Beneficiation Plants and Pelletizing Plants for Utilizing Low Grade Iron Ore

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Recently, the grade of iron ore deposits has deteriorated and further development of low grade deposits is desired. Presently, the most effective and often followed route taken to utilize such deposits is the provision of beneficiation plants for upgrading iron ore and pelletizing plants for agglomerating. Kobe Steel has much experience in constructing both beneficiation and pelletizing plants and has its own pelletizing process (KOBELCO pelletizing system). This paper contains general information on beneficiation and pelletizing plants, including future expectations for them, and introduces the latest activities in connection with the KOBELCO pelletizing system, with a view to the future.

Introduction

The production of iron and steel has significantly expanded in recent years, particularly in newly developing countries such as China and India. This has resulted in a large increase in the demand for iron ore. The quality of iron ore deposits, however, has deteriorated worldwide as a result of long-term mining, and the existing mines are having increasing difficulty in producing ore with a high grade of iron by simple screening. Currently, blast furnaces are mainly used for ironmaking. They would suffer from greatly reduced productivity and a high energy consumption rate, if low-grade ore were charged as-is. The same applies to direct reduction furnaces. Thus, there is a strong desire to improve the iron grade at the stage of raw material preparation. One of the most common approaches is a method of upgrading ore by a beneficiation process using a physical separation technique, and a number of existing mines have introduced such beneficiation processes to upgrade their ore. Furthermore, low-grade mines, which were formerly not profitable, are being intensively developed by incorporating beneficiation plants right from the beginning.

In a beneficiation process, ore is finely ground to separate impurities. Therefore, the product ore inevitably becomes finer. Fines generated during the screening of high-grade ore can be agglomerated in a sintering plant; however, the finer fines resulting from the beneficiation process cannot usually be processed in a sintering plant and must be agglomerated in a pelletizing plant. Therefore, a greater number of pelletizing plants are expected to be built in the future.

Kobe Steel's pelletizing process, called the KOBELCO Pelletizing System, has various advantages and incorporates many improvements made on the basis of R&D and operating experiences at the company's own facility. Kobe Steel has constructed and delivered a number of such plants across the world. The specifics of these plants are also explained in this paper.

1. Iron ore – supply and demand outline

1.1 Types of iron ore

Iron ores can be classified in different ways. The most important has to do with the iron content. In many cases, ore with a total iron content of 60% to 63%, or greater, is regarded as high grade, and ore with a lower iron content is regarded as low grade. Ores are also classified as follows, according to their size and the processing method.

- Lump: Ore lumps have diameters of approximately 10mm to 40mm and are charged as-is into a blast furnace or into a direct reduction furnace.
- Fine: Ore fines have diameters of approximately 0.15mm to 10mm and are agglomerated by a sintering plant before being charged into a blast furnace.
- Pellet feed: Pellet feeds have diameters smaller than approximately 0.15mm and are agglomerated by a pelletizing plant before being charged into a blast furnace or into a direct reduction furnace.
- Concentrate: Concentrate is ore upgraded by a beneficiation process.
- Sintered ore: Sintered ore is ore agglomerated by a sintering plant.
- Pellet: Pellet is ore agglomerated by a pelletizing plant.

1.2 Outline of iron ore production

The production of iron and steel in China has increased dramatically. In response to the increasing demand, China has greatly expanded its domestic production of iron ore. However, this expansion is still insufficient, and the country is importing an increasing amount of iron ore. On the other hand, China's domestic production seems to be reaching its peak, due to a deterioration in mine quality.[1)] India used to be a prominent exporter of high-grade iron ore, but started to tax the export of iron ore in 2007 to prioritize its own domestic demand, and it will become difficult for India to export iron ore in the future.[2)] Contrary to these forecasts of increasing demand, there are predictions that steel scrap will be increasingly generated as a result of past steel production, and this will lead to an increase in the amount of steel produced using scrap and a decrease in the amount using raw iron. Overall, considering the balance of both of the above trends and also the increase in the demand for steel associated with world economic growth, the demand for iron ore is predicted to remain relatively strong.[3)]

