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Environmentally Friendly Process Technology at Hirohata Works

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Abstract

In 1993, Nippon Steel Corporation Hirohata Works commercially established a new process, called scrap melting process (SMP). The SMP utilizes steel scrap as its principal metal source to produce hot metal saving the reduction energy of iron ore. The SMP then served as the core process to recycle raw materials and fuels including waste tires. This paper outlines Hirohata's activities to recycle steelmaking dust and waste tires and the environmentally friendly technology that support these activities.

1. Introduction

Different from iron ore, steel scrap does not require energy for its reduction; thus, its active use is meaningful toward encouraging energy conservation as well as solving the problems related to the depletion of natural resources and the environmental issues due to the emission of carbon dioxide. Based on this understanding, Nippon Steel Corporation Hirohata Works has put emphasis on effective use of resources including steel scrap using the SMP as its core recycling process.[1)]

Waste discharge has increased as a result of diversified economic activities and mass consumption, causing environmental problems worldwide. Consequently, discharge control, adequate treatment, and recycling of waste have become increasingly important. In view of the situation, the company has adopted "zero emission" measures to actively use scrap iron, dust generated from steel production processes, and waste tires as effective resources. This article presents the dust and waste-tire recycling activities at Hirohata Works, and outlines their environmentally friendly processes and equipments.

2. Importance of Resource Recycling

The dust generated from steel production processes consists mainly of iron oxide powder. Because it is highly oxidized and contains other oxides such as CaO and SiO_2, it cannot be used for the present steel production processes as collected. Thus, it is mixed with coal as its reducing agent, and reduced by approximately 90% in rotary hearth furnaces (RHFs). The reduced product is used as a source of iron for steel production. This recycling route covering various works within and outside the company is aiming at realizing "zero emission".[2, 3)]

The scrap melting furnace uses coal as the main fuel and waste tires recovered from the market as a substitute fuel.[4)] In addition, waste tires are also thermally cracked in rotary kilns into gas, oil, and steel; these products are consumed inside the works to decrease the country's waste discharge.

Hirohata Works converts waste that cannot be used as collected into useful materials and fuels, with an aim toward establishing steel production processes with minimum waste discharge.

3. Establishment of Environmentally Friendly Processes

After the last blast furnace at Hirohata Works was shut down in 1993 the works developed the scrap melting process (SMP) modifying a former converter vessel to continue the hot metal supply to the steelmaking plant. Since then, the SMP has recycled scrap iron and other wastes as useful materials and fuels. Then, in 1999, the Works began recycling of waste tires into fuel. In 2000, the first RHF was commissioned and began to produce direct reduced iron (DRI) from dust recovered from inside the works; the DRI was melted through the SMP into molten pig iron.

In regards to the dust recycling system, a second RHF was constructed in 2005 in order to increase efficiency, expand processing capacity, and enhance productivity. At the same time, a furnace to melt DRI into molten iron was added, and the new process was named the DRI smelting process (DSP). To further increase the dust recycling capacity and expand the variety of recycled dust, additional two RHFs were built in 2008 and 2011. In addition, a process to form DRI into briquettes, Hot Briquette Iron (HBI), was introduced

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in 2008 to increase the amount of dust recycling into hot metal through the SMP.

The combination of the melting furnaces (SMP, DSP) and the RHFs offers the advantages of efficient separation of gas, slag, and metal at high temperature and substantial flexibility in the chemistry and shape of the feed stock. The process yields high-quality molten pig iron whereas the byproduct gas, slag, and dust are collected and recycled inside the works.

The environment-friendly processes at Hirohata Works comprising the melting furnaces and the RHFs, as well as the progress of the recycling of raw materials and fuels, are explained in more detail in the following sections.

4. Scrap Melting Process (SMP)

As shown in the left-hand frame of **Fig. 1**, the melting furnace of the SMP is a modification of a common converter vessel with additional facilities to blow in fine coal from its bottom. **Fig. 2** shows the steps of the melting process at the SMP. Scrap iron and other sources are charged into the vessel, where some molten metal of the previous heat is left over. Then, the feed stocks are melted by the combustion heat of the bottom-blown fine coal with oxygen from the top blowing lance. The carbon of the injected coal penetrates into the metal (carburizing), which enables melting of the metal in the same temperature range as that in blast furnaces. After completion of the melting, molten metal is tapped and slag is discharged, but a part of the molten metal is left in the furnace for the subsequent heat. The SMP is characterized by the following five points:

(1) Rapid and stable melting of scrap iron, making use of high-carbon molten metal of the previous heat left over in the vessel.
(2) Production of hot metal suitable for stable production of high-purity steel by conventional converters.
(3) Low heat load on the furnace refractory on account of low-temperature melting;
(4) Heat generation sufficient for scrap melting by adequate control of the secondary combustion rate and use of recovered combustible gas.
(5) Great flexibility in the selection of feed stock equipped with chutes for scrap iron and continuous top charging facilities for other materials.

