KOBELCO Pelletizing Process

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Kobe Steel's history of pelletizing plants began when the company built a plant at its Kobe Works in 1966. This paper introduces the history of pelletizing plants, including process outlines and the latest achievements in the construction of plants overseas. In the past, plant owners had focused mainly on the quality of the product pellets and plant equipment, as well as the cost of the plants. Lately, however, the environmental aspects of plant operation have also been attracting more attention. Kobe Steel, with its experience in design, construction and operation, is contributing to the further improvement and development of pelletizing plants that meet all the requirements.

Introduction

In 1966, Kobe Steel installed a pelletizing plant based on the kiln process at its Kobe Works. Since then the company has built and run many pelletizing plants using this process. This paper introduces the history of the development of pelletizing plants and the features of various processes. Also included are the advantages of KOBELCO pelletizing, as well as the current status of the projects conducted by Kobe Steel.

There are two major methods of ironmaking: (1) ironmaking on large-scale using a blast furnace and (2) ironmaking on small-to-mid scale using an electric arc furnace (EAF). The raw materials for ironmaking that are charged into a blast furnace include lump ore, sintered ore and pellets. The ones charged into an EAF include iron scrap, reduced iron pellets and reduced iron briquettes. Sintered ore is made by partially melting and sintering coarse iron ore 1 to 3mm in size into products having a size of 15 to 30mm. The sintering process uses the combustion heat of coke breeze (fuel). Pellets are made from iron ore that is finer than that used for sintered ore. The ore fine is formed into spheroids, called green balls, approximately 12mm in diameter. The green balls are fired into product pellets. The pellets are used as the raw materials not only for blast furnaces but also for gas-based direct reduction furnaces, the process becoming popular among natural gas producing countries.

The history of pellets began in 1912 when A.G. Andersson, a Swede, invented a pelletizing method. The commercial use of pellets, however, began in the USA after World War Ⅱ. Various studies were conducted with the aim of developing the vast reserves of taconite in the area around the Great Lakes. In 1943, Dr. Davis, a professor at the University of Minnesota, Mines Experiment Station, invented a method for processing taconite containing low grade iron ore. His process involved grinding taconite to remove gangues and upgrading the iron ore (i.e., an ore beneficiation process). The resultant high-grade ore is in the form of fine particles, as small as 0.1mm or less, which are not suitable for sintering. This issue led to the use of pelletizing.

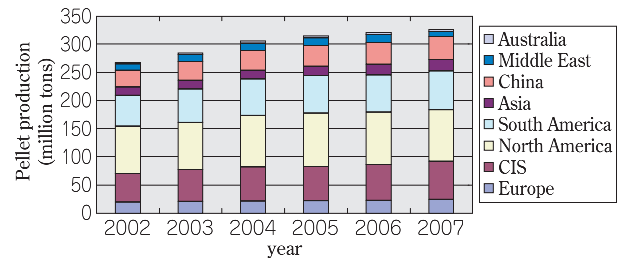

Fig. 1 Worldwide pellet production

Pelletizing plants are expected to play an important role in an era when the global reserve of high-grade lump ore is shrinking. The plants promote the concentrating of low-grade ore into upgraded pellets, which will be increasingly used by blast furnaces and direct reduction furnaces.

Fig. 1 shows the total global production of pellets along with the regional production[1)].

1. Equipment for pelletizing plants

A pelletizing plant includes four processes:
1) raw material receiving,
2) pretreatment,
3) balling, and
4) indurating.

This chapter outlines these processing steps.

1.1 Process of receiving raw material

The location of a pelletizing plant affects the method of receiving raw materials such as iron ore, additives and binders. Many pelletizing plants are located near ore mines. This is because these plants were developed to pelletize the raw materials that are beneficiated at these mines. Such plants receive the raw materials via railways and/or slurry pipelines. Other pelletizing plants exist at a distance from and independent of ore mines. In such cases, the receiving method involves the transportation of the ore in a dedicated ship, unloading the ore at a quay and stockpiling it in a yard. Iron ore must be shipped in bulk for maximum economy.

1.2 Pretreatment process

In this process, the iron ore is ground into fines having qualities required for the subsequent balling process. The pretreatment includes concentrating, dewatering, grinding, drying and prewetting.

In general, low-grade iron ore is ground into fines to upgrade the quality of the iron ore, remove gangues containing sulfur and phosphorus, and control the size of the grains. In the case of magnetite, a magnetic separator is employed for upgrading and gangue removal. With hematite, on the other hand, these operations are accomplished by gravity beneficiation, flotation, and/or a wet-type, high-magnetic separator. **Fig. 2** schematically shows a magnetic separator, a typical machine used for magnetite beneficiation[2].

The grinding methods are roughly categorized as to the following three aspects:

1) wet grinding – dry grinding
2) open-circuit grinding – closed circuit grinding
3) single stage grinding – multiple stage grinding

These methods are used in combination depending on the types and characteristics of the ore and the mixing ratio, taking into account the economic feasibility. A wet grinding system (**Fig. 3**) accompanies a dewatering unit with a thickener and filter, while a dry grinding system (**Fig. 4**) requires a prewetting unit. Drying is usually provided in association with dry grinding. Prewetting includes adding an adequate amount of water homogeneously into the dry-ground material to prepare pre-wetted material suitable for balling. This is a process for adjusting the