1.3 Structure of iron ore supply

The suppliers of iron ore have undergone strategic restructuring since 2000. Three majors, namely, Vale (Brazil), Rio Tinto, and BHP Billiton (the latter two companies having two head offices, in the UK and Australia), now account for approximately 65% of the iron ore traded across the world. In addition, semi-majors such as Fortescue Metals Group Ltd, AU, and Anglo American, UK, and many other smaller businesses are producing iron ore; however, they will have limited strategic impact on the pricing and development of iron ore mines and the above three majors have a strong influence on the world market.

2. Outline of Beneficiation plant

2.1 Screening

Run-of-Mine (ROM) excavated from an ore deposit is loaded on a heavy-duty truck by a shovel or wheel loader and is transferred to a crushing process. The primary crushing is usually carried out by a gyratory crusher. This is followed by secondary crushing by a cone crusher or jaw crusher. The ore is then separated into lumps and fines. In the case of high-grade mines, the ore is shipped at this stage as the product.

2.2 Beneficiation process

In the case of low-grade mines or where the product iron grade needs further improvement, the secondary crushing is replaced by a beneficiation process. As shown in **Fig. 1**, the beneficiation process mainly comprises the sub-processes of grinding, separating and dewatering.

2.2.1 Grinding

Grinding is a sub-process of finely grinding ore in advance, such that the ground output can be physically separated into iron ore and impurities in the downstream sub-process. In many cases, an autogenous mill (AG mill) or a semi-autogenous mill (SAG mill) is used for the primary grinding, and a ball mill is used as the secondary for further grinding. An AG mill uses larger rocks of ore, while an SAG mill uses both larger rocks of ore and steel balls for the grinding. The ore to be ground is charged into a shell containing the larger rocks (and steel balls); it is cylindrical in shape and has a relatively large diameter and short length. As the shell rotates, its contents are raised high, then dropped, and the ore inside the shell is ground by the impact of the fall. A ball mill is equipment that solely uses steel balls to grind ore, and its shell body has a smaller diameter and longer length compared with an AG mill or with an SAG mill.

2.2.2 Separation

The ground material is separated into useful ore and impurities in a separation process. Two types of separators: i.e., a separator based on the difference in

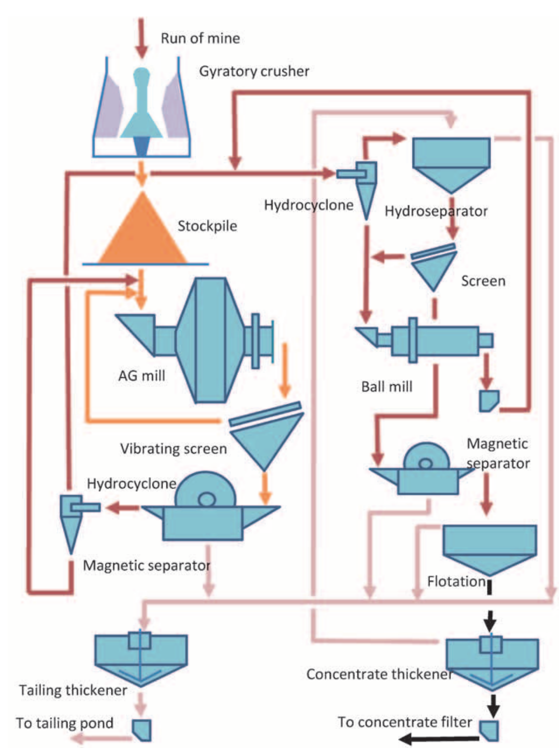

Fig. 1 Example of process flow in beneficiation plant

physical properties (e.g., gravity separator, magnetic separator or flotation separator) and a separator based on size (e.g., screen and screw classifier) are usually provided together.

