The Development of New Iron Making Processes

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Kobe Steel, along with MIDREX Technologies, is the world leader in direct reduction (DR) technologies. Kobe Steel has developed a coal based DR process which utilizes non-coking coal as a reductant instead of natural gas and is expanding the market share in the coal-based iron-making field. FASTMET, FASTMELT and ITmk3 are low cost processes that produce directly reduced iron (DRI) without coke, hot-metal without fired- pellets and iron-nuggets without lump-ore, respectively. These processes are currently being, or are about to be used commercially.

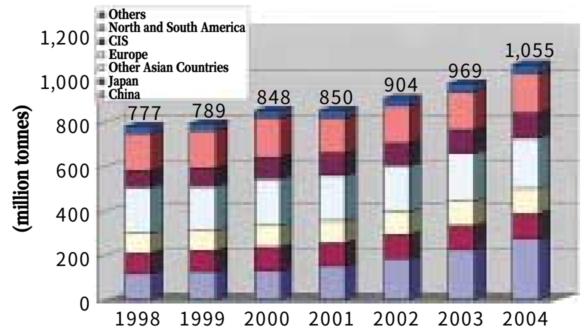

Fig. 2 World crude steel production

Introduction

We have been continuing business of iron reduction plant since we supplied the direct iron making plant by MIDREX® process to Qatar Steel Company which started production in 1978. The process uses natural-gas originated CO and H_2 gases which reduce iron-oxide pellets and iron-ores in a shaft furnace to produce reduced iron (DRI). Approx. 64% of the direct iron in the world is produced by this process (**Figure 1**). We acquired Midrex Technologies Inc. in 1983 and enhanced our iron reduction plant business. We also have developed a process of using coal instead of natural gas to produce reduced iron and have become the world leader in the sales and development of new iron reduction plant.

The direct-reduction iron-making plants require neither large plant-investment nor coke, required by blast furnaces, and have been built as iron-sources of steel making plant mainly in developing countries producing natural gas. Recently, demands for reduced iron are increasing in advanced countries including the USA as a clean iron source substitute for scrap. The production volume of directly reduced iron increased 60 times from approx. 800 thousand tons in 1970 to approx. 50 million tons in 2003, while the annual increase of total steel production is only a few percent world-wide.

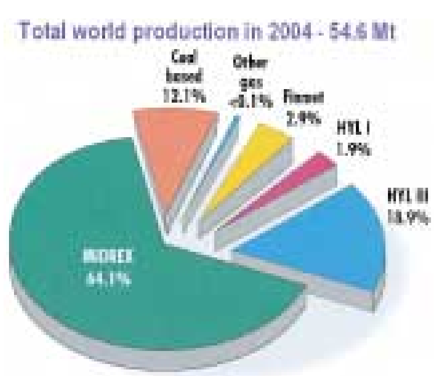

Fig. 1 World DRI production by process

Currently, constructions of new iron-reduction plants are being planned or commenced because of the global increase of demand for steel (**Figure 2**) and increase of reduced-iron market price (**Figure 3**), which is caused by the demand increase, especially in China.

1. MIDREX® process

Figure 4 shows the standard flow of the MIDREX process[1)], and **Photo 1** shows the view of a MIDREX DR plant. Our continuous research and development, which continued even after we placed the plant on the market, have reduced specific consumptions of natural gas of the DR plant, made the plant capable of utilizing various grades of raw materials, increased temperatures for reductive reaction, improved performances of catalysts, enlarged the plant and made reduced iron into sea-transportable briquettes. More recent technological developments are as follows.

1.1 Oxygen injection and partial combustion (Figure 5)

Oxygen injected in the reducing gas burns partially, increasing the temperature of reducing gas and thus increasing the reductive reaction rate in shaft furnaces. A temperature increase of 10℃

