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Development of High-performance Direct Melting Process for Municipal Solid Waste

Hideharu SHIBAIKE*1 Ken TAKAMIYA*1
Yasusuke HOSHIZAWA*1 Yasuhiko KATO*1
Hirokazu TANAKA*1 Kazuhiko KOTANI*2
Takeshi NISHI*1 Junichi TAKADA*1

Abstract

The shaft-furnace direct melting process, which is one of the gasification-type melting systems for municipal solid waste, is effective in prolonging the life of final disposal sites and reducing harmful substances such as dioxins. Recently, however, the development of high performance in the direct melting process has become necessary to meet users' diverse and complex needs, such as prevention of global warming, treatment of a wider variety of waste, and the melting furnaces of larger sizes. Accordingly, the authors tackled technical development for combustible injection and some improvement of the melting furnace, using a direct melting experimental plant and some commercial facilities in operation. As a result, the combustible injection through tuyeres is effective in reducing the coke consumption in the direct melting furnace. The results also indicate that high-ash waste such as excavated waste can be treated by adjusting the operating conditions of melting furnace and a 200t/d commercial melting furnace has operated stably by optimizing the profile on a large scale.

1. Introduction

Approximately 50 million tons of municipal solid waste arises in Japan annually; nearly 80% of it is incinerated[1)], and most of the incineration residues are finally dumped for landfill. However, existing landfill sites are becoming saturated, new sites are becoming difficult to find, while environmental problems such as emission of dioxins are becoming major concerns. In this situation, gasification and melting of wastes came to attract attention since the 1990s. Different from conventional incineration processes, the gasification and melting process burns wastes not directly but after thermally decomposing and gasifying them, and for this reason, it has advantages such as excellent combustion controllability and production of recyclable slag and metal instead of incineration ash, realizing significant volume reduction of residues to finally bury in the soil.

Nippon Steel Corporation's direct melting process (direct melting and recycling system) for municipal solid waste is a forerunner of this concept: it employs a shaft furnace to gasify and melt wastes at high temperatures, and is characterized especially by the formation of a high-temperature coke bed layer at the lower portion of the furnace. The process was developed based on blast furnace technologies that had been accumulated during long years of iron- and steelmaking, and counts more than 20 years of commercial operation. Handling and distribution systems for the effective utilization

*1 Environmental Plant Project Div.
*2 Nittetsu Environmental Plant Service Corporation

of product slag and metal have already been established.

The number of orders for waste gasification and melting plants in Japan surpassed that for stoker plants, the mainstream plant type of the conventional waste incineration processes, for the first time in fiscal year 2000[2]. While this exemplifies the latest growing expectations for the gasification and melting process, requirements of plant users are becoming diversified and sophisticated. To cope with the diversification, Nippon Steel has actively promoted development of related process technologies using a direct waste melting test plant and other facilities since 1993. These new technologies include that for appropriately processing in a direct melting furnace not only municipal solid waste but also high-ash-content or high-moisture wastes that incineration processes cannot treat properly, and another for size expansion of the direct melting furnace to cope with demands for waste processing plants covering a wide area and big projects in large urban centers. Besides these, in view of the latest growing need for preventing the global warming and reducing operating costs, the company has enhanced the functions of the direct melting process through measures such as the development of a method of injecting combustibles into the furnace to reduce coke consumption.

This paper focuses, among others, on the technologies for combustible injection through tuyeres, the diversification of the kinds of wastes to process and furnace size expansion.

2. Development of Combustible Injection through Tuyeres

2.1 Development target

A coke bed layer is formed in the lower part of a direct melting furnace for municipal solid waste and it is kept at high temperatures by coke combustion; this system is effective in melting wastes stably and accelerating their thermal decomposition and gasification. Nippon Steel has studied measures to reduce coke consumption while maintaining the advantages of coke in the process, and focused attention on a multi-level air blowing method[3,4]. This method uses tuyeres arranged in two or more levels in the furnace height direction, and aims at accelerating the in-furnace combustion of carbon in waste residues to use the combustion heat for drying, cracking and gasifying wastes as a partial substitute for the coke. The multi-level air blowing method proved effective in reducing coke consumption to 5 to 6% in terms of the coke weight consumed per ton of waste processed.

It was noted, in addition, that the temperature of molten matter discharged from the furnace bottom tended to lower and the Pb concentration in slag to increase when the coke consumption was lowered under the air blasting through multi-level tuyeres (see **Figs. 4** and **5**). This is presumably because the amount of carbon in the coke that acts as the melting heat source and reducing agent was insufficient in the lower furnace portion. At this, the authors thought that it would be necessary to provide an additional carbon source (a combustible) in the lower furnace portion in order to further decrease the coke consumption, and began developing a technology for injecting a combustible through lower tuyeres. Here, it was essential that the combustibility of the combustible to be injected be equal to or better than that of coke, and materials such as fine grains of waste plastics and combustible dust generated from the very melting furnace looked promising for the purpose.

