding a high temperature mixed gas (HTMG) generator, a flue gas recirculation fan, and an ash treatment furnace directly linked to the bottom ash chute. The grate system was also modified from the original air-cooling type to water-cooling type.

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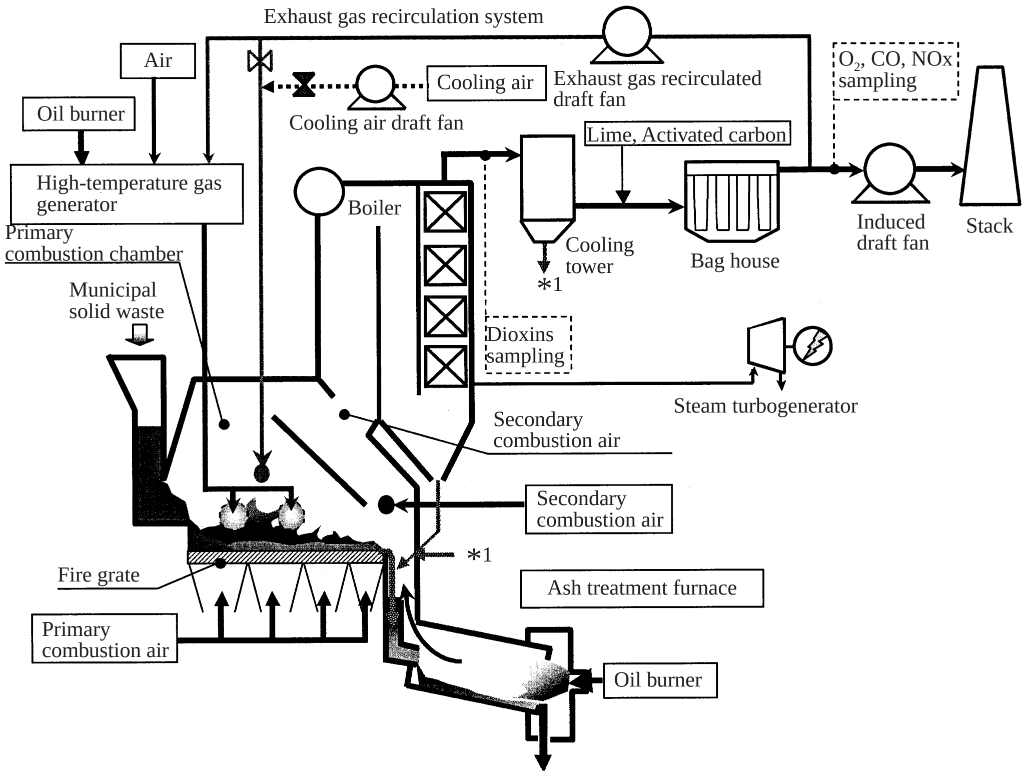


Fig. 1 Schematic flow of the commercial plant with an advanced stoker system

Table 1 Specifications of the commercial plant

Plant	Numanohata Clean Center Tomakomai City
Incineration type	JFE Hyper stoker-type incinerator
Throughput	105 t/d × 2 lines
Flue gas cooling	Heat recovery boiler (2.8 MPa, 300°C) and cooling tower
Flue gas treatment	Bag house with lime and activated carbon supply
Heat utilization	Steam turbine (2.6 MPa, 295°C) and generator (2 000 kW)

2.2 Experimental Conditions

It was previously reported[2)] that in the experiment performed under the condition of injecting the HTMG at a temperature of 400°C, various advantages over conventional combustion were verified. These advantages included reduction in the flue gas flow rate at the stack, reduction in the concentrations of environmental pollutants (NOx and dioxins) in flue gas, and increase in the heat recovery rate (increase in steam generation).