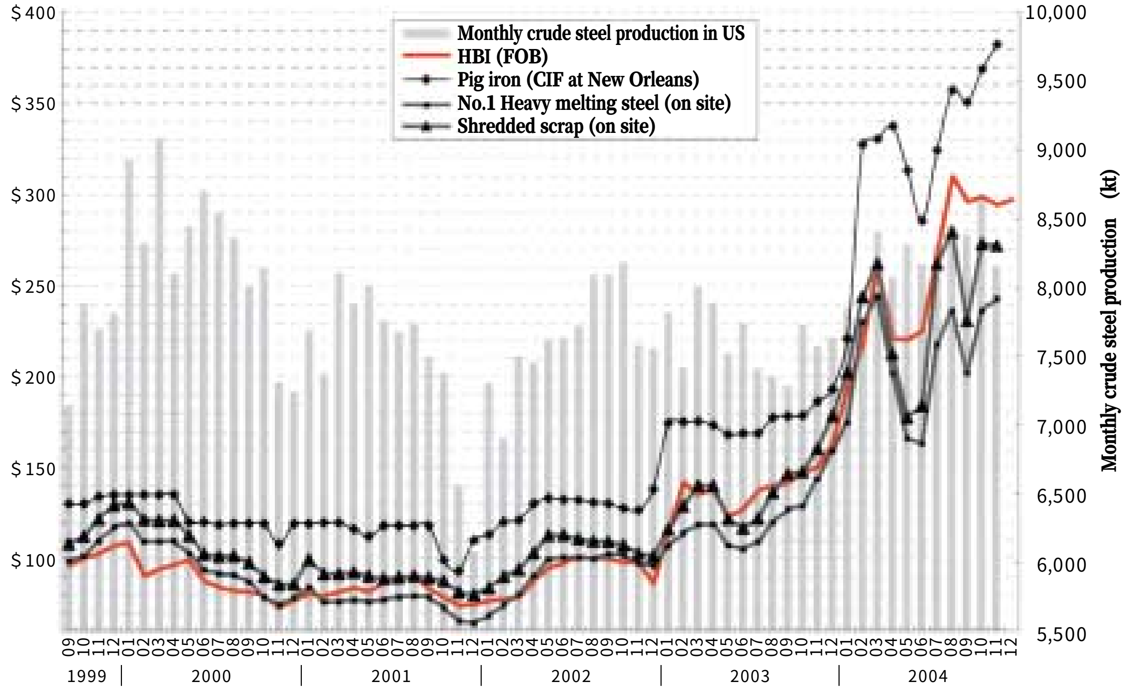

Fig. 3 Market price of scrap and HBI

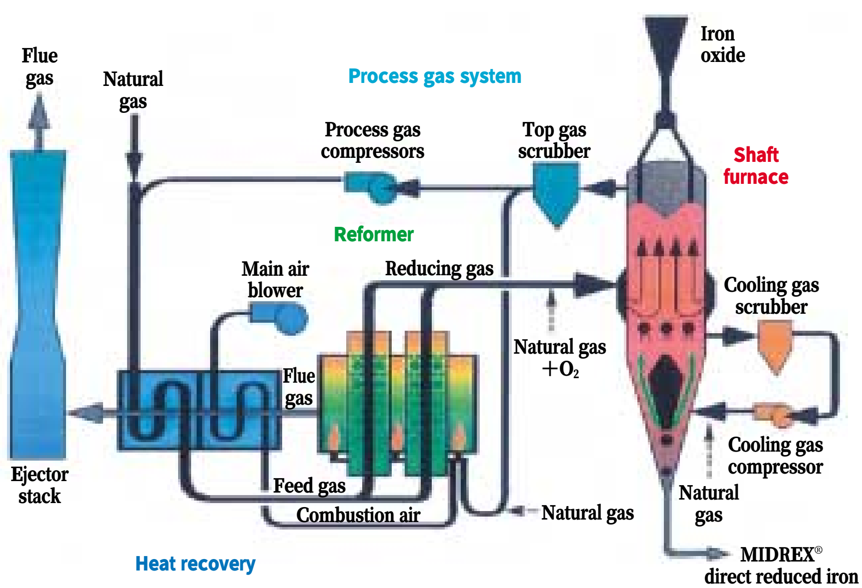

Fig. 4 Standard MIDREX process flowsheet

Photo 1 MIDREX DR plant

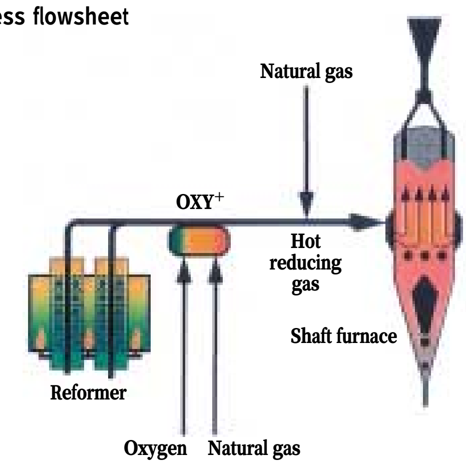

Fig. 5 Schematic of MIDREX OXY^{+}

of reducing gas improves productivity by 1.5 to 2%. If an existing plant has excessive oxygen, the productivity can be increased without installing a new reforming furnace, or by a smaller new reforming furnace. This process is further developed into a partial combustion process (OXY+® Burner method[2)]). Natural gas is partially burned by oxygen to produce reducing gas and thus reduce the burden on the reforming furnace.

1.2 Reduction of specific energy consumption by hot-charging into electric furnace

In general practice, reduced iron is cooled and stored before it is charged into an electric furnace. However, the heat can be utilized sensibly by hot charging the reduced iron into the electric furnace. We have developed technologies to convey hot reduced-iron from the bottom of the shaft furnace to the top of the electric furnace and to directly charge the hot reduced iron into an electric furnace by gravity from a raised shaft furnace bottom. Both the technologies are being used in the new plants under construction.

1.3 COMBO plant enabling versatile operation between electric furnace and MIDREX® plant

In the conventional MIDREX process, the cold DRI (directly reduced iron for in-house electric furnace) and HBI (hot briquetted iron for outside sales) are processed separately (**Photo 2**). The HBI/DRI COMBO plant accommodates both the production of DRI and HBI and brings flexibility to operation and management of the plant. The plant is being built in Qatar currently.

The MIDREX process has undergone various technical improvements to meet market requirements, has found more new applications[Note 1)] and will play a major role in the directly reduced iron market.

2. FASTMET®/FASTMELT® process