1) Gravity separation

The true specific gravity of iron ore is approximately 5t/m^3 and is quite different from the specific gravities of major impurities such as silica and alumina (approximately 2.7t/m^3). Gravity separation is a method of separating iron ore from impurities on the basis of the difference in their specific gravities. Gravity separators include jig separators, which utilize the difference in the fall velocity in water of objects with different specific gravities, and spiral separators and cyclone separators, which utilize centrifugal force. These separators are the least expensive of the various apparatuses used for the separation process. Some beneficiation processes rely solely on gravity separation, and many others incorporate gravity separation as a pretreatment step for flotation separation and magnetic separation. Gravity separation is used for relatively coarse ore (diameters of approximately 0.1mm to 1.5mm.)

2) Magnetic separation

Magnetic separation is a technique for separating iron ore from impurities on the basis of the difference in their magnetic properties. This type of separation is widely used for the beneficiation of magnetite ore. A drum with a permanent magnet is rotated in slurry and the result is that magnetite ore, which is magnetic, becomes attached to the surface of the drum and is separated from the slurry, while non-magnetic impurities remain in the slurry, thus accomplishing the separation. The separation of hematite ore, which is weakly magnetic, employs an apparatus with an electromagnet that can generate a stronger magnetic force. Recently, such an apparatus is also being used commercially to collect hematite ore from the tailings. Magnetic force separation is applied to relatively fine ore with diameters of approximately 0.05mm to 1mm.

3) Flotation separation

Flotation separation is a technique utilizing the difference in the hydrophilicity of ore surfaces. This technique is used for raw materials with small diameters of approximately 0.01mm to 0.1mm and is often applied to the final stage of grade improvement, or to the removal of impurities such as sulfur and phosphorus. The iron ore and major impurities have a similar hydrophilicity; but adding a chemical (collector agent) that is adsorbed selectively to either iron ore or impurities makes the surface with the adsorbed agent hydrophobic. Air bubbles are then charged from the bottom to be trapped by the hydrophobic surfaces, after which, they float up due to the decrease in density caused by the trapped air. This phenomenon is used to accomplish flotation separation.

2.2.3 Dewatering

The above separations are usually performed in wet conditions for ease of handling and to prevent dust generation. Hence, the separated concentrate is in the form of slurry and requires dewatering. This dewatering is done by filtering the concentrated slurry. Vacuum filters are widely used; however, it is difficult to decrease the water content of the cake after filtration to 9% or lower, and the residual water content increases when the ore is finer, or when the system is installed at a high altitude. A gradually increasing number of systems have recently been employing pressure filters, adapting pneumatic pressure or hydraulic pressure to reduce the moisture content to a level of 8%.

2.3 Transportation

Usually, the transportation from a mine to a shipping port is done by rail. Fine ore, on the other hand, can be transported through pipelines in the form of slurry. A typical example of this is found in projects at Samarco in Brazil. Samarco uses two pipelines, each having a total length of 396km, to transport 24 million tonnes per year of iron ore. One of the two was inaugurated in 1977 and still is used. Even though it calls for a booster pump to provide the pressure required for the long distance transportation, the running cost is lower compared with transportation by rail. Therefore, slurry transportation is effective for beneficiation plants as long as a sufficient amount of water is available.

3. Outline of agglomeration plant

Among iron ore products, fines and pellet feed are so fine that they cannot be charged as-is into a blast furnace or into a direct reduction furnace. The processes for agglomerating them into chargeable material are sintering and pelletizing; the main raw material for the former is fines and for the latter, pellet feed.

