Prospects for Coal-based Direct Reduction Process

Haruyasu MICHISHITA[*1], Hidetoshi TANAKA[*2]
[*1] Technology & Process Engineering Department, Iron Unit Division, Natural Resources & Engineering Business
[*2] Research & Development Department, Iron Unit Division, Natural Resources & Engineering Business

Kobe Steel has developed coal-based direct reduction (DR) technologies, the FASTMET, FASTMELT and ITmk3 processes, which reduce carbon composite agglomerates (pellets or briquettes) on the hearth of a rotary hearth furnace (RHF). This paper outlines the features of each process, status of technical development and commercialization. Also described is the contribution of these technologies to environmental compatibility and the security of raw materials, which are becoming critical issues for the steel industry worldwide.

Introduction

Unlike blast furnaces, direct reduction ironmaking plants using natural gas (e.g., the MIDREX® process and HYL process) have the characteristics of requiring a smaller capital expenditure and no coking coal. Many direct reduction plants have been built in developing contries, particularly those that produce natural gas. In recent years, there has been an increased demand for direct reduced iron (hereinafter referred to as "DRI") as an alternative to high quality scrap. Electric arc furnace (EAF) mills are dominant in the steel industry in advanced countries, which is boosting the demand for DRI. **Fig. 1** shows the annual increase in DRI production[1]. The natural-gas-based DRI processes, however, limit plant locations to places where natural gas is available. On the other hand, coal-based DRI plants are flexible as to plant location, because coal is widely distributed in large deposits and is easy to transport. This has significantly increased the production of coal-based DRI. Out of the global DRI production of 68.5 million tonnes in 2008, the production of coal-based DRI occupies 17.6 million tonnes, which equates to 25.7% of the total[1]. Most coal-based reduction processes including SL/RN[2] employ rotary kilns. Pellets, or lump-ore, mixed with coal are/is charged into the rotary kilns[2] and heated by coal burners to produce DRI. To avoid the significant formation of the kiln rings, their operating temperatures must be maintained in a range from 1,000 to 1,100℃[3]. As a result, the processes require about 12 hours of reduction time. Thus, the productivity of the processes is limited to a range between 150 and 250 thousand tonnes/year, which is rather low for steel plants. Because of this, there has been a need for an alternative process.

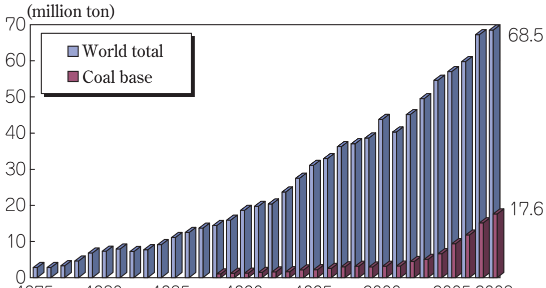


Fig. 1 World DRI production by year [1]

With this background, Kobe Steel has developed a coal-based reduction process using a rotary hearth furnace (RHF) in collaboration with MIDREX Technologies, a subsidiary of Kobe Steel in the USA. This process involves carbon composite agglomerates, in the form of pellets or briquettes, laid on the hearth of the RHF, in which the composite agglomerates are heated and reduced in a static manner. Because of this, the furnace can be maintained at a temperature in the range from 1,300 to 1,400℃, which is higher than that for rotary kilns and increases the reduction rate and productivity. The process is also characterized by flexibility regarding various raw materials, including iron ore fines, steel mill waste and non-coking coal.

This paper outlines the features and development status of Kobe Steel's coal-based reduction processes, each employing an RHF for reducing carbon composite agglomerates. Also described is the role of these processes in resolving the issues faced by the steel industry, e.g., securing raw materials and preserving the environment.