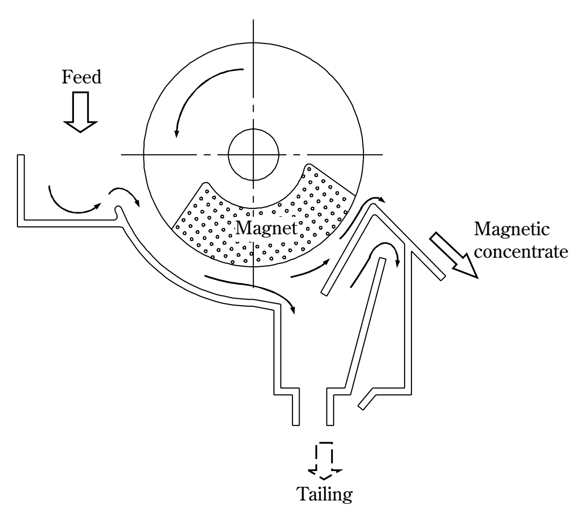

Fig. 2 Magnetic separator

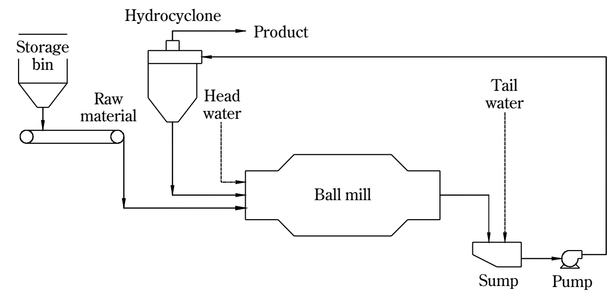

Fig. 3 Flow of closed circuit wet-grinding system

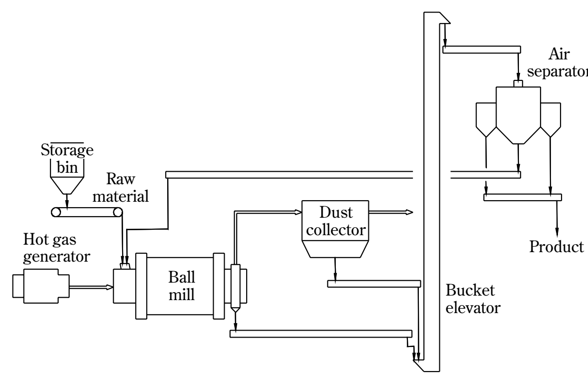

Fig. 4 Flow of closed circuit dry-grinding system

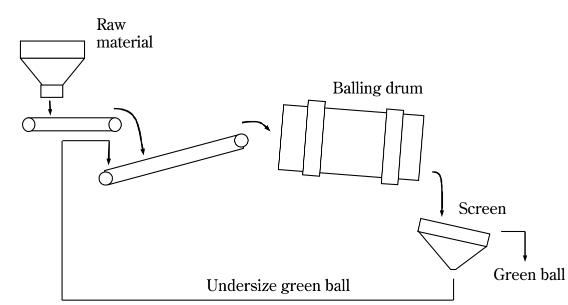

Fig. 5 Flow of balling drum

characteristics of the material that significantly affect pellet quality. Occasionally, the chemical composition of the product pellets is also adjusted in this process to produce high quality pellets. A typical binder is bentonite or organic binder. Adding lime and/or dolomite to the ore adjusts the pellets so as to have the target chemical composition[3].

1.3 Balling process

In this process, balling equipment produces green balls from the pre-wetted material prepared in the previous process. The green balls are produced either by a balling drum (**Fig. 5**), or by a balling pan (disc) (**Fig. 6**). Both of the units utilize centrifugal force to form the fine materials into spheroids. The green balls produced by a drum are not uniform in diameter. A significant portion of the discharge (about 70%) is smaller than target size and must be returned to the drum after screening. It is difficult

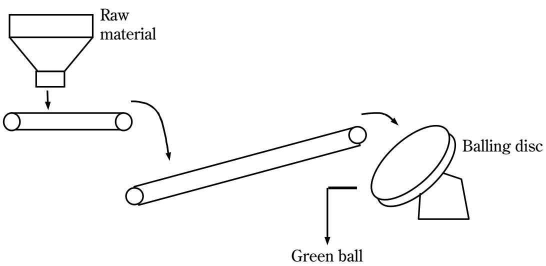

Fig. 6 Flow of balling disc

to adjust the drum operation for varying raw material conditions. The operation, however, is stable for uniform raw material conditions (chemical composition, particle size, moisture, etc.). A balling disc, on the other hand, classifies green balls by itself, reducing the amount of pellets returned. The disc operation can easily be adjusted for varying raw material conditions by changing the revolution, inclined angle and depth of the pan.

1.4 Indurating process

The firing of pellets establishes the binding of hematite particles at an elevated temperature ranging from 1,250 to 1,350℃ in oxidizing condition. Slag with a low melting point may form in the pellets during this firing step, if the raw material contains fluxed gangue, or if limestone is added to it. In these cases, the product may have an intermediate structure with both hematite binding and slag binding. The firing process is characterized by process temperatures lower than those required by sintering which requires partially melting and sintering fine ore mixed with coke breeze, a fuel which generates combustion heat.

Three systems are used for indurating pellets, i.e., a shaft furnace system, a straight grate system and a grate-kiln-cooler system. Shaft furnaces are the most traditional facilities; however, few plants use this system these days because of their limited scale. A straight grate system emerged in the industry soon after the shaft furnaces. It consists of a single unit which moves a static layer of pellets. The system has a simple structure for drying, preheating, firing and cooling pellets. Due to its relative ease of operation, along with ease of scaling-up, makes the system one used by many plants. A grate-kiln-cooler system consists mainly of a grate, a kiln and a cooler, respectively designed for drying/preheating, firing, and cooling the pellets. The system is easy to control, and the product pellets have a uniform quality. It can also be scaled up to a fairly large degree, and these systems are used by many plants along with straight grate systems.

