Features of FASTMET® Process

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Over the past 10 years, Kobe Steel and its US subsidiary company, MIDREX Technologies, Inc., have been developing the FASTMET process. This process enables the conversion of metallic oxides from either steel mill waste or iron ore fines, into metallized iron in a rotary hearth furnace (RHF) using solid carbon sources, such as coal, as the reductant. Since 2000, the current commercial operations have enabled steelmakers to deal with metallic waste problems. In 2009, Kobe Steel filled order for two new FASTMET plants, each with 190,000 tonnes/h capacity. One of these is the third plant for Nippon Steel Hirohata Works with the first FASTMET-HBI process, and the other is the first plant for JFE Fukuyama Works, which produces DRI as a supplemental source for blast furnaces.

Introduction

Reducing iron ore in a rotary hearth furnace (hereafter referred to as an "RHF") was first attempted by Midland Ross Co., a forerunner of MIDREX Technologies, Inc., currently a U.S. subsidiary company of Kobe Steel. The process, called "Heat Fast", was unique in that it involved composite pellets, consisting of iron ore and carbonaceous material, which are pre-heated in a grate, pre-reduced in an RHF and cooled in a shaft cooler. A pilot plant was constructed in 1965, tests being conducted until 1966. The Midland Ross Co., however, prioritized the development of a process using natural gas, which is currently known as the MIDREX® process. The then low price of natural gas made this process seem more feasible, and as a result, the Heat Fast process was not commercialized.

In the 1990s, the price of natural gas rose; then Kobe Steel and MIDREX Technologies, Inc. collaborated to restart the development of the reduced ironmaking process using an RHF. A demonstration pilot plant was built in 1995 at Kobe Steel's Kakogawa Works. Through various demonstration operations conducted there, Kobe Steel and MIDREX Technologies, Inc. had established the FASTMET process for commercialization.

In 2000, a first commercial FASTMET plant was supplied to the Hirohata Works of Nippon Steel Co. for reducing 190,000 tonnes/year of steel mill waste. A second commercial plant was delivered in 2005 to the same company. The process was recognized for its ability to efficiently recycle ironwork dust. These achievements led the FASTMET process to win the Minister's award, Resources Recycling Technology and System, from the Clean Japan Center.

Table 1 Delivery record of FASTMET plant

Plant	Startup	Capacity (t/y)
1) Kobe Steel Kakogawa Works FASTMET	2001 Apr.	14,000
2) Nippon Steel Hirohata Works FASTMET No.1	2000 Mar.	190,000
3) Nippon Steel Hirohata Works FASTMET No.2	2005 Feb.	190,000
4) Nippon Steel Hirohata Works FASTMET No.3	2008 Dec.	190,000
5) JFE Steel West Japan Works (Fukuyama) FASTMET No.1	2009 Apr.	190,000

In 2008, a third plant was delivered to the Hirohata Works of Nippon Steel Co., and in 2009, JFE Steel, West Japan Works, Fukuyama (**Table 1**), took delivery of its first plant. Both plants have a processing capacity of 190,000 tonnes/year. The following introduces these plants and outlines the FASTMET process.

1. Features of the FASTMET process

The FASTMET process is clearly different from the gas-based reduction process using reforming gas derived from natural gas, in that it heats and reduces composite agglomerates, each consisting of iron ore, or steel mill waste, and coal. This simple and unique process involving rapid heating accomplishes a rapid reduction reaction. The agglomerates are placed in one or two even layers over the hearth and are heated using radiation heat. This prevents the oxidation of agglomerates, despite the in-furnace condition of combustion exhaust gas, which has a significant oxidation potential[1)]. It is important to mention that the process can achieve the heating and reducing of the agglomerates simultaneously and effectively at an ideal air-gas ratio in a furnace. In addition, the combustible gas generated from the carbon in the agglomerates burns in secondary combustion above them. This significantly suppresses the emission of NOx, despite the fact that this is a furnace that burns at high temperatures, another feature of the FASTMET process.

Raw materials such as steel mill plant dust may occasionally generate dioxin as they burn. In the FASTMET process, however, the furnace temperature is 1,300℃ or higher, which is high enough to suppress the generation of dioxin. The exhaust gas from the furnace is cooled rapidly through the temperature region in which dioxin may recombine, thus preventing it from recomposing.