1. Features of reduction process using carbon composite agglomerates

The reduction reaction kinematic for conventional pellets and sintered ore is controlled by reduction gas diffusion from outside. On the other hand, the reaction of carbon composite agglomerates occurs inside the agglomerates themselves, which consist of iron ore fines and pulverized coal. Once the agglomerates are heated, carbon monoxide is generated inside them, promoting the reduction of iron oxide. Thus, the reduction reaction proceeds

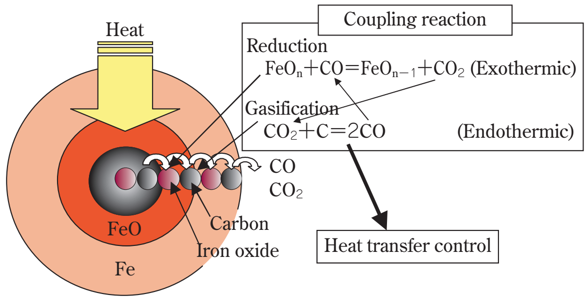


Fig. 2 Reduction mechanism of carbon composite pellet

faster in the carbon composite agglomerates than in conventional pellets and sintered ore, whose reaction is controlled by diffusion from outside. **Fig. 2** shows the reduction mechanism of a carbon composite pellet, where the following reactions are considered to occur:

$$Fe_xO_y + yC \rightarrow xFe + yCO \text{ (endothermic)} \quad \cdots\cdots\cdots(1)$$
$$CO_2 + C \rightarrow 2CO \text{ (endothermic)} \quad \cdots\cdots\cdots(2)$$
$$Fe_xO_y + yCO \rightarrow xFe + yCO_2 \text{ (exothermic)} \quad \cdots\cdots(3)$$

At temperatures at which the iron ore does not melt, it has hardly any direct reaction with solid carbon such as pulverized coal and coke. In other words, the reaction as expressed by Equation 1 does not dominate the reaction kinematics. At elevated temperatures no lower than 1,000℃, the following reactions proceed in series inside the carbon composite agglomerates: the generation of carbon monoxide by carbon solution loss (Eq. 2) and the reduction of iron oxide by carbon monoxide (Eq. 3)[2).

In the reduction reaction described above, CO gas generation (Eq. 2) controls the reaction kinematics with its highly endothermic nature[2). Therefore, to promote the reaction, it is essential to supply the heat required for the reaction to the inside of a carbon composite agglomerate at an elevated temperature of 1,000℃ or higher. In other words, heat must be transferred efficiently by radiation from the atmosphere to the surface of the agglomerate and, by conduction from the agglomerate surface to its interior.

It should be noted that coal accounts for about half of the volume of each agglomerate. Thus the agglomerates become porous as the reduction reaction proceeds, decreasing the strength of the DRI. The carbon composite agglomerates become progressively weaker until they reach the temperature at which sintering occurs. This may cause fragmentation due to reduction degradation.

Although fragmentation increases the surface area for thermal transfer, it makes the CO gas generated prone to being released from the agglomerates without contributing to the reduction reaction. It also decreases the shielding effect of CO gas and allows some re-oxidation of the reduced iron. Thus, it is important to prevent the agglomerates from fragmentizing inside the furnace.

2. FASTMET® process

A process of creating a thin layer of carbon composite agglomerates on the hearth of an RHF and heating the layer statically to subject it to a reduction reaction is being contemplated. In such a process, heat transfer occurs efficiently by radiation, with much less risk of reduction fragmentation. Thus, this process would be more advantageous than any conventional process using a rotary kiln or a shaft furnace. In the early 1960s, Midland Ross Corp., the predecessor of MIDREX Technologies, started developing a process called "HEATFAST," which involves carbon composite pellets reduced in an RHF. In 1965, the company built a pilot plant having a capacity of 2 tonnes/hour.

The development of the HEATFAST process, however, did not reach the point of commercialization. Due to the current low price of natural gas, the company's priority has shifted toward the gas-based MIDREX process.

In the 1990s, when the price of natural gas increased, Kobe Steel and MIDREX Technologies (hereinafter collectively referred to as "the companies") began to collaborate in developing a new process, named "FASTMET," for producing DRI from carbon composite pellets charged into an RHF.

In 1992, the companies built a pilot plant with a capacity of 160kg/h, at the MIDREX Technical Center in North Carolina, USA. In 1995, after a series of fundamental test runs, the companies constructed a demonstration plant with a capacity of 16,000 tonnes/year at the Kakogawa Works of Kobe Steel. By 1998, the demonstration plant had not only substantiated the applicability of various raw materials, such as iron-ore, dust and coal, but also yielded the various data necessary to design a commercial plant. In 2001, Kobe Steel modified the demonstration plant into a commercial plant for processing steel mill dust generated at the Kakogawa Works.