Table 1 compares a grate-kiln-cooler system and a straight grate system.

Table 1 Comparison of grate-kiln-cooler process and straight-grate process

No.	Items	Grate-Kiln -Cooler	Straight -Grate	Comments
1	Pellet quality			
	a) Uniformity	○	△	Grate-Kiln-Cooler process enables all pellets to be uniformly and adequately heat-hardened by tumbling action and be held at the peak temperature for longer period than in Straight-Grate.
	b) Cold compression strength	○	△	
	c) Tumble index	○	△	
	d) Chemical composition	○	○	Iron grade and impurity contents are basically influenced by ore beneficiation processes, but not by the pelletizing process.
	e) Reducibility	○	○	Reducibility (final reduction degree in DR) and clustering tendency depend basically on the characteristics of iron ore itself. Generally, the higher iron content of pellets have the higher reducibility and the higher clustering tendency. Remark: Addition of lime (hydrated lime or limestone) and/or dolomite to iron ore results in lower clustering tendency of pellets and higher compression strength of sponge iron.
	f) Clustering tendency during reduction	○	○	
	g) Disintegrating tendency during reduction	○	△	The pellets uniformly and adequately heat-hardened in Grate-Kiln-Cooler process have lower disintegrating tendency.
2	Fuel consumption	○	△	Grate-Kiln-Cooler process attains lower fuel consumption, due to the followings ; a) No hearth layer and side layer b) Efficient heat transfer mechanism in grate, kiln and cooler to meet each specific requirement
3	Power consumption	○	△	No requirement of hearth layer and low height of pellet bed on the grate of Grate-Kiln-Cooler process lower the pressure drop across the pellet bed, which reduces the power consumption of process fans.
4	Maintenance cost	○	△	Straight-Grate process needs more spare parts of grate bars which suffer from considerable cyclic thermal stresses through drying, preheating, firing and cooling.
5	Process versatility	○	△	Grate-Kiln-Cooler process allows independent operation adjustment of grate, kiln and cooler, which enables the operators ; a) to, easily and without any risk, decrease and increase the rate of pellet production. b) to overcome radical changes in the characteristics of iron ore materials fed to the pelletizing plant, and to utilize various kinds of additives ; bentonite, hydrated lime and/or limestone. c) produce pellets of differing metallurgical characteristics. The single burner applied for Grate-Kiln-Cooler process simplifies the process control. When required, the burner has ability to simultaneously fire two fuels, gas and oil, and switch on-stream from one fuel to another.
6	Plant availability	○	○	No specific difference on plant availability

2. Kobe Steel pelletizing plants

A pelletizing plant was built at the Kobe Works of Kobe Steel in September 1966, with the aim of increasing the productivity of the blast furnaces by utilizing pellets. This involves optimizing the raw materials. The raw materials are separately treated, depending on their characteristics, in a sintering plant and a pelletizing plant. This makes the pretreatment more versatile and enables the use of fine ores.

The raw material for the plant includes fines of various hematites such as limonite. Thus the plant adopts a dry grinding/pre-wetting system suitable for such raw material. For the indurating process, Kobe Steel introduced a Grate-kiln system developed by Allis-Chalmers for assuring homogenous firing at a high temperature. The plant had a capacity of one million tonnes/year.

Then Kobe Steel built the No.1 pelletizing plant at the Kakogawa Works in 1970 and the No.2 pelletizing plant in 1973, each having a production capacity of 2 million tonnes/year. The only pelletizing plant still in service is the No.1 pelletizing plant at the Kakogawa Works. The plant now has an increased capacity of about 4 million tonnes/year, the result of various modifications for capacity enhancement, labor-saving and energy-saving.

Kobe Steel is in the advantageous position of operating its own pelletizing plants and using the product pellets for its own blast furnaces. This has led the company to the practical application of self-fluxed pellets and the development of dolomite pellets. Kobe Steel has taken a leading position in utilizing pellets for large blast furnaces in Japan.

Fig. 7 depicts the typical flow in a KOBELCO pelletizing plant.

3. Features of pellet indurating equipment

As described previously, Kobe Steel built pelletizing plants based on the Grate-kiln process at the Kobe Works and Kakogawa Works. After many unique modifications, the company constructed various pelletizing plants as KOBELCO pelletizing systems, not only domestically, but also overseas. All the systems adopt a grate-kiln-cooler process for their indurating step.

This chapter describes more details of the three indurating systems[4].

3.1 Shaft furnace system

A shaft furnace (**Fig. 8**) in an old system employs an external combustion chamber to generate the heat required for indurating and introduces the hot gas into the furnace. The green balls, charged from the furnace top, make contact with the hot gas as they descend and exchange heat to increase their temperature. The heated pellets pass a cooling zone before being discharged outside the furnace. The pellets charged from the furnace top come into sufficient contact with the hot gas to ensure high thermal efficiency, which is a feature of shaft furnaces. However, it is difficult to attain a uniform temperature distribution in the furnaces. This results

