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Thermoselect Waste Gasification and Reforming Process†

YAMADA Sumio[*1] SHIMIZU Masuto[*2] MIYOSHI Fumihiro[*3]

Abstract:

The Thermoselect process is a completely new solid waste treatment process which achieves pollution-free recycling of municipal solid waste and industrial waste by a high temperature gasification and reforming process. The process effectively recovers fuel gas from waste and recycles metal and other byproducts as resources. A stable gas engine power generation system using purified synthesis gas from the Thermoselect process was also developed.

1. Introduction

Japan has made various laws related to recycling, beginning with the Basic Law for Establishing a Recycling-based Society, the Law on Promoting Green Purchasing, and others aimed at creating a recycling-based society. The general purpose of these laws is to reduce waste discharges, promote reuse, and prevent illegal disposal. Reducing discharges and material recycling are essential. However, since some remaining wastes are difficult to recycle as materials, development of an appropriate treatment method for these types of waste is also an important task.

The Thermoselect process[1)] is a gasification and melting technology which uses a gas reforming process[2)] to recover purified synthesis gas from municipal waste and industrial waste by gasifying the waste and reforming the gas obtained. While minimizing environmental impacts, the process also realizes chemical recycling.

In 1997, the former Kawasaki Steel (now JFE Group) was licensed with the basic technology from Thermoselect S.A., and in 1998, with the financial support of New Energy and Industrial Technology Development Organization (NEDO), began construction of a 300 t/day scale plant called the Chiba Recycling Center (Waste treatment capacity: 150 t/day × 2 lines, **Photo 1**) at the present JFE Steel's East Japan Works (Chiba District). In FY 1999, as part of joint research with Chiba Pref. and Chiba City, the plant completed a demonstrating operation of municipal waste treatment in this facility for a continuous period of 93 days and a total of more than 130 days.[3,4)] This was the first demonstration in Japan of a gasification, reforming, and melting equipment on an actual plant scale. Based on these results, Japan Waste Management Association issued a summary of technical verification and confirmation.[5)] In FY 2000, the plant began an industrial waste treatment/fuel production business which treats industrial wastes on consignment, producing fuel gas for power generation in the steel works. In 2000, the Thermoselect process became the first gasification and melting plant to receive New Energy Award. In Jan. 2001, the Chiba Recycling Center was transferred to Japan Recycling, a subsidiary of JFE Steel specializing in waste treatment.

This paper describes the results of a performance

Photo 1 Chiba Recycling Center

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*2 Project Manager,
Thermoselect Process Technical Coordination Project Team,
Environmental Industries Engineering Div.,
JFE Engineering

*1 General Manager,
Environmental Business and Technology Development Dept.,
Environmental Industries Engineering Div.,
JFE Engineering

*3 Manager,
Thermoselect Process Technical Coordination Project Team,
Environmental Industries Engineering Div.,
JFE Engineering

study of municipal solid waste treatment at the Thermoselect process Chiba plant, the condition of the industrial waste treatment/fuel gas business, including the characteristics and use of the gas, and a newly developed gas engine electric power generation system suitable for use with smaller-scale Thermoselect waste treatment plants in areas without major fuel gas-consuming industries.

2. Outline of Thermoselect Technology

2.1 General Process Flow

The standard treatment flow of the Thermoselect process is shown in **Fig. 1**. Wastes are compacted without pretreatment, followed by drying and pyrolysis by indirect heating in the degassing channel. The pyrolyzed waste product is then charged into the high temperature reactor, where it is melted at high temperature by reaction with oxygen and pyrolyzed carbon to form gas. This gas passes through the gas reforming/quenching/refining process and is recovered as a clean synthesized fuel gas.

2.2 Features of Process

The features of the Thermoselect process are described in outline below.

(1) Extremely low emission of dioxins and no generation of fly ash are possible.

Generated gas is held at 1 200°C for 2 s or longer, followed by quenching to approximately 70°C in an oxygen-free condition, to suppress the generation of dioxins to an absolute minimum, and is then recovered as fuel gas.

(2) 100% recycling of wastes is possible.

100% of waste input is converted into purified synthesis gas or recovered in the form of granulated slag, metals, metal hydroxides, S, mixed salts, and other substances which can be used effectively as resources, resulting in zero landfill disposal.

(3) Clean gas can be recovered by gas reforming.