Injection of a combustible through tuyeres had long been practiced at blast furnaces using pulverized coal or similar. However, whereas there is a raceway space in front of tuyere tips of a blast furnace and the air blown into it is heated, there is no such space in a melting furnace and the air is not heated; therefore the combustion of the injected combustible was expected to be quite different from that in a blast furnace. In consideration of the difference, the authors investigated the combustion behavior of combustibles in the coke bed of a melting furnace, and studied the effects of the combustible injection on the coke consumption and changes of other operation parameters under the process conditions of the gassification and melting of municipal solid waste.

2.2 Combustion behavior of combustibles injected into coke bed

The authors conducted tests simulating the coke bed in the lower portion of a direct melting furnace using the high-temperature combustion test furnace of Ironmaking R&D Div., Technical Development Bureau of Nippon Steel[5]. Coke was charged into the test furnace beforehand and heated by blowing hot air that was heated with nitrogen plasma into the furnace, and then oxygen-enriched air was blown at normal temperature into the furnace through lower tuyeres. The thickness of the coke bed decreased from time to time during the test, and the change of the thickness was measured with a mechanical level gauge. The combustibles shown in **Table 1** were blown into the furnace under an air blowing condition similar to that of a direct melting furnace for waste, and their in-furnace reactions were investigated. Polyethylene for industrial use was used as the plastic and the dust generated from an operating melting furnace as the dust.

Fig. 1 shows the change of the coke bed height over time, or the change of its lowering rate. The graph compares the case in which no combustible was injected into the furnace in which the coke bed had been formed and others in which the plastic or the dust was injected. In the case without the combustible injection, the coke bed height lowered substantially linearly with the lapse of time as a re-

Table 1 Properties of combustibles

		Plastic	Dust
Chemical composition (%)	C	85.6	34.5
	H	14.3	1.0
	O	< 0.1	6.3
Ash (%)		–	55.9
Lower calorific value (MJ/kg)		44	12
Mean size (mm)		0.7	0.06

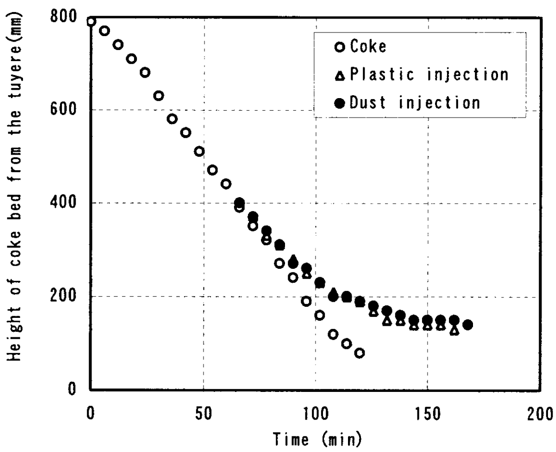

Fig. 1 Change of coke bed height at combustible injection

sult of coke consumption through the coke combustion in front of tuyere tips ($C+O_2 \rightarrow CO_2$) and a solution-loss reaction ($C+CO_2 \rightarrow 2CO$). In contrast, when a combustible was injected, the lowering rate of the coke bed height decreased as seen in the graph. This showed that the combustible injected through the tuyeres burned in preference to coke, confirming the possibility of reducing coke consumption.

2.3 Effects of combustible injection under conditions of municipal solid waste processing

Based on the results described in the preceding sub-section, the authors conducted injection tests on a direct melting test plant for municipal solid waste, using fine grains of plastics and combustible dust. As is schematically shown in **Fig. 2**, the test plant was composed of a direct melting furnace, combustion chamber, gas treatment equipment and recycling equipment for molten matter, and its processing capacity was approximately 20 t/d.

Fig. 3 shows the combustible injection system of the test plant. The combustible was discharged from the feeder bin by a table feeder, transported to each of the lower tuyeres simultaneously by airflow, mixed with the draft air and oxygen, and blown into the furnace.

The fine plastic grains specified in Table 1 were also used for the tests, and were fed into the feeder bin as required. On the other hand, the combustible dust was collected from the thermally decomposed gas from the melting furnace by a cyclone separator provided between the furnace and the combustion chamber, and was fed to the feeder bin after cooling and sieving. The lower calorific value of the combustible dust collected in the tests was 11 to 13 MJ/kg, and its mean grain size was 50 to 80 μm or so.