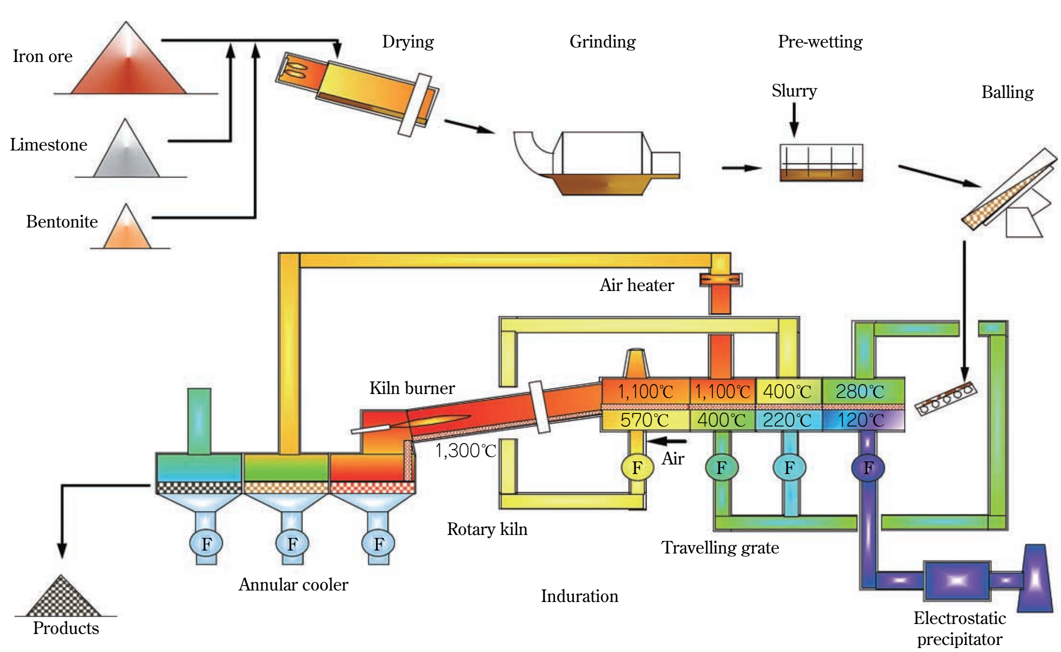

Fig. 7 Typical flow of KOBELCO pelletizing plant

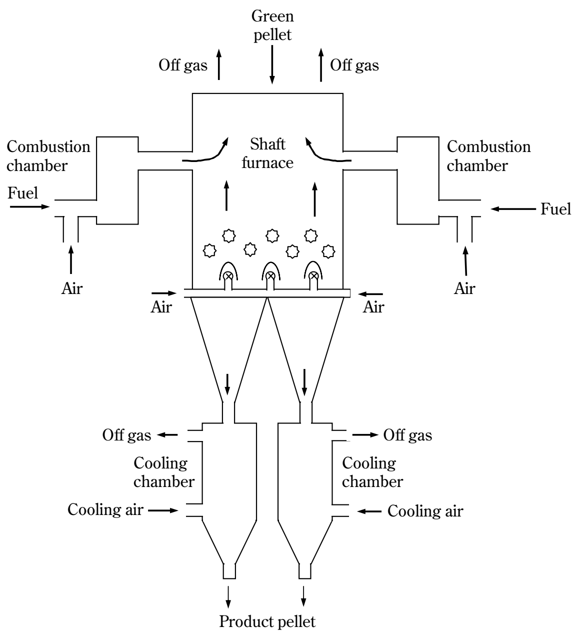

Fig. 8 Flow of shaft furnace system

in nonuniform heating of the pellets, causing them to cluster and/or to adhere to the furnace wall, leading to difficulty of operation. In addition, the scale of the plant is limited to about 450 thousand tonnes/year at maximum, which limits the cost savings. This technology has become obsolete due to the difficulty of increasing the furnace size.

3.2 Straight grate system

A straight grate system (**Fig. 9**) emerged in the industry soon after shaft furnaces. The system comprises a grate which transfers green balls charged onto it. The grate feeds the green balls sequentially through the steps of drying, preheating, firing and cooling. The advantage of a straight grate over a shaft furnace exists in the wider range of temperature control for the processing steps of drying, preheating, firing and cooling. This system, however, suffers from the disadvantage that a change in the grate speed at once changes all the conditions for the subsequent process steps.

A straight grate machine includes an endless grate car consisting of grate bars with side walls. A layer (about 100mm thick) of fired pellets is placed on the grate bars and on the side walls (**Fig.10**). Green balls are placed on top of this to form a layer of about 300mm in thickness. The layer of fired pellets protects the grate bar and side wall from high temperatures and prevents the green balls from being inhomogeneously fired. The green balls on the grate pass through the zones for drying, preheating, firing and cooling. Each zone is held at a predetermined temperature, and heat exchange occurs via hot air and/or combustion gas to fire the pellets.

The straight grate system, consisting essentially of a single unit which moves a static layer, is easy to operate. However, the system must re-circulate a portion of the fired pellets to form the layers on the grate bars and side walls to protect the mechanical

