Development of Advanced Shaft Furnace
～Innovative system where significant reduction in coke use can be achieved～

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Abstract

The global environmental issues have been receiving increased interests. From the perspective of global warming prevention, a higher level of reduction in carbon dioxide emissions has been required in the field of waste management. In order to meet such a social requirement, “Advanced Shaft Furnace”, which can dramatically reduce carbon dioxide emissions from fossil fuel, was developed. Advanced Shaft Furnace is the innovative system where significant reduction in coke use can be achieved, while taking over advantages of a conventional shaft-type gasifier. Also, it is possible to reduce fossil carbon dioxide emissions down to null, when substituting fossil coke with biomass coke. This report shows the result of the performance test that was carried out in a 65-t/d commercial plant. In the test, it was confirmed that Advanced Shaft Furnace has a long-term availability and good prospects for commercial application.

Key word : Disposal of waste, Low-carbon technology, Recycling society, Global warming

1 Introduction

Direct melting furnace for municipal solid waste (direct melting system ;DMS), which is the shaft-type high temperature gasification and melting system, burns coke in the lower part of the gasifier to form a high temperature coke bed layer that ensures stable melting conditions and facilitates the thermal decomposition and gasification of solid waste. These effects enable the processing of various types of solid waste, producing high quality slag and metal that can be reutilized. In addition to that, the subsequent combustion chamber is capable of complete combustion. However, in recent years, along with the growing concern about global environment issues in the field of waste management, reduction of CO_2 emissions has been required in view of global warming.

As measures for reducing coke consumption, multi-stage tuyeres, injection technology of various combustibles (plastics, combustible dust, and fuel gas) into tuyere of gasifier, and others have been developed.[1),2),3)] While multi-stage tuyeres and combustible dust injection have already been confirmed to have the effects as described in the report[2)] and have been put into practical use. However, the social demand for the reduction of CO_2 emissions from fossil fuel today is stronger than ever before, and further reduction of coke consumption is required. Amid this, in the pursuit of making the best use of the energy from solid waste, an improved shaft furnace (hereinafter referred to as the "advanced shaft furnace") has been developed. In this technology, significant reduction in coke consumption as a heat source is achieved through the improvement of the blasting mechanism at the upper-stage tuyere of a shaft furnace in order to increase the efficiency of drying and thermal decomposition of waste. [4),5),6),7)]

After a process check test at a 20 t/d-pilot plant, a demonstration test was completed at a 65 t/d-facility, through which the reduction effect of the use amount of coke and equipment reliability of the advanced shaft furnace have been confirmed. We hereby report this established technology.

2 Overview of the Advanced Shaft Furnace

Figure 1 shows a schematic view of the advanced shaft furnace. The advanced shaft furnace has been designed for uniform blasting from the entire surface of the lower part of the shaft by improving the upper blasting mechanism responsible for drying and thermal decomposition of solid waste. Hot air passing the shaft part more evenly than before improves the heat exchange efficiency with solid waste in the gasifier. In the case of conventional shaft furnaces, it was difficult to have the air flow from tuyere evenly pass up to the center of the horizontal cross-section. In some cases, undried solid waste descends to the lower part of the gasifier, which demands a larger amount of coke for drying moisture. In contrast, the advanced shaft furnace has the heat exchange efficiency that is significantly improved with the uniform air flow from the entire surface of the lower part of the shaft. In addition, an appropriate feeding speed of thermal decomposition residue to the bottom part of the gasifier and the air flow rate can be maintained according to the combustion temperature of the bottom part of the gasifier. The sufficient drying/thermal decomposition of solid waste is achieved before being supplied to the bottom part of the gasifier, leading to no extra coke consumption for moisture removal other than the amount necessary for ash melting. In the bottom part of the gasifier, the ash in solid waste is completely melted, and slag and metal with as high quality as those produced by conventional shaft furnaces are discharged. Thus, the advanced shaft furnace has realized a significant reduction of the coke ratio, while maintaining the advantage of the conventional shaft furnaces such as; no pretreatment (e.g. crushing and sorting) is necessary, and various types of waste can be processed, and all the slag and metal produces are reusable.

