Improvements and Recent Technology for Fluidized Bed Waste Incinerators

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Fluidized bed waste incinerators remain popular for industrial waste incineration, although the demand for these incinerators has been decreasing for municipal waste incineration. This is partly because the release of dioxins from waste incineration has recently become a significant social problem in Japan. NKK has continually improved fluidized bed technology to solve the dioxin problem, as well as to obtain heat recovery from waste combustion. Our most recently delivered fluidized bed incinerator for municipal waste incorporated these improvements and achieved very low dioxin concentrations of 0.00058ng(TEQ)/Nm^3 at the stack. This result is equivalent to that of very large-scale stoker type incineration plants. Furthermore, NKK developed technology for effectively recovering heat from the furnace bed to achieve highly efficient power generation. The estimated corrosion rate of the furnace bed boiler tubes is as low as 0.4mm/year.

1. Introduction

Orders for fluidized bed incinerators for the disposal of urban refuse have recently decreased as a result of problems with dioxin control and the development of gasification furnaces. At the same time, the ability of these incinerators to process industrial waste ensures that the demand will remain firm, both within Japan and overseas.

Within this context, NKK expended considerable effort to improve the technology for fluidized bed incinerators in order to make more effective use of wastes and to solve the dioxin problem.

This paper introduces NKK's record of deliveries in this field and describes the operational record of equipment installed in the most recent waste disposal plants. Improvements are also described in the method of supplying waste to the incinerators, which is an essential technology for fluidized bed incinerators.

Heat-recovery techniques that are employed in the fluidized bed and sand layer at the base of the incinerator to improve the efficiency of the thermal recycle are also described from the point of view of the effective use of waste products.

2. Deliveries

2.1 Delivered systems

NKK began the development of fluidized bed incinerators for waste disposal in 1984 and has delivered 15 plants to date. See **Table 1**.

Agreements have also been concluded with Jindo Corp. of South Korea and Vølund Corp. of Denmark to supply this technology. Jindo Corp. has already constructed three plants using this technology in South Korea.

2.2 Recent operating experience

The operating experience with recent urban refuse processing installations is described using a plant for the city of Obama in Fukui Prefecture in Japan as an example. See **Fig.1**.

The primary characteristics of this plant are as follows.

(1) The crusher and screw feed mechanism provides a stable and measured supply of waste.

(2) Activated carbon absorption equipment ensures that the system easily meets the maximum dioxin concentration requirement of 0.1 ng. Performance tests confirmed dioxin concentrations in the exhaust gas of 0.00058 ng (TEQ)/Nm^3, a figure equivalent to that obtained with

Table 1 Delivered fluidized bed incinerators

Plant location	Incineration capacity ton/operating hour	Completion date	Characteristic
1) Municipal solid waste incinerator in JAPAN			
Iwate pref. Shiwa district	35t/16h×2 furnace	Mar. 1990	Waste cal. value is high (3500kcal)
Chiba pref. Yotsukaidoh city	55t/16h×2 furnace	Mar. 1992	Semi dry exhaust gas treatment
Ishikawa pref. Kahoku district	10t/16h×2 furnace	Dec. 1990	Sludge incineration with plastic
Yamaguchi pref. Shuyoh district	30t/16h×2 furnace	Mar. 1994	Designed on the old DXN guide line
Chiba pref. Sanbu district	36.5t/16h×2 furnace	Mar. 1996	Designed on the DXN guide line
Fukui pref. Obama city	28t/16h×2 furnace	Mar. 2000	DXN's assurance : 0.1ng
2) Industrial solid waste incinerator in JAPAN			
Tokyo met. Hamura city	60t/24h×1 furnace	Mar. 1992	Exhaust gas boiler
Aichi pref. Toyota city	135t/24h×1 furnace	Jun. 1997	Exhaust gas boiler
Kanagawa pref. Kawasaki city	70t/24h×1 furnace	May 2001	Exhaust gas boiler & Turbine gen.
3) NKK test plant			
Miyagi pref. Sendai city	24t/24h×1 furnace	Apr. 1987	NKK's First FBC
Kanagawa pref. Yokohama city	24t/24h×1 furnace	Apr. 1996	Exhaust gas boiler, Turbine fan
4) Abroad			
Korea Kumi city (Bulit by NKK licensee)	60t/24h×1 furnace	Mar. 1995	Sludge incineration with plastic
Korea Shihwa city (Bulit by NKK licensee)	100t/24h×1 furnace	Mar. 1998	Exhaust gas boiler & Turbine gen.
Korea Yong In city (Bulit by NKK licensee)	35t/24h×2 furnace	Sep. 1999	DXN's assurance : 0.1ng
Thailand Bangpoo city	100t/24h×1 furnace	Mar. 2002	Exhaust gas boiler