FASTMET is a unique process using an RHF to reduce agglomerates containing coal with a high reduction ratio and high productivity. The reduced iron can be fed, not only into a blast furnace, but also directly into a melting process.

Fig. 1 shows a typical flow of the FASTMET process. The FASTMET process includes mixing steel mill waste consisting mainly of fine ore (i.e., iron oxide) with pulverized coal, agglomerating the mixture into pellets or briquettes using a pelletizer or a briquetter, drying the agglomerates in a dryer, and placing the agglomerates over the hearth of an RHF in one or two even layers.

The pellets or the briquettes must be isolated from air when they enter the furnace. Their feed rate must be controlled precisely at the same time. FASTMET contains a feed pipe system enabling the adjustment of the number of pipes according to the size of the furnace, thus simultaneously achieving isolation from the air and volume control[2]. A screw-type leveling system is adopted for placing the agglomerates in one or two even layers[3].

A rapid heating method, a proprietary technology of Kobe Steel[1], is adopted for heating the pellets or briquettes laid over the hearth, rapidly attaining a high temperature of 1,350℃. This heating generates the reaction of oxides and carbon as described in the formulae (1). Dwelling for 8 to 16 minutes, the agglomerates are converted into direct reduced iron (hereinafter referred to as "DRI"), which is discharged out of the furnace or supplied to the downstream process, at a temperature of 1,200 to 1,000℃ (**Fig. 2**).

$$\left.\begin{array}{l} Fe_2O_3 + 3C = 2Fe + 3CO \\ Fe_3O_4 + 4C = 3Fe + 4CO \\ Fe_2O_3 + 3CO = 2Fe + 3CO_2 \\ Fe_3O_4 + 4CO = 3Fe + 4CO_2 \\ FeO + CO = Fe + CO_2 \\ ZnO + CO = Zn + CO_2 \end{array}\right\} \cdots\cdots\cdots\cdots(1)$$

The stable and continuous discharge of DRI out of the furnace at a high temperature is achieved by such proprietary technology of KSL as elevating the hearth of a reduction furnace[4]. Unlike blast furnaces, the FASTMET can start and stop operation with relative ease depending on the amount of production, which enables production in response to demand.

