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Chapter 3

Iron Ore Pelletizing Process: An Overview

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.73164

Abstract

The iron ore production has significantly expanded in recent years, owing to increasing steel demands in developing countries. However, the content of iron in ore deposits has deteriorated and low-grade iron ore has been processed. The fines resulting from the concentration process must be agglomerated for use in iron and steelmaking. This chapter shows the status of the pelletizing process with a special focus on binders. Bentonite is the most used binder due to favorable mechanical and metallurgical pellet properties, but it contains impurities especially silica and alumina. The importance of many researches concerning alternative binders is also discussed in this chapter. Better quality wet, dry, preheated, and fired pellets can be produced with combined binders, such as organic and inorganic salts, when compared with bentonite-bonded pellets. While organic binders provide sufficient wet and dry pellet strengths, inorganic salts provide the required preheated and fired pellet strengths.

Keywords: iron ore, pelletizing process, binder, bonding mechanism, induration technology

1. Introduction

Iron ore and iron ore pellets are important sources of iron for manufacturing steel. The iron ore production has significantly expanded in recent years, owing to increasing steel demands in developing countries, such as China and India. However, the content of iron ore in deposits has deteriorated and low-grade iron ore has been processed. The fines resulting from the enrichment by separation after liberation by size reduction must be agglomerated in a pelletizing plant. Consequently, the number of pelletizing plants is expected to increase in the future.

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The quality requirements of pellet, such as physical, chemical and metallurgical specifications, depend on each ironmaking furnace and those requirements influence the operation of the iron ore pelletizing plant.

The idea of rolling moist fine ore in a drum to form balls and then drying and firing it was first patented by A. G. Andersson in Sweden in 1912. Further development was performed to bring the idea to reality. In 1943, E. W. Davies and co-workers demonstrated the process using an experimental shaft furnace. Commercial operation started in the 1950s in Sweden using vertical-shaft-kilns for firing the pellets. Plant capacities were between 10,000 and 60,000 tons/year [1].

The world installed pelletizing capacity is currently estimated to be 480.7 million tons/year [2]. As shown in **Figure 1**, China presents the largest production capacity, followed by the United States and Brazil.

The iron ore pelletizing process consists of three main steps:

1. Pelletizing feed preparation and mixing: the raw material (iron ore concentrate, additives —anthracite, dolomite—and binders are prepared in terms of particle size and chemical specifications, dosed, and mixed together to feed the pelletizing process;
2. Balling process: the green pellet is the rolled pellet without any thermal process. It is obtained under strict control of moisture and has a spherical shape and diameter of 8–16 mm;
3. Induration process: the green pellets are hardened in a high temperature processing at controlled heating rates, and aiming to achieve the physical and metallurgical requirements for handling, transportation, and final application.

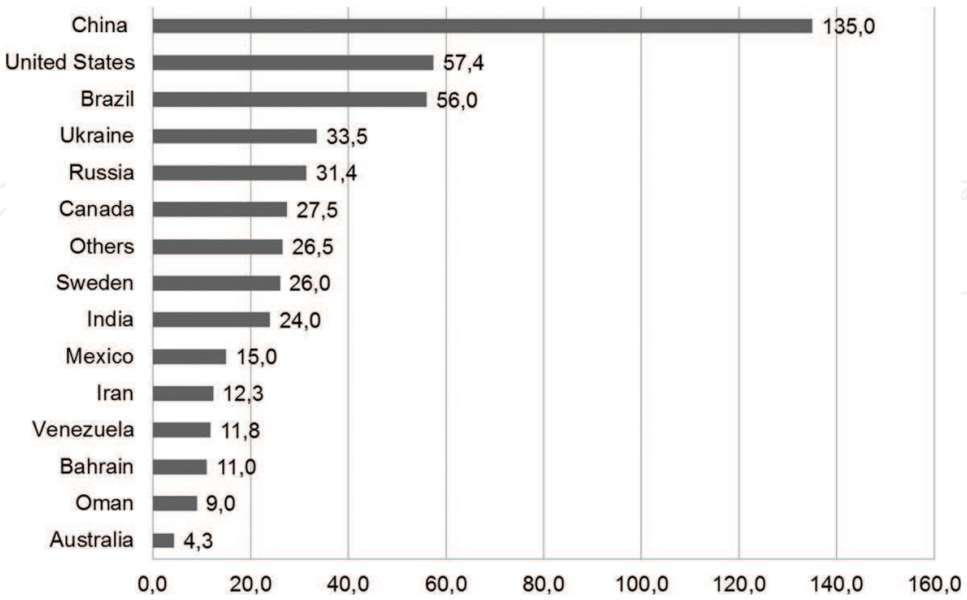


Figure 1. World installed pelletizing capacity (millions of tons/year). Source: Prepared by the authors with data from Tuck and Virta [2].

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This chapter aims to provide an overview and the evolution of iron ore pelletizing process including:

- Pelletizing process and raw materials
- Balling technologies
- Bonding mechanisms
- Evolution of binders for iron ore pelletizing
- Induration technologies
- Challenges and innovations in iron ore pelletizing

2. Pelletizing process and raw materials

The iron ore is mined mostly from open pit deposits through mining operations and the raw product, "run of mine," is subjected to mineral processing. Thus, the material is exposed to a series of operations of fragmentation, separation by size, concentration, dewatering, etc., aiming to adequate the chemical, physical, and metallurgical characteristics to meet the demands of ironmaking processes. The particle size distribution of iron ore is a very important requirement to be characterized after its mineral processing.

Materials containing a very fine particle size distribution are not adequate to be used directly in the reduction reactors, requiring to be agglomerated by different processes such as sintering or pelletizing.

The main used reduction reactors are the blast furnace (BF) and direct reduction reactors (DR). In the blast furnace, iron is reduced and melted and the most common product is liquid iron called hot metal. In direct reduction, iron remains in solid state and the product is the so-called direct reduced iron (DRI).

Generically, the iron ore products for ironmaking can be classified as shown in **Table 1**.