Table 2 shows some of the test results. The injection ratio of the plastic grains to the weight of the wastes processed was set at 3%. The dust collected by the cyclone accounted for approximately 5% of the wastes, and it posed no problem in the transportation up to the tuyeres. The coke charging ratio was set at 3% for either the plastic or dust injection, and the waste charging rate was kept at 20 t/d. The discharge of the molten matter was smooth during the tests. The production of the molten matter increased especially with the dust injection; this indicates that combustible matter in the dust burned in front of tuyere tips and ash in it melted.

Fig. 4 shows the relationship between coke consumption and the

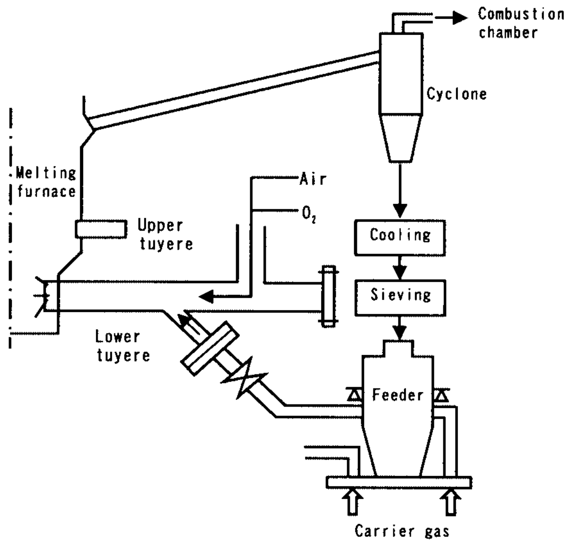

Fig. 3 Flow diagram of combustible dust injection system

Table 2 Operating results of combustible injection

	Conventional	Plastic injection	Dust injection
Coke consumption ratio (%)	5.0	3.2	3.0
Waste treatment rate (t/d)	20.0	21.8	21.9
Molten matter ratio (kg/t-waste)	127	125	155
Molten matter temperature (°C)	1596	1491	1500
Lower calorific value of MSW* (MJ/kg)	9.2	8.3	7.0

* MSW : Municipal solid waste

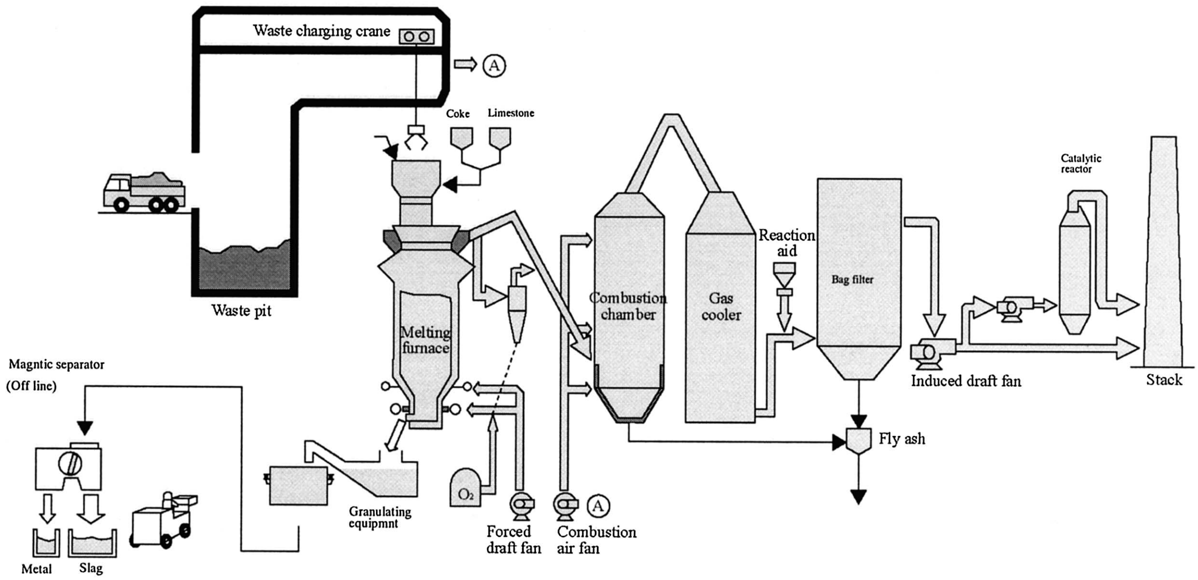

Fig. 2 Flow diagram of direct melting experimental plant

temperature of the molten matter. It is desirable to keep the molten matter temperature at 1450°C or higher for producing good-quality slag and maintaining stable operation, however the temperature tended to fall when coke consumption was decreased under the condition of multi-level air blowing without the combustible injection. On the other hand, when the combustibles were injected, the molten matter temperature did not fall below 1450°C even with a coke consumption of 3%. This is presumably because the injected combustible served as a substitution of coke in the furnace lower portion and decreased its consumption.