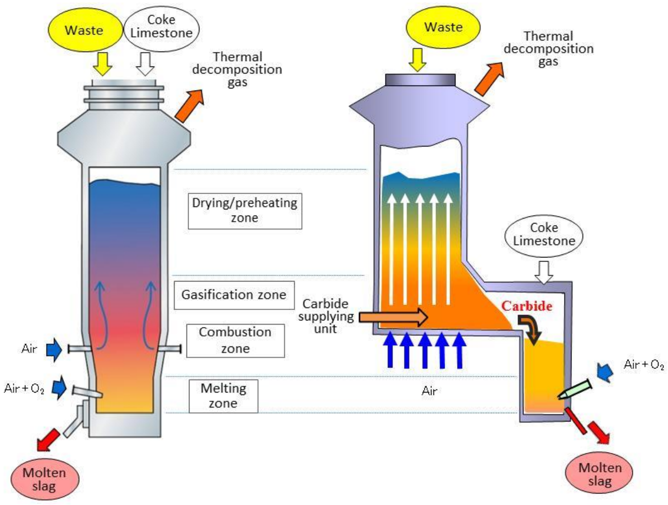


Figure 1: Overview of the low-carbon waste melting plant (Comparison to conventional type)

3 Process Confirmation Test Results of a Pilot Plant

A pilot plant (shaft-type gasification and melting furnace: 20 t/d scale) owned by NSENGI (NIPPON STEEL & SUMIKIN ENGINEERING CO., LTD.) was modified to an advanced shaft furnace, and processing test of municipal solid waste (MSW) was conducted to evaluate the performance of reduction in coke consumption. The waste processed was MSW, and proximate composition of the waste is shown in Table 1.

Table 1: Proximate composition of the MSW, processed in the pilot plant

		Average waste characteristics
Moisture content	% a.r.	41
Combustible content	% a.r.	48
Ash content	% a.r.	11
Low heating value	kJ/kg	9,200

In the pilot plant, 15 trials for a total of 101 days were conducted. As shown in Table 2, the advanced shaft furnace was continuously operated consuming coke at 14 kg/t-waste. (The normal coke use level of conventional shaft furnaces is about 40 kg/t-waste.) The temperature of molten material was almost equivalent to that when 40 kg/t was used in a conventional shaft furnace, and a high temperature at the gasifier bottom was maintained. Stable operation for 30 consecutive days was confirmed, showing the capability of long-term stable operation in the advanced shaft furnace.

Table 2: The coke consumption at the pilot plant

Data period	days	15
Waste through put	t/d	25
Coke consumption	kg/t-waste	14
Molten material produced	kg/t-waste	100

Furthermore, it was confirmed that the concentration of dioxins in flue gas measured during the operation for 30 consecutive days was below the standard value of 0.1 ng-TEQ/Nm^3. The advanced shaft furnace is able to suppress the generation of dioxins by gasifying the combustible content and completely burning it at high temperature in the subsequent combustion chamber.

Table 3 and Table 4 show the results of a JIS leaching tests of the slag produced in the pilot plant test, according to JIS K0058-1 and JIS K0058-2, respectively. With all items meeting the standards, the advanced shaft furnace was confirmed to be able to secure the slag safety.

Table 3: The results of slag leaching test according to JIS K0058-1 (discharged from the pilot plant)

		Result	Standard value
Cadmium	mg/L	<0.001	≤0.01
Lead	mg/L	<0.005	≤0.01
Hexavalent chromium	mg/L	<0.01	≤0.05
Arsenic	mg/L	<0.005	≤0.01
Total mercury	mg/L	<0.0005	≤0.0005
Selenium	mg/L	<0.002	≤0.01
Fluorine	mg/L	<0.1	≤0.8
Boron	mg/L	<0.02	≤1.0

Table 4: The results of slag content test according to JIS K0058-2 (discharged from the pilot plant)

		Result	Standard value
Cadmium	mg/kg	<1	≤150
Lead	mg/kg	<20	≤150
Hexavalent chromium	mg/kg	<1	≤250
Arsenic	mg/kg	<1	≤150
Total mercury	mg/kg	<0.05	≤15
Selenium	mg/kg	<1	≤150
Fluorine	mg/kg	<200	≤4000
Boron	mg/kg	<250	≤4000