Pellets are balls formed by rolling moist concentrates and fines iron ores of different mineralogical and chemical composition, with the addition of additives and binder, in a horizontal drum or in an inclined disc [1, 4].

Product	Size range (mm)	Basic application
Lump	6.3–31.7	Directly fed to blast furnace and direct reduction
Sinter feed	0.15–6.3	Agglomeration by sintering to be fed in blast furnaces
Pellet feed	<0.15	Agglomeration by pelletizing to be fed to blast furnace and direct reduction

Table 1. Iron ore products classification for ironmaking [3].

Pellets produced to be used in ironmaking processes must have characteristics that meet the list of quality specifications regarding physical, chemical, and metallurgical properties. Almost all of those properties are standardized as shown in **Table 2**.

Aiming to achieve those specifications, binders and additives are used in the pelletizing process. Additives such as limestone, dolomite, and hydrated lime are used to modify the chemical composition of the pellets, most often for correction of the basicity.[1] Certain substances such as hydrated lime serve as both additive and binder. Fines of anthracite or coke are also added during the pelletizing process for reducing the consumption of fuel required for internally heating the ball [7].

Pellets are obtained by adding an appropriate amount of water to the iron ore concentrate; this is a fundamental factor in the formation and growth of pellets, which creates a surface tension that holds the mineral grains cohesive, thus allowing their handling [6, 8].

This cohesive tension of fine particles due to water is called neutral tension. Neutral tension, however, is not sufficient to keep cohesive grains as dense as iron minerals. Furthermore, when the pellet is heated, the vaporization of water occurs and the pellets tend to disintegrate.

Type of specification	Norm	Description
Physical	ISO 4701	Determination of size distribution by sieving
	ISO 4700	Determination of the crushing strength
	ISO 3271	Determination of the tumble and abrasion index
	JIS M 8711	Determination of shatter strength
	Internal procedures (pelletizing companies)	Determination of crashed resistance by the number of drop falls
Chemical		Chemical property of the pellets
Metallurgical	ISO 4698	Determination of the free-swelling index
	ISO 13930	Determination of low-temperature reduction-disintegration index by dynamic method
	ISO 11257	Determination of the low-temperature reduction-disintegration index and degree of metallization
	ISO 11256	Determination of the clustering index
	ISO 7992 / ISO 7215 / ISO 11257	Determination of reduction under load/Determination of the reducibility by the final degree of reduction index/Determination of the low-temperature reduction-disintegration index and degree of metallization
	Internal procedures (pelletizing companies)	Porosity

Source: elaborated by the author with data from Campos et al. [5] and Moraes [6].

Table 2. Quality specification of iron ore pellets.

[1]Basicity in this context is the ratio between the weight percent of CaO and SiO_2.

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To avoid such effects, binders are added to the material to be pelletized, aiming to:

- increase the strength of pellets before heating (green strength);
- prevent the collapse of pellets during the initial stages of heating, when a large volume of gas generated by water vaporization tends to crack the pellets.

Evenly distributed moisture and binder in the feeding process is decisive to improve the characteristics of pellets, especially to avoid the formation of undesirable agglomerates before the pellet formation.

Bentonite is an effective, widely used binder in the iron ore pelletizing process. Its low price is an important factor for its extensive use.

However, bentonite incorporates silica and alumina, which are undesirable contaminants to pellets. Additionally, it is a natural material with variable composition depending on its origin. Obtaining a suitable binding effect requires a relatively large amount of material, around 0.5% by weight, which makes handling more difficult and increases logistics costs.

Figure 2 shows a flowchart of a typical pelletizing plant, highlighting the additive preparation, mixing and pelletizing feed preparation, the balling step, in this case using a disc pelletizer, and the induration step.

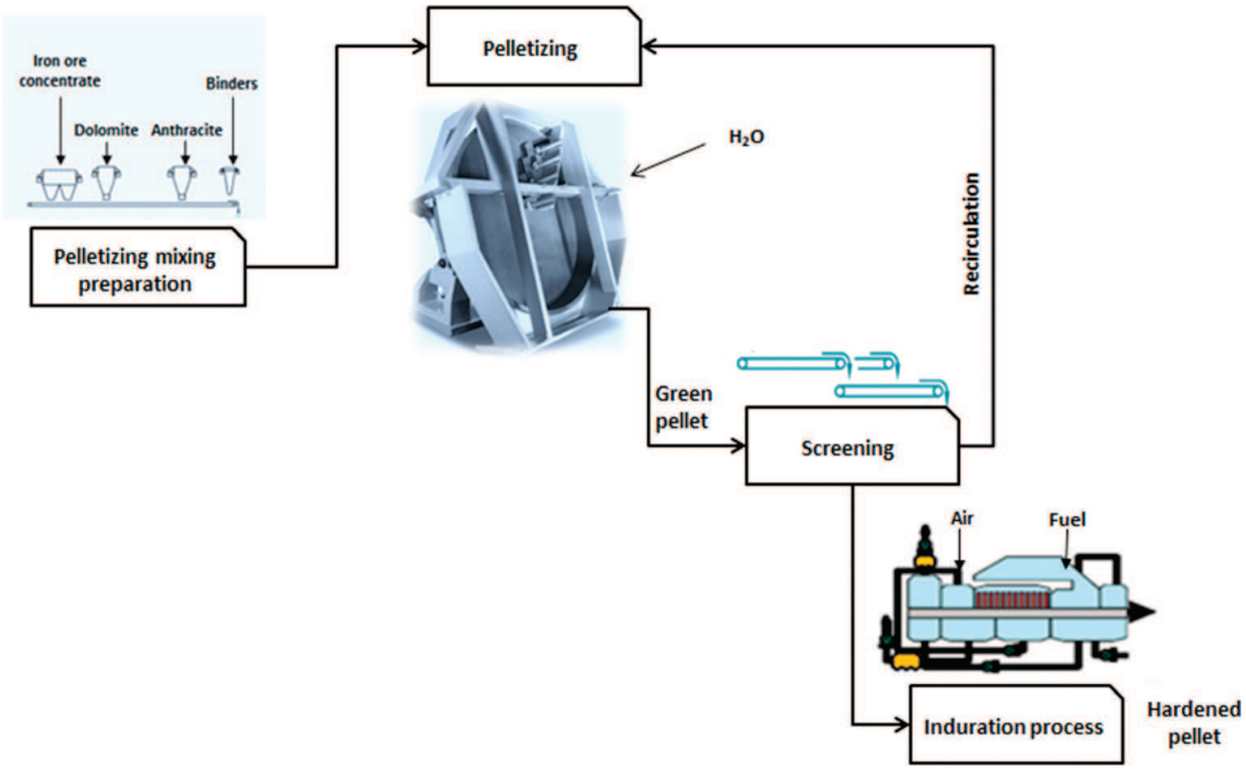


Figure 2. Typical pellet plant using disc pelletizer as balling technology. Source: Elaborated by the authors from Metso [9] and Vale [10].