As shown in **Fig. 5**, the Pb concentration in the slag tended to rise when the coke consumption was lowered without the combustible injection. This is because the temperature in the furnace lower portion fell as the coke amount decreased, the furnace atmosphere became less reducing, the volatilization of Pb was suppressed, and more Pb was trapped in the slag. In contrast, when either the plastic grains or the dust was injected, the Pb concentration in the slag remained low even with a low coke consumption. One can presume from this that the combustible injected through tuyeres has an effect to substitute the reducing capacity of coke. Thus, the above test results confirmed that it was possible to partially replace coke with the plastic grains or the dust injected through the lower tuyeres, and that the combustible injection would decrease the coke consumption, keeping the temperature and reducing capacity of the furnace atmosphere at high levels.

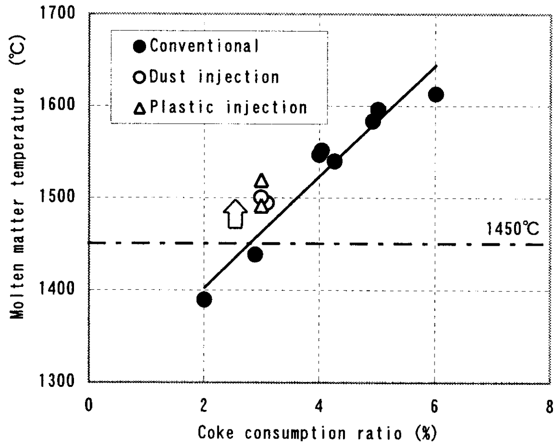

Fig. 4 Effect of coke consumption ratio on molten matter temperature

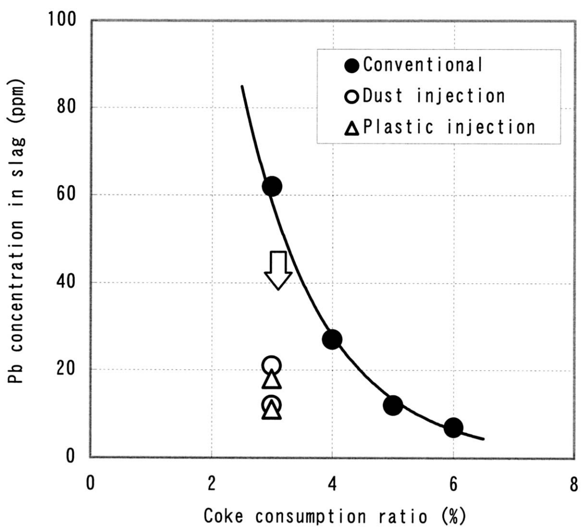

Fig. 5 Effect of coke consumption ratio on Pb concentration in slag

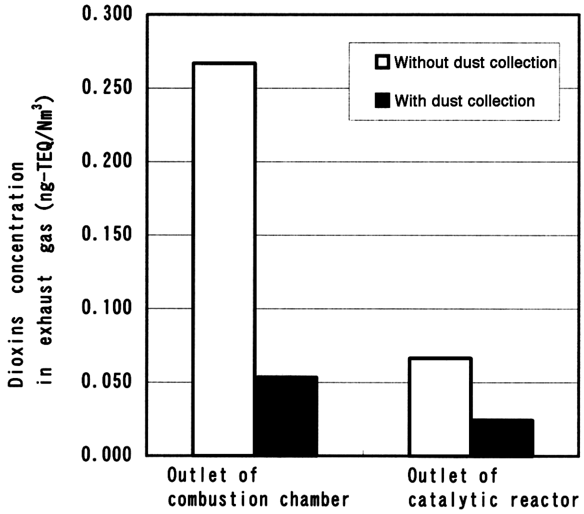

Fig. 6 Dioxins concentration in exhaust gas

In addition, it is possible to melt ash contained in the combustible dust that forms in the melting furnace and turn it into a component of the slag by collecting the dust and injecting it back into the furnace. This also decreases the amount of fly ash that is collected by the bag filter to nearly a half. As a side effect, the combustible injection also reduces the amount of solids burned in the combustion chamber. **Fig. 6** shows the results of the measurement of the concentration of dioxins in the combustion exhaust gas. The measurement was done three times each with and without the dust collection by the cyclone separator, simultaneously at the exits from the combustion chamber and the catalytic reactor. Whereas the average dioxin concentration without the dust collection was 0.27 ng-TEQ/Nm^3 at the exit from the combustion chamber and 0.07 ng-TEQ/Nm^3 at the exit from the catalytic reactor, the same with the dust collection was as low as 0.05 ng-TEQ/Nm^3 at the former and 0.02 ng-TEQ/Nm^3 at the latter. As seen in the above, the collection and injection of the dust improved the combustion in the combustion chamber, suppressed the generation of dioxins and decreased their concentration at the exit from the catalytic reactor yet further.