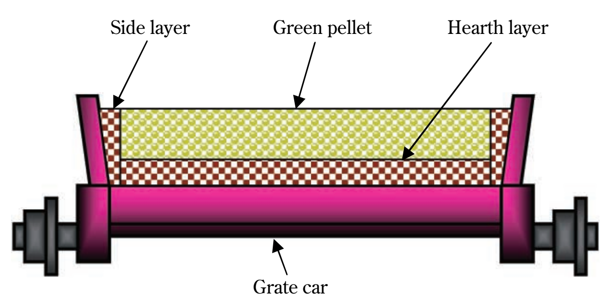

Fig.10 Cross sectional sketch of straight grate

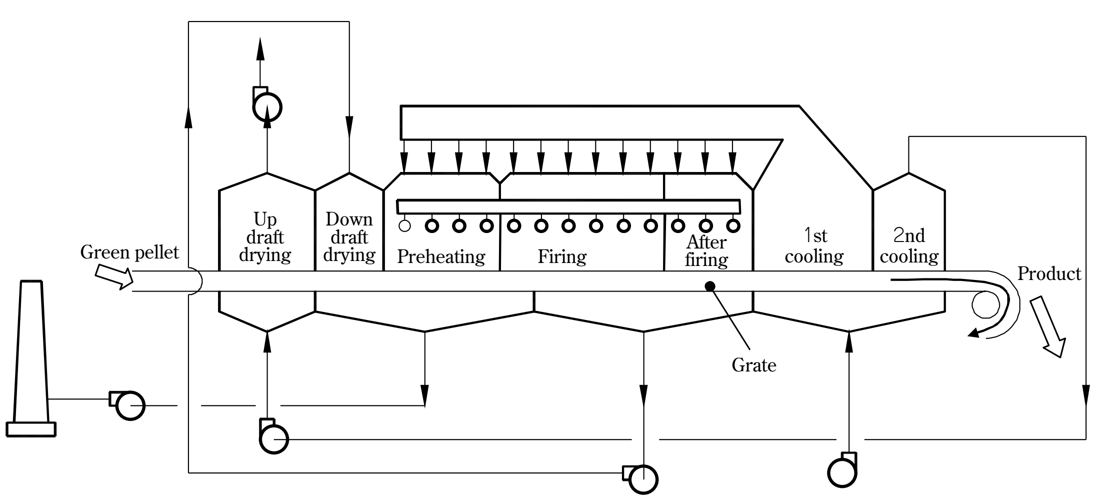

Fig. 9 Flow of straight grate system

parts and prevent variations in pellet quality. Despite this protection, the pellets are subject to wear when passing through the process steps at elevated temperatures. In addition, as previously described, this system involves a thick layer (300mm), which is prone to temperature variation between its top and bottom portions. This leads to variations in the quality of the product pellets.

3.3 Grate-kiln-cooler system

A grate-kiln-cooler system (**Fig.11**) consists of three major components: a grate (e.g., a traveling grate), a kiln (e.g., a rotary kiln) and a cooler (e.g., an annular cooler). The green balls, fed uniformly onto the grate, pass sequentially through the steps of drying and preheating. The preheating step hardens them to a strength great enough to endure the tumbling and heating that occur in the subsequent kiln step. The pellets, after being fired at an elevated temperature inside the kiln, are cooled in the following step to produce fired pellets.

The basic concept for designing a system including a grate, kiln and cooler consists in allocating the thermal transfer, occurring at temperatures from ambient to 1,300℃ or higher, to each process step so as not to cause any mechanical problems.

The grate is partitioned into drying zones and preheating zones. In these zones, heat exchanges at relatively low temperatures occur for drying and preheating the green balls. Forced convection is applied to the heating for high thermal efficiency. The source of the heat for drying and preheating the pellets is not only the kiln off gas, but also recoup gas from the cooler, an arrangement that gives the plant as a whole high thermal efficiency.

A kiln with a relatively short length is connected with the grate at its inlet and with the cooler at its outlet. The kiln is lined with refractory materials for firing the preheated pellets discharged from the grate. The firing is conducted at an elevated temperature, and radiation heating is applied to fire the pellets efficiently and homogeneously. The kiln is placed at a slight incline to the discharge and rotates at a low revolution. The pellets tumble inside the rotating kiln to be fired at a predetermined temperature (**Fig.12**) and are subsequently transferred to the cooler. The tumbling action ensures the homogenous heating of all the pellets inside the kiln and consistently yields high quality.

An annular-shaped, horizontally rotating cooler decreases the temperature of the fired pellets to a level suitable for subsequent transportation. This step employs the forced convection of air blow for cooling. A part of the hot gas collected from the cooler is used as secondary air for fuel combustion in the kiln. The hot gas is also used for the process steps of drying and preheating the green balls, making the entire system thermally efficient.

A grate-kiln-cooler system has the following features:

1) The system produces homogeneous products, since the pellets are subject to tumbling action during the firing in the kiln.
2) Each of the steps of preheating, firing and cooling can be controlled either in conjunction with the others, or independently from the others, as needed. This enables heating the hot

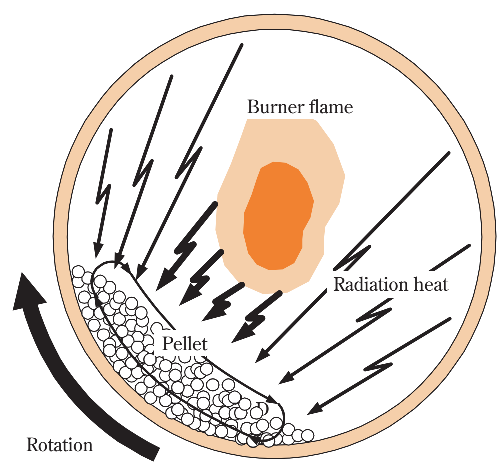

Fig.12 Cross sectional sketch of rotary kiln

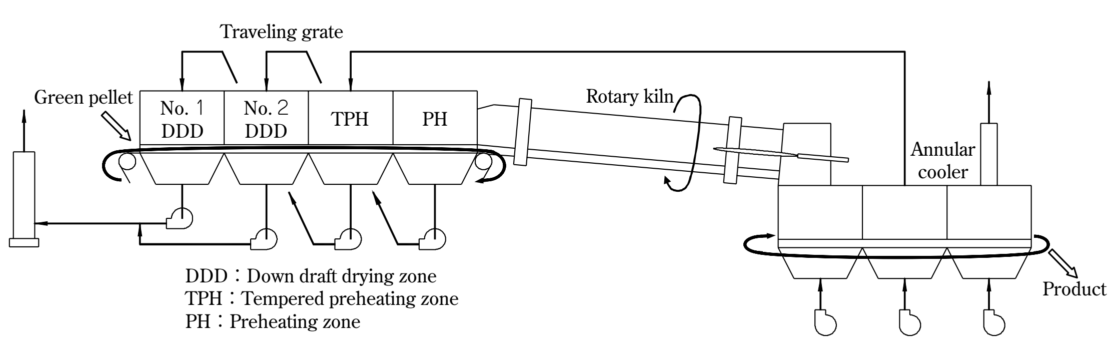

Fig.11 Flow of grate-kiln-cooler system

gas and pellets in the pattern most suitable for each process step and makes the process versatile with regard to variations in raw material quality and the production rate.