Fig. 3 shows the FASTMET process flow. The process includes mixing ore fines with pulverized coal, agglomerating the mixture into pellets or briquettes, and placing them onto the hearth of an RHF in one or two layers. For raw materials superior in pelletizing characteristics with a pan pelletizer or a balling drum, pellets with a spherical shape are applied. For other material not suitable for pelletizing, briquettes made with a dual-roller type briquetting machine are applied. The agglomerates

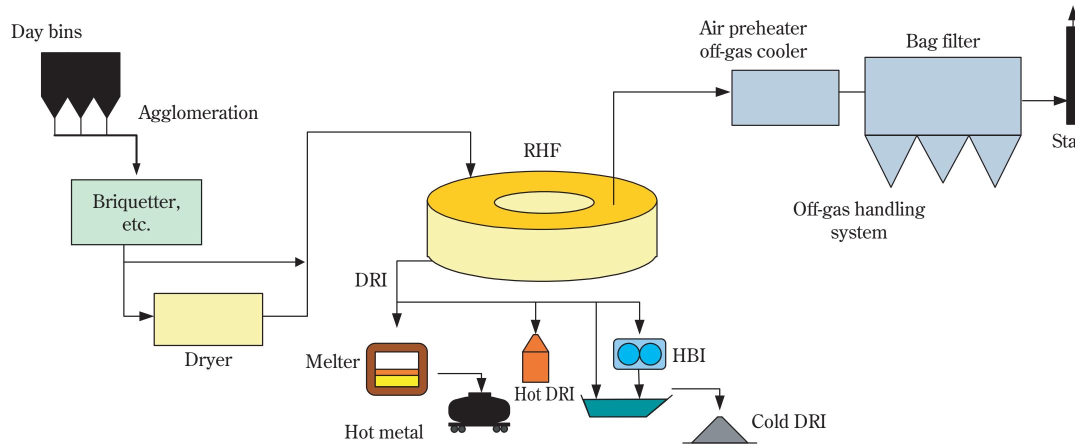


Fig. 3 Process flow sheet for FASTMET

are dried before being charged into the RHF. In the RHF, the temperature of the agglomerates is increased rapidly to 1,350℃ or higher and maintained for 6 to 12 minutes before they are discharged as DRI. The process, involving carbon composite agglomerates placed statically on the hearth, prevents them from breaking into fragments and generates few dust particles that could become entrained in the exhaust gas. The reduction reaction at high temperature reduction reaction vaporizes metallic zinc and lead in the exhaust gas.

The exhaust gas contains almost no unburned components (CO and H_2), because the CO gas generated through the reduction reaction is completely combusted by secondary combustion in the furnace. The process further includes cooling and cleaning the exhaust gas, as well as recovering sensible heat, using a heat exchanger, before discharging to the atmosphere. The vapor of zinc and lead in the furnace exhaust gas is oxidized, solidified, and thereafter collected by a bag filter together with the dust entrained in the exhaust gas.

As described above, the FASTMET process was originally developed as an alternative to gas-based DRI, making DRI from iron-ore and coal. The process, however, has a drawback: the DRI produced may have a decreased iron content and/or increased sulfur content, depending on the quality of the coal used. This impedes the commercial use of the process for producing DRI from iron ore.

On the other hand, with an eye to resource sustainability, various methods have been tried for recycling the dust generated in ironworks. Conventional sintering/pelletizing facilities and blast furnaces, however, have difficulty in using dust with a high zinc content and is alkaline, which has been an issue in the industry. The FASTMET process enables the separating of zinc contained in the dust as crude zinc-oxide and recycling it as the raw material for zinc refining. The process recycles the remaining iron as DRI. With this feature, the FASTMET process is commercially used for processing steel mill dust.

Currently, five commercial plants are producing DRI from the iron bearing dust generated in iron- and steel-making processes (**Table 1**).

The DRI takes one of two forms: 1) DRI maintaining the form of pellets/briquettes charged into the RHF and 2) The HBI (hot briquetted Iron) having strength and weather resistance for transportation and storage.