In this study, the low excess air ratio combustion experiments were performed, mainly aiming at further reduction in the concentrations of environmental pollutants and further increase in the heat recovery rate, the following improvements were made:

(1) The HTMG-injecting temperature was lowered from 400°C to 250°C (a temperature level obtainable by conventional heat exchangers such as GAH and SAH) in order to improve the running costs.
(2) An oxygen analyzer was added at the outlet of the boiler in order to improve the controllability of the incinerator during low excess air ratio combustion.
(3) The automatic combustion control (ACC) system was improved in order to minimize the fluctuation of the combustion in the primary combustion zone.

The ash melting experiment was performed in the same means as that previously reported[2)]. Bottom ash discharged from incinerator and ash from the boiler and cooling tower were fed continuously to the ash treatment furnace without crushing or other pretreatment. Ash which was unsuitable for melting, such as large lumps and other materials were separated before the ash feeder. The basic features of the ash treatment furnace were previously reported. In this study, the latest results of research on the energy input and heat recovery are reported. In addition, the results of verifying the detailed properties of the melting slag are presented.

3. Experimental Results and Discussions

3.1 Low Excess Air Ratio Combustion

3.1.1 Properties of flue gas

The changes in the CO and NOx concentrations at the stack and in the O_2 concentration at the boiler outlet under the low excess air ratio condition (λ = 1.3) and

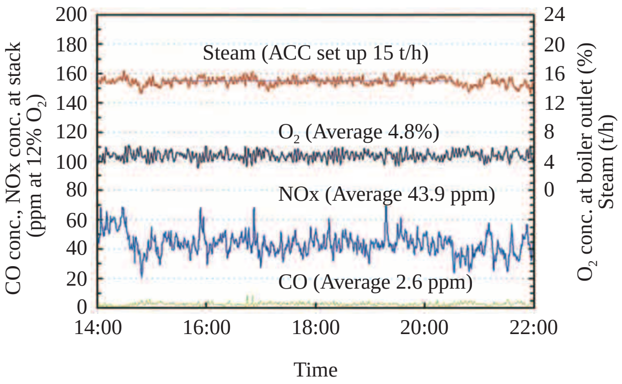


Fig. 2 Changes in O_2, CO_2, and Nox in flue gas and steam with time

the HTMG-injecting temperature of 250°C are shown in **Fig. 2**. As shown in the figure, the CO concentration was extremely low and at the same level as in conventional combustion even when the HTMG-injecting temperature was 250°C, demonstrating that stable combustion was realized. The NOx concentration was 43.9 ppm on average, which was a reduction of more than 40% compared with conventional combustion[2)]. A stable amount of steam was generated over a long period of time even under the low excess air ratio condition due to the effect of the advanced ACC and other improvements added to the system.

3.1.2 Combustion behavior in boiler

There was a concern that the low excess air ratio combustion might lead to an increase of the emissions of the unburned gas from the incinerator compared with conventional combustion as the excess air was lowered. In this experiment, CO concentration was measured along the flue gas flow route from the secondary combustion zone to the boiler outlet. The results are shown in **Fig. 3**. Under conventional combustion, the CO concentration in the secondary combustion zone (mixing chamber) is almost 0 ppm, indicating that the flue gas was burned out completely complete in this zone. In contrast, under the low excess air ratio combustion, CO of several tens of ppm remains. However, the remaining CO continues to be burned until the flue gas reaches the boiler inlet and its concentration lowers to less than 5 ppm. Moreover, it was confirmed that there was not much difference between the CO concentration at the boiler outlet and that from conventional combustion. The reason why the CO concentration in the secondary combustion zone is high compared with that in conventional combustion is supposedly attributable to the following factors. The amount of O_2 fed into the incinerator is inherently limited under the low excess air ratio combustion. The O_2 concentration in the primary combustion zone is further lowered by the HTMG injection into the primary combustion zone. The O_2 concentration thus lowered leads to mild combustion compared with conventional combustion, and thus results in the higher CO concentration in the secondary combustion zone.