3. Balling technologies

The balling equipment that can be either a disc or a drum produces green pellets in a variable size distribution.

3.1. Balling disc or disc pelletizer

Figure 3 schematically shows a laboratory disc pelletizer. The balling disc basically consists of a pan with a peripheral wall, which rotates with a certain inclination to the horizontal [1]. In general, in a balling disc, the pan angle can be adjusted between 40 and 60° [11].

When the disc rotates, the feed material with less moisture than that required for the pellets formation, is charged to the bottom of the disc, where it get in contact with the water from the sprayers, initiating the nucleation stage. At this stage, the nuclei begin to take the form of small pellets, which by rolling action, occur in the lower section, to the left of the disc, toward the top. As the added ore aggregates unto the surface of the pellets, they increase in size and the coefficient of friction is reduced causing the pellets to acquire a centrifugal force that carries them out of the nucleation zone. This movement takes the pellets to the top of the disc following a semicircular trajectory before returning to the base of the disc [1, 12].

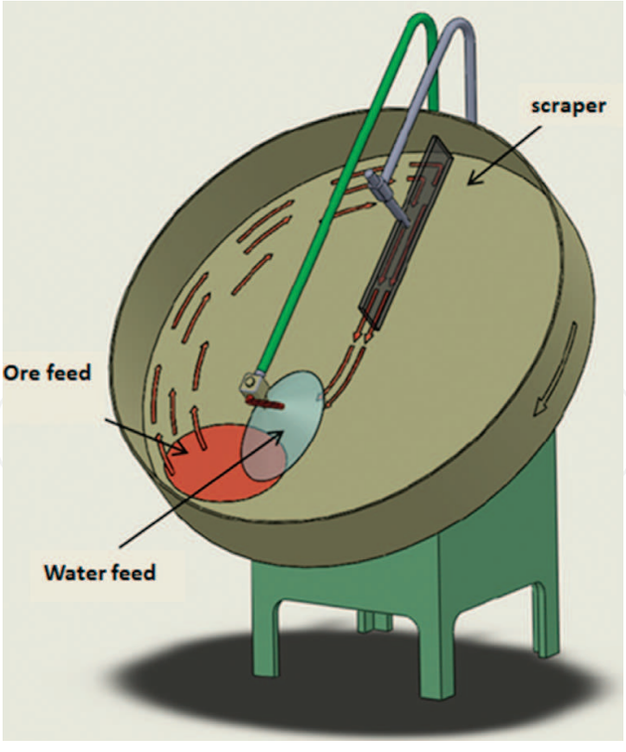


Figure 3. Schematic diagram of laboratory balling disc. Source: Modified by the authors with data from Ball [1].

The height and width of the trajectory increase as the ball size increases until the balls hit the scraper blades. After that, they move down and pass under the water sprayers so that they can find fresh feed.

The balling disc works in close circuit with the screening step, where pellets smaller than 8 mm or larger than 16 mm are desegregated and the material is recirculated to the balling process.

3.2. Balling drum

The balling drum equipment fundamentally consists of an inclined rotating cylindrical shell with water sprays in its inlet end, where the feed material is introduced to make balls. All formed pellets are discharged, regardless of particle size, which is different from the disc where only balls larger than a certain size are discharged. Because of this, the product has to be screened by a roller screen, which has increasingly replaced vibrating screen to extract undersize and oversize [4].

The small pellets in the undersize will serve as seeds forming rightly sized pellets [4], the oversize is shredded, and both return to the feed addition point, forming a closed circuit. The water sprays promote nucleation and seed growth in the feed addition zone, while the assimilation process, responsible for the ball growth, occurs along the length of the drum [1].

The drums usually have a length-to-diameter ratio of 2.5–3.5 and very low slope with angles of inclination of the drum axis to the horizontal between 6 and 10°. The optimum rotating speed is generally between 25 and 35% of the critical speed that is the speed in which balls will centrifuge causing their degradation [1]. Speed control is necessary to develop a correct rolling and tumbling action to produce balls.

The rotation speed, the depth of the material in the drum (controlled by scrappers), and the time required for balling are constraints that need to be satisfied. The residence time in a drum is given by Eq. (1):

$$T = \frac{0.0037(\alpha + 24)L}{nDS} \tag{1}$$

where: T is the residence time (minutes).

L is the drum length (feet).

D is the drum diameter (feet).

n is the speed of revolution (revolutions per minute).

S is the slope of the drum (inches/foot length).

α is the angle of repose of the feed material.

Figure 4 shows a balling drum arrangement.