While the above results were obtained on the 20-t/d test plant, Nippon Steel conducted similar dust collection and injection tests jointly with the City Government of Ibaragi, Osaka Prefecture, installing test facilities to an actually operating150-t/d waste melting furnace of the City[6]. The results were substantially the same as those obtained on the 20-t/d test plant: the furnace operated stably at a coke consumption as low as 3% with the dust collection and injection. The technology of the dust collection and injection has been applied to many commercial waste melting plants since 2002.

3. Expansion of Kinds of Wastes to Process

3.1 Technologies

In the direct waste melting process, a single shaft furnace has the functions of drying, thermally decomposing/gasifying and melting waste, and these functions work flexibly according to the widely varied characteristics of wastes, enabling their appropriate processing.

Besides municipal solid waste, it is desirable to treat many other kinds of wastes by melting. These include incineration residues of waste incineration plants, high-moisture sewage sludge, mixture of miscellaneous wastes excavated from final-disposal landfill sites (hereinafter called excavated wastes), many kinds of industrial wastes such as automobile shredder residues[7)] and chlorofluorocarbons[8)], which destroy the ozonosphere.

As seen in **Fig. 7**, the lower calorific values and ash contents of these wastes are widely varied. The direct melting process is capable of treating a variety of wastes either through individual processing or mixed processing together with municipal solid waste according to their properties. Nippon Steel has tested many of these kinds of wastes using the direct melting test plant and other facilities to confirm their processability and establish adequate processing conditions before their commercial processing.

Table 3 shows some examples of the above kinds of wastes that are actually processed at commercial direct melting plants mixed with municipal solid waste. In all these cases, these wastes are stably processed at a mixing ratio of 10 to 20% to municipal solid waste. Among the cases listed in Table 3, the case of the Maki Town Union is explained below; the plant processes excavated wastes, and the case is attracting attention as one suggesting a promising measure to revitalize waste landfill sites.

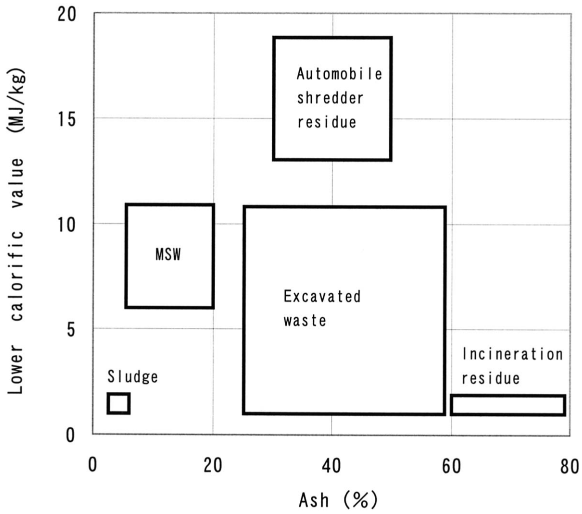

Fig. 7 Properties of waste

Table 3 Waste mixed with MSW in commercial plants

Waste	Facility	Start-up
Sludge	Iizuka City, Fukuoka Pref.	1998.4
Sludge	Kochi West Union, Kochi Pref.	2002.12
Sludge	Tajimi City, Gifu Pref.	2003.4
Incineraton residue	Kazusa Clean System Co., Ltd., Chiba Pref.	2002.4
Incineration residue	Toyokawa-hoi Union, Aichi Pref.	2003.4
Sludge and incineration residue	Akita City, Akita Pref.	2002.4
Excavated waste	Kameyama City, Mie Pref.	2000.4
Excavated waste	Maki Town Union, Niigata Pref.	2002.4

3.2 Melting system for excavated wastes

Fig. 8 shows the waste treatment and disposal process flows of the Maki Town Union's plant, called Yoroigata Waste Disposal Plant, before and after the introduction of the direct melting process. The new plant is composed mainly of two shaft-type waste melting furnaces and a recycling center. Besides combustible wastes and dewatered sewage sludge, the melting furnaces process crushed bulky wastes, which would be disposed conventionally by landfill, and the wastes not suitable for incineration treatment such as plastics and vinyl resins. The recycling center was constructed within the same premises to reduce the volume of wastes and promote their recycling; the residues from the center are also processed by the melting furnace. Since all the molten matter from the melting furnace is recycled, the waste volume to finally dispose by landfill was greatly reduced. In addition to the above, the melting furnace also processes wastes excavated from a final landfill site at a mixing ratio of 10 to 15% to create space at the site for disposing the fly ash newly generated from the melting furnace.