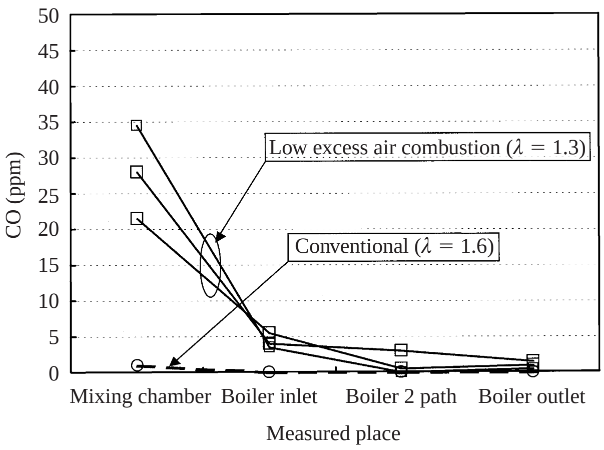


Fig. 3 CO concentration in boiler

3.2 Ash Treatment

3.2.1 Properties of slag

Properties of the slag obtained in the ash melting experiment are shown in **Tables 2** and **3**. The melting

Table 2 Slag properties

Item		Result	Regulation TR A 0017 FM2.5
Unit weight	(kg/*l*)	1.77	–
Dry density	(g/cm³)	2.88	> 2.45
Absorption ratio	(%)	0.16	< 3.0
Metallic iron	(%)	< 0.7	< 1.0
Size distribution percentage passing	4.75 mm	100	100
	2.36 mm	90	85–100
	0.075 mm	2	0– 10
Leaching test (mg/*l*)	Cd	< 0.005	< 0.01
	Pb	< 0.005	< 0.01
	Cr^{6+}	< 0.04	< 0.05
	As	< 0.005	< 0.01
	Total Hg	< 0.000 5	< 0.000 5
	Se	< 0.005	< 0.01

Table 3 Heavy metal contents in slag

Element	Content (mg/kg) Result	Content (mg/kg) Regulation*
Cd	< 5	≦ 150
Pb	31	≦ 150
Cr^{6+}	< 2	≦ 250
As	< 5	≦ 150
Total Hg	< 0.05	≦ 15
Se	< 5	≦ 150
Cyanogen	< 5	≦ 50
F	36	≦ 4 000
B	150	≦ 4 000

* The Soil Pollution Control Law

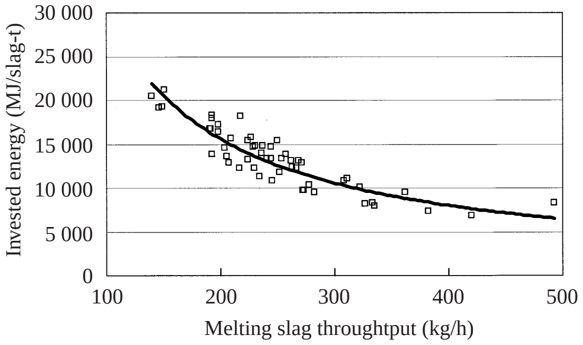


Fig. 4 Relationship between slag throughput and invested energy

slag was subjected to grain size adjustment after magnetic separation. These properties of the slag satisfy both the regulation for "general waste and sewage sludge etc, melt-soliditied products derived aggregate for road construction (Molten slag aggregate for road construction)" (TRA0017) and the regulation for heavy metal contents in Soil Pollution Control Low, fully demonstrating its potential for use as roadbed material and concrete products.