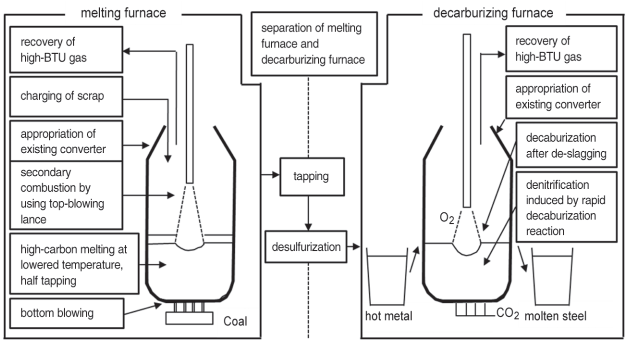

Fig. 1 Scrap melting process appropriating converter

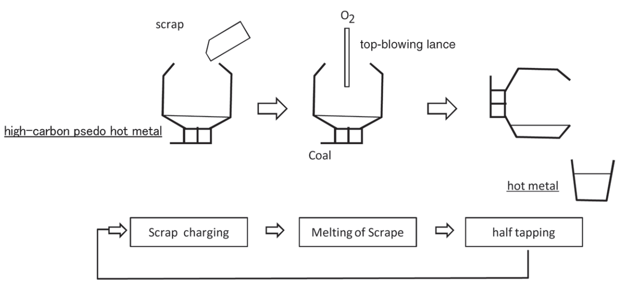

Fig. 2 Melting process flow

5. Recycling of Waste Tires through SMP

The diversification of economic activities and consumption lifestyle has led to increased discharge of wastes, which in turn have caused environmental problems worldwide. As a consequence, discharge control, adequate treatment, and recycling of wastes have become increasingly important. Hirohata Works has used chips of waste tires for the SMP as partial replacements for the scrap iron and fine coal since 1999 (see **Fig. 3**) to contribute to solving these waste problems. As seen in **Table 1**, the components of tire rubber are similar to those of coal, and steel cords are melted as scrap. Besides the recycling through the SMP, waste tires are also thermally cracked into gas and used inside the works as a high calorific fuel. Waste rubber crawlers of construction machines are also recycled; bucket chutes are used for charging them into the furnace because these bucket chutes are of a larger size than the tire chips.

6. Waste Tire Gasification Plant

After establishing the recycling of waste tires through the SMP, Hirohata Works began studying another technology to further expand the recycling of waste tires. It was found possible to thermally decompose waste tires into products that could be used effectively for steel production, and a new recycling process for waste tire gasification was developed.

The zero-emission initiative, determined as the principal philosophy for regional economic development, aims at reusing all wastes discarded from one industry as a raw material for another industry so that no wastes are discharged to outside the society. In 1997, the Government of Japan adopted the initiative to create environment-harmonizing local societies all over the country and launched the "Eco-town Project" to promote creation of advanced environmentally friendly local communities. Hirohata Works joined the Eco-town Project in Hyogo Prefecture in 2003 and began to play a core role in it. In addition to the waste-tire recycling through the SMP, another recycling system of waste tires by gasification was commissioned in 2004. To this end, Nippon Steel Corporation established a specialist company—Kansai Tire Recycling Co., Ltd.—to operate the system, which comprised two external-heating rotary kilns, the

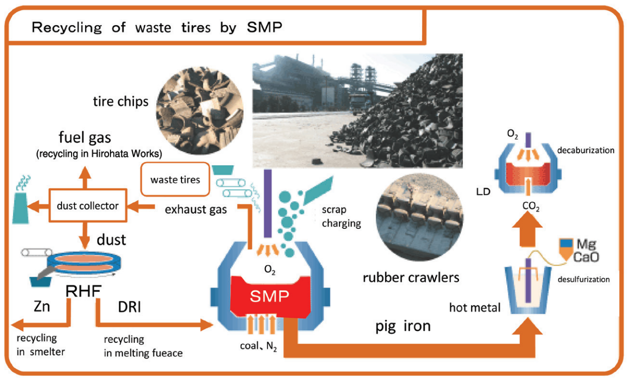

Fig. 3 Recycling of waste tire by SMP

Table 1 Components of waste tires (mass%)