3.1 Outline of sintering plant

Fig. 2 depicts the process flow of a sintering plant. Raw materials including iron ore fines, limestone and coke breeze (in addition, burnt lime and dolomite as required) are mixed and placed

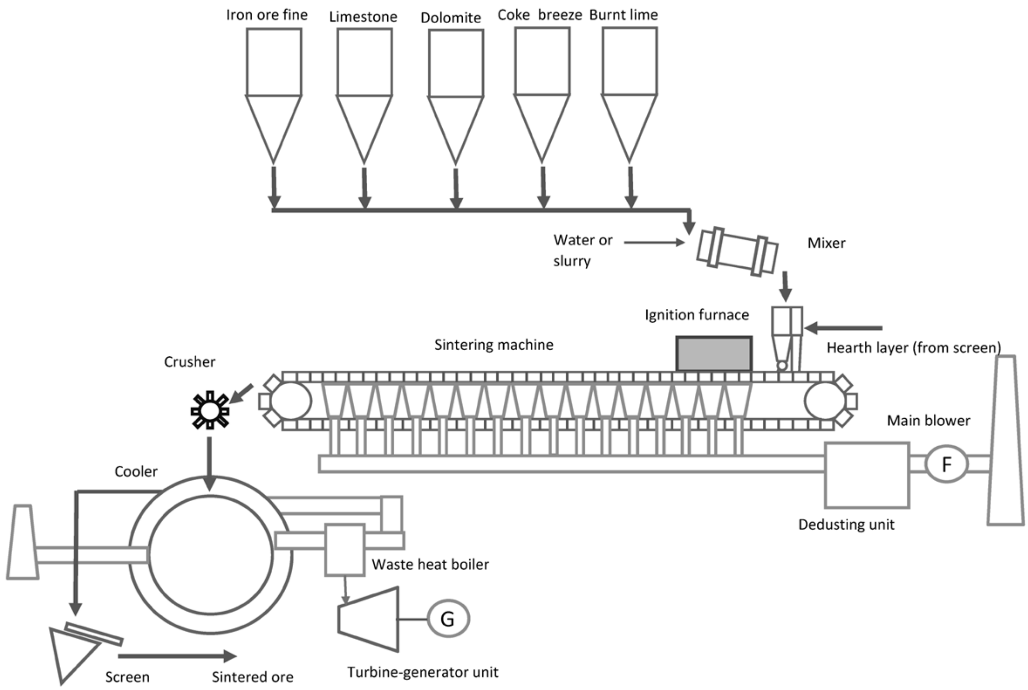

Fig. 2 Typical flow of sintering plant

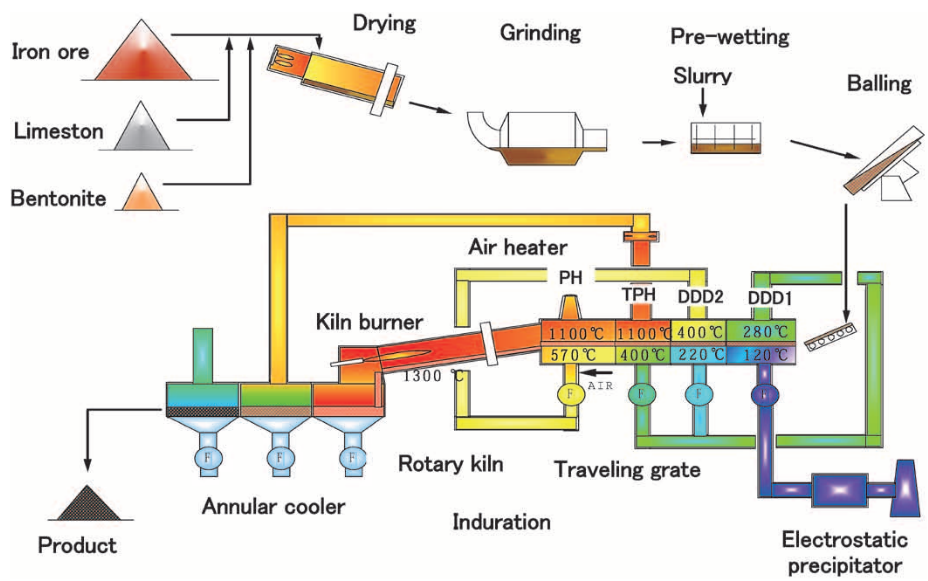

Fig. 3 Typical flow of KOBELCO pelletizing system

uniformly on moving cars that have a grate structure. The coke breeze is ignited in an ignition furnace and the mixture is agglomerated by the heat of the combustion of coke breeze. The agglomerated materials are cooled in a cooler that is either circular or linear and are delivered as products. In many cases, the sensible heat of the exhaust air from the cooler is recovered by a waste-heat boiler.

The sintered ore thus produced is un-uniform in shape and generates dust during transportation. Because of this, sintering plants are usually built in steelworks. Typically, these plants have capacities of 5 Mt/y to 6 Mt/y, while larger plants with capacities of 8 Mt/y to 8.5 Mt/y are also in service. Sintering plants can recycle relatively coarse dusts generated in steelworks. On the other hand, they consume a large amount of coke breeze, and their exhaust gas contains a certain amount of sulfur oxides. For this reason, an increasing number of sintering plants are equipped with exhaust gas desulfurization systems.

3.2 Outline of pelletizing plant

Fig. 3 illustrates the flow of a pelletizing plant (KOBELCO pelletizing system).[4] Finely ground raw material is mixed with binder and is granulated into balls (green balls) with a diameter of approximately 12mm. These balls are dried, preheated, fired and cooled to become product pellets.