Table 2 shows the typical chemical compositions of DRI and secondary dust (zinc dust), both made

Table 1 FASTMET commercial plant specifications

	NSC Hirohata #1	NSC Hirohata #2	NSC Hirohata #3	JFE Fukuyama	KSL Kakogawa
RHF feed rate (t/y)	190,000	190,000	190,000	190,000	14,000
Raw materials	BOF dust	BOF dust	BOF dust	BF dust BOF dust	BF dust BOF dust EAF dust
Product application	BOF feed DRI	BOF feed DRI	BOF feed HBI	BF feed DRI	BF & BOF feed DRI
RHF outer dia. (m)	21.5	21.5	21.5	27.0	8.5
Operation start	Apr. 2000	Jan. 2005	Dec. 2008	Apr. 2009	Apr. 2001

Table 2 Anaysis of DRI and zinc dust

(1) Dry ball and DRI analysis (wt%)

	T.Fe	M.Fe	FeO	C	S	Zn
Dry ball	50.0	4.3	17.7	11.1	0.29	0.33
DRI	72.9	56.2	16.9	0.2	0.44	0.009

(2) Secondary dust (wt%)

	Zn	T.Fe
Dust	63.4	1.11

from steel mill waste by the FASTMET process[5]. The FASTMET process produces DRI at a high reduction ratio and crude zinc oxide of high purity, as it gives rise to little entrained metal dust. This characteristic of the process contributes to the recycling of iron and zinc from steel mill waste.

3. FASTMELT® process

As previously mentioned, the higher gangue and sulfur content derived from the coal is an issue with DRI produced by the FASTMET process. To resolve this issue, the companies developed a process called "FASTMELT." The process includes producing DRI using an RHF (the FASTMET process), transferring the DRI at a high (as-discharged) temperature to a furnace, melting the DRI in the furnace, and removing sulfur and separating slag to produce molten iron[6, 7]. The melting furnace can be either an electric arc furnace[6] or a coal-based melter[7] using the thermal energy of coal and oxygen that are supplied.

In 1995, MIDREX Technologies built a pilot plant based on the FASTMELT process by adding an electric arc furnace to the FASTMET pilot plant at the MIDREX Technical Center (**Fig. 4**). Various tests had been conducted at the pilot plant to prove the production of high quality molten iron from DRI made by the FASTMET process. The campaigns also provided various process parameters.

In 2006, Kobe Steel built a pilot plant using a coal-base melter of 16,000 tonnes/year capacity at the Kakogawa Works (**Fig. 5**). This pilot plant project was funded by the Ministry of Economy, Trade and Industry (METI). The plant operated continuously to produce high quality hot metal, as shown in **Table 3**[9], using DRI made from steel mill waste. **Table 4** shows a comparison of carbon unit consumption at the pilot and the commercial plant[9].

A FASTMELT plant consists essentially of an RHF and a melting furnace. The RHF discharges DRI with a metallization of about 85% at a high temperature. The DRI is then transferred, while hot, to the melting furnace, either by gravity or by a hot transfer conveyor. To adopt gravity transfer, the RHF must be placed higher than the melting furnace. The furnace, either an EAF or a coal-based melter, turns the DRI into molten iron, during which the coal-derived ash and sulfur content transfers into slag, and the slag is removed to produce clean hot metal. The exhaust gas from the melting furnace, which consists mainly of CO, is used as a fuel for the RHF.

The FASTMELT process, which can produce molten iron from iron ore fines and non-coking coal, provides a solution to the current issues of securing stable supplies of lump ore and coking coal and the associated price increase. A commercial scale FASTMELT plant has a molten iron discharging capacity of from 300 to 800 thousand tonnes/year. Such plants are expected not only to supply molten