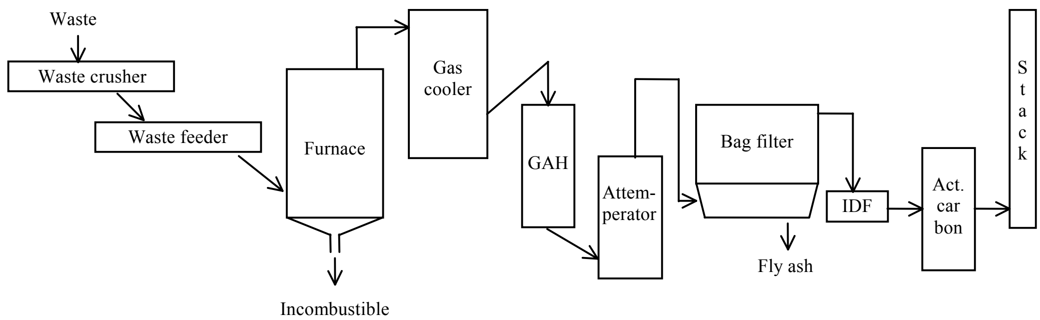

Fig.1 Flow chart for NKK fluidized bed incinerator

large stoker furnaces (See **Table 2**). The carbon monoxide concentration is described in the following chapter as an index of stable combustion.

Table 2 Results of exhaust gas analysis

Run no.	Dioxins (CO-PCB included) ng-TEQ / Nm^3 (12%O_2)			CO ppm (12%O_2)
	Furnace outlet	BF outlet	Stack	Stack
1	0.578	0.00914	0.00058	15
2	0.156	0.01016	0.00067	15

3. Improvements in supply of wastes

A stable supply of wastes has a major effect on the combustion efficiency because waste is immediately combusted within seconds of entering the fluidized bed incinerator.

NKK has used the feed mechanisms shown in **Fig.2** since the very first stages of development of its fluidized bed incinerators.

(1) Bag breaker and pusher feed mechanism
(2) Crusher and screw feed mechanism
(3) Crusher and spiral feed mechanism