The product pellets are spherical with high strength and thus generate little dust during transportation. The plants are usually built in the vicinity of a mine, or near the ore shipping port; however, as in the case of Kobe Steel's Kakogawa works, a pelletizing plant is often built in steelworks. The granulation is done by a balling disc or by a balling drum. The firing is performed in a grate-kiln-cooler system, as adapted by the KOBELCO pelletizing system, or in a Straight grate system[5] similar to the one used for a sintering plant.

Until 2000, there had been only two lines of plants with a capacity of 6 Mt/y; however, the enlargement of the plant progressed rapidly thereafter, and nine lines are currently in service with capacities exceeding 6 Mt/y. In addition, three more production lines are to be built in few years. The maximum capacity among these lines is to be 8.3 Mt/y (under construction), which compares with the capacity of a sintering plant. On the other hand, a number of small facilities (0.6 Mt/y to 1.2 Mt/y) have been built and are in service in the vicinity of mines in India and China.

4. Development of state-of-the-art technology for Kobe Steel's pelletizing plant

The specifics and features of the Kobe Steel's pelletizing plant were introduced previously.[4] This paper focuses on the technologies developed since then.

4.1 Selective non-catalytic reduction

Countries throughout the world, including developing nations, require that everything possible be done to reduce the environmental impact. With this in mind, a new method has been developed for reducing nitrogen oxide (NOx). The new technique belongs to the category of selective non-catalytic reduction (SNCR) and comprises the spraying of ammonia in a relatively high temperature (900 to 1,200℃) zone for a relatively long period of time to have it react with nitrogen oxide in the zone. A newly devised spraying method has enabled the features of high efficiency and a significantly reduced amount of leakage ammonia, as shown in **Fig. 4**. This method is applied to the preheating (PH) zone of the traveling grate, which enables the reduction of the amount of nitrogen oxide without much additional capital investment. A typical flow of this process is shown in **Fig. 5**.