The final landfill site is a control-type disposal area having a capacity of 98,000 m^3; approximately 80,000 t in total of miscellaneous objects that an incineration furnace cannot deal with, such as incineration ash and fly ash from the old incineration plant, plastic polymer wastes, crushed bulky wastes and non-burnable wastes, had been dumped there as of the end of fiscal year 2000 (March 2001). **Table 4** shows the analysis results of wastes excavated from three locations in the site.

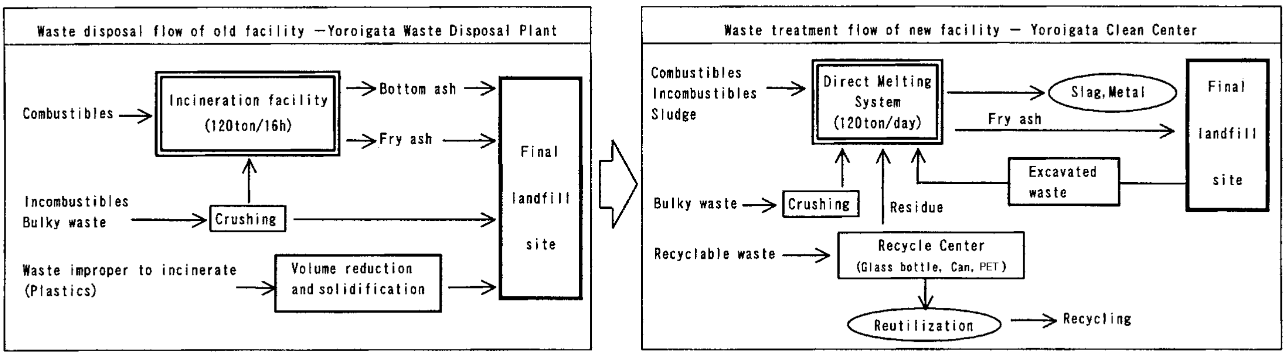

Fig. 8 Waste disposing process flow comparing old and new facilities

Table 4 Properties of excavated waste

		Point A –3m depth	Point B –3m depth	Point C –3m depth
Moisture	(%)	22.0	20.4	21.5
Combustible		40.7	10.6	22.4
Ash		37.3	68.9	56.1
Lower calorific value	(MJ/kg)	13.9	1.1	4.7
Specific gravity	(t/m^3)	0.64	1.27	0.92

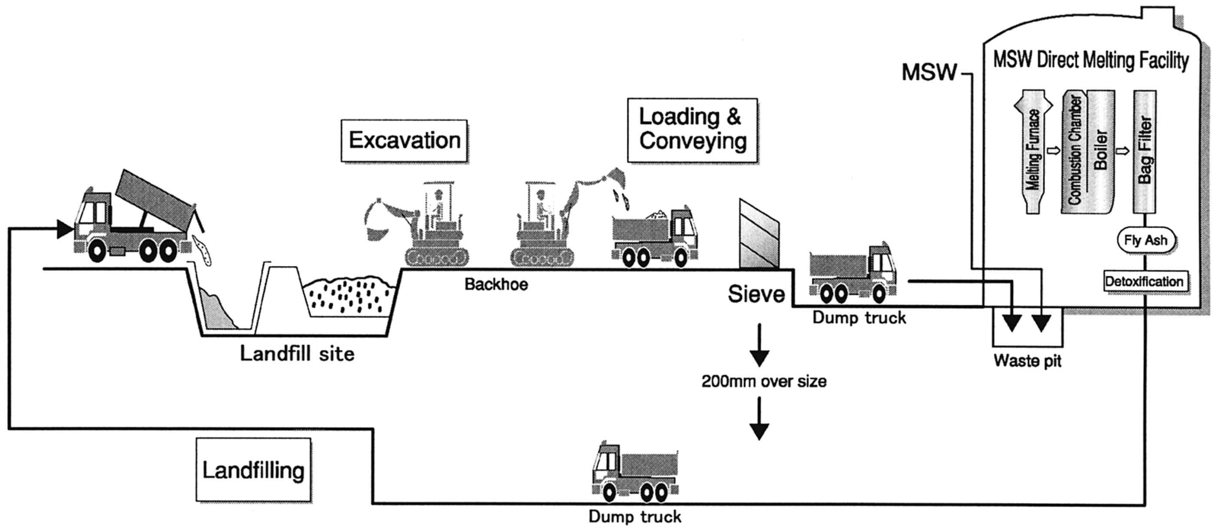

Fig. 9 Flow diagram of treating excavated waste

Fig. 9 illustrates the process flow of the melting treatment of the excavated wastes.