	TB bias	TB radial	PC bias	PC radial	Radial tire of pickup truck	Radial tire of mini-vehicle
Gum	40 - 55	40 - 50	30 - 55	35 - 55	40 - 50	35 - 55
Carbon	15 - 30	15 - 30	20 - 35	20 - 30	22 - 30	20 - 30
Sulfur	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5	0.5 - 3	0.5 - 1.5	1 - 3
Softener	2 - 10	1 - 5	7 - 20	3 - 12	2 - 11	2 - 12
Zinc oxide	1 - 2.5	0.5 - 2.6	1 - 1.5	1 - 4	1 - 2	1 - 4
Vulcanization matericals	2 - 13	3 - 10	2 - 8	1 - 7	1 - 7	1 - 7
Fiber (nylon polyester)	7 - 15	0 - 4	5 - 18	2 - 10	2 - 10	2 - 8
Steel	3 - 10	15 - 40	2 - 10	5 - 16	5 - 17	5 - 16

	Bike	Scooter	Self-sealing tire	Construction vehicle tire		Flap
				Bias	Radial	
Gum	30 - 50	35 - 55	45 - 60	40 - 55	40 - 55	35 - 55
Carbon	25 - 35	25 - 35	10 - 30	20 - 30	20 - 30	20 - 35
Sulfur	0.5 - 1.5	0.5 - 1.5	0.5 - 2	0.5 - 2	0.5 - 2	0.5 - 1
Softener	7 - 22	6 - 22	3 - 10	2 - 20	0 - 10	8 - 24
Zinc oxide	1 - 2	0.5 - 1.5	1 - 2.5	1 - 3	1 - 3	1 - 2
Vulcanization matericals	1 - 5	1.5 - 5	1 - 25	2 - 16	2 - 16	1 - 15
Fiber (nylon polyester)	5 - 11	3 - 10	0 - 15	5 - 25	0 - 20	0 - 2
Steel	3 - 12	2 - 6	3 - 10	0 - 5	0 - 30	0

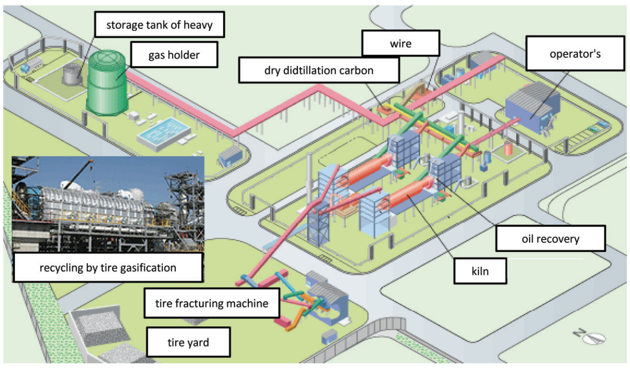

Fig. 4 Outlines of tire gasification plant

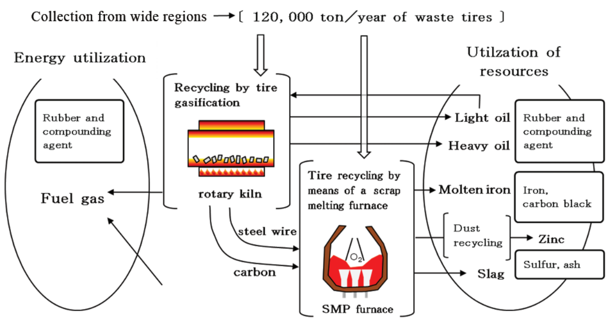

Fig. 5 Waste tire recycling system

world largest of this kind, to thermally crack waste tire chips collected from different regions of the country.

Fig. 4 schematically illustrates the gasification plant. Waste tire chips are charged into the kilns, and their rubber component is thermally cracked into gas under non-oxidizing atmosphere. The discharged gas is then cooled and separated into oil and high-BTU gas at the following oil recovery unit. The residues after the cracking (carbon and steel cord) are discharged separately from the delivery ends of the kilns.