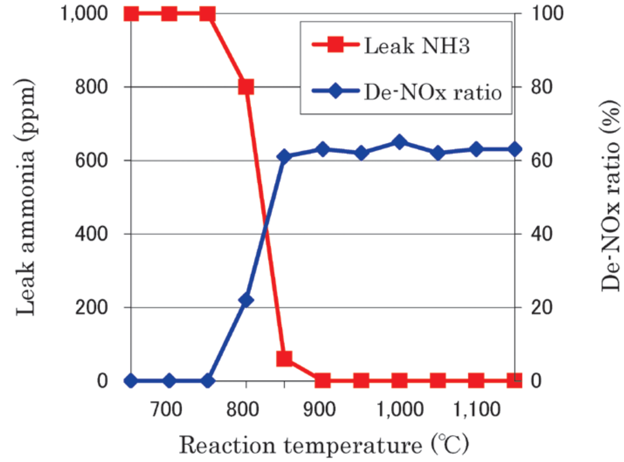

Fig. 4 Typical example of effects of SNCR system

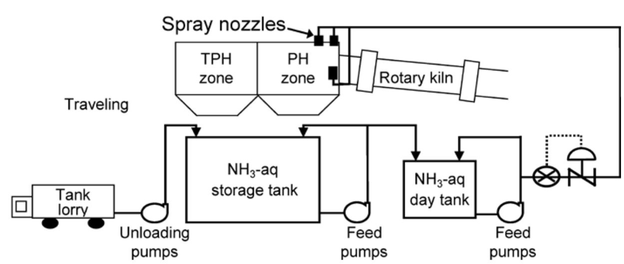

Fig. 5 Typical application of SNCR system on pelletizing plant

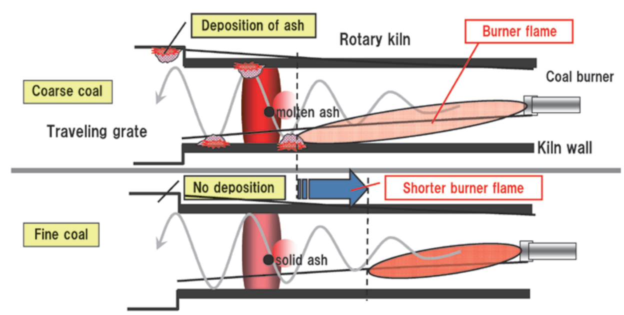

Fig. 6 General image showing relationship between kiln burner and coal ash deposition

4.2 Increased applicability of coals for kiln

The KOBELCO pelletizing system uses a kiln for firing, enabling the replacement of its main fuel, expensive oil and gas, with inexpensive coal. Inexpensive coal, however, contains a certain amount of ash, which can be deposited on and adhere to the interior of the kiln; this may disturb gas passage in the kiln. Several measures have been devised to prevent such troubles. Of all these measures, shortening the flame of the kiln burner and using more finely ground coal have been found to be particularly effective. This has also been confirmed by actual operation. **Fig. 6** [6] shows a general image of the kiln burner and the deposition of coal ash. In a case where the flame reaches the

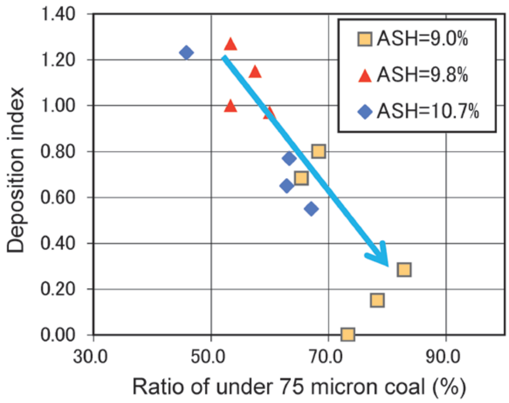

Fig. 7 Relationship between coal fineness and ash deposition

interior wall of the kiln, coal ash reaches the wall in a molten state, being deposited on and adhering to the wall surface. When the flame is shorter, the ash is cooled before it reaches the interior wall and is solidified, which prevents it from adhering to the wall. **Fig. 7** is the result of an operational test showing the relationship between the fineness of the coal and the deposition of coal ash at the kiln inlet.[6] The finer the coal is ground, the smaller the deposition index (relative amount of deposition).