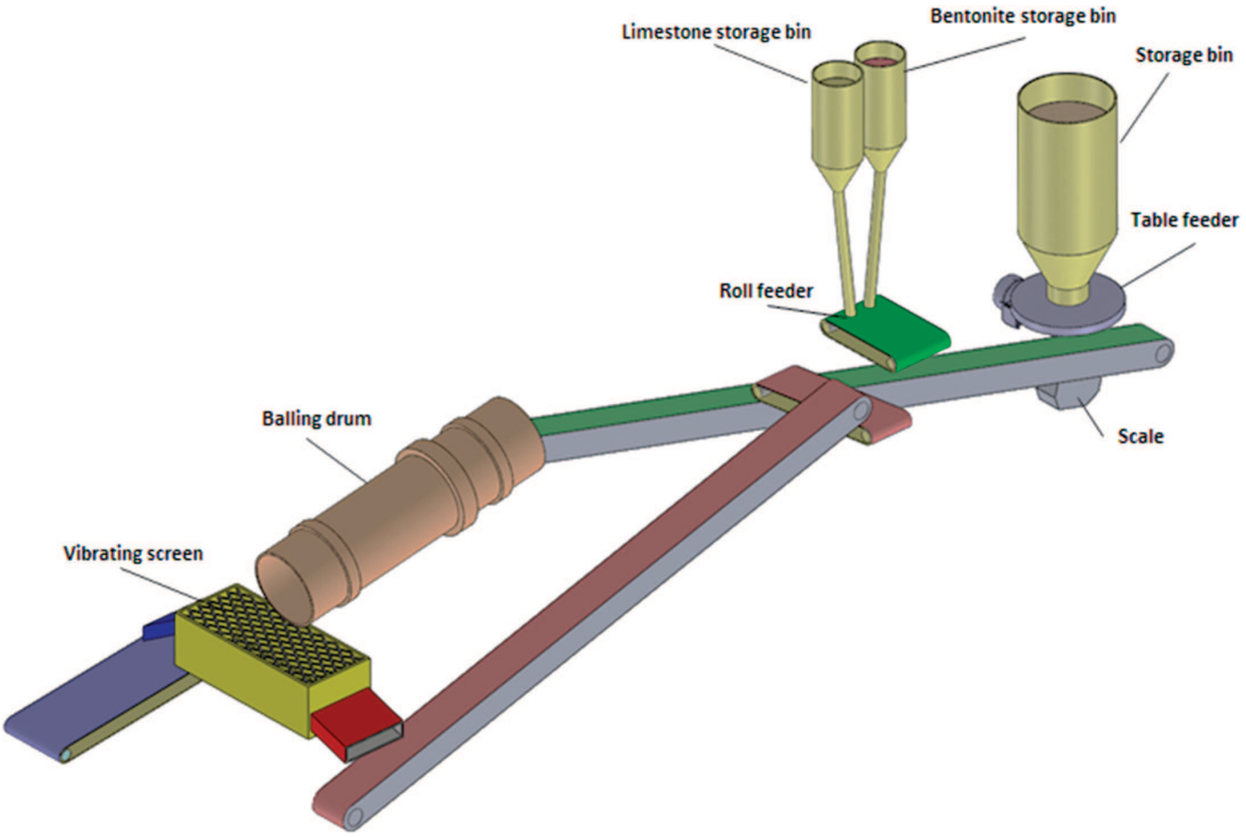


Figure 4. Typical balling drum arrangement. Source: Modified by the authors with data from Ball [1].

4. Bonding mechanisms

The main bonding mechanisms of size enlargement are described as being [11, 13]:

a. solid bridges between agglomerating particles, which may occur by sintering, partial melting, chemical reaction, hardening binders, recrystallization of dissolved substances, and deposition of colloidal particles;

b. interfacial forces and capillary pressure in movable liquid surfaces (liquid bridges);

c. adhesional and cohesional forces in bonding bridges, which are not freely movable (highly viscous binder), adsorption layers <3 nm thickness);

d. attraction between solid particles: molecular forces (Van der Walls forces, free chemical bonds—valence forces—associations—nonvalence—and hydrogen bridges), electric forces (electrostatic, electrical double layers, excess charges), and magnetic forces;

e. interlocking, depending on the shape of particles, for example, fibers, threads, or lamellae.

The agglomerated growth mechanism was defined by Sastry and Fuerstenau [14], considering that in industrial balling systems, the balling devices are continuously operated and the new feed is constantly supplied to previously seed pellets. The authors describe five agglomerate growth mechanisms as shown in **Figure 5**.