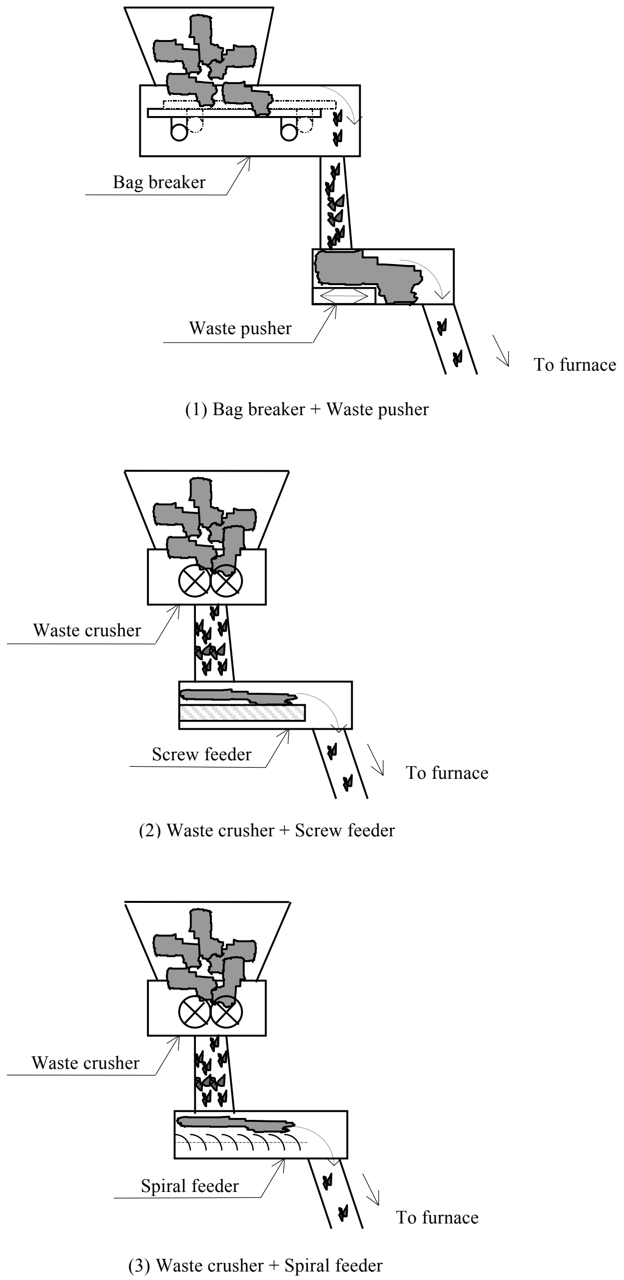

Fig.2 Waste feed system

3.1 Bag breaker and pusher feed mechanism

The dioxin problem was not recognized during the early stages of development. The design of the feed mechanism therefore focused on minimizing power consumption, while minimizing the possibility of feeding unsuitable materials to the furnace.

This feed mechanism was suitable for waste supply items such as mattresses and motor vehicle tires[1]. NKK's proprietary incinerator bed design allows the discharge of large non-combustible objects such as motor vehicle wheels with absolutely minimal problems and remains in use in current designs.

3.2 Crusher and screw feed mechanism

Industrial waste incinerators handle a high proportion of the larger size waste items and must incorporate measures to handle dioxins. The guaranteed maximum dioxin concentration in the exhaust gas is 0.1ng, even for municipal wastes. The NKK feed mechanism was developed for this reason. The crusher is based on the twin axis shearing method.

Waste is pre-processed to an average particle width of approximately 50 mm. Particles produced with the bag breaker are approximately 120 mm in width.

Changes over time in the carbon monoxide concentration of the exhaust gas from general waste incinerators that use the two feed mechanisms noted above are shown in **Fig.3**. Along with the improvements in feed mechanisms, increased sophistication in combustion control[2] and the use of the crusher and screw feed mechanism have produced a dramatic increase in the stability of operation. This increase has been obtained in spite of differences in the properties of the waste materials used.

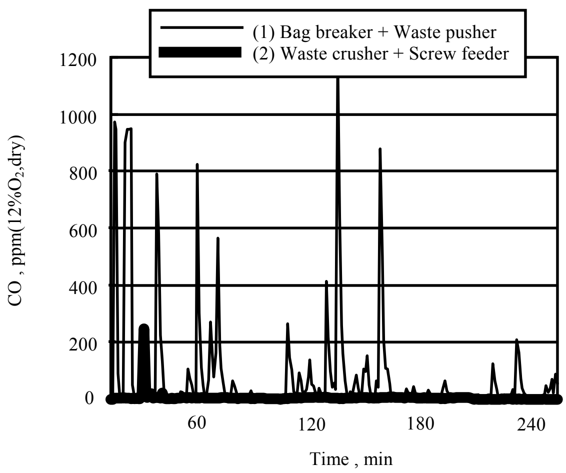

Fig.3 Carbon monoxide concentration in smokestack of fluidized bed incinerator

3.3 Crusher and spiral feed mechanism

The development of the screw feed mechanism was complicated by significant problems resulting from waste getting wrapped around the screw axis. A solution to this problem was essential to ensure that the equipment could operate continuously for months. This problem was resolved by adapting the spiral conveyor used by NKK for transporting ore.