5. Future trends in pelletizing plants and Kobe Steel's actions

5.1 Future trends in the agglomeration process

As has been described, the deterioration of mines has increased the introduction of beneficiation processes. Involving grinding, these processes produce concentrate that consists of extremely fine grains. The grains are so small that their use in a sintering plant is limited and they will be increasingly used in pelletizing plants. Meanwhile, it has been recognized that, with the improvement in the high-temperature properties of pellets, high iron grade pellets can be charged into a blast furnace at a high mixing ratio so as to effectively decrease the amount of slag, reductant and CO_2 emissions.[7] Therefore, it is envisaged that part of the sintered ore charged into a blast furnace will be replaced by pellets. This trend will be accelerated because the environmental impact of pellet production is much smaller than that of sintering processes that consume large amount of coke breeze.

It should also be noted that there will be a further increase in the consumption of pellets by the direct reduction process. Pellets usually contain a high grade of iron and generate little dust. With these favorable features, pellets are predominantly used as a raw material for direct reduction. The direct reduction process is expected to greatly expand in the future, because the demand for inexpensive raw iron that exploits shale gas is increasing, and so is the demand for direct reduced iron (DRI) and hot briquetted iron (HBI) as clean raw iron for steelmaking processes based on scrap. Hence, the demand for pellets is also expected to increase significantly.

5.2 Future trends in large-scale plants

Where there is a large deposit of iron ore, a large-scale pelletizing plant is planned because of its investment efficiency. The construction site is selected near a shipping port to facilitate construction and operation. With the recent increase in the scale of pelletizing plants, each pelletizing plant is required to have a production capacity of 6 Mt/y or greater. It must run with a low consumption rate and produce high quality pellets to keep its product competitive. In particular, there is a stringent requirement for its products to generate as little dust as possible because they are shipped all over the world.

In 2010, Kobe Steel constructed a pelletizing plant with a production capacity of 6 Mt/y in Bahrain, and with this experience, the company will now be able to build a plant with a capacity of 8 Mt/y. Compared with Straight grate systems, the KOBELCO pelletizing system uses less process gas and operates with a thinner bed of green ball, thus consuming less electric power for its process fan. This system also realizes low fuel consumption, one of the lowest in the world, thanks to its optimized heat recovery process. Moreover, the kiln used for the firing process enables the pellets to be fired while tumbling. This tumbling action makes the pellets stronger with less strength variation, as shown in **Fig. 8**,[8] which effectively prevents the pellets from breaking during long-distance transportation. In a Straight grate system, heating is applied only from above the static layer of pellets, which causes a large difference in strength between the top layer and bottom layer. The pellets in the bottom layer, which are weaker, tend to break during transportation. Increasing the average strength of the pellets may improve this issue; however, this may lead to the inclusion of pellets with excessively high strength. When producing HBI in a direct reduction process, these excessively strong pellets make briquetting difficult. Thus Kobe Steel's process, capable of producing homogeneous pellets, is more suitable for HBI production.