Fig. 4 Test furnace at the MIDREX Technical Center

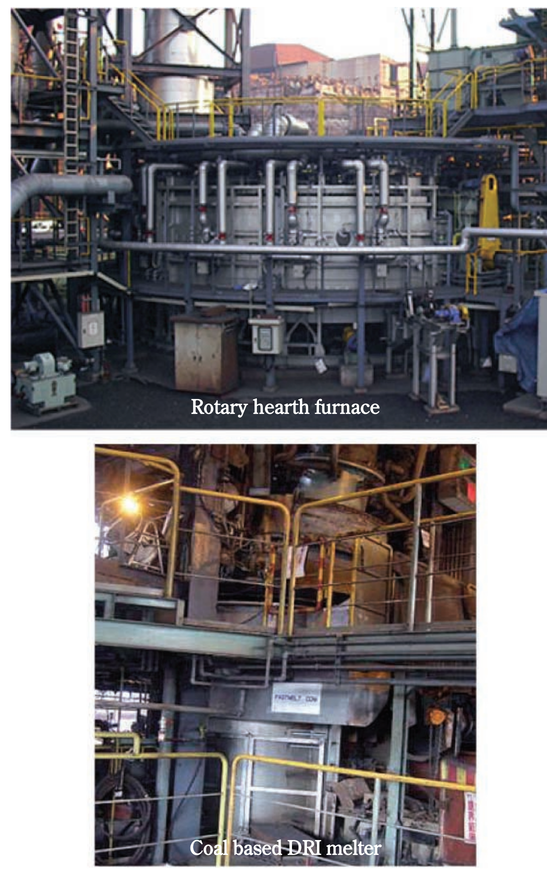
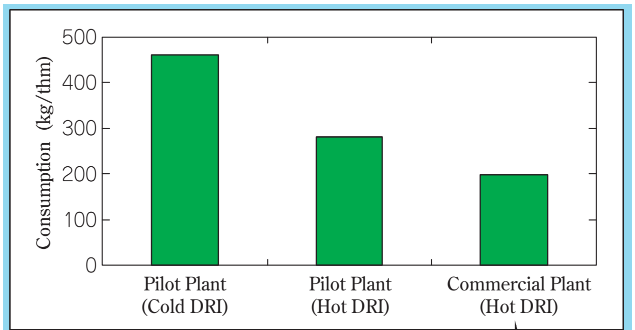


Fig. 5 FASTMELT Kakogawa pilot plant

Table 3 Typical chemical analysis of charging hot-metal (%)

C	Si	S	P
4.3～4.7	0.15～0.30	0.030～0.060	0.090～0.120

Table 4 Prediction of total carbon unit consumption for pilot plant and commercial plant



		Pilot plant (Cold DRI)	Pilot plant (Hot DRI)	Commercial plant (Hot DRI)
DRI temperature	℃	25	800	800
Hot metal production rate	t/h	1.1	1.7	67
Coal+Coke breeze	kg/thm	1008	798	707
Coal for RHF	kg/thm	547	517	509
Coke breeze for melter	kg/thm	461	281	198
Oxygen	Nm^3/thm	415	237	206

Energy saving by hot DRI charge

iron to EAF mills, but also to become supplemental iron sources for blast furnace based integrated steel mills.

FASTMELT plants have an advantage over mini blast furnaces of similar capacity, which have recently become popular and are being operated in Southeast Asia, as FASTMELT does not generate any by-product gas, are energy self-sufficient, and consist of simple equipment because it requires fewer ancillary facilities, such as those for pre-treating utilities and raw materials.

4. ITmk3® process

In 1995, the companies found a clue to a new process while conducting an experiment for the FASTMET process. The experiment, which involved an RHF operating at a high temperature, revealed that the high temperature process can separate metallic iron from slag to produce pure DRI. This led to the development of a new process, ITmk3, for producing the granulated iron called "iron nuggets" from carbon composite agglomerate.

The ITmk3 process includes placing carbon composite pellets on the hearth of an RHF in a manner similar to that in the FASTMET process, heating and reducing the pellets in a temperature range that will melt DRI, and separating the slag to produce the granulated iron, iron nuggets[8]. ITmk3 is now defined as a third-generation ironmaking process based on a concept totally different from other conventional processes using carbon composite agglomerate[5].

Since 1996, Kobe Steel and others, e.g., domestic and overseas institutes, conducted fundamental research on this process. In 1999, Kobe Steel built a pilot plant at the Kakogawa Works to verify the process concept.

In 2002, a pilot demonstration plant was built in Minnesota, USA. Demonstration testing continued until 2004, by which time, all the engineering data had become available for continuous operation and for designing a commercial plant. In 2009, the first commercial plant, with a capacity of 500 thousand tonnes/year, was built in Minnesota. The plant started producing iron nuggets on a commercial basis in January, 2010. **Table 5** summarizes the specifications of the pilot, demonstration and commercial plant.