3.2.2 Invested energy in ash treatment

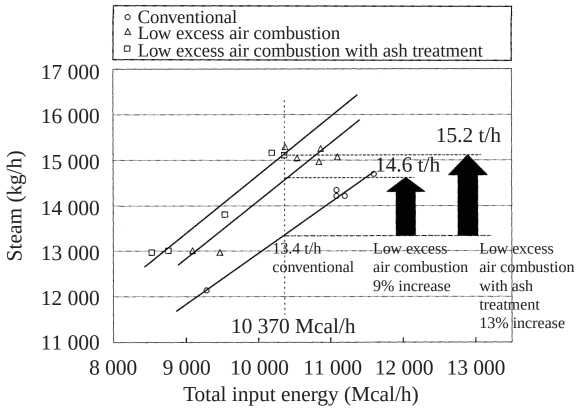
The relation between the slag throughput and the energy invested in ash treatment is shown in **Fig. 4**. Since the bottom ash is directly fed from the incinerator to the ash treatment furnace, the slag throughput fluctuates depending on the amount of the bottom ash discharged from the incinerator. When the slag throughput is equal to the rated capacity of the ash treatment furnace (420 kg/h), the energy to be invested is approximately 8 000 MJ/of slag.

3.3 Dioxin Emissions

The dioxin concentration in each substance discharged from the system when low excess air ratio combustion with HTMG injection was performed while at the same time the ash treatment furnace was operated is shown in **Table 4**. The dioxins concentration in the flue gas at the boiler outlet under the low excess air ratio combustion was reduced by 70% from that under conventional combustion (0.78 ng-TEQ/Nm^3)[2] due to the improvement made in the ACC for the low excess air ratio combustion. A calculation made from these concentrations indicates that the overall dioxin emissions from this system are approximately 1.5 μg-TEQ/t-waste treated. If it is assumed that the dioxins in the fly ash are further reduced to 0.01 ng-TEQ/g by applying the volatilization and decomposition process[3] or other means, the overall dioxin emissions will be lowered to approximately 0.09 μg-TEQ/t-waste treated.

3.4 Heat Recovery

Amounts of waste heat recovered by the boiler attached to the incinerator are shown in **Fig. 5** for the following three cases. The first is the case where the incinerator was operated under the conventional combustion mode. The second is the case where the incinerator was operated alone under the low excess air ratio



Note: Heat value of kerosene for manufacturing the high-temperature mixed gas is included, but that of kerosene for ash treatment is not included.

Fig. 5 Relationship between total energy input and steam recovery

Table 4 Dioxin emissions

	Flow/Feed rate	Dioxins concentration	Amount of dioxins
Flue gas at boiler outlet	–	0.17 ng-TEQ/Nm^3	–
Flue gas at stack	20 300 Nm^3/h	0.000 15 ng-TEQ/Nm^3	3 ng-TEQ/h
Fly ash	34.2 kg/h	0.18 ng-TEQ/g	6 156 ng-TEQ/h
Fly ash (De-dioxins)	(34.2 kg/h)	(0.01 ng-TEQ/g)	(342 ng-TEQ/h)
Melting slag	281.6 kg/h	N.D.	0 ng-TEQ/h
Unsuitable for melting	39 kg/h	0.000 5 ng-TEQ/g	20 ng-TEQ/h
Total (After fly ash de-dioxins treatment)			6 179 ng-TEQ/h (365 ng-TEQ/h)
Waste throughtput	4.27 t/h	Amount of dioxins per waste throughput (After fly ash de-dioxins treatment)	1.45 μg-TEQ/t-waste (0.09 μg-TEQ/t-waste)

Table 5 Economic estimation

		Test result			Design standard for new plant
		Conventional combustion	Low excess air combustion		
Energy resource	Burner	–	Oil burner	Oil burner	–
	Steam heating	–	SAH	–	SAH
Gas temperature	(°C)	–	400	250	250
Steam recovery	(t/h)	13.5	15	15	15
Increased steam recovery	(t/h)	–	1.5	1.5	1.5
Oil (kerosene) consumption	(*l*/h)	–	27.3	14	0
Preheating	(t/h)	–	0.16	0	0.11
Increased sales of electricity*	(yen/h)	–	822	1 003	885
Oil (kerosene) expense**	(yen/h)	–	−1 010	−518	0
Profit	(yen/d)	0	−4 506	11 640	21 237