Since the main components of the recovered synthesis gas are H_2 and CO, the gas can be used not only as a fuel for power generation, but also as a chemical feedstock. The fuel gas is applicable to a wide range of power generation methods, including gas engine, fuel cell, gas-fired boiler, and gas turbine combined-cycle power generation, allowing the user to select an optimum generation method from the view points of equipment scale and site conditions.

(4) The process offers excellent economy.

The Thermoslect process utilizes the energy contained in waste to perform melting and eliminates the need for separate treatment processes for dioxins and fly ash with high heavy metal contents. As a result, the total cost is lower than the conventional “incinerator + ash melting”. Moreover, because the Thermoselect process eliminates the need for landfill disposal, users can avoid the costs associated with constructing, managing, and maintaining landfills.

3. Results of Waste Treatment at Chiba Plant

3.1 Demonstration of Municipal Solid Waste Treatment

In the demonstration test, approximately 15 000 t

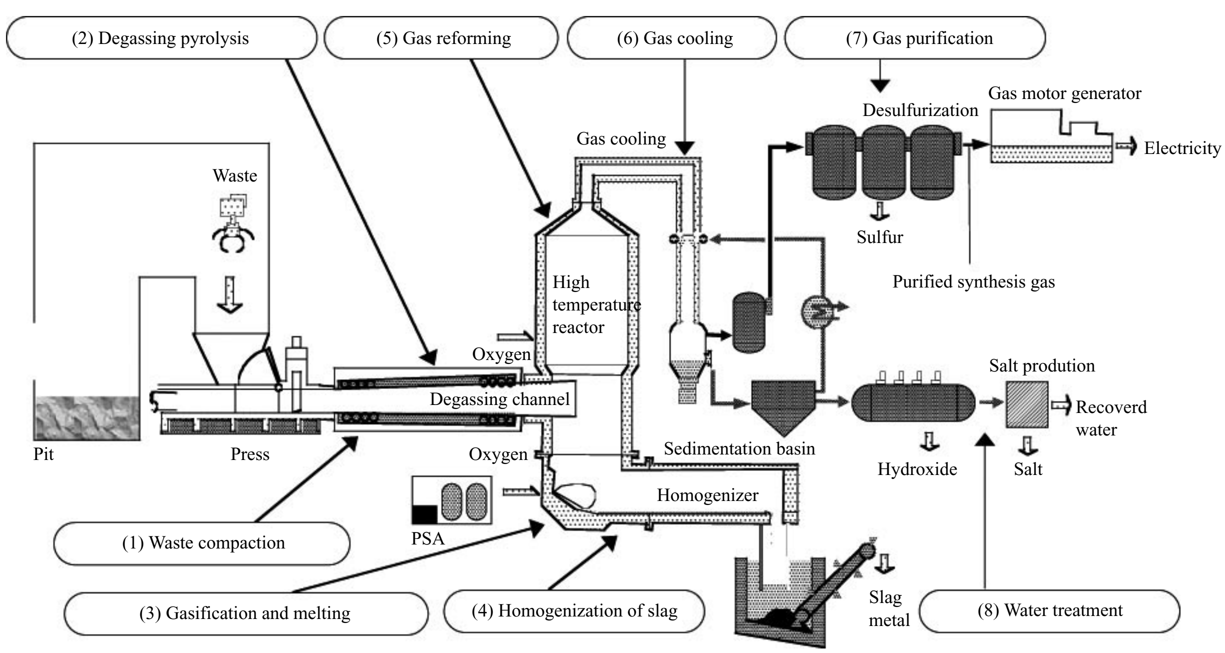

Fig. 1 Thermoselect process

Table 3 Total dioxins emitted at the Chiba Recycling Center (MSW)

By-product	Dioxins content	Recoverd quantity	Dioxins output (μg-TEQ/t-waste)
Synthesis gas	0.000 39 ng-TEQ/Nm^3	722 Nm^3/t-waste	0.000 28
Slag	0.000 7 ng-TEQ/kg-dry	65 kg/t-waste	0.000 04
Sulfur	0.35 ng-TEQ/kg-dry	0.52 kg/t-waste	0.000 18
Metal hydroxide	0.29 ng-TEQ/kg-dry	0.63 kg/t-waste	0.000 18
Recoverd water	0.000 01 ng-TEQ/*l*	680 *l*/t-waste	0.000 01
Total dioxins emitted			0.000 69