3) The ease of temperature control enables the homogenous production of self-fluxed pellets, whose production requires strict temperature control.
4) Low fuel and power consumption can be achieved.
5) The grate, kiln and cooler of the system are independently designed and constructed according to their respective thermal loads. This reduces the frequency of replacing parts such as the refractory material and grate-plate, and consequently improves the availability of the plant.

4. Product quality and features

The quality of the pellets depends on the process of pellet production. A straight grate system transfers pellets as a static layer. The system consists of a single unit for drying, preheating, firing and cooling the pellets. The pellet layer is relatively thick, about 300mm, causing a difference in the heating profile of pellets in the upper and lower portions of the layer. This causes variations in pellet quality, especially in compression strength and tumble strength.

On the other hand, the pellets produced by the KOBELCO pelletizing system have been heated uniformly by the tumbling action inside the kiln during the firing step. The firing temperature can be adjusted with ease and accuracy by controlling the fuel ratio for the kiln burner.

Fig.13 compares the distribution in the compression strength of pellets produced by the KOBELCO pelletizing system and those produced by the straight grate process.

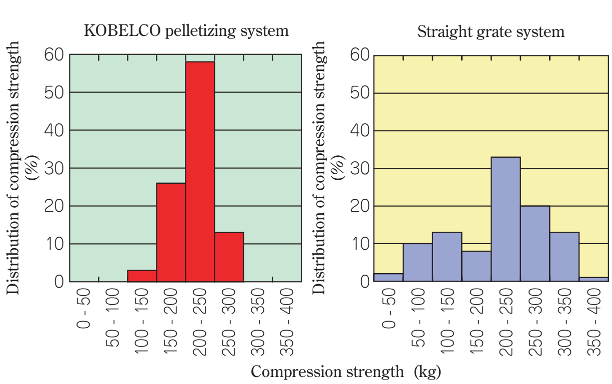

Fig.13 Comparison of product pellets

5. Ability to adapt to various raw materials

In a grate-kiln-cooler system, the drying/preheating, firing and cooling steps are performed by separate units, making it possible to control each of the steps independently. An advantage of the grate-kiln-cooler system is its capability of providing the heat patterns most suitable for various raw materials. In other words, it can accommodate any mixture of ore, from 100% magnetite to 100% hematite. In a case where the raw ore contains a large amount of crystal water, the crystal water may explosively vaporize to cause bursting of the green balls. KOBELCO pelletizing systems can avoid such bursting by providing a dewatering step, performed at a relatively low temperature to prevent rapid heating of the green balls.

6. Sample test and process design

When designing a pelletizing plant, the equipment must be sized appropriately to achieve the most suitable process conditions determined by the types of ore to be processed by the plant.

More specifically, the approach involves

- computing the material and heat balance based on the design conditions, such as the plant capacity, types of raw materials and the properties required for the product pellets, and
- determining the heat patterns best suited for the grate, kiln and cooler.

The computation is conducted by a process-designing simulation program owned by Kobe Steel. The program's calculation parameters are based on the company's wide experience. The heat patterns thus determined are applied to sample tests to confirm the qualities of the preheated pellets and fired pellets.

The heat pattern thus obtained determines the size of the grate, kiln, cooler, and other process equipment, such as process fans and dust collectors, all of which are reflected in the plant design.

The sample test involves the actual ore to be processed, the ore being subjected to tests simulating actual processes to confirm the qualities required for the pellets.

Kobe Steel owns the following testing apparatuses to conduct the process designing based on the above procedure.

1) Batch-type ball mill : This apparatus is used to grind iron ore and additives to predetermined sizes and adopts the dry-grinding method described in 1.2.
2) Batch-type mixer : This apparatus mixes raw materials, such as iron-ore, binder and

additives, together homogeneously. The mixture may also be moistened by this mixer for the subsequent balling step.

3) Continuous disc type balling apparatus (**Fig.14**) : The apparatus produces green balls to verify the green ball quality required by actual plants. If the required quality is not achieved, the balling test is repeated for different fineness of iron ore and binder types until an optimal result is obtained.
4) Pot grate (**Fig.15**) : This pot grate dries and pre-heats the green balls. The apparatus allows for freely setting the temperature and flow rate of the process gas, as well as the process time. In an actual plant, pellets are transferred from a grate to a kiln via a chute and are tumbled inside the kiln. Thus, the preheated pellets must have a certain strength. This apparatus can be used to confirm whether or not the grate can produce such preheated pellets. To produce preheated pellets satisfying required specifications, the temperature and flow rate of process-gas, as well as the process time, must be controlled to establish an appropriate heat pattern and grate size.
5) Batch type kiln (**Fig.16**) : This apparatus is used for firing the preheated pellets produced by the pot grate. Since it allows for freely setting the firing temperature and process time, the apparatus is used to determine the firing temperature and process time for achieving the qualities required for the pellets.