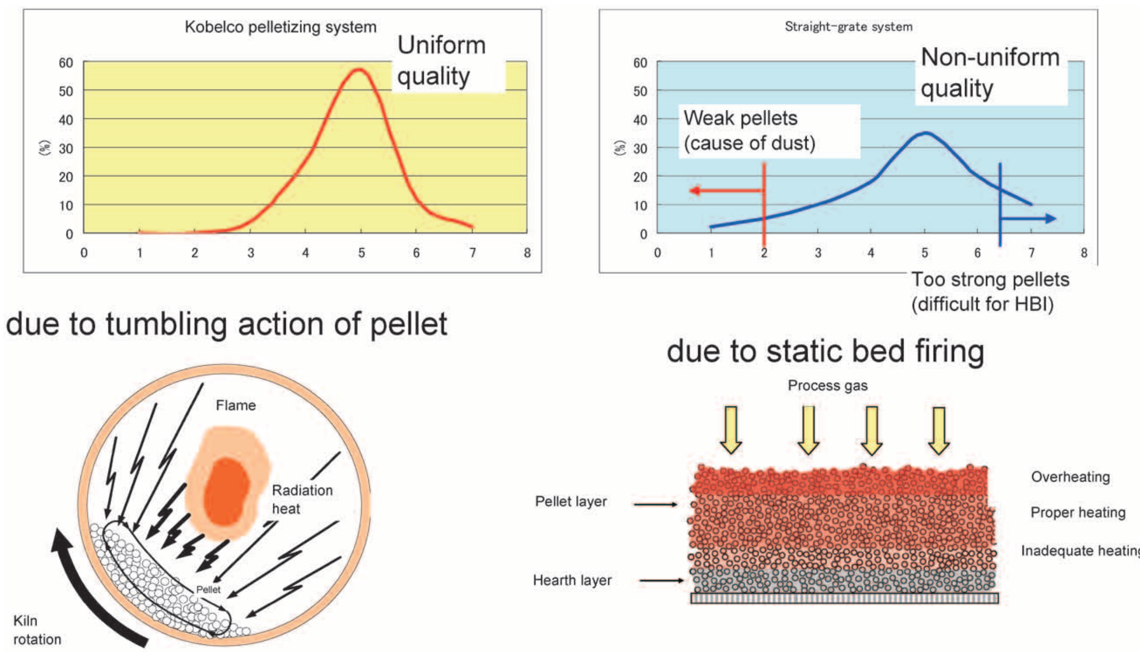

Fig. 8 Comparison of product pellets

5.3 Future trends in medium-scale plants

Investing in medium-scale plants is less efficient than investing in large-scale plants. Therefore, medium-scale ones are usually built on the sites of steelworks so as to realize advantages that compensate for the investment inefficiency. A production capacity of 3 to 4 Mt/y is required. Such a built-in plant has the following advantages over stand-alone plants:

- It can utilize a small-scale feed of iron ore as a part of the raw material.
- It can produce pellets of a quality optimally designed for the steelworks of the owner company.
- It can use byproduct gases of the steelworks as a fuel for pelletizing, which enables the low-cost production of pellets.
- It can be both maintained and managed by the same personnel.
- It can recycle dust generated in other facilities as raw material for pelletizing.

Kobe Steel owns a pelletizing plant in the company's integrated steelworks with blast furnaces and has accumulated a wealth of knowledge and experience from it. For example, the company effectively recycles and utilizes converter furnace dust as the raw material of pellets. Such fine dust can work as a binder, and the converter furnace dust has actually been confirmed to reduce the amount of binder used as a secondary effect. The coal utilization technology described above has enabled the use of inexpensive steaming coal to be used for the pelletizing process, which has decreased the fuel cost.

5.4 Future trends in small-scale plants

A number of mines with relatively small deposits are found in India and China, but they had never been the objects of development due to the low return on investment. With the recent continued high price of iron ore, however, it is anticipated that there will be more and more development of these mines.

In the case of small mines, pelletizing plants are most likely to be built with beneficiation plants in the vicinity of the mines. Such integration of plants makes it possible to do without facilities for storing concentrate. In addition, collective construction can suppress construction costs. Kobe Steel has a lineup of small-scale standard plants with a capacity of 2.5 Mt/y and aims at expanding their sales in the future.

Conclusions

Regarding the future production of iron, steel and iron ore, a steadily increasing number of projects will be launched that involve beneficiation processes to upgrade ore and to produce pellets. Kobe Steel has its own pelletizing technology and has built eleven pelletizing plants in six countries so far. The company is highly reputed for the quality of its product pellets and for its know-how in using coal as the main fuel. In addition, the company has built a large-scale beneficiation plant for iron ore. Kobe

Steel will continue to strive to expand the sales of these plants and to contribute to the development of iron ore and steel industries.

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