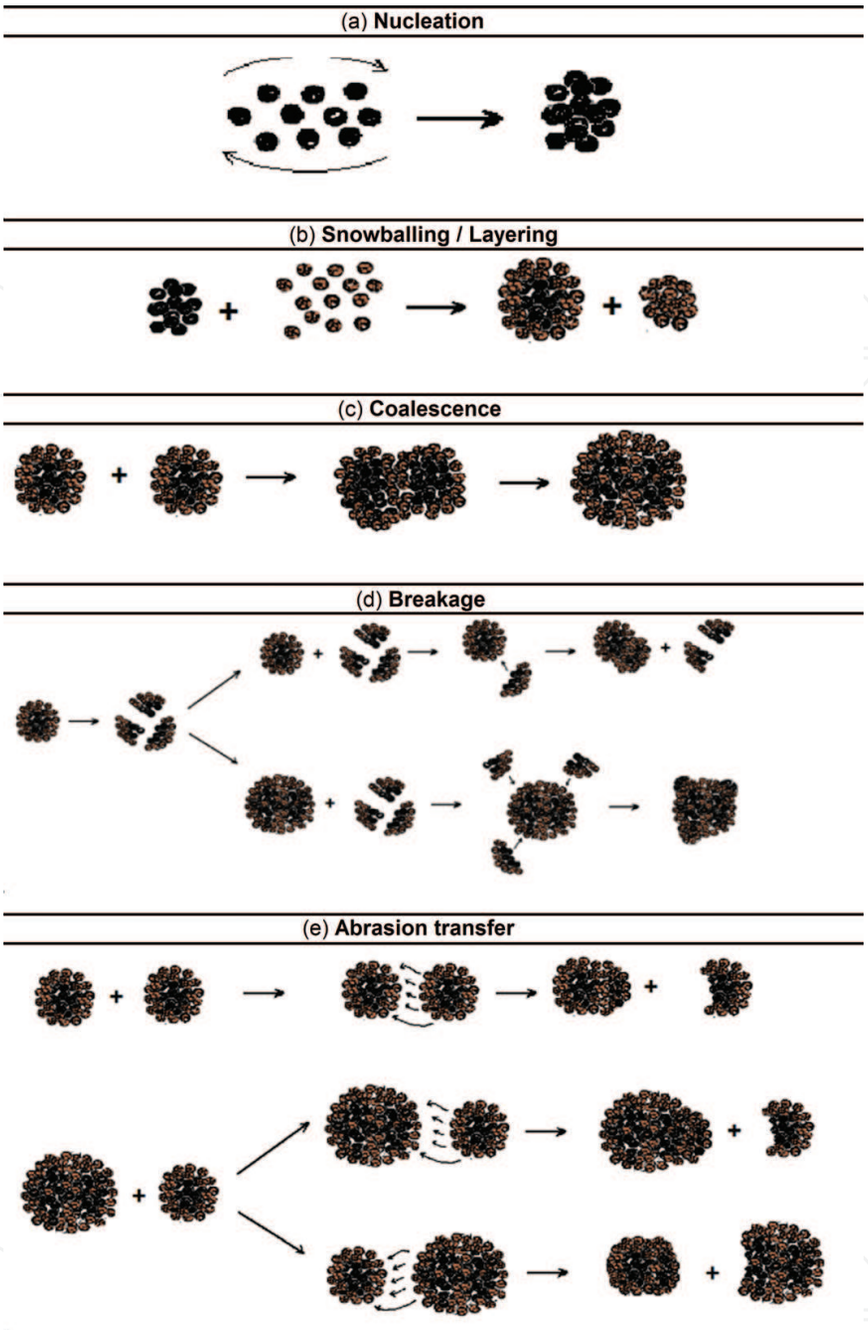


Figure 5. Details of the mechanisms proposed by Sastry and Fuerstenau [14]. (a) Nucleation, (b) snowballing/layering, (c) coalescence, (d) breakage, and (e) abrasion transfer.

Nucleation (**Figure 5a**) is defined as any formation of new pellets in an agglomeration system from an extra feed of moist material. The nucleation of new species results from the capillary attraction between a collection of individual moist feed particles. Thus, the occurrence of nucleation promotes changes in the mass and number of well-formed species in the system.

Whenever a new feed is supplied to a pelletizing system, the pellets act as seeds and tend to accumulate the newly added moist material. This mechanism is called snowballing or layering (**Figure 5b**). In this case, it is considered that all new moist feed nuclei are of unit mass and are

not considered to belong to the population of agglomerates undergoing size change. In addition, the snowballing mechanism is considered to cause continuous change in pellet size, resulting in an increase in the total mass of the system and does not change the total number of pellets.

Coalescence (**Figure 5c**) refers to the production of large-size species through the aggregation of two or more colliding granules. Binary coalescence is considered an elementary event. Thus, the collision coalescence of two agglomerated species leads to the formation of a larger sized pellet with mass. The coalescence mechanism causes discrete changes in the agglomerate mass and contributes to the decrease in the number of pellets, but does not change the total mass of the system.

The breakage of pellets (**Figure 5d**) leads to the formation of a collection of fragments that are considered to belong to the class of well-formed species. These fragments are redistributed on the surviving pellets, causing the so-called layering according to the layering mechanism.

In the abrasion transfer mechanism (**Figure 5e**), a certain mass of material is transferred from one species to another due to the interaction and abrasion of the agglomerate during the pelletizing process. Mathematically, it is expected that on each encounter between species, an infinitesimal mass of material will be transferred from one to the other, with no preference of exchange in any direction. The abrasion transfer growth mode does not change the total number or total mass of pellets in the system, causing only continuous changes in size.

The optimum moisture content and particle size distribution are two decisive factors for green pellets formation. The moisture interferes with two important properties of green pellets: compressive strength and drop resistance. These two properties are complementary; to obtain a high compressive strength a lower water addition is necessary, whereas to achieve better resistance to drop the pellet should present higher moisture content [4].

Urich and Han [15] studied the effect of grind on the quality of pellet of specular hematite and found that as the amount of particles smaller than 44 μm increases, the compressive strength (both green and indurated pellets), abrasion resistance, and other related properties improve considerably.

5. Evolution of binder for iron ore pelletizing

Binders are used in the pelletizing of iron ore aiming to improve the performance of the process in the following aspects [1, 4, 11, 16, 17]:

- promoting and facilitating the balling;
- increasing the green and dry strength of the pellets;
- preventing the collapse of pellets in the initial stages of heating, when a large volume of gas generated by water vaporization tends to crack pellets;
- improving the properties of the fired pellets.

Bentonite, an inorganic binder, has been the main binder used in the iron ore pelletizing process since the beginning of pellet production in the 1950s. Bentonite promotes the formation of ceramic bridges between particles, which can minimize the number of pellets that collapse during firing. Despite its low cost, the inorganic compounds from bentonite are contaminants increasing the amount of acid gangue in the pellet. This increases the amount of slag formed in iron and steelmaking, which add to the energy needs of such processes [18].

Organic binders have been used as an attractive alternative to bentonite in iron ore pelletizing process, mainly because it burns without leaving any residue in the final pellet. There are two main types of organic binders, those based on cellulose compounds and other based on polyacrylamide polymers.

Table 3 shows some patents from chemical industries claiming the employment of organic binders in iron ore pelletizing aiming to replace bentonite in the process. The effectiveness of the binders is given in terms of compressive strength of pellets compared with the results from using bentonite.

Regarding research papers, **Table 4** lists some publications, which report studies applying organic binders to iron ore pelletizing since the 1980s. All analyzed publications show results of compression strength (green and dry) and drop test from using organic binders. In some cases, the characterization of binders is also presented along with the discussion of their effects on the pellet properties. However, these studies do not explain how organic binders act to improve the properties of the pellets.