Table 1 Characteristics of municipal solid waste (MSW)

3 components	
Moisture content (%)	47.7
Ash content (%)	6.7
Volatile matter (%)	45.6
Measured lower heat value (MJ/kg)	8.5

Table 2 Characteristics of synthesis gas

	Concentration
Component	
H_2 (%)	30.7
CO (%)	32.5
CO_2 (%)	33.8
N_2 (%)	2.3
Dioxins (ng-TEQ/m^3)	0.000 39
Dioxins (O_2:12% conversion value) (ng-TEQ/m^3)	0.000 09

of municipal solid waste (MSW) from Chiba City were treated at the Chiba Recycling Center. The characteristics of this burnable MSW are shown in **Table 1**. An example of the properties of the synthesis gas obtained by treating the MSW is shown in **Table 2**. The concentration of dioxins in the fuel gas was 0.000 39 ng-TEQ/Nm^3 (0.000 09 ng-TEQ/Nm^3, O_2: 12% conversion value[6)]), or less than 1/1 000 of the 0.1 ng-TEQ/Nm^3 standard set by Japan's Ministry of the Environment.[7)]

Slag quality satisfied the leaching standard in Guideline for Recycling of Melted Solids of Municipal Waste. In the demonstration with MSW from Chiba City, the main metal component was Fe. However, since the average Cu content was as high as 17.5%, it was recovered as a material for Cu smelting. S was recovered as material for H_2SO_4, and metal hydroxides were used as material for Zn smelting as they had a high Zn content. Total release of dioxins was 0.000 69 μg-TEQ/t-waste, which is far below the future target value of 5 μg-TEQ/t-waste (**Table 3**). Considering the fact that the content of dioxins in the charged waste is currently assumed to be around 10 μg-TEQ/t-waste, the Thermoselect process clearly proved its performance in decomposition of dioxins.

3.2 Industrial Waste Treatment/Fuel Production Business

Treatment of industrial waste on a consignment basis began in Apr. 2000. In Apr. 2001, the Chiba Recycling Center also entered the plastic recycling business (licensed for plastic gasification) under the Containers and Packaging Recycling Law. As of Mar. 2003, a cumulative total of more than 170 000 t had been received.

The plant mainly treats construction industry waste. Categories of industrial waste include waste plastics, sludge, wood chips, waste paper, and others, as shown in **Fig. 2**, which also shows the amounts and composition of wastes received. It may be noted that the waste which is classified here as waste plastics (according to industrial waste control manifests) also contains a considerable amount of waste from other categories.

An example of the analysis of received waste is shown in **Table 4** (example of average composition of waste in pit, Sept.–Nov. 2001). Wastes A–D are examples of analysis for each lot of received waste, while waste D is an example of packaging waste plastics. Because the heating value, ash content, and other characteristics of this waste fluctuate widely by lot in comparison with MSW, it is also more important to stabilize waste quality by waste mixing control in this case. The plant therefore adjusts waste receiving, maintains a stock yard, and performs operation with special attention to mixing in the pit.

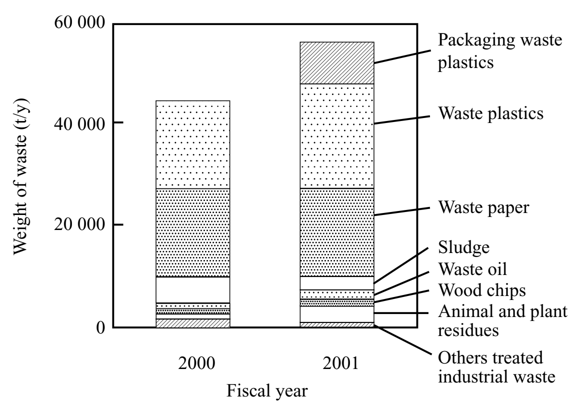

Fig.2 Composition of waste

Table 4 Characteristics of industrial waste

Industrial waste	LHV* (MJ/kg)	3 Components			Cl (%-wet)	S (%-wet)
		Moisture content (%)	Ash content (%)	Volatile matter (%)		
A	16.1	22.2	15.4	61.9	1.29	0.97
B	5.5	26.8	42.7	30.5	1.11	1.66
C	18.2	46.3	2.0	51.7	0.15	0.17
D	38.3	1.3	1.8	96.9	0.01	–
Average	13.7	44.4	9.8	45.8	1.15	0.64
MSW**	8.5	47.7	6.7	45.6	0.19	0.04