This design retains the lead portion of the screw axis but uses a spring-shaped transport mechanism without central shafts (**Fig.4**).

The design ensures that the waste material is not compressed between the feed shaft and the casing. While the conventional screw-feed mechanism consumes 15 kW of power at a processing rate of 3 tons/hr, this system consumes 2.2 kW at the same processing rate, a significant contribution to energy efficiency.

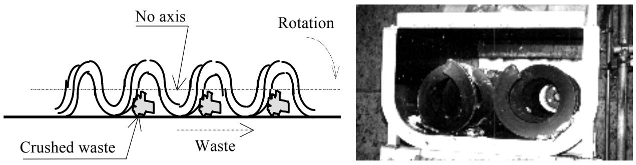

Fig.4 Spiral feed mechanism

4. Current status of heat recovery technology

Technology for recovering heat in fluidized bed incinerators that use a bed was developed as a means of using waste more effectively. The coefficient of heat transfer for the heat-exchange tubing buried in the fluidized bed is approximately 200 kcal/m^2h ℃, so greater energy recovery efficiency is possible than by recovery of heat from the flue gas. Recovery of heat from the bed reduces the volume of water spray needed for sand temperature control, and the consequent reduction in the volume of the flue gas also improves the efficiency of heat recovery.

4.1 Shape of tubing

Previously, the heat-exchange tubing projected into the bed horizontally from the incinerator wall. However, this design resulted in corrosion and damage to the tubing due to the presence of incombustible materials. Replacement of the damaged tubing required the removal of sand below the points at which it enters the wall. This in turn required that the incinerator be shut down for a considerable period of time, thus reducing its efficiency of operation. The design shown in **Fig.5**, in which the heat-exchange tubing is inserted into the bed from above, was therefore adopted. This method allows replacement of the tubing without the need to remove bed sand, thereby greatly reducing the downtime.

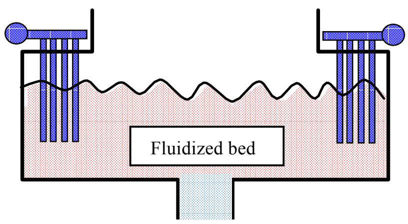

Fig.5 Shape of boiler tube

4.2 Corrosion test

An investigation of the corrosion and abrasion of the heat-exchange tubing was of particular importance prior to implementing the bed heat recovery system.

4.2.1 Test method

HCl gas, salts and sulfates in the bed cause corrosion of the heat-exchange tubing in fluidized bed, waste disposal incinerators, while abrasion is due to the vigorous movement of the sand in the bed. The effects of corrosion and abrasion in the sand bed interact in operation, so basic testing was required to quantify the effect of each factor on heat-exchange tubing. The small-scale testing equipment used for this purpose is shown in **Fig.6**.

This testing equipment was used to evaluate the corrosion and abrasion of test pieces that were 25 to 40 mm in diameter and placed in a bed in a stainless steel container with an inside diameter of approximately 70 mm. The temperature in the bed and the temperature and flow of the air in the test piece were adjusted using a heater and flow controller. The testing equipment allowed injection of both air and hydrogen chloride gas into the bed.