Fig.14 Photograph of balling disc

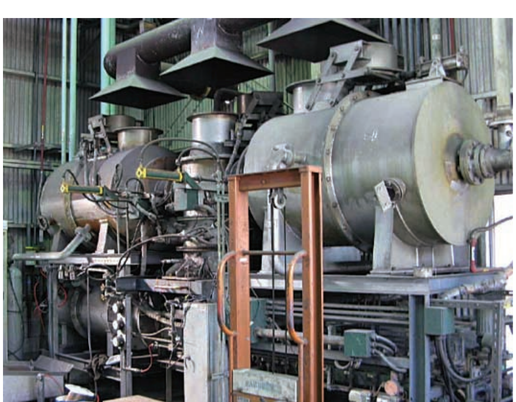

Fig.15 Photograph of pot grate

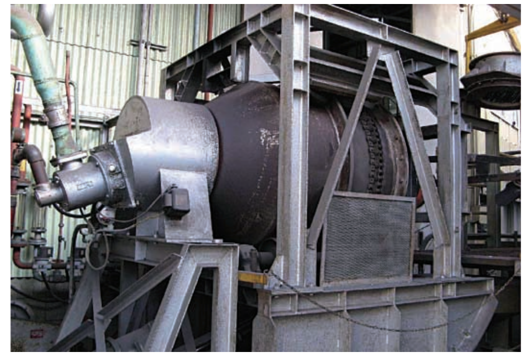

Fig.16 Photograph of batch type kiln

Table 2 Typical required figures for pellets

Phase	Physical propertty	Typical target figure
Green ball	Drop strength	>5
	Compression strength	>1kg
Product pellet	Compression strength	>250kg
	Tumble strength	>95%
	Abrasion Index	<4%
	Reduction behaviour	
	(a) For BF pellet	
	Reducibility	>60%
	Swelling	<15%
	(b) For DR pellet	
	Metallization	>92%
	Fragmentation	<3.5%

6) Batch type cooler : This cools the pellets fired by the kiln.
7) Quality testing apparatuses for pellets : The apparatuses determine pellet qualities, such as their physical properties, reduction characteristics and chemical composition.

Kobe Steel designs pelletizing plants by conducting sample tests using the above apparatuses for appropriate equipment sizing.

Table 2 summarizes the typical values for the pellet qualities that provide indices for the process designing and sample test[5].

7. Pelletizing plants recently constructed

The following outlines the pelletizing plants constructed by Kobe Steel in recent years. **Table 3** summarizes the main specifications for each pelletizing plant.

1) Iran : Ardakan Pelletizing Plant (**Fig.17**)

This plant is located near the city of Yazd, an inland area of Iran. The contract covered the entire pelletizing plant, from receiving the concentrate to the loading out of the product pellets, both by

Table 3 Reference list of pelletizing plant

Plant	FMO Venezuela	Chador Malu Ardakan / Iran	GIIC No.2 Bahrain	Vale Sohar / Oman
Nominal capacity	3,300,000 ton/year	3,400,000 t/year	6,000,000 t/year	4,500,000 t/year×2 lines
Start-up	1994	2007	2009	2010
Feed material	Hemetite	Magnetite-Hematite	Hematite	Hematite
Product	DR Pellet	DR pellet	DR pellet	DR pellet
Balling disc	ϕ7,500mm×5units	ϕ7,500mm×6units	ϕ7,500mm×9units	ϕ7,500mm×7units (×2 lines)
Travelling grate	4,716mm W×66,388mm L	4,716mm W×63,975mm L	5,782mm W×83,020mm L	4,716mm W×68,801mm L (×2 lines)
Effective area	284.5m^2	273.1m^2	440.8m^2	295.9m^2
No. of windbox	25	24	25	26
Length/bay	2,413mm	2,413mm	3,050mm	2,413mm
Rotary kiln	6,000mm ID×46,000mm L	6,000mm ID×46,000mm L	7,200mm ID×50,000mm L	6,900mm ID×45,000mm L (×2 lines)
Annular cooler	ϕ18,500mm×2,800mm W	ϕ20,000mm×3,100mm W	ϕ22,000mm×3,700mm W	ϕ22,000mm×3,700mm W (×2 lines)
Effective area	145.5m^2	177.5m^2	234.0m^2	234.0m^2

Fig.17 Photograph of Ardakan pelletizing plant

Fig.18 Photograph of GIIC No.2 pelletizing plant

railway. A consortium was set up by Kobe Steel, TAIM-TFG, S.A. (Spain), and ABB (Swiss), Kobe Steel taking charge of designing the process, supplying the processing equipment and managing construction, while TAIM supplied the material handling equipment, and ABB assumed responsibility for the electric equipment and control system.

This pelletizing plant receives iron ore concentrate (a mixture of magnetite and hematite) produced by the ore beneficiation plant of a mine located about 200km away. The ore beneficiation plant, also constructed by Kobe Steel, has a capacity of 5 million tonnes/year.

The product pellets are used as a raw material for direct reduction furnace feed and are delivered by rail to, for example, Mobarakeh Steel, one of the companies operating a gas-based direct reduction plant with the MIDREX process, which was constructed by Kobe Steel.

General-purpose equipment, such as small fans and pumps, and the plate working used for the pelletizing plant were locally procured from domestic companies in Iran. With various sorts of training on production and project management, the construction was completed successfully and the plant inaugurated in 2008.

2) Bahrain : The No.2 pelletizing plant, Gulf Industrial Investment Co. (GIIC: **Fig.18**)

The No.1 plant, constructed by Kobe Steel in 1985, led to the contract for the No.2 plant. This project was on a full turnkey basis, including the designing, equipment supply, construction and commissioning of the plant, encompassing everything from the receiving of raw materials to the shipping of product pellets.

The pellets produced by the No.1 plant are delivered to direct reduction plants with the MIDREX process utilizing natural gas in the countries neighboring Bahrain. The high quality of the products, as well as the high achievement of the direct reduction plant constructed by Kobe Steel in Qatar, led to the contract for the No.2 plant.