The locations of MIDREX plants are limited to places where the natural gas resource is abundant since the plants use natural gas for iron reduction. In order to spread out the application worldwide, it is necessary to invent an iron reduction process using coal, which has more abundant reserves in widespread areas. A process using neither coking-coal nor coke is preferable for the effective utilization of underground mineral resources and for environmental protection.

Photo 2 DRI and HBI

We have developed in cooperation with Midrex Technology Inc. a process (FASTMET) of producing reduced iron from iron ore fines and non coking-coal.[Note 2)]

2.1 FASTMET® process

In the FASTMET process, iron ore fines and pulverized coal are mixed and consolidated into pellets or briquettes and then fed into a rotary hearth furnace (RHF) in one or two layers. The pellets/briquettes are heated rapidly to max. 1,350℃ to be reduced within 6 to 12 min of dwell time and are discharged outside the furnace (**Figure 6**). The CO gas generated from the pellets/briquettes is used as the fuel of the RHF and significantly reduces the fuel burnt by the burner.

A FASTMET demonstration plant with approx. 20 thousand ton annual capacity was built at our Kakogawa Works and was run for 3 years from Dec. 1995. The FASTMET process reduces iron ores at high temperatures above 1,300℃, evaporates heavy metals such as zinc and lead in the dust, and produces directly reduced iron without heavy metals. The processing of dust had been an urgent issue in steel making facilities. In the FASTMET process the elements evaporated from the reduction furnace are oxidized in the exhaust gas and collected as valuable crude zinc-oxide.

In 2000 we supplied the first commercial plant to recycle iron dust to the Hirohata Works of Nippon Steel Corporation (**Photo 3**).[3)] **Table 1**

Note 1)
Application of the coal gasification equipment is being considered for the production of reductant gas.

Note 2)
The FASMET/FASTMELT can utilize not only coking-coal but any materials containing fixed carbon.

Photo 3 FASTMET commercial plant

Table 1 Chemical composition of dry ball and DRI

(Unit : wt%)

	T. Fe	M. Fe	FeO	C	S	Zn
Dry ball	58.70	17.10	36.60	11.90	0.17	0.75
DRI	82.20	74.20	7.40	3.30	0.23	0.05

shows the chemical compositions of the dry ball pellet and DRI. Three plants including our own in the Kakogawa Works are currently in operation.