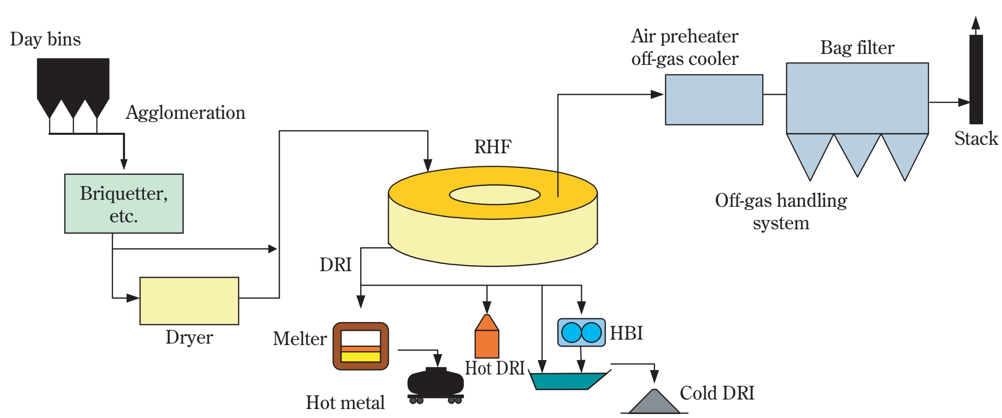

Fig. 1 FASTMET process flow

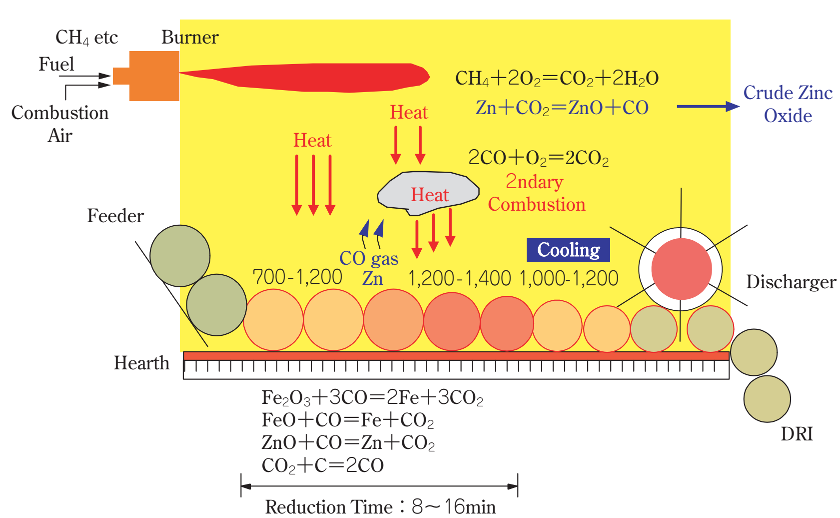

Fig. 2 Schematic drawing of reduction in FASTMET furnace

The DRI, discharged out of the furnace, is either transferred to a melting furnace in a transportation container, or is cooled and supplied into a blast furnace.

The DRI has many pores left after the reduction process. If exposed to air for a long time, the metallic iron reoxidizes into iron oxide, deteriorating its quality. If DRI is not used immediately as raw material for a melting furnace or a blast furnace, compacting and densifying the DRI into hot briquette iron (HBI) prevents reoxidation; this allows the storage of reduced iron for an extended period of time without quality degradation. The stored HBI can be fed to a melting furnace or to a blast furnace. Otherwise, the HBI can be transferred or sold to others.

Whether the reduced iron produced by the FASTMET process is used as DRI in the form of pellets/briquettes or is formed into HBI using HBI equipment depends on the application of the product (iron source) and its storage period.

The combustion gas (CO gas) emitted from the pellets/briquettes as a result of the reduction reaction can be used as a fuel for the RHF, which significantly decreases the amount of fuel supplied to the burner. The ore dust generated in steel mills has conventionally been pelletized or sintered in-house to recycle the dust as a raw material for blast furnaces. The blast furnace raw material, however, contains volatile components, particularly zinc, which vaporizes in the high temperature zone of a blast furnace. However, not all the vapor escapes from the furnace; some portion of it, cooled and trapped by newly-charged materials, remains in the furnace. The accumulated volatile components decrease the permeability of blast furnaces, and significantly impair their productivity.

The FASTMET process vaporizes heavy metals such as zinc and lead, which had inhibited the recycling of scrap iron, and converts them into crude zinc oxide and the like. This allows the discharging of these elements into exhaust lines without circulating them in the process. The off-gas treatment facilities are equipped with a Kobe Steel original cooling & dust collection system[5], which, combined with air cooling and water cooling, prevents the volatile components from adhering to the equipment walls. This has enabled stable and continuous operation for an extended period of time and the collection of crude zinc oxide and the like, using a bag filter. The collected crude zinc oxide is a valuable resource and is recycled along with the reduced iron.

A heat exchanger installed on the off-gas treatment equipment converts the energy contained in the high temperature exhaust into energy for heating the air that is used for either burning or drying the raw materials. This reduces the overall energy consumption.

2. FASTMET-HBI process, No. 3 plant at the Hirohata Works, Nippon Steel Co.

Kobe Steel delivered the FASTMET No. 1 plant (**Fig. 3**) to the Nippon Steel Hirohata Works in 2000. Another plant with a similar scale, the FASTMET No. 2, was delivered to the same site in 2005. The demonstration plant constructed at Kobe Steel's Kakogawa Works in the 1990s is still at work, recycling reduced iron from ore-dust generated in the ironworks, and contributing to resource reduction (**Fig. 4**).

Yet another plant, the FASTMET No. 3 (**Fig. 5**,

Fig. 3 No. 1 FASTMET plant in Nippon Steel Hirohata Works

Fig. 4 FASTMET plant in Kobe Steel Kakogawa Works

Fig. 5 No. 3 FASTMET plant in Nippon Steel Hirohata Works

hereinafter referred to as "the present plant"), was delivered to the Nippon Steel Hirohata Works. It has a dust-processing capacity of 190,000 tonnes/year, equal to the capacity of the No. 1 and No. 2 plants. The end product of the No. 1 and No. 2 plants is DRI, while that of the present plant is HBI, a hot-compressed, compacted form of DRI. In other words, the present plant is the first commercial plant adopting the FASTMET-HBI process.