(Patent N°)	Binder	Others compounds	Compressive strength (kg)	
			Green	Dry
Allied Colloids Limited (EU 0225171—1987)	Copolymer of acrylamide	Sodium acrylate (Na_3Citrate) Na_2CO_3	0.4–0.71	2.07–6.02
Allied Colloids Limited (US 4.684.549—1987)	Copolymer of acrylamide/ Carboxymethyl cellulose	Sodium acrylate (Na_3Citrate) Na_2CO_3	0.4–0.71	2.07–6.02
Aqualon Company (US 4.863.512—1989)	Carboxymethyl cellulose	Sodium tripolyphosphate	0.77–1.54	4.76–7.85
Peridur® Nobel (US 5.698.007—1997)	Carboxymethyl cellulose (Peridur®)	Source of hydroxide ions (NaOH)	—	0.64–5.4
Peridur® Nobel (US 6.071.325—2000)	Carboxymethyl cellulose (Peridur®), polyacrylate, polyacrylamide, cellulose derivatives, guar gum, starches, dextrins, pectins	Source of hydroxide ions (NaOH)	—	0.68–3.22
Clariant S.A. Brazil (EP 2548978 A1—2013)	Homopolymer of methacrylic acid, acrylamide, maleic acid	Limestone/esmectite	1.24–1.61/ 1.44–2.61	2.9–6.59

Table 3. Patents about organic binders in the iron ore pelletizing process.

Iron ore	Binder	Characterization		Reference
		Binder	Pellets	
Hematite (CVRD nowadays VALE)	Peridur® and bentonite	No	Drop number, compressive strength (green, dry)	[19]
Magnetite	Peridur®	No	Drop number, strength (green, dry)	[20]
Taconite (Minnesota, USA)	CMC (Na_2CO_3, NaCl), Peridur®, bentonite	Substitution degree, viscosity	Drop number, strength (green, dry, fired) chemical and metallurgical properties	[21]
Magnetite	Organic binders and bentonite	PWA (plate water absorption test) Viscosity	Drop number, strength (green, dry, fired)	[18]
Magnetite (Carol Plant, Canada)	Organic binders (including Peridur®) and bentonite	No	Drop number, strength (green, dry, fired), metallurgical properties	[22]
CVRD Hematite (nowadays VALE)	CMC, TPP	No	Drop number, strength (green, dry)	[8]
Hematite (Ferteco)	CMC, TPP, organic binders	No	Drop number, strength (green, dry)	[23]
Pellet feed (China)	S-1 (modified starch type) and Funa (substance rich in humic acids obtained from lignite by caustic extraction)	Molecular design, wettability, ionization potential, electron affinity, binding energy	Drop number, strength (green, dry), thermal shock (820–780°C)	[24]
Pellet feed (Russia)	(Floform 1049 V) polyacrylamide	No	Physical, chemical and metallurgical properties	[25]
Iron ore concentrate	HS (Humic substances extracted from lignite)	Viscosity as a function of pH and temperature, adsorption	Drop number, strength (green, dry), thermal shock (550–600°C)	[26]
Pellet feed (Baiama Plant—China)	MHA (fulvic acid and humic acid)	Viscosity, zeta potential, pH, adsorption kinetic	Drop number, strength (green, dry), firing	[27]

Source: elaborated by the author with data from [8, 18–27].

Table 4. Scientific papers which investigated the effect of organic binders in iron ore concentrate pelletizing.

There are currently some organic binders available in the market for palletization of iron ore such as Peridur® from Akzo Nobel, Alcotac® from Basf Corporation, FLOFORM™ from SNF Floerger, KemPel™ from Kemira, FLOTICOR PA 8000 from Clariant among others.

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6. Induration technologies

The final use of iron ore pellets in ironmaking reactors requires minimum mechanical properties. Pellets must withstand tumbling and falling during transport and mechanical loading inside the reactors due to the charge weight. In order to increase its mechanical strength, green pellets are thermally treated in the induration process.

Pellets undergo drying, firing, and cooling steps. First, the water in the form of moisture is removed from the pellets in the drying steps. There is water in the pores and capillaries of pellets, that is, between different ore particles. In the case of porous ores, water may also be found in the pores of individual grains. Since this type of pores are normally smaller in size than the pellet pores, the temperature required to eliminate this water is expected to be higher. In the industrial process, the maximum temperatures reached in the solid phase during the drying steps are approximately 300°C.

After drying, pellets undergo firing steps, at which temperatures may reach 1350°C. In these steps, the roasting of all pellets components (ore, limestone, binders, etc.) occurs, liberating chemically bonded water and CO_2. Additionally, the sintering of ore grains also happens, leading to the development of mechanical strength. This sintering may be caused by solid state interaction of particles, but also with the presence of liquid phase, which can act as transport media increasing the sintering rate. The liquid phase also acts as bonds among ore particles.

The presence of liquid or semi-liquid phases is more pronounced in fluxed pellets where acid constituents normally from the ore (e.g., SiO_2 and Al_2O_3) may react with basic ones added in the form of fluxes (e.g., CaO and MgO). This reaction may result in the formation of a slag phase. **Figure 6** shows the phase diagram of the ternary system Al_2O_3-CaO-SiO_2 at 1200°C. At this temperature, liquid phase is present and indicated as "ASlag – liq." The reaction between iron oxide and fluxes or impurities is also possible. The interaction of CaO with Fe_2O_3 may lead to the formation of liquid phase below 1250°C.

The major development regarding pellet strength occurs at temperatures above 1200°C and is caused by the formation of necks between ore grains followed by pellet densification. These mechanisms are typical of solid state sintering. Pellet densification with increase in strength is controlled by the rate of oxygen diffusion in the hematite crystal [28].

To finalize the induration process, pellets are cooled down by contact with flow of ambient air. The resulting heated air is used in the upstream steps of firing and drying.