2.2 FASTMELT®

Ash and sulfur contents in coals tend to migrate into reduced iron. The FASTMELT process (**Figure 7**) was developed to resolve this issue of migration. The process melts reduced iron, hot-transferred from the FASTMET process, and separates it into molten-metal and slag, desulfurizing the melt at the same time. The gas discharged from the melting furnace consists mainly of CO and is used for the fuel gas of the RHF.

Either electricity or coal can be used as the energy source of melting and the choice of energy source depends on the plant site conditions. Use of coal as the energy source increases the amount of

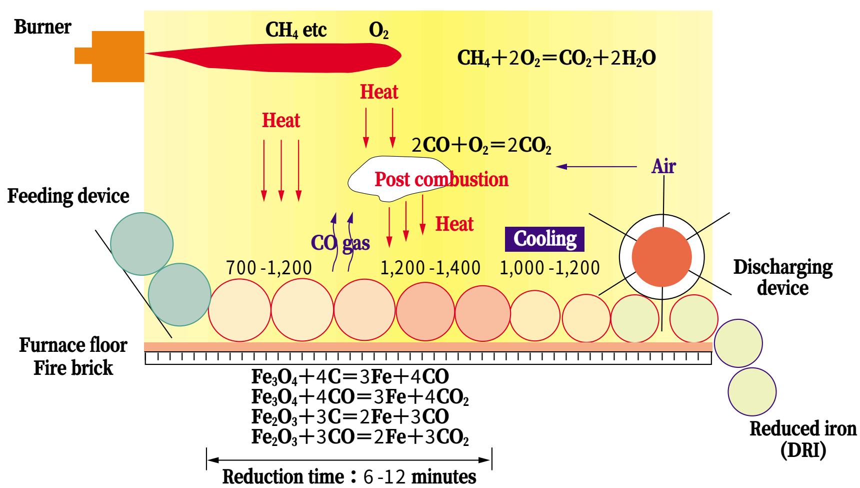

Fig. 6 Reduction in RHF

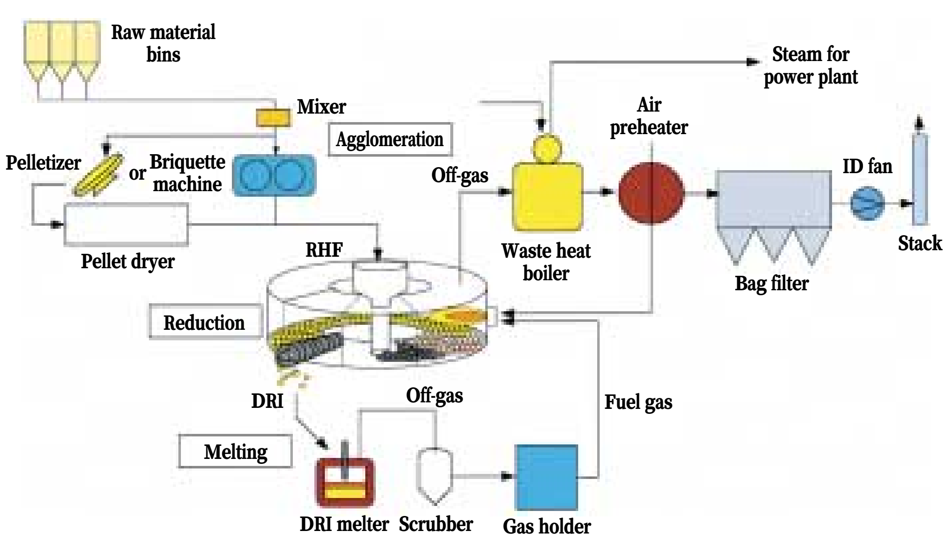

Fig. 7 FASTMELT process flowsheet

discharged gas and reduces the need for external fuel gas such as natural gas.

A unit of FASTMELT commercial plant produces roughly 500 thousand tons of molten iron annually. Since the plant produces molten iron, it can supply to mini-mills where steel is made by electric furnace. It is also expected to increase the production at large-scale integrated blast-furnace steel plant.