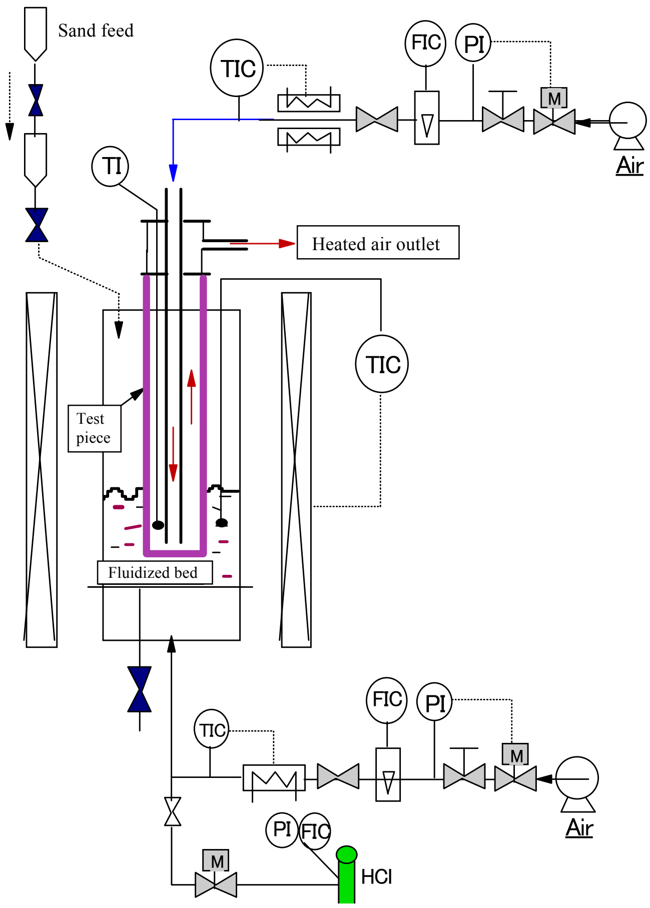

Fig.6 Heat-exchange tubing test schematic

The test pieces were SUS 310S and 625 Alloy. The atmosphere surrounding the test pieces was maintained at a temperature of 727℃, while the temperature of the air within the test pieces was maintained at 500℃. Test pieces were exposed for a continuous period of 600 hours under the following four conditions.
(1) Without bed, 1000ppm of HCl, in air
(2) With bed (new sand), in air
(3) With bed (new sand), 1000ppm of HCl, in air
(4) With bed (used sand), in air

Silica sand having a SiO_2 content of at least 95% was used as new sand, and sand previously used in a fluidized bed incinerator for municipal rubbish was employed as used sand. The used sand contained 30 to 40% SiO_2, with the balance consisting of various metallic oxides, chlorides, and sulfates, as well as crystalline aggregates of these materials. The chloride concentration in the sand was approximately 0.4%.

Heating the beds of used sand to temperatures in excess of 700℃ evaporates the low boiling point materials. This reduces the corrosive constituents of the sand, so that daily replacement of the sand was required during the period of continuous testing. The results of this testing are shown in **Table 3**. The depth of erosion in the table is the maximum erosion depth measured during testing (i.e., reduction in wall thickness due to corrosion and abrasion + grain boundary corrosion), converted to an annual equivalent.

Table 3 Corrosion testing of heat-exchange tubing

(mm/y)

	SUS 310S	625 Alloy
HCl only	0.55	0.18
FB (new sand)	0.06	0.84
FB (new sand)+HCl	2.20	1.32
FB (used sand)	6.40	2.50

4.2.2 Results

In a fluidized bed of new sand with no corrosive constituents, SUS 310S exhibited almost no abrasion and a maximum reduction in wall thickness of 0.1 mm/year. However, in an atmosphere containing HCl gas, corrosion resulted in a wall thickness reduction of approximately 0.5 mm/year.

SUS 310S is highly resistant to abrasion and has low resistance to corrosion, so its use in a bed containing corrosive constituents resulted in grain boundary corrosion of the surface during testing. The weakened corroded area was then subject to abrasion in the bed, with the processes of abrasion and corrosion interacting to result in a very significant degree of erosion.