* Lower heating value, ** Demonstration

Table 5 Total dioxins emitted at the Chiba Recycling Center (Industrial waste)

By-product	Dioxins content	Recoverd quantity	Output of dioxin (μg-TEQ/t-waste)
Synthesis gas	0.000 30 ng-TEQ/Nm^3	826 Nm^3/t-waste	0.000 248
Slag	0.000 49 ng-TEQ/kg-dry	109 kg/t-waste	0.000 053
Metal	0.000 13 ng-TEQ/kg-dry	24.1 kg/t-waste	0.000 003
Sulfur	0.002 2 ng-TEQ/kg-dry	2.23 kg/t-waste	0.000 005
Metal hydroxide	0.000 68 ng-TEQ/kg-dry	2.29 kg/t-waste	0.000 002
Recoverd water	0.000 06 ng-TEQ/*l*	899 *l*/t-waste	0.000 000
Total dioxins emitted			0.000 31

Table 6 Characteristics of synthesis gas

Component		Concentration
H_2	(%)	32.4
CO	(%)	43.1
CO_2	(%)	18.8
LHV	(MJ/Nm^3)	8.9

The average properties of the waste in the pit after mixing include a lower heating value (LHV) of 13.7 MJ/kg, and ash content of 9.8%, Cl content of 1.15%, and S content of 0.64% (waste standard).[8] Thus, in comparison with MSW, LHV is large and the ash, Cl, and S contents are high (compared with MSW received from Chiba City during demonstration). Based on the large amount of metal hydroxides recovered, this industrial waste also has a high content of heavy metals (**Table 5**).

Table 6 shows an example of the characteristics of the synthesis gas obtained by treating industrial waste. Table 5 shows the distribution and total amount of dioxins. Total emission of dioxins was 0.000 30 μg-TEQ/t-waste, which is virtually the same level as in the demonstration with MSW.

Slag quality satisfies leaching standards. Slag quality control includes on-line size adjustment and magnetic classification. Quality confirmation tests with recycling contractors have been completed for respective applications, and Thermoselect slag is now being used as fine aggregate for interlocking blocks, etc.[9]

3.3 Use of Purified Synthesis Gas

Since 1987, JFE Steel's East Japan Works (Chiba District) has operated a gas turbine combined-cycle power plant[10] using byproduct gases generated in the steel works (Blast furnace gas, coke oven gas, etc.; LHV: 4.6 MJ/Nm^3). Therefore, the purified synthesis gas recovered by the Thermoselect process is transferred to the works, where it supplies part of the fuel for the combined-cycle power plant. **Figure 3** shows the energy flow at Chiba District of East Japan Works, including the purified synthesis gas from the Chiba Recycling Center.

In cases where a Thermoselect process plant is sited at a steel works or similar energy-consuming facility, it is possible to use the purified synthesis gas in the works. However, under general siting conditions, highly efficient power generation on a comparatively small scale is required in order to utilize the purified synthesis gas recovered by waste treatment. Conceivable generating methods for such small-scale waste treatment operations include gas engine power generation and fuel cells, as these methods offer high generating efficiency with small-scale equipment.

To demonstrate the effectiveness of the Thermoselect process in this type of power generation, a 1.5 MW gas engine generator was installed at the site of the Chiba Recycling Center for demonstration. The appearance of the generator is shown in **Photo 2**; its main specifications are shown in **Table 7**. A demonstration test of gas engine power generation was performed using part of the