As described above, in a case where reduced iron is stored in the atmosphere for an extended period of time, e.g., for sales, DRI is hot-compacted (briquetted) into HBI (**Fig. 6**), a form without pores. The briquetting of DRI to be used in a gas-based direct reduction ironmaking plant was developed in the 1990s, for the first time ever, by Kobe Steel and MIDREX Technologies, Inc. The knowledge accumulated to date has led many MIDREX process direct reduction plants to adopt the DRI-briquetting technology.

The FASTMET-HBI process is based on this proven process and uses a DRI cooler as ancillary equipment. Due to the difference in the discharge temperature of DRI, the MIDREX process does not use this DRI cooler. The DRI cooler is designed to bring the DRI, which is discharged from an RHF at a temperature of around 1,000℃, down to a temperature in the range of about 600 to 800℃. An HBI briquetter efficiently compacts it to obtain high quality HBI (**Fig. 7**).

In order to establish the technology for producing HBI from the DRI made by an RHF, an HBI pilot plant was built at the Kobe Steel Kakogawa Works as early as 1996, where forming campaigns were conducted[6]. **Table 2** shows the specifications of the pilot plant.

These experiments provided information on the way in which porosity and apparent density, typical characteristics of HBI, affect the weather resistance and strength required of it, as well as information on the conditions of temperature and residual carbon content required for HBI forming. On the basis of the results of the experiments, Kobe Steel proved that DRI reduced from raw materials such as iron-ore and steel mill waste (total iron content higher than about 50%), processed by an RHF operating under normal conditions (surrounding temperature: 1,200 to 1,400℃, residual carbon in DRI: 2 to 6%), can be formed, in a temperature range of about 600 to 800℃, into briquettes suitable for long-term storage and for charging into blast furnaces[6].

Fig. 8 contains an experimental result showing the relationship between residual carbon content and strength, an indicator of HBI quality, for given briquetting temperatures[7].

It was also found that when briquetting HBI, the higher the degree of metallization near the surface and the higher the residual carbon content toward the center of the DRI, the better the quality of the HBI, with increased adhesiveness among the briquettes[7]. **Fig. 9** is a full view of the HBI pilot plant in the Kakogawa works. **Fig. 10** shows the pilot plant producing HBI. **Table 3** summarizes the properties of the HBI that is produced. The experimental results obtained by this pilot plant have provided

Fig. 6 Sectional view of HBI

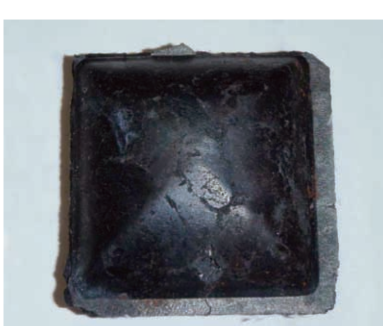

Fig. 7 Appearance of HBI

Table 2 Specifications of hot briquette machine of pilot plant[6]

Hot briquette machine	Roll Diameter	1.0 m
	Allowable feed temp.	800℃
	Feed material temp. (typical)	658℃
	Feeder speed (typical)	86 rpm
	Roll pressure (typical)	16.5 MPa
	Roller speed (typical)	5 rpm
	Production rate (typical)	9.5 t/h
	Motor Power	200 kW

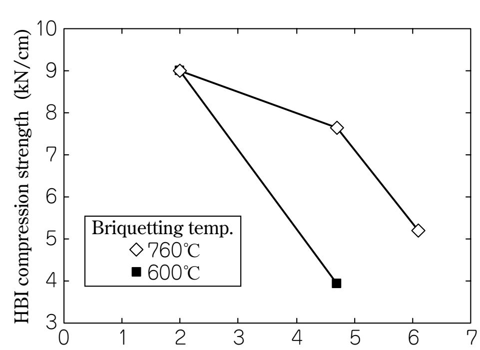

Fig. 8 Relationship between compression strength and carbon content of HBI

Fig. 9 Kakogawa HBI pilot plant

Fig.10 Agglomerate test in Kakogawa HBI pilot plant

Table 3 Properties of HBI produced by the pilot plant

Metallization:		80−85%
Carbon:		2−6%
Density:		4.2 g/mL
Compression Strength:		5−7 t/HBI
Drop Strength	+38.1mm:	85%
	6−38.1mm:	11%
	−6 mm:	4%

information on the required heat transfer dimensions and the cooling time of the DRI cooler located between the RHF and the HBI briquetter, as well as the influence of the DRI cooler on HBI quality.