Fig. 5 outlines the material flow of the waste tire gasification process and the SMP, as well as the final use of the recycled products. The recovered materials and fuels (oil, gas, carbon, and steel wire) are utilized effectively in steel production processes.

Hirohata Works alone recycles more than 10% of waste tires discharged from all over Japan through the gasification plant and the SMP. Its annual waste tire recycling capacity by the two process routes is 120,000 t, which is equivalent to the saving of approximately 140,000 t of natural resources or in terms of energy, that of 100,000 kl of heavy oil.

7. RHF Equipment and Operation

To use iron-containing dust generated from steel producing processes more effectively, a rotary hearth reduction furnace (RHF) was constructed in the works premises in 2000. The iron-oxide dust is mixed with fine coal as its reducing agent and formed into briquettes. The briquettes are then heated in the RHF and reduced into DRI. **Figs. 6** and **7** show the process flow and the outlines of the equipment.

Before being charged onto the hearth of the RHF, the briquettes are dried to prevent decrepitation by rapid heating. The dried briquettes are heated to 1,300 - 1,350°C in the RHF, 21.5 m in diameter, and their iron oxide contents are reduced. The product DRI (temperature approximately 1,000°C) is released from the RHF by a screw discharger. The sensible heat of the exhaust gas from the furnace is used to heat the air for combustion and the air for the briquette dryers, which improves the fuel efficiency. During the reduction reactions of the iron oxide of the briquettes, the zinc component is also reduced and evaporated into the exhaust gas. Then the extracted zinc, which turns into zinc oxide in the exhaust gas system, is recov-

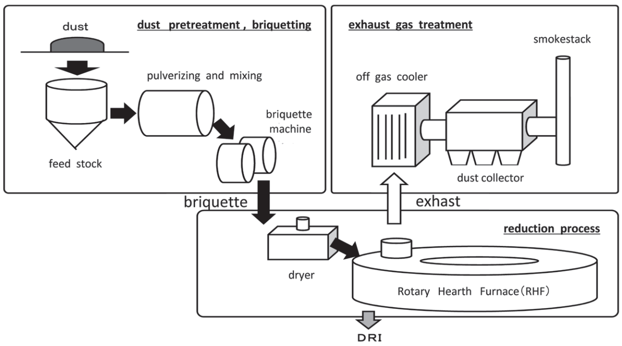

Fig. 6 Process flow of dust recycling

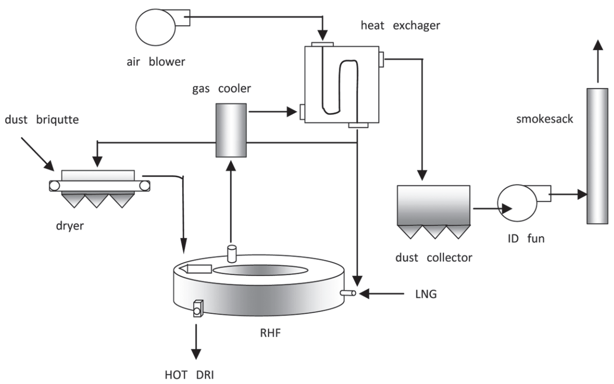

Fig. 7 RHF and related facilities

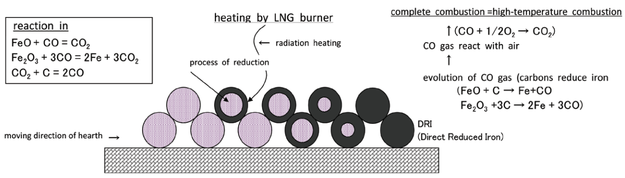

Fig. 8 Reduction reaction in RHF

Table 2 Typical composition of dust and DRI

	T.Fe	M.Fe	FeO	C
Dust	62%	4%	61%	2%
DRI	77%	63%	18%	4%

ered as raw zinc oxide in bag filters (see **Fig. 8** and **Table 2**).