Wastes are excavated from the landfill site using backhoes, transported to a simple sieving facility adjacent to the site for classification. After removing large bulks, the wastes are classified into oversize mainly consisting of plastics and undersize mainly incineration ash, and they are transported separately to the waste pit of the direct melting plant by dump trucks. Each of the excavated areas of the landfill site is covered with rubber sheets and used, one after the other, as a final disposal space for the fly ash from the direct melting plant.

The excavated wastes transported to the pit is mixed there with other kinds of wastes, and charged into the melting furnaces (2 × 60 t/d). The coke consumption of the furnaces is set higher by approximately 2% than that without the excavated wastes. The slag generated from the melting furnaces is used mainly for interlocking blocks and as a road construction material, and the metal as a reducing agent for non-ferrous metal refining processes. Only the fly ash from the melting process is finally dumped for landfill after detoxification treatment.

The plant began operation in April 2002 and is stably processing 30,000 t in total of wastes annually, including approximately 3000 t (3000 m^3) of the excavated wastes mixed at a ratio of 10%. On the other hand, the weight of the matter finally dumped at the landfill site decreased markedly to 1600 t (1600 m^3) per annum, about one-third that of the old waste treatment facility. An estimation of the future amount of landfill based on the actual figures of fiscal year 2002 (ending March 2003) tells that, as seen in **Fig. 10**, the landfill amount at the final disposal site will decrease after hitting a peak in fiscal year 2001, and as a result, the waste processing plant will be able to count on the final disposal site for about 50 years.

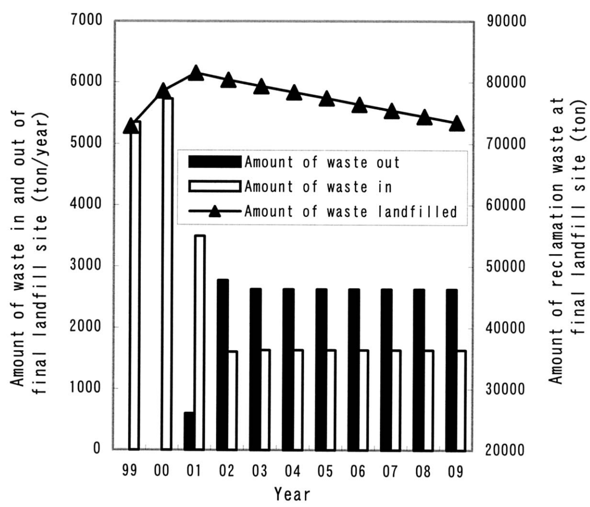

Fig. 10 Effect of prolonging the life of final landfill site

4. Size Expansion

4.1 Technologies

For meeting requirements of a large waste processing plant in a large urban center or that covering a wide area, it is necessary to expand the size of a melting furnace, or make the inner volume of a melting furnace larger. What is important in the design of the profile of a melting furnace is how to secure stable gas and material flow especially in the furnace shaft; an index of this is the cross sectional waste treatment rate in the shaft, which is the waste treatment rate per unit sectional area of the shaft of a melting furnace per hour.

In the case where a melting furnace mainly processes municipal solid waste, Nippon Steel sets the cross sectional waste treatment rate in the furnace shaft in a range of 600 ± 100 kg/m^{2}h as shown in **Fig. 11**. The waste treatment plant at Akita City having two furnaces, 200 t/d each, is one of the largest waste gasification and melting plants in Japan; the furnaces were designed according to the above cross sectional waste treatment rate. The operation of the furnaces is explained below.

4.2 Operation of large-size melting furnaces

The melting furnaces of the waste treatment plant of Akita City were constructed as replacements for old waste incineration furnaces (2 × 150 t/d), and constitute the core equipment of the City's policy to construct a recycling-oriented municipality. **Table 5** outlines the plant facilities. The melting furnaces process municipal solid waste, sewage sludge and incineration residues from stoker furnaces of another plant at prescribed mixing ratios.