Like the FASTMET process, the ITmk3 process involves producing carbon composite pellets from ore fines and pulverized coal, pre-drying the pellets using a dryer and charging the pellets into an RHF. Heating the carbon composite pellets at a temperature between 1,350 and 1,450℃ in the RHF promotes the generation of CO gas, which reduces the iron oxide to produce metallic iron, as described previously. The metallic iron is carburized simultaneously, which causes the iron to coalesce and separates the slag from the molten iron faster at a lower temperature, in comparison with blast

Table 5 ITmk3 plant specifications

	Kakogawa pilot plant	Mesabi pilot demonstration plant	1st commercial plant
Location	KSL Kakogawa works	Northshore, MN, USA	Hoyt Lake, MN, USA
Operating period	1999/8 ~ 2000/12	2003/5 ~ 2004/8	2010/1~
Capacity (t/y)	3,000	25,000	500,000
RHF diameter (m)	5	14	60

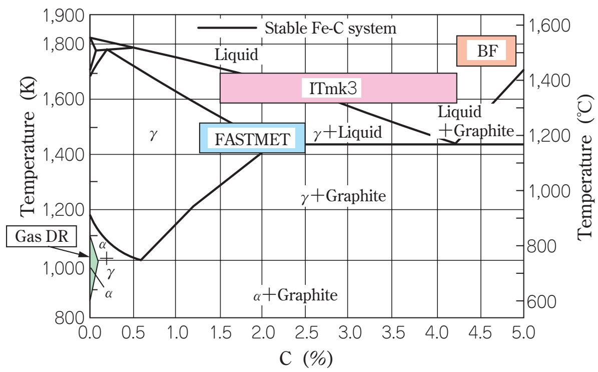


Fig. 6 Fe-C phase diagram

Table 6 Iron nugget specifications

Metallic Iron	96～97%
Carbon	2.5～3.0%
Sulfur	0.05～0.07%
Size	5～25mm

Fig. 7 Iron nugget shape

furnaces, as explained by the phase diagram in **Fig. 6** [4]. After cooling, the solid nuggets and slag are discharged out of the RHF. This series of reactions is completed within 8 to 10 minutes, during which time, the iron is distinctly separated from the slag[4].

The features of the ITmk3 process include flexibility as to the raw materials used and the high value added to the product. **Table 6** [4] summarizes the quality of the iron nuggets that are a typical product of the process, and **Fig. 7** [4] shows their appearance. The iron nuggets are free of slag and have a high iron content with an adequate amount of carbon. In addition to excellent chemical characteristics, they have superior physical properties, including suitability for handling, transportation and storage, as well as excellent melting characteristics. Thus, they are expected to be used as a raw material (pure iron source) for steelmaking furnaces such as BOFs and EAFs and improve productivity, unit consumption and product quality.

5. Prospects for coal-based reduction processes

The steel industry is facing the issues of securing raw materials and decreasing CO_2 emissions. With this background, the following describes the role expected for the coal-based reduction process.

5.1 Securing iron raw material

World crude steel production reached 1.33 billion tonnes in 2008, of which China was responsible for 500 million tonnes. It was 900 million tonnes in 2002, with 180 million tonnes in China. Thus, the global production increased by 1.5 times and Chinese production increased by a factor of 2.8 during this period. This pushed up the price of iron ore from 20 to 30 USD/tonne (CIF Japan) in 2002 to a level exceeding 100 USD/tonne. The price of coking coal soared, from 50 USD/tonne (CIF Japan) in 2002 up to 130 USD/tonne in 2009.

The production and prices of crude steel have stabilized in major countries since the financial crisis in 2008. In the mid- to long-term, however, newly industrializing economies such as India will follow China, further increasing the global demand for crude steel. As the iron ore and coal markets become increasingly controlled by mining majors, concern is growing as to whether the necessary amounts of raw material can be secured at reasonable prices.

Most high-grade iron ore with an iron content of 60% or higher is mined from banded iron formations (BIFs) of hematite. BIFs typically exist in the form of upthrust sedimentary deposits, with enriched iron content due to the weathering action of rain water or water heated by igneous rocks. Such deposits are found only in limited areas of the earth and are bound to become depleted.

As a result, the iron ore commonly available will shift to the low grade ore mined from sedimentary deposits, which requires beneficiation to upgrade them. To facilitate beneficiation, the separation of iron from gangue, low grade ore must be ground into fines with a size distribution of -44 μ > 80%. Such ore fines must be pelletized before being charged into a blast furnace. However, the price-cost margin for the pelletizing process is so slim that a pelletizing plant is only feasible on the condition that a large scale plant be built together with a sufficient infrastructure, including a port and harbor. Thus, ore-fines produced by small mines are being abandoned, which promotes oligopoly by mining majors.