The dust generated at ironworks includes blast furnace dust, steelmaking dust and sludge. They are generated in many different ways and it is difficult to determine at the planning stage if such dust can be reduced at a commercial level, or whether it can be formed into HBI. Kobe Steel has testing equipment, such as apparatuses for testing reduction and briquetting, which enables appropriate assessments, such that suitable feasibility studies can be conducted in the planning stage. In the case of the No. 3 plant at the Nippon Steel Hirohata Works, planning began in 2005, exploiting the above environment, and the detailed designing began in 2007 after confirming the commercial feasibility.

Kobe Steel designed and supplied the RHF, HBI-making plant, briquette dryer and exhaust treatment system, and began installation in May 2008. Test operation began in October, and hot operation in December, filling the order within a short lead time. Commercial operation started at the end of December.

The HBI equipment, which is located below the RHF, fits in a very compact layout and has a height almost the same as that of the previously delivered No. 1 and No. 2 plants, which did not have HBI equipment.

Its environmentally-conscious design includes dust collectors disposed at various locations to prevent dust from generating during the transfer of the raw material, dust briquettes.

In both the No. 1 plant and the No. 2 plant, the DRI discharged from the RHF is transferred to the downstream steelmaking process, while being maintained at a high temperature. On the other hand, in the FASTMET-HBI process at our plant, the DRI discharged from the RHF passes through a screen[8] to remove foreign matter, a DRI cooler that cools the DRI to a temperature suitable for hot briquetting, and a hopper that supplies the DRI to an HBI briquetter which forms the DRI into HBI (**Fig.11**).

During the time in the DRI cooler, it is important that the temperature of the DRI be maintained in a range suitable for briquetting. If the temperature at the outlet of the DRI cooler is too high, the rolls and feeder of the HBI briquetter rapidly wear out, increasing the cost of maintenance. If the temperature is too low, the ductility of the DRI is decreased, and that also causes rapid wearing of the rolls. Decreased ductility is also detrimental to certain qualities of the HBI; for example, it may not

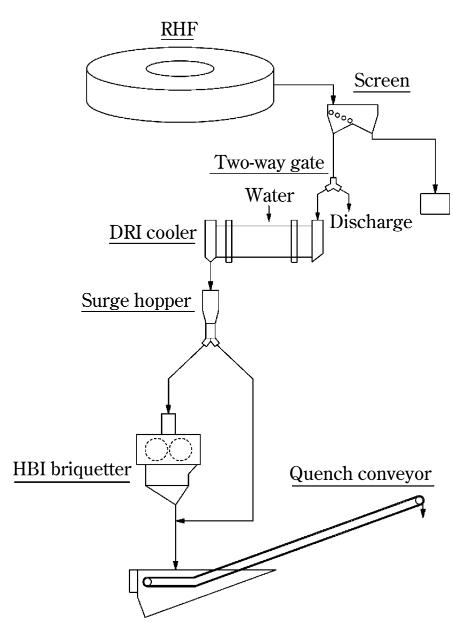

Fig.11 HBI line process flow of 3rd FASTMET plant in Nippon Steel Hirohata Works

attain the required degree of strength. The DRI cooler adopts an indirect water-cooling drum system. The DRI cooler of the present plant allows temperature control for the first time, not only by adjusting drum revolution, but also by adjusting the volume of nitrogen that is supplied to the DRI cooler, as nitrogen gas maintains an inert atmosphere in the HBI system. This has been confirmed to provide a suitable control[9].

A surge hopper is provided as a buffer to adjust the difference in the DRI production volume of the RHF and the HBI production volume of the briquetter. Since the inside of the hopper is always at a high temperature, it is not easy to measure, from outside, the amount of DRI left inside. There are level meters that use gamma rays for similar applications. However, for safety reasons, such meters require the strict management of radiation sources, which increases the maintenance load and decreases the flexibility of operational adjustment. In order to lessen the maintenance load, the present plant adopts a level meter using microwaves, a first for this application, and the meter has proven to adjust well.