Since the processes use only iron ore fines and non coking-coal, FASTMET and FASMELT are expected to be the iron making processes of the 21st century, especially with the current roaring prices for lump-ore and coking-coal.

3. ITmk3® process

The ITmk3 separates "nugget iron" and slag directly from the iron ore fines and pulverized coal. We regard ITmk3 as the 3rd generation iron-making process, whereas the current mainstream process of blast-furnace/converter is the 1st generation and the direct reduction process such as MIDREX is the 2nd generation. The process is based on a totally different concept[4)] from the conventional processes.

We started the development of the process in 1996, built a pilot plant in the Kakogawa Works to prove the process concept, constructed a demonstration plant with 25 thousand ton annual capacity in the USA (**Photo 4**) and completed the demonstration in 2004. A plan for a commercial plant with 500 thousand ton annual capacity is progressing currently.

Photo 4 RHF in demonstration plant of ITmk3

3.1 Process concept

The following reactions proceed when the carbon composite pellet is heated to 1,350 to 1,450℃.

$$Fe_xO_y + yCO = xFe + yCO_2 \quad (1)$$
$$CO_2 + C = 2CO \quad (2)$$
$$C\,(s) = \underline{C}\ (\text{carburized}) \quad (3)$$
$$Fe\,(s) = Fe\,(1)\ (\text{molten}) \quad (4)$$

The series reactions complete in approx. 10 min and separate iron and slag completely.

3.2 Process flow and future perspective

The practical operation of the process proceeds as follows and the process-flow is shown in **Figure 8**.

① Iron ore fines and pulverized coal are agglomerated into composite pellets.
② The pellets are charged into a rotary hearth furnace, heated to 1,350-1,450℃, reduced, melted and separated into iron and slag.
③ The molten iron is solidified into nuggets in the furnace, discharged after cooling and separated from the slag.

The ITmk3 enables use of various raw materials including non coking-coal, low-grade ore without using rather expensive coke, and is a simple and environment-friendly process. Typical appearances of the "iron nuggets" are shown in **Photo 5** and their composition quality in **Table 2**. The process supplying iron at low cost is expected to improve productivity, specific units and quality of the steel-making processes such as the converters and electric furnaces.

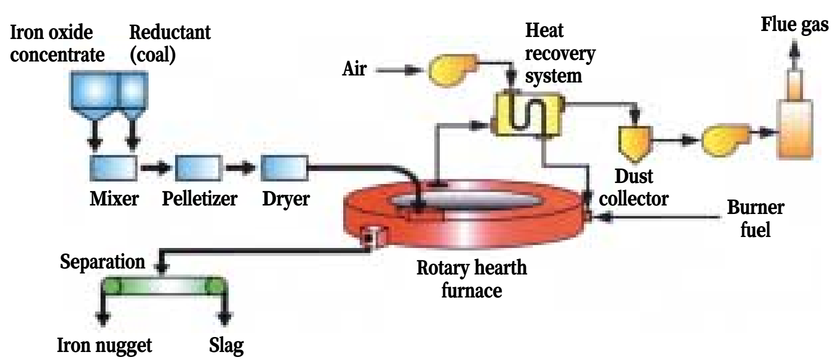

Fig. 8 ITmk3 process flowsheet

Photo 5 ITmk3 product " Iron nuggets "

Table 2 Chemical analysis of iron nuggets

Item	Content (%)
M. Fe	97.0
C	2.0 - 2.5
P	0.01 - 0.02
S	0.07 - 0.11

Conclusions

The direct-reduction iron-making process suffers much less from the restriction of raw materials and is superior in energy efficiency. With the growing concerns about the conservation of resources and environment, the process is receiving more and more attention. We will continue to develop and supply the direct-reduction iron-making plants and will contribute to both the growth of the iron-making industry and the improvement of the global environment.

References

1) A. R. Elliot, *DIRECT FROM MIDREX* 3rd Quarter 2004, p. 8.
2) R. M. Klawonn, et al., *DIRECT FROM MIDREX* 4th Quarter 2002, p. 3.
3) T. Harada, et al., *R&D Kobe Steel Engineering Reports*, Vol. 51, No 2, p. 23 (2001).
4) H. Tanaka, et al., *R&D Kobe Steel Engineering Reports*, Vol. 52, No 3, p. 113 (2002).