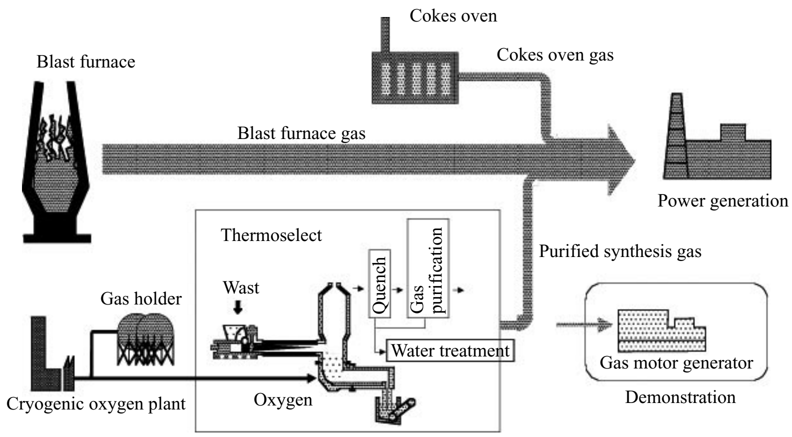

Fig. 3 Energy flow at Chiba District of East Japan Works

Photo 2 Gas motor generator

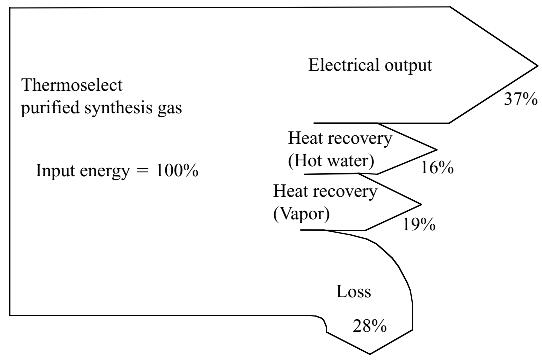

Fig. 4 Energy balance at 100% load

Table 7 Specifications of gas motor generator

Type	Lean-burn engine
Electrical output (kW)	1 507
Cylinders	20
Bore/Stroke (mm)	190/220
Rotation (rpm)	1 500
Maker	Jenbacher

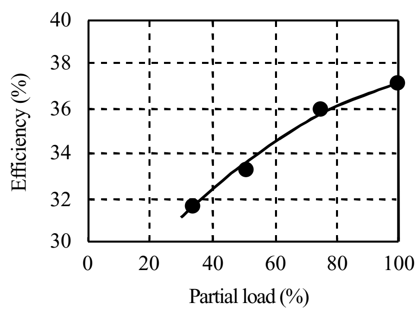

Fig. 5 Electrical efficiency in partical load

Table 8 Emission of gas-engine

DXNs	(ng-TEQ/Nm^3)	0.000 007 2
Dust	(mg/Nm^3)	0.2
NOx	(ppm)	14
HCl	(mg/Nm^3)	< 5

fuel gas supplied to the steel works. Since the properties of the gas generated by the Thermoselect process tend to fluctuate, depending on waste properties, the gas engine generating system includes a control system which maintains a constant output based on external signals by changing the air ratio in response to the change in heating value of the fuel gas. Constant generating operation was possible in spite of fluctuations in the heating value of the fuel gas. The energy balance in gas engine generation at 100% load is shown in **Fig. 4**. The generating efficiency of the gas engine generator itself was 37% at rated load, and combined efficiency was 72%. **Figure 5** shows generating efficiencies under various partial load conditions. In comparison with 37% efficiency at 100% load, 33% efficiency was maintained at 50% load, which was a decrease of only 4% from rated (100%) load.

Table 8 shows an example of the measured values of toxic substances in the gas engine exhaust gas by O_2: 12% conversion, which confirm that the dioxin content of the gas engine exhaust gas is low. Exhaust gas NOx is also low, even without denitrification.[11)]

At present, a highly efficienct (50–60%) fuel cell is being developed. Thus, in the future, it will be possible to achieve even higher equipment efficiency by applying the Thermoselect process.

4. Summary

The Thermoselect process described in this paper offers numerous advantages as a waste treatment system. In particular, it can cope effectively with a diverse range of wastes in fuel gas recovery, it has demonstrated outstanding dioxins decomposition performance, and it is capable of direct reduction of nonferrous metals such as Zn at the site. JFE Engineering is confident that this technology can contribute to realizing a recycling-based society without final landfill disposal sites.

At present, orders have been received for the following Thermoselect process waste treatment facilities, which are now under construction.

(1) Mizushima Eco-Works Corp. (Okayama Pref.)
Treatment capacity: 555 t/d
(scheduled startup: 2005)

(2) Kenoukennan Regional Environmental Association (Nagasaki Pref.)
Treatment capacity: 300 t/d
(scheduled startup: 2005)

(3) Cyuoukouiki Environmental Facility Association (Tokushima Pref.)
Treatment capacity: 120 t/d
(scheduled startup: 2005)

(4) Yorii ORIX Eco Services Corp. (Saitama Pref.)
Treatment capacity: 450 t/d
(scheduled startup: 2006)

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