Coal-based reduction processes allow the use of iron ore fines and do not require a pelletizing plant. The processes are applicable to various types of ores, including those from small-scale mines. Further, the production scale of an ITmk3 plant well fits the production scale of small mines. Beside the mines, an ITmk3 plant can be built to produce a valuable product in the form of iron nuggets. This is a new business model which allows the use of low grade ore that was never before utilized. The first commercial ITmk3 plant, build in Minnesota, USA, is not an exception. An American EAF maker seeking for a stable source of iron purchased an abandoned iron mine where high grade ore had been depleted and only low grade ore can be mined. The company produces iron nuggets for its own use, using the low grade ore at the ITmk3 plant.

Thus, the coal-based reduction process by Kobe Steel promotes the supply of iron from mines that are producing low grade ore on a small scale. The process is expected to prevent an oligopoly by mining giants and contribute to a stable supply of iron at a reasonable price.

The possible depletion of coking coal is another concern. Blast furnaces require high grade coking coal. The reserve for such coking coal is estimated to be only 10% of the total coal reserves. Coke ovens also pose issues of environmental burden, including CO_2 emissions. Decrepit coke ovens, existing mainly in advanced countries, are difficult to refit or replace, making the supply of coke to blast furnaces tighter and tighter. Coal-based reduction that enables the use of non-coking coal is now drawing attention as a coke-less ironmaking process.

5.2 CO_2 emission reduction by utilizing scrap

At COP15 held in September 2009, the Japanese government committed to decrease CO_2 emissions by 25% of the 1990 level by 2020. Now the Japanese iron and steel industry, responsible for approximately 16% of the country's total CO_2 emissions, is under even greater pressure. The ironmaking process, in particular, is responsible for more than 60% of the industry's CO_2 emissions, which makes it important to decrease the CO_2 emissions from this process.

In the iron & steel making process at a blast furnace integrated steel works, the largest amount of energy is consumed in reducing iron ore. The BF (blast furnace) - BOF (basic oxygen furnace) process emits approximately two tonnes of CO_2 in producing one tonne of molten steel. On the other hand, an EAF process emits only a quarter of that amount, or approximately 0.5 tonnes, of CO_2 when it melts scrap to produce the same amount of molten steel. Thus, shifting from the BF (blast furnace) - BOF (basic oxygen furnace) process to the scrap-based EAF process is an effective approach for reducing CO_2 emissions.

The BF (blast furnace) - BOF (basic oxygen furnace) process has utilized scrap in recent years; however, there is a limit to the quantity of scrap that can be used. Blast furnaces can process only a limited amount of scrap because zinc contained in the scrap can adhere to the top shell of the furnace. Scrap is also difficult to handle using the existing equipment for charging raw materials. A BOF (basic oxygen furnace) can melt only a limited amount of scrap without supplemental energy. Further, the impurities contained in the scrap may impair the product quality, which also limits the applicable amount. As a result, the BF (blast furnace) - BOF (basic oxygen furnace) process can use only up to 10 to 15% of scrap.

On the other hand, the EAF process can effectively use scrap to decrease CO_2 emissions; however, this process is susceptible to issues of scrap quality and the fluctuation of scrap prices. General scrap contains tramp elements, such as Cu and Sn, which can adversely affect the quality of downstream processes, including continuous casting and rolling. These tramp elements are difficult to remove from molten iron or steel. Thus their content must be controlled either by choosing clean scrap free from these elements or by diluting the scrap with clean iron such as DRI and pig-iron. Despite the growing trend toward scrap recycling, it is unlikely that the amount of available clean scrap, such as machining scrap, will increase significantly. Securing high quality scrap will become more difficult.

Thus, as more scrap is used, the demand for clean iron such as DRI will certainly increase to maintain the quality and cost of products. On the other hand, there is concern as to whether the supply of DRI can meet the growing demand for clean iron. Seventy-five percent of DRI is currently produced by the natural gas based direct reduction process, but its production is limited to locations where natural gas is available. In addition, the process can use only high quality pellets specially produced for the process.