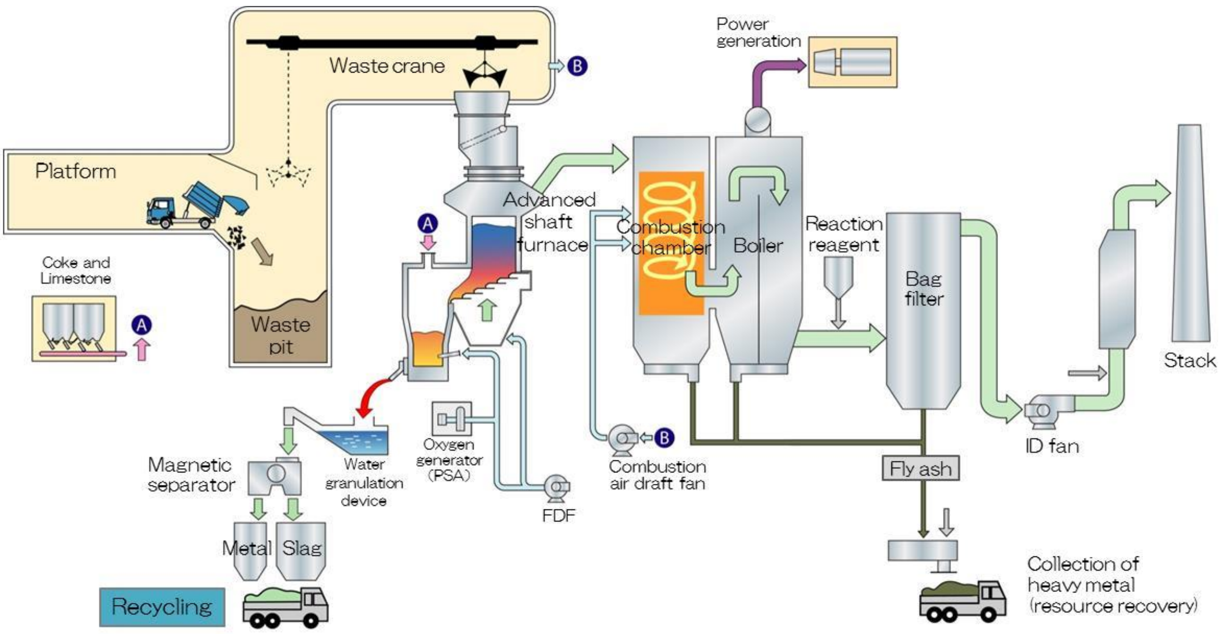


Figure 2: The process flow of the 65-t/d demonstration plant

4 Demonstration Test Results at a 65 t/d-Facility

4.1 Overview of the demonstration test

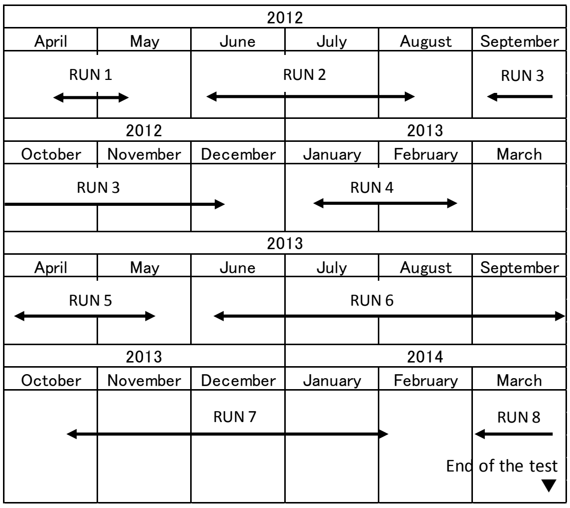
With an eye toward putting the advanced shaft furnace to practical use based on the results accomplished by the test using the 20-t/d pilot plant, a conventional shaft furnace in a 65-t/d commercial facility was modified to an advanced shaft furnace. A demonstration test was started in April 2012. Figure 2 shows the flow of the overall process of the facility. The waste for treatment was general waste consisting of MSW and non-combustible residue after recycling. Table 5 shows proximate composition of the waste processed. In comparison with the waste treated in the pilot plant, the waste used in the demonstration test has: (1) higher ash content proportion; and (2) lower heating value.

