CONTRIBUTIONS TO THE TECHNOLOGY COMPARISON BETWEEN STRAIGHT GRATE AND GRATE-KILN*

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Abstract
As the world's reserves of coarse and high-grade iron ores continue to shrink, beneficiation is becoming increasingly important. The resulting concentrates cannot be used directly as feedstock for iron making, but require an additional agglomeration step. Pelletizing is preferred, because the uniform chemical, physical, and metallurgical characteristics of pellets make them a more desirable feed for the iron making processes. The heat hardening or induration of pellets is typically done in shaft furnaces, grate-kiln systems or on straight grates. Rotary kilns were originally developed in the late 19th century for Portland cement production [1]. The main development work for the successful adaptation of the process to the thermal treatment (induration) of green balls from iron ore was performed by Allis Chalmers in Milwaukee, Wisconsin, USA in the 1960's [2].The straight grate process, which was first used in 1955 at Silver Bay, Minnesota, was a dedicated development with the aim to pelletize and indurate magnetite (taconite) concentrate [2]. There are various important technical and economical distinctions between the two pelletizing technologies. The most important differences include that a grate-kiln has three distinct pieces of equipment, a preheat grate, a rotary kiln and an annular cooler, whereas in the case of a straight grate, the entire indurating process is done on one piece of equipment only. In addition, both technological solutions have differences in their recuperation systems, direction of air flow in drying, number of burners, form of pellet movement, etc., which cause differences in raw material suitability, process control, economical aspects, plant operation and product pellet quality.

Keywords: Pelletizing; Induration; Straight Grate; Grate Kiln

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1 INTRODUCTION:

With the depletion of rich and coarse iron ores and the production of finer concentrates, pellets have become an important feedstock for blast furnaces and direct reduction furnaces. The most common pelletizing methods in the world are the straight grate and the grate-kiln technologies. Other technologies, such as shaft furnaces or the production of cold-bonded pellets play only a marginal role.
The pelletizing process consists of three principal steps:

1. The preparation of raw materials, especially the grinding to pelletizing fineness, if the material is not yet fine enough,
2. The formation of green pellets on a pelletizing disk or in a pelletizing drum,
3. The thermal treatment of pellets, including drying, preheating, firing (or induration) and cooling.

While the first two steps in the pelletizing process do not differ significantly between the two main technologies, the thermal treatment of the pellets is carried out in significantly different equipment.
The grate-kiln process, which has been inspired from furnaces designed in the cement industry, uses three distinct pieces of equipment to carry out the induration process: a preheat travelling grate, a rotary kiln, and an annular or straight cooler. Drying and preheating of the green pellets is accomplished on the preheat grate, while the pellets are fired in the rotary kiln and finally cooled in the annular or straight cooler.
In the straight grate technology, all thermal process steps are done in one piece of equipment, the traveling straight grate. It consists of a stationary furnace with an endless, revolving chain of pallet cars, carrying the pellets through the furnace, where they are dried, indurated and cooled [3].

2 TECHNICAL ASPECTS:

2.1 CAPACITY:

Since the inception of the pelletizing technology in the 1950’s when the first industrial plants were designed with capacities of 200 000 t/a, the plant and strand capacity has evolved substantially.
Today, grate-kiln systems are built and operated in units with up to 6 million t/a capacity (Bahrain Steel) , whereas straight grates produce up to 8.5 million t/a in individual strands (Samarco 4).
The biggest pelletizing complexes are situated in Brazil, where Vale operates the Tubarão complex with a maximum installed capacity of 36 million t/a (100% straight grate), In the Swedish province of Norbotten, where LKAB operates 4 grate-kiln and 2 straight grate plants with a total capacity of 16.5 million t/a (2/3 grate kiln, 1/3 straight grate) and in Canada, where IOC operates 4 straight grates at Carol Lake, New Foundland, with a combined capacity of 13 million t/a.
The installed pelletizing capacity world-wide amount totals 685 million t/a with 410 million t/a coming from straight grates and 226 million t/a coming from grate-kilns. The balance comes from other technologies, including shaft furnaces and cold-bonded pelletizing.

The capacity development is characterized by very active periods in between 1970 and 1980, and between 2005 and 2015, when 200 and 185 million t/a were added. A relatively quiet period was between 1980 and 2005, where the installed capacity remained almost stable between 350 and 400 million t/a.