The 625 Alloy tested in a bed of new sand exhibited a reduction in wall thickness of more than ten times that for SUS 310S. However, it also exhibited superior resistance to the corrosive constituents of the sand, and the erosion depth was limited to approximately 2 mm/year under the conditions prevailing in a bed of used sand.

The next stage of testing investigated the relationship between the temperature of the air within the test samples and the rate of corrosion. The bed consisted of used sand at a temperature of 727℃, with SUS 310S test samples. The air temperature within the test samples was varied between 150℃ and 500℃, and exposure tests for a continuous period of 600 hours were conducted under each set of conditions. See **Fig.7**.

As shown in **Fig.7**, the depth of erosion exhibited by the test samples decreased with decreasing temperature - a reduction in the air temperature within a sample from 500℃ to 200℃ resulted in a reduction in wall thickness erosion by a factor of 0.25.

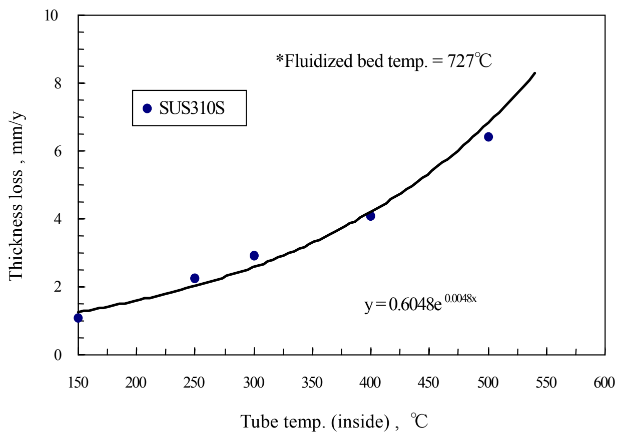

Fig.7 Relationship between air temperature within samples and erosion depth

Fig.8 shows the estimated erosion depths of SUS 310S and 625 Alloy samples with steam recovery at 200℃ from a fluidized bed at a temperature of 727℃ based on the trend of erosion with differences in recovery temperatures and on the results shown in **Table 3**. These figures reflect the results shown in **Table 3**.

The use of low-temperature (200℃) steam in combination with evaporator tubes for heat recovery, rather than heat recovery from steam at 500℃, limited the erosion

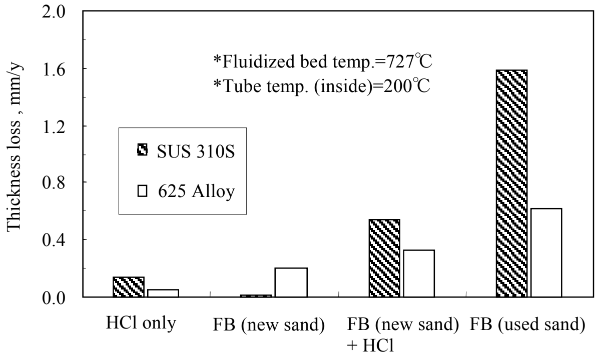

Fig.8 Erosion depth of samples during heat recovery

depth of SUS 310S tubing to approximately 1.6 mm/year and to approximately 0.6 mm/year for 625 Alloy. A report indicated that reducing the furnace temperature from 727℃ to 627℃ decreased the thickness loss for heat-exchange tubing installed in the waste incinerator flue gas flow to approximately one quarter of that at the higher temperature[3)].

The resistance of SUS 310S to abrasion in the bed is excellent. If similar tendencies in the thickness loss of SUS 310S tubing are assumed for bed heat recovery systems as described above, a reduction in the bed temperature from 727℃ to 627℃ will result in a rate of erosion for the SUS 310S of approximately 0.4 mm/year. Thus, a thickness of 4 mm should be sufficient for a life of approximately five years.

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