The pelletizing plants constructed by Kobe Steel had a maximum capacity of 4 million tonnes/year. As the No.2 plant constructed for GIIC, Bahrain, a plant with a capacity of 6 million tonnes/year was developed in response to the client's requirement for upsizing. The plant started operation at the end of 2009, as planned.

3) Oman : Vale/Sohar pelletizing plant (**Fig.19**)

This is the first overseas pelletizing plant for Vale, a Brazilian mining giant and the world's largest

Fig.19 Bird's-eye view of Sohar pelletizing plant

producer of iron ore. The plant is being constructed in Sohar, Oman, as a base for supplying ore and pellets to the Middle East. Kobe Steel has received an order for the basic design of the process area, including the processes of mixing and pre-wetting of raw materials, balling, indurating and screening. The basic designing of facilities for port, yard, ore-grinding and utility is being done by Vale and other Brazilian firms. In the first phase, two lines, each having a capacity of 4.5 million tonnes/year (4.5 million tonnes/year×2), are being constructed. Similarly, two lines (4.5 million tonnes/year×2) are to be constructed in the second phase, for a total pellet production capacity of 18 million tonnes/year. The plant is to become a supply base stockpiling forty million tonnes of iron ore.

All the pelletizing plants owned by Vale in Brazil have straight grate systems. The choice of a KOBELCO pelletizing plant was made in consideration of the high quality pellet production of Kobe Steel's grate-kiln-cooler system. Construction work started in 2009, with operations to begin in 2010.

4) Malaysia : Vale pelletizing plant

This is the second overseas pelletizing plant for Vale and is to be constructed in Perak, Malaysia, as a base for supplying ore and pellets to Asia. The plans call for a pelletizing plant having four lines, each with a capacity of 4.5 million tonnes/year (4.5 million tonnes/year×4). The plant adopts Kobe Steel's KOBELCO pelletizing in the same manner as the one in Oman. Designing started at the end of 2009.

8. Environmental responsiveness of pelletizing plants

The environmental regulations applied to pelletizing plants are becoming more and more stringent in developing nations. The regulations that a pelletizing plant is required to follow in order to reduce environmental pollution are almost the same as those in Japan.

The following describes the environmental regulations relating to pelletizing plants and the measures taken to comply with them.

1) Dust

The dust generated by the process is collected by dust collectors, such as electrostatic precipitators, bag filters and scrubbers, without being emitted into the atmosphere. The collected dust is reused as one of the raw materials. In recent years, dust emission control at material handling areas such as stock yards has become a concern for developing nations. Measures are being implemented to prevent the scattering of dust by sprinkling water and erecting large fences.

2) Sulfuric oxide (SOx)

Raw materials, such as iron ore, lime, bentonite and dolomite contain sulfur in various amounts, as do fuels such as natural gas, oil and coal. Sulfur is fed into the process along with various materials used for pellet production. All the sulfur is oxidized in the pelletizing process, generating SOx, most of which is emitted as exhaust.

Unlike nitrogen oxide (NOx), SOx can not be reduced by the process itself. There are two ways of reducing SOx in the exhaust. One is to use raw materials and fuels containing less sulfur. The other way is to install desulfurization equipment for removing the SOx that is generated.

A typical desulfurization method, called the lime slurry method, involves mixing water and lime into slurry, which reacts with SO_2 in the exhaust to collect sulfur in the form of gypsum ($CaSO_4 \cdot 2H_2O$).

3) Nitrogen oxide (NOx)

The heat for a grate-kiln-cooler system is supplied by a burner provided with the kiln; the burner uses the hot air from the cooler as combustion air. The temperature of this combustion air is in the range from 1,000 to 1,100℃, while the flame temperature is 1,600℃ or higher. Thus the NOx generated is, for the most part, thermal NOx, a product of the nitrogen being oxidized in the combustion air.

More thermal NOx is generated as the temperatures of the burner flame and combustion air rise. There are two approaches to reducing NOx emissions. One is low-NOx combustion and the other is installing a de-NOx system. Low-NOx combustion is an approach to reduce NOx generation by improving the process and adopting low NOx burners. This approach includes

- decreasing the amount and/or temperature of the combustion air
- reducing the kiln burner's fuel combustion by providing additional burners for the grate,

・reducing NOx generation by creating a localized reducing atmosphere inside the flame, and
・making the flame area larger to decrease the flame temperature and to reduce the amount of NOx generated
(but this may reduce the thermal efficiency of the entire process).

There are two de-NOx approaches for reducing generated NOx using a reductant and/or catalyst.
・Selective non-catalytic reduction (SNCR)
・Selective catalytic reduction (SCR)

Both methods use ammonia or urea to reduce NOx. In SNCR, ammonia (urea) is blown into the atmosphere at a temperature from 900 to 1,000℃. In SCR, the reduction reaction is promoted by a catalyst at a temperature between 250 and 380℃.

For a newly constructed pelletizing plant using natural gas or heavy oil for its fuel, the NOx reduction achieved by a low NOx burner (i.e., about a 20% reduction) may not be enough to keep the plant within the environmental limits. In such a case, the addition of a de-NOx system may be required[6].

Conclusions

In the past, countries constructing new plants focused on the quality of the product pellets and equipment and the cost, and Kobe Steel responded to these concerns. In recent years, however, the focus has shifted to environmental issues, making environmental responsiveness an important factor in contemplating a plant.

Pelletizing plants are playing a more and more important role as they are integrated into iron ore terminals all over the world. Some of them are being integrated into direct reduction plants with EAF steelmaking plants in their downstream.

Kobe Steel continues to accumulate experience in the construction and operation of pelletizing plants and thus contribute to the development of technologies in this field.

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