Considering these characteristics, the target value of the coke consumption was set to 20 kg/t-waste or less from 60 kg/t-waste of that before the furnace modification. Figure 3 shows the test schedule. The demonstration test consisted of eight trials that were scheduled by the end of March 2014. The total number of operation days was 489 days, and the total waste amount processed was 30,791 tonnes. Since the end of the demonstration test, the facility has continued the stable operation. During RUNs 1 and 2 when the test was just beginning, data on basic process data was obtained, and tuning of control systems and operating conditions was performed. During RUN 3, the long-term continuous operation and reduction effect of coke were confirmed. During RUN 4, a biomass coke application test was conducted. During RUN 5, a further reduction of coke was pursued. During RUN 6, long-term continuous stable operation was performed with a reduced amount of coke. During RUNs 7 and 8, in order to improve the combustion stability, optimization and find adjustment of operating conditions was performed. In the period between each RUN, an inspection of the equipment was carried out, and some improvements were performed based on the test results.

Table 5: Proximate composition of the waste, processed in the demonstration plant

		Average waste characteristics
Moisture content	% a.r.	38
Combustible content	% a.r.	49
Ash content	% a.r.	13
Low heating value	kJ/kg	8,137

Figure 3: The schedule of the demonstration test



4.2 Reduction of coke consumption

As shown in Table 6, after the adjustment of the operating conditions in each RUN, the coke consumption was reduced to a level of 15 kg/t-waste during normal operation. RUN 5 continued stable operation for 44 days, and RUN 6 continued for 94 days. Throughout these long-term test periods, the target reduction value of coke was achieved.

Table 6: The coke consumption at the demonstration plant

		RUN 5	RUN 6
Data period	days	44	94
Waste through put	t/d	71	70
Coke consumption	kg/t-waste	14.8	15.1
Molten material produced	kg/t-waste	122	99

4.3 Ability of long-term continuous stable operation

Although initial failure occurred during RUNs 1 and 2 in an early phase of the test, no problem remained after the equipment modification based on the results of an operation analysis conducted following these trials. RUN 3 achieved 92-day continuous operation with a coke consumption level of 23.9 kg/t-waste including the startup and shutdown of the furnace. RUN 6 achieved 113-day continuous operation with a coke consumption level of 16.4 kg/t-waste including the startup and shutdown of the furnace (Table 7). No RUNs experienced operation interruption due to any equipment problems, continuing stable operation.

Regarding the equipment durability (service life), a thorough inspection was conducted after the continuous operation for 113 days (RUN 6), through which no large damage was found, confirming that the equipment had sufficient durability. On the refractor wall in the gasifier as well, almost no damage or wear was found. It was confirmed that the refractor wall of the advanced shaft furnace was no less durable for long-term operation than that of conventional shaft furnaces. These results confirmed that the advanced shaft furnace was capable of continuing stable operation for a long span of time, and of having high reliability of equipment.

Table 7: The results of long term continuous test

		RUN 3	RUN 6
Data Period	days	92	113
Waste through put	t/d	62	70
Coke consumption	kg/t	23.9	16.4
Molten material produced	kg/t	115	101

4.4 Slag quality

Table 8 and Table 9 show the results of a JIS leaching test and JIS content analysis for the molten slag produced by the operation of the 65-t/d advanced shaft furnace at a coke consumption level of 15 kg/t-waste. All items satisfied the standards, confirming that the advanced shaft furnace was capable of securing slag quality as well as conventional shaft furnaces.

Table 8: The results of slag leaching test according to JIS K0058-1(discharged from the demonstration plant)

		Result	Standard value
Cadmium	mg/L	<0.001	≤0.01
Lead	mg/L	<0.005	≤0.01
Hexavalent chromium	mg/L	<0.02	≤0.05
Arsenic	mg/L	<0.01	≤0.01
Total mercury	mg/L	<0.0005	≤0.0005
Selenium	mg/L	<0.001	≤0.01
Fluorine	mg/L	<0.1	≤0.8
Boron	mg/L	0.02	≤1.0

Table 9: The results of slag content test according to JIS K0058-2(discharged from the demonstration plant)

		Result	Standard value
Cadmium	mg/kg	<5	≤150
Lead	mg/kg	<10	≤150
Hexavalent chromium	mg/kg	<5	≤250
Arsenic	mg/kg	<5	≤150
Total mercury	mg/kg	<0.05	≤15
Selenium	mg/kg	<5	≤150
Fluorine	mg/kg	120	≤4,000
Boron	mg/kg	100	≤4,000

4.5 Biomass coke application test

In RUN 4, a test was performed to entirely replace fossil coke with carbon-neutral biomass coke (Figure 4). As a result, the treatment operations performed using biomass coke were no less stable than that using normal coke. Also, it was confirmed that there was no problem with slag quality and flue gas properties resulting from the treatment with biomass coke. This marked a success in achieving zero CO_2 emissions derived from fossil fuel in the advanced shaft furnace.