Induration processes were initially developed for ores composed of magnetite, since they are oxidized, producing hematite, and generating heat (−482.4 kJ/mol of Fe_3O_4). In the case of ores composed of hematite, this heat liberation does not happen and needs to be compensated. For this reason, hematite is agglomerated with controlled amounts of carbon (1–2% wt.) that burns during induration, generating the required heat. For both cases, heat is induced inside the pellet by the diffusion of hot air through the pores of pellets and subsequent chemical reaction. In the case of magnetite, heat generation is more uniform over the pellet volume, while for hematite it will be concentrated around carbon particles that must be evenly distributed. This

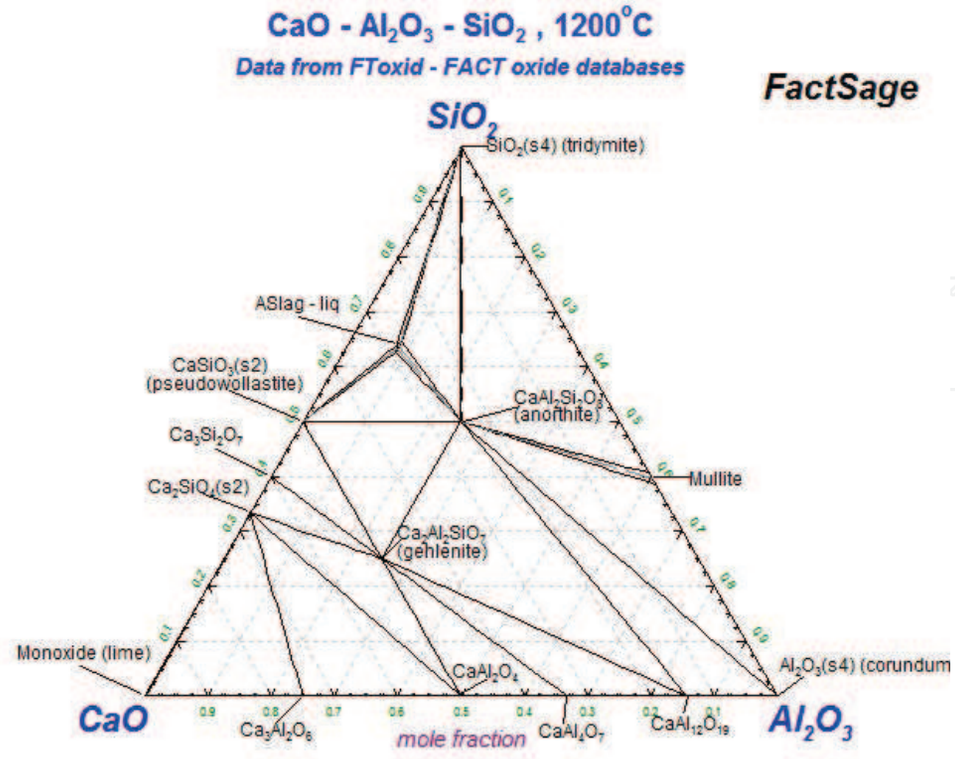


Figure 6. Isotherm at 1200°C phase diagram of CaO-SiO_2-Al_2O_3 system.

is the reason for using very fine solid fuels such as anthracite or coke breeze in the mixture to be agglomerated during balling.

The most widely used industrial processes for pellet induration are the straight grate and the grate-kiln.

The straight grate process is composed of a single furnace where an endless line of pallet cars moves. A layer of indurated pellets is arranged at the bottom of each car to protect it against the heat. The green pellets are then charged on top of the hearth of indurated pellets. A schematic diagram of this process is shown in **Figure 7**.

The process is designed to enhance heat recovery. Therefore, two flows of ambient air are heated while cooling the hot indurated pellets. These flows are directed to other zones of the furnace. This is a way of recovering the latent heat present in the hot indurated pellets.

The drying of green pellets is performed in two stages by blowing warm air through the bed of pellets. In the first stage, the hot air from the cooling zone is blown from the bottom. In the second drying stage, hot air from the firing zone is blown on the top of the car. The use of both updraft and downdraft drying ensures a more uniform treatment along the height of the bed of pellets.

The high temperature phase is divided into three steps: pre-heating, firing, and after-firing. In all these phases, pre-heated air is fed into burners to produce flue gases that flow through the bed of pellets from the top. The burners are usually fired with gaseous fuels, such as natural gas or atomized liquid fuels, such as diesel.

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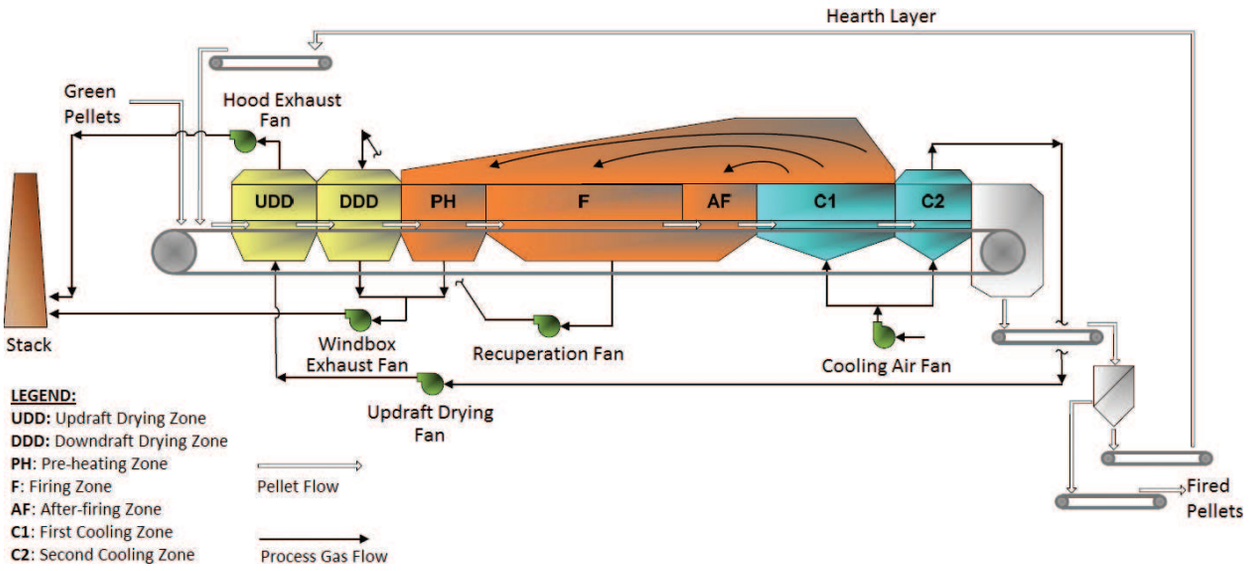


Figure 7. Schematic diagram of the straight grate induration process [29].