Under such circumstances, coal-based direct reduction is gaining attention as an alternative process for producing clean iron such as DRI, which will fill the supply and demand gap. The process is expected to promote shifting from the BF (blast furnace) - BOF (basic oxygen furnace) process to the scrap-based EAF process and eventually reduce CO_2 emissions in the iron and steel industry.

5.3 Processing ironmaking dust

The FASTMET process not only recovers iron from ironmaking dust, which otherwise would be

Table 7 EAF dust, DRI and crude zinc oxide analysis

(1) EAF dust analysis (wt%)

	T.Fe	Zn	Pb	C	CaO	SiO_2	S	Cl
Dust #1	31～33	17～19	1	3	3～4	4～8	0.4	1～2
Dust #2	21～25	26～29	1～3	3～6	2～4	3～5	0.4～0.6	5～7

(2) DRI analysis (wt%)

	T.Fe	M.Fe	Zn	Pb	C	CaO	SiO_2	S
Dust #1	46～53	40～46	0.7～2.4	0.1	5～11	5～8	9～13	0.6
Dust #2	42～50	35～41	1～4	0.1～0.6	3～15	6～12	8～14	0.6～1.0

(3) Crude zinc oxide analysis (wt%)

	T.Fe	Zn	Pb	C	CaO	SiO_2	S	Cl
Dust #1	～0.2	64～70	3～4	～0.1	0.1～0.2	0.1～0.2	0.4	5～8
Dust #2	～0.7	57～62	4～6	～0.1	0.1～0.8	0.1～0.2	0.2～0.5	9～16

discarded, but also is effective in reducing CO_2 emissions. In ironmaking dust, iron (Fe) exists as a partially oxidized mixture of Fe and FeO. Using such dust decreases the reduction energy. In addition, the carbon contained in the dust is utilized as a reductant, which decreases the consumption of coal and coke and, thus, reduces CO_2 emissions.

It is anticipated that, even if the amount of scrap used by the BF (blast furnace) - BOF (basic oxygen furnace) process remains at the same level, the quality of scrap will deteriorate as the content of zinc and alkali increases. Thus, the demand is expected to grow for the FASTMET process, which separates out zinc and alkali elements and enables iron recycling in the form of DRI.

The amount of dust generated from EAFs is expected to increase as the conversion from BF (blast furnace) - BOF (basic oxygen furnace) to EAF proceeds. As shown in **Table 7**[6], typical EAF dust has a high content of zinc and salt and a low iron content. Thus, EAF dust has been mostly disposed of in landfills.

Under the circumstance, the FASTMET process is expected to provide a solution to this sort of issue by treating EAF dust to recover iron and zinc. EAF dust processing has been demonstrated by the pilot plant at the Kakogawa Works of Kobe Steel. Now that the experimental and demonstration stage has ended, FASTMET is ready to be applied at the commercial-scale EAF dust processing plant.

5.4 Utilizing green energy

All three of the FASTMET, FASTMELT and ITmk3 processes involve reductant carbon and burner fuel. It is technically possible to utilize the carbon derived from biomass such as wood chips and to utilize the synthetic fuel gas derived from the biomass or industrial waste. These processes will reduce CO_2 emissions.

One idea is to recycle municipal solid waste, sewage sludge and industrial waste as environmentally sound carbon sources for DRI. Such a system may be incorporated into the social infrastructure.

Another idea may be to grow biomass in the vast land surrounding a mining site where an ITmk3 plant is built. The biomass would be used as a renewable energy source for DRI production.

Conclusions

1) Supplies of high grade iron ore and coking coal are becoming tight. Securing them is becoming more and more difficult. Coal-based direct reduction processes are expected to diversify the sources of raw materials, since they are coke-less processes and flexible as to raw materials. This will stave off an oligopoly by mining giants and ensure a stable supply of raw materials for the steel industry.
2) Having a stable supply of clean iron produced by a coal-based reduction process will make up for the shortage of high grade scrap, while scrap quality is expected to deteriorate in future. This will promote the conversion to the scrap-based EAF process and eventually decrease CO_2 emissions in the steel industry.
3) A DRI production technology developed for utilizing not only steel mill waste, but also municipal waste and biomass, will help the steel industry sustain its activity in harmony with the environment.

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