* Average of day price and night price: 6.8 yen/kWh
** Price: 37 yen/*l*

combustion mode without operating the ash treatment furnace. The third is the case where the incinerator was operated under the low excess air ratio combustion mode simultaneously with the ash treatment furnace. Compared with Case 1 (conventional combustion), the steam generation rate was increased by approximately 9% in Case 2 (low excess air ratio combustion without ash treatment). In Case 3 (low excess air ratio combustion with ash treatment), the steam generation rate was further increased by approximately 4 points over Case 2, achieving the combined total increase of around 13% over Case 1. When converted to the energy unit, it amounts to about 1 400 × 10^3 MJ/h, indicating that approximately 40% of the total energy input into the ash treatment furnace is recovered in the form of steam.

3.5 Economic Estimation

The economy of the HTMG production in the Hyper 21 Stoker System was experimentally calculated. The results are shown in **Table 5**. Through the realization of stable low excess air ratio combustion with the HTMG-injecting temperature lowered to 250°C, the increase of income by selling the electricity generated by the increased steam generation (i.e., increased heat recovery rate) exceeds the cost of fuel consumed for producing the HTMG. The profit margin further increases when the HTMG is produced only using the heat of steam recovered in this system.

3.6 Operational Status of Water-cooled Grate System

The grate system is composed of 18 steps in total. Among these, the upstream 12 steps were converted to the water-cooled grate. The grate temperature reaches the highest level in No. 2 wind box area where the heat

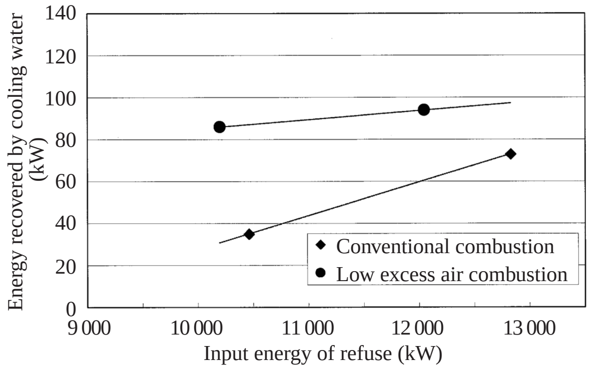


Fig. 6 Tendency of heat load to the grate

load is the highest. However, stable results were obtained in both conventional combustion at 85 to 110°C and low excess air ratio combustion at 85 to 130°C, proving that the durability of the grate system is improved by converting it to a water-cooled one. The rate of energy recovery by grate cooling water under the low excess air combustion is compared with that under conventional combustion in **Fig. 6**. These values also indicate the magnitude of heat load on the grate bars under these two combustion modes. The rate of energy recovery by cooling water under the low excess air combustion is nearly twice as large as that under conventional combustion. This is presumably because a stable flame region is maintained immediately above the waste layer due to the HTMG injection and the radiation to the grate bars from this stable flame to the waste layer increases.

4. Conclusion

The results of the demonstration test of the Hyper 21 Stoker System applied to a commercial plant were presented in this paper. Stable low excess air ratio combustion technology was developed based on the high-temperature air combustion technology unique to JFE Engineering, and realized a reduction in the emissions of environmental pollutants, an increase in the energy recovery rate, and a reduction in the running costs. These achievements were recognized by the Combustion Society of Japan and its Technology Award was given in 2003. It was verified that bottom ash generated from an incinerator could be treated at low cost and recycled as useful material by applying the technology of integrating ash melting treatment with waste incineration. These results demonstrate the potential of the advanced stoker-type waste incineration system that has excellent operational stability and thus is easy to operate. This system is not only applicable to new incinerator construction, but also can be retrofitted to an existing incinerator.

JEF Engineering continues to improve on the Hyper 21 Stoker System and enhance its technological capability.

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