The plant became commercially operational in April, 2002, and is stably processing approximately 130,000 t of wastes per annum. **Table 6** shows the amounts of wastes processed and those of molten matter and detoxified ash generated in fiscal year 2002. The average daily waste processing amounts are 206 t/d for the No. 1 Furnace and 205 t/d for the No. 2 Furnace. The melting furnaces process all the sewage sludge and incineration residues arising from the city area; the mixing ratios of the sludge and the incineration residues to the total amount processed are 8.7 and 3.1%, respectively. The product metal is used as a reducing agent for non-ferrous metal refining processes, and the slag for concrete secondary products and civil construction work inside the plant premises. The municipal and prefectural governments are planning to use the slag for public construction work in the form of composite asphalt material. When this is done, what has to be finally dumped for landfill will only be detoxified ash, and a volume reduction ratio of approximately 1/138 will be attained.

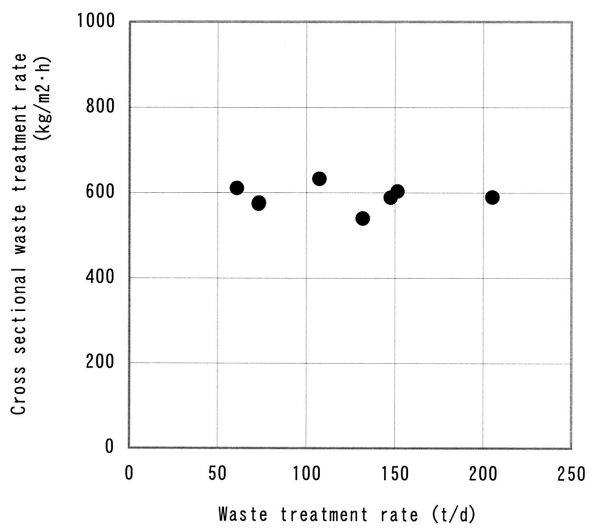

Fig. 11 Cross sectional waste treatment rate in the shaft

Table 5 Outline of Akita Total Environment Center Facility

Processing capacity	400 t/d (200 t/d × 2 furnaces)
Furnace type	Shaft furnace type gasification and melting furnace
Power generation facilities	Designed power capacity: 8,500 kW Steam condition: 400°C, 4MPa
Treated waste	(1) Domestic waste (2) Residue from the recycle facility (3) Sludge from sewage and human waste (4) Residue from bulky waste (5) Incineration residue from stoker furnace

Table 6 Material balance in fiscal 2002

		Weight (t)	Rate to total throughput (%)
Total throughput	Waste	111,169	88.2
	Incineration residue	3,816	3.1
	Sludge	11,002	8.7
	Total	125,987	100.0
Slag		13,698	11.0
Metal		2,212	1.8
Detoxification ash		3,553	2.8

Thanks to the stable operation of the melting furnaces, the plant generates high-temperature, high-pressure steam at 400°C and 4 MPa, and the steam is used for generating electric power. Actually, the plant sells excess power to outside even when only one of the furnaces is in operation. The combustible dust injection technology has been applied to the furnaces to successfully decrease coke consumption and the generation of fly ash.

5. Summary

For the purpose of enhancing the performance of direct melting furnaces for municipal solid waste, the authors developed technologies for combustible injection through tuyeres, the diversification of the kinds of wastes to process and the expansion of furnace size, and obtained the following results:

(1) Combustibles (plastics and combustible dust) injected into a direct melting furnace through lower tuyeres were confirmed to burn in preference to coke. The combustible injection through tuyeres reduces coke consumption and maintains the temperature and reducing capacity of the furnace atmosphere at high levels.

(2) Adequate control of melting furnace operation conditions makes it possible to diversify the kinds of wastes to process. The capability especially of processing wastes excavated from final landfill sites is effective in extending the available life of landfill sites.

(3) Appropriate enlargement of the profile of a melting furnace increases its processing capacity. Large melting furnaces having a capacity of 200 t/d have been constructed as a result, and are operated stably.

Waste processing requires sophisticated technologies suitable for environmental conservation including countermeasures against the formation of dioxins and for realizing a recycling-oriented society. In such a situation, the waste gasification and melting technology, capable of adequately processing wastes meeting the requirements, is expected to play an increasingly important role in waste treatment.

Nippon Steel's direct waste melting and recycling system is a forerunner in the field of gasification and melting of wastes. It has been brought up to the present state through long-accumulated experience and many supply references, and promises to be a technology that will meet the severest of requirements. The authors intend to introduce further technical improvements making the most of the characteristics of the process to contribute to the solution of environmental problems and the construction of a resource recycling society.

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