The RHF consists of six zones, wherein each zone's temperature is individually controlled to be within 1,100 - 1,350°C, depending on the treatment rate and the endotherm of the reduction reactions. The zones are separated by partitions hanging down from the furnace ceiling. In Zone 1, immediately after the briquette charging port, the briquettes are quickly heated to the temperature range of reducing reactions; at the same time, the temperature is controlled so as to prevent the briquettes from decrepitation by thermal strain of rapid heating. After Zone 2, the furnace temperature is operated to maintain an appropriate balance between productivity and fuel consumption. Each zone is equipped with burners, and an adequate amount of air is provided to burn all the CO gas released from the reduction reactions.

The product DRI is charged into the SMP and melted into molten pig iron.

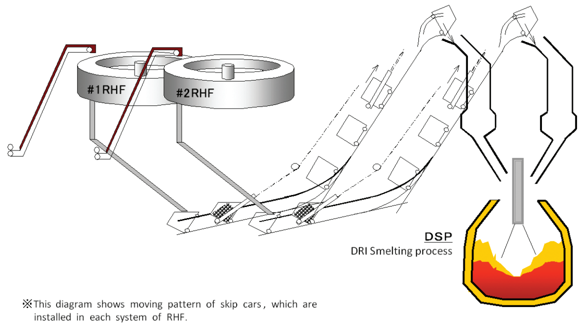

Fig. 9 Schematic diagram of RHF-DSP

8. Construction of DRI Smelting Furnace and Expansion of Dust Recycling

To increase the dust treatment capacity, a second RHF was constructed in 2005. Its specifications are the same as the No. 1 RHF; thus, the process capacity was doubled. In addition, to enhance thermal efficiency and promote dust recycling, a dedicated furnace for smelting DRI into molten metal (DRI Smelting Process, DSP) was installed adjacent to the No. 2 RHF, completing an integrated iron-making process from dust to molten pig iron. The DSP was installed close to the delivery side of the RHFs to significantly decrease the heat loss associated with transportation from the RHF to the distant melting furnace.

The DSP is basically identical to the SMP, where iron is melted by the combustion heat of bottom-injected fine coal with top-blown oxygen. However, the DSP is equipped with skip conveyers linking between the RHFs and the furnace and charging facilities dedicated for continuous charging of hot DRI from the furnace top (see **Fig. 9**).

9. Further Expansion of Dust Recycling through Additional RHFs

To further increase the dust recycling capacity of the SMP, diversify the types of recycled dust, and utilize dust from other steel works, Nos. 3 and 4 RHFs were constructed in 2008 and 2011 as well as a briquetting process to agglomerate DRIs into HBI.

Fig. 10 gives a panoramic view of the No. 3 RHF. The Nos. 3 and 4 RHFs have the same specifications as the existing ones. To improve the melting efficiency in the SMP furnace and promote dust recycling, HBI production equipment was installed. Hot DRIs are pressed into briquettes with higher density to prevent air and moisture from permeating and oxidizing the DRI.

Fig. 10 Whole view of No. 3 RHF

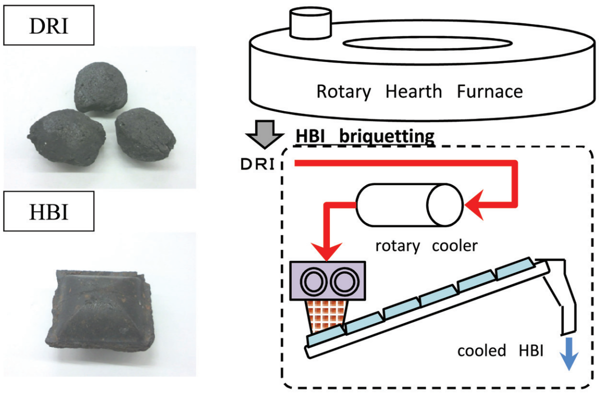

Fig. 11 Outline of HBI production equipment

Fig. 11 schematically illustrates the process flow of the HBI production and the external appearances of the product DRI and HBI.

The HBI production equipment enables the DRI, which is now cooled and briquetted into HBI, to be continuously charged into the SMP while avoiding its oxidation using its top charging facilities during melting operation. As a result, the utilization of the dust-origin DRI for the ironmaking process increased significantly, and the dust recycling amount reached approximately 50,000 tons per month.

10. Summary

Nippon Steel Corporation Hirohata Works has developed the process for recycling steelmaking dust generated from steel production and waste tires using the scrap melting process (SMP) as its core facility. Hirohata Works will establish the advanced environment-friendly steel works by further expanding the variety of recycled wastes to those that are difficult to be processed in other places utilizing the SMP and RHF.

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