Figure 4: Biomass Coke

4.6 Improvement of combustion stability

The advanced shaft furnace has been developed to have uniform gas flow from the entire surface of the lower part of the shaft t. This has realized stable heat exchange between waste and hot gas. Furthermore, in the thermal decomposition and gasification zone, the waste feeding speed and blast rate to the gasifier bottom part are optimized according to the combustion temperature and waste characteristics in order to appropriately control the appropriate amounts of partial combustion and thermal decomposition of waste, thereby stabilizing the syngas amount.

The boosted combustion stability described above led fluctuation percentage ε of live steam flow of the boiler to be significantly improved from 6.7% of conventional shaft surfaces to 3.3% (Figure 5 and Figure 6).

Fluctuation percentage ε was calculated using the following formula.

$$\varepsilon = \frac{2 \times \sigma}{\bar{q}} \times 100$$

ε: Percentage of boiler live steam flow fluctuation (%)

σ: Standard deviation of boiler live steam flow(t/h)

$\bar{q}$: Mean value of boiler live steam flow(t/h)

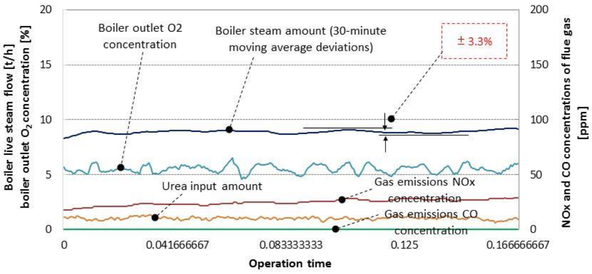


Figure 5: The boiler live steam flow of the conventional shaft furnace

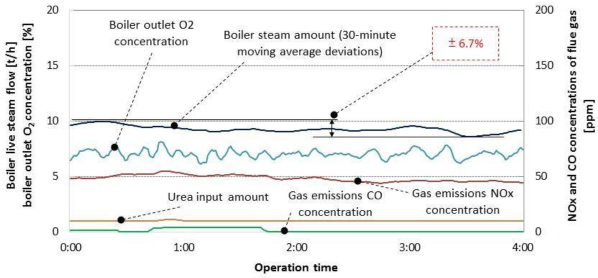


Figure 6: The boiler steam live flow of the advanced shaft furnace

As shown in Table 10, the excess air ratio of the advanced shaft furnace was 1.46 [-], while that of a conventional shaft furnace was 1.64 [-]. The advanced shaft furnace reduces the amount of surplus combustion air by stabilizing the fluctuation in syngas flow rate, leading to a reduction of the excess air ratio. This in turn wakes via gas emissions heat loss reduced. Therefore, higher power generation efficiency can be expected in the advanced shaft furnace system.

Table 10: The comparison of excess air ratio and flow gas quality

		Advanced shaft furnace (65-t/d)	Conventional shaft furnace (65-t/d)	Regulation value (One hour moving average)
Boiler outlet O_2 concentration	%	5.5	7.0	
Excess air ratio		1.46	1.64	
Urea consumption	L/h	10	10	
NOx concentration	ppm	25	48	100
CO concentration	ppm	0	1	50

5 Conclusion

The tests as described above confirm that the advanced shaft furnace not only has the same ability and advantages as the conventional shaft furnaces (1) to stably process various types of waste, and (2) to produce safe and high quality molten material, but also to significantly reduce the coke consumption. The tests also show that it can be put into practical use in terms of the equipment reliability. In addition, the advanced shaft furnace has an innovative system in which use of biomass coke can completely prevent the emission of CO_2 from fossil fuel.

The system of the advanced shaft furnace controls the thermal decomposition and gasification of waste as well, thereby improving the combustion stability. The future target is to improve the power generation efficiency in combination with the combustion technology described in 4.6 as part of the initiatives to spread the use of the advanced shaft furnace. Actually, as application to a new facility, the construction of a 100-t/d commercial facility with an advanced shaft furnace is under construction. NSENGI will strive to continuously contribute to resolving the resource and energy issues.

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