In order to prevent reoxidation, the HBI compacted by the HBI briquetter is cooled to nearly room temperature by a water spray in a quench conveyer and is then stored in a yard for transportation by belt conveyers or by trucks. Because HBI is known to lose its strength if cooled rapidly, Kobe Steel uses its original slow cooling technology, a slow quench system[10].

The fines of HBI that are generated during the cooling and handling in the quench conveyor are collected by a fine conveyor disposed underneath the quench conveyor, if they are large enough. Fine dust carried into the cooling water is sorted by a separator using gravity (a dust catcher), so that the fines will not clog the inlets of transfer pumps, for example.

An example of the characteristics of the HBI produced by the present plant is shown in **Table 4**, which indicates the high quality of the HBI produced.

In addition to the HBI system described above, the present plant has a new secondary combustion chamber at the off-take of the RHF. This is to prevent the combustion gas generated in the RHF from discharging into the exhaust system without being utilized and to exploit and burn the gas efficiently in the furnace as the heat source for the reduction reaction. The secondary combustion chamber is provided with a temperature monitoring system, which enables the adjusting of combustion in the chamber so as to adapt to changes in the combustion conditions; these changes are due to variation in the characteristics of the raw material.

Table 4 Properties of HBI produced by No. 3 FASTMET plant in Nippon Steel Hirohata Works

Metalization	$>$85%
Carbon	$<$3%
Density	$>$5g/mL

Fig.12 Exhaust gas cooler of No. 3 FASTMET plant in Nippon Steel Hirohata Works

The exhaust gas discharged from the RHF via the off-take must be cooled to a temperature which permits collection by a bag filter. Thus the off-gas treatment system is provided with a gas cooler, typically of the water-spray type. However, this sort of gas cooler has suffered from a problem; the water spray combined with the dust contained in the exhaust, such as zinc oxide, and was then deposited on the interior walls of the cooler, where it inhibited the flow of gas.

To prevent this, the present plant newly adopts opposed flow at the gas inlet of the cooler (**Fig.12**). The operation so far has proven to run stably for an extended period of time without disturbance due to deposit formation[11].

3. No. 1 FASTMET plant at JFE Steel West Japan Works

JFE Steel West Japan Works (Fukuyama) received its first FASTMET plant (**Fig.13**) in 2009. The company's order for this plant arose from its high appreciation of the achievements of the process at the Kobe Steel Kakogawa Works and the Nippon Steel Hirohata Works.

This plant is to reclaim the high zinc content dust emitted from the blast furnaces and steelmaking in the ironworks, and has a dust processing capacity

Fig.13 FASTMET plant in JFE Steel West Japan Works (Fukuyama)

rated at 190,000 tonnes/year. The produced DRI is charged into blast furnaces, contributing to the zero-emission operation of the ironworks.

The scope of Kobe Steel's work on this plant covered the designing, manufacturing, construction and dispatching of supervisors for commissioning of the RHF, off-gas treatment equipment and DRI cooling & transferring equipment. Designing began upon receipt of the order in September of 2007. The project was completed within a short period, the installation of machinery beginning in June of 2008, commissioning taking place in January of 2009, and operations beginning in April of 2009. In June of 2009, the plant ran at the rated capacity, achieving its guaranteed performance and demonstrating the possibility of inaugurating the process in a short time.

The DRI produced by this plant, which is charged into blast furnaces, must have enough strength not to be crushed before being charged into a blast furnace and must have a low zinc content so as not to increase the amount of zinc circulating in the furnace.

In order to maintain the strength of DRI at a high level, DRI must be sufficiently reduced, and its residual carbon content must be kept low. Sufficient reduction time must be allowed for reducing and vaporizing the zinc contained in the dust. To meet these requirements, this plant has an RHF with an effective hearth diameter of 27m, making it the largest FASTMET plant ever built. After adjustment during commissioning, this plant can produce DRI with the characteristics shown in **Table 5**. The DRI is currently being used for blast furnaces, and no problems have been observed.