Since the hot air flows from the top of the bed in the high temperature steps, firing of pellets is not homogeneous. Pellets close to the top are treated at higher temperatures for longer times, while pellets at the bottom reach lower peak temperatures for shorter residence times. It is been reported [30] that pellets at the top may reach 1300°C for 6 minutes while pellets at the bottom peak at 1200°C with no residence time. These values may vary, but the difference is large enough to generate pellets with different mechanical strengths and different metallurgical proprieties. This is a disadvantage for the straight grate in comparison to the grate-kiln process.

In the grate-kiln process, shown in **Figure 8**, there are three different reactors. The drying, preheating, and cooling steps are similar to that of the straight grate process. The general concept

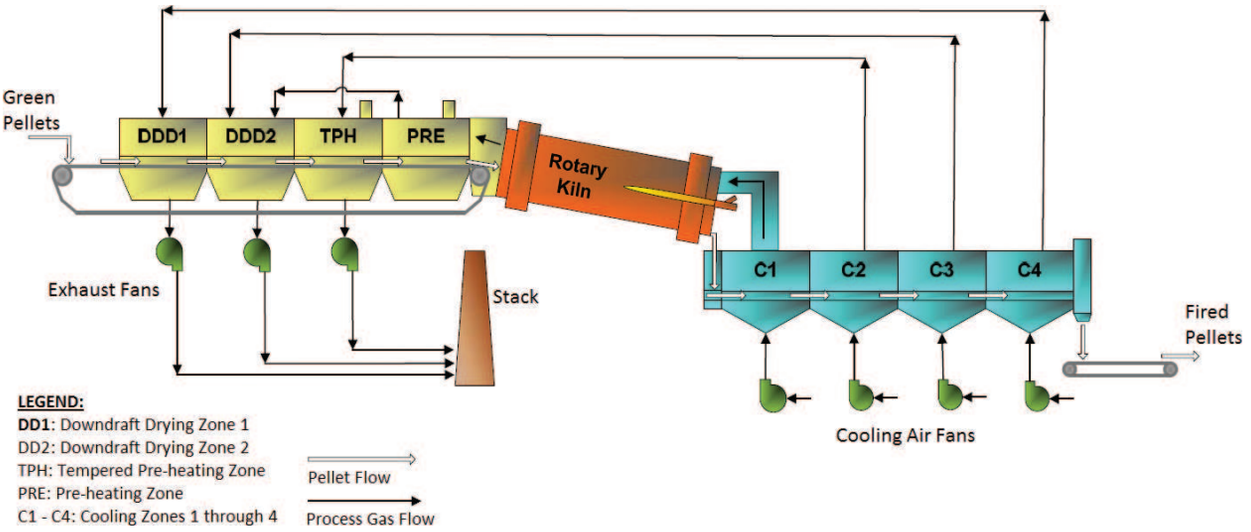


Figure 8. Schematic diagram of the grate-kiln induration process [29].

of heat recovery by using hot gases from downstream in the process for drying and for feeding the burners is also present. However, a rotary kiln is used for the firing step.

The pre-heating zone is divided into two steps: tempered pre-heating zone and pre-heating zone, where maximum temperatures may reach between 1000 and 1100°C. Pellets need to gain some mechanical strength during pre-heating to withstand the tumbling inside the rotating kiln where firing is performed.

The firing in the rotating kiln generates pellets with more uniform properties. The movement of the kiln causes pellets to mix during the firing treatment and the temperature is more even among different pellets. The furnace is heated with a flame on the discharge side. The use of fuel is more flexible in this case in comparison to the straight grate. Besides gaseous and liquid fuels, solid fuels such as coal may also be used. This is of particular interest in regions with availability of cheap solid fuels.

After firing, pellets are discharged in a pallet car for the cooling stages.

Therefore, pellets undergo more charging and discharging operations during the grate-kiln process than in the straight grate. This causes a greater generation of fines during the process. However, the final pellet properties are more uniform, and fines generation during transport for final use is therefore expected to be lower for pellets produced in the grate-kiln process.

The worldwide pelletizing capacity is divided into 60% for the straight grate process and 40% for the grate-kiln. Both systems are used to produce quality blast furnace and direct reduction pellets.

7. Challenges and innovations in iron ore pelletizing

The properties of iron ore depend much on its genesis. Different ores have distinct characteristics and varying performances in the mining and in the metallurgical processes. Ore particle shape, size, texture and capability of water retention, capillarity and cohesive strength among different particles determine the velocity of pellet growth during balling and pellet porosity. Ore characteristics also influence on the required amount of binder to produce pellets with satisfactorily quality. The use of iron ores with smaller crystal size and less dense structure usually results in pellets with better reducibility, impacting the performance of ironmaking reactors. Therefore, different iron ores should be valued in function of the benefit from their use [3].

The influence of ore characteristics on beneficiation, concentration, and pelletizing are important for process optimization, improving product quality, and consequently, more efficient use of natural resources and energy. Hence, as described by Moraes and Ribeiro [31], the growing importance of this topic that is referred to as geometallurgy is evident.

Mining companies work toward obtaining pellets with customized properties for each type of ironmaking process and also to meet specific requirements of different iron- and steelmaking

companies. Hence, the amount and quality of supplied iron ore products are important but also to provide a diversity of types of pellets.

Therefore, the reasons why new investments in pelletizing capacity are likely to occur are the following [29]:

- the pelletizing process is currently the most widely used option for producing suitable agglomerates for ironmaking applications from fines of iron ore concentrates;
- quality requirements for DR pellets are higher and since lump ore of the required quality is not available, pellets are the only viable feed for new DR plants;
- pellets provide advantages to end users, such as improved productivity of blast furnaces, opportunity to increase the Fe content of the charge materials, and superior environmental performance of pellet plants as compared to sinter plants;
- the main iron producing systems, blast furnace, and DR reactors, will not be replaced in the near future.

Acknowledgements

The authors would like to thank assistant researcher Dafne Pereira da Silva and interns (mining engineering students) Milton Candido Torres da Silva and Lucas Shin Takyia for helping find and organize figures and references.

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