Fig.14 shows the DRI cooling and transportation line flow of the plant. The DRI is reduced in the RHF and discharged from it at a high temperature of around 1,100℃. A cooler, an indirect cooling drum type, is used to cool the DRI down to 200℃. The drum has a transfer blade and a cooling fin inside it. Water is sprayed onto the outer wall of the drum. As the drum rotates, the transfer blade moves the DRI toward the outlet, and the DRI is simultaneously cooled by its contact with the drum wall and the cooling fin.

The DRI cooler is provided with a dual damper at its discharge outlet and with a seal at the sliding portion of the drum, in which nitrogen is blown into the damper and seal as seal gas. This makes it possible to maintain an inert atmosphere inside the DRI cooler and prevents the DRI from reoxidizing.

It is important that the temperature at the outlet of the DRI cooler be sufficiently low so that the discharged DRI does not reoxidize rapidly and can be transferred without any trouble. On the other hand, an indirect cooler requires a large heat transfer surface when the subject to be cooled reaches a temperature near the ambient temperature, where the cooling efficiency decreases. This increases the

Table 5 Properties of DRI

Reduction degree	>80%
Zinc removal degree	>90%
Compression strength	>100kg/piece

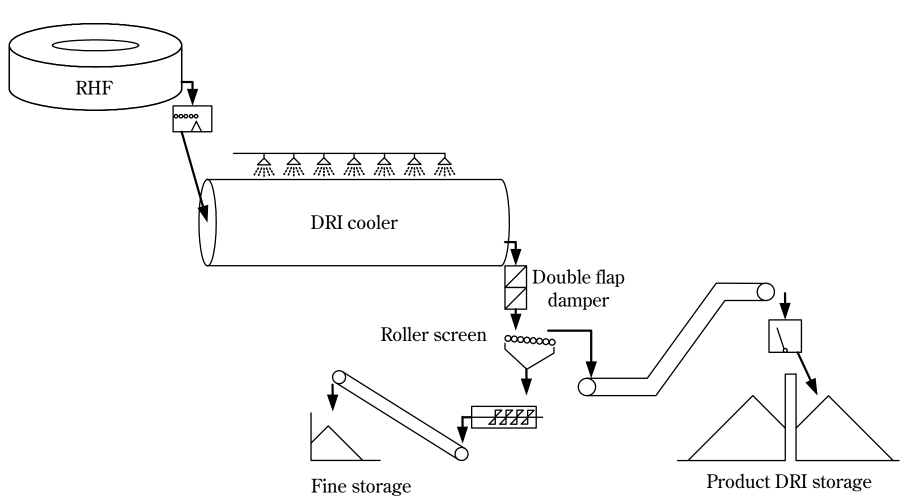

Fig.14 DRI line flow of Fukuyama Works

size of the equipment. Because of this, the temperature at the outlet of the DRI cooler of this apparatus is set to 200℃.

The DRI discharged from the DRI cooler is sieved using a roller screen to separate fines and is transferred to a product yard by a conveyor.

The off-gas system, which treats the exhaust gas from the RHF, adopts a gas cooler and heat exchanger proven in the past. The gas cooler, in particular, is a new type which adopts opposed flow for its gas inlet. In this, it is similar to the one installed in the No. 3 plant at the Nippon Steel Hirohata Works and has been running without problems for an extended period of time.

The combustion fuel for the RHF is coke oven gas (COG), which has been used by the demonstration plant in Kakogawa. Coke oven gas has lower heat value (approximately 18MJ/Nm^3) than other types of fuel such as LNG. This makes a greater amount of exhaust gas, discharged as off-gas, than the amount from the FASTMET plant installed at the Hirohata Works. Thus, it was necessary to upsize the equipment for the off-gas system. However, as described previously, the plant achieved a predetermined capacity, including the off-gas system equipment, at an early stage of its start-up.

The dust, captured by the bag filter in the off-gas system and consisting mainly of crude zinc oxide, is transferred by a conveyor to four hoppers for temporary storage before shipment.

Conclusions

It has been shown that steel mill waste containing zinc, dust which was hard to recycle, can now, using the FASTMET process, be efficiently recycled on a commercial scale, which enables the effective recycling of resources for iron and zinc. With the ever-increasing importance of environmental problems, such as the depletion of global resources and the need to reduce CO_2 emissions, it is expected that there will be an increasing need for introducing the FASTMET process.

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