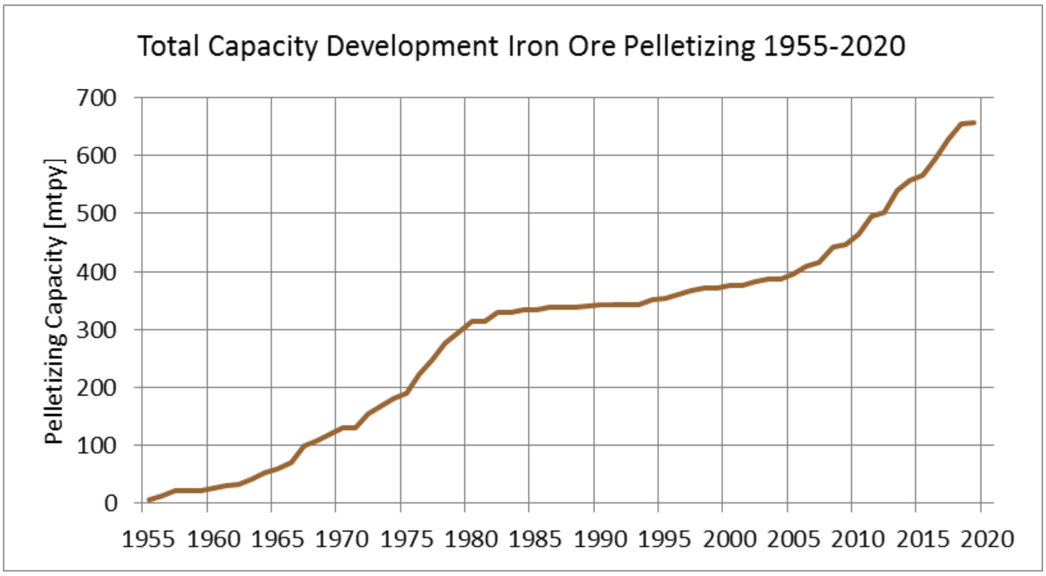

Figure 1: Capacity Development in Iron Ore Pelletizing

2.2 GEOGRAPHICAL DISTRIBUTION

Out of the total installed pelletizing capacity of 685 million t/a, 61% use straight grate technology, 33% grate-kiln technology, 5% shaft furnaces and 1% other technologies.
The principal pellet producing countries are the USA with 102 million t/a capacity (50% grate-kiln, 38% straight grate), India with 97 million t/a (82% straight grate, 16% grate-kiln), China with 73 million t/a (65% grate-kiln, 18% straight grate), Brazil with 73 million t/a (98% straight grate) and Iran with 64 million t/a (69% straight grate). Relevant shaft furnace capacity can be found in the USA, China and Canada, but all plants, except those in China and Australia, are shut down.
For the straight grate technology principal pellet producing countries are India (80Mtpa), Brazil (72Mtpa) and Iran (45Mtpa), and for the grate-kiln technology the USA (50 Mtpa), China (48 Mtpa) and Iran (20Mtpa).

2.3 PROCESS PRINCIPLES

2.3.1 PELLET TRANSPORT

The transfer of intermediate products is a critical element in the process chain and special attention needs to be given in the grate-kiln process, in particular the transfer of preheated pellets from the preheat grate to the rotary kiln. Such as depicted in figure 2, the cold compression strength of pellets depends on the firing temperature and differs significantly between hematite and magnetite ores.

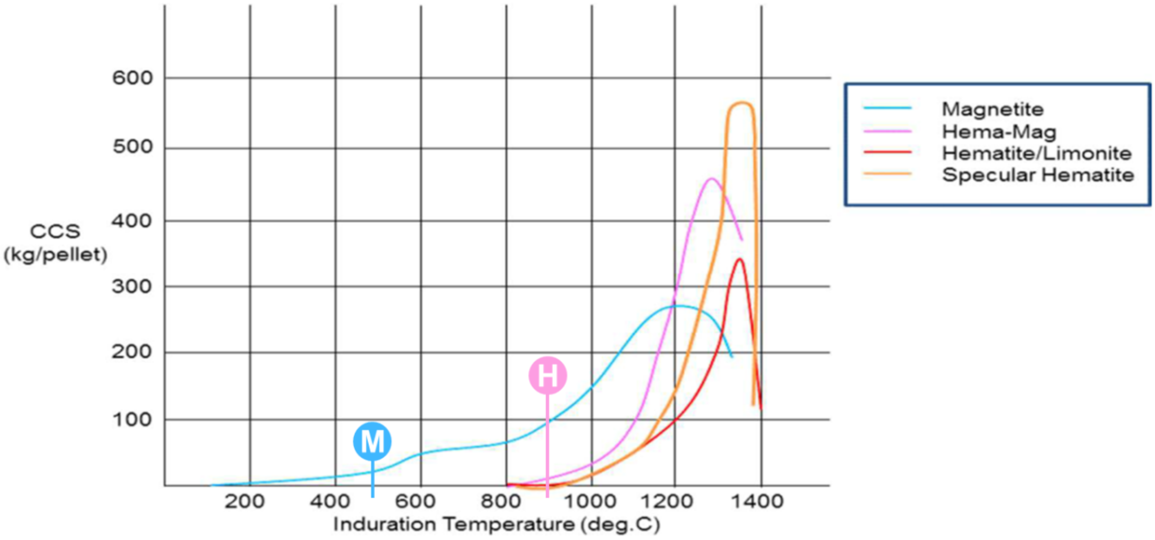

Figure 2. Relation between CCS and induration temperature for different type of iron ore [5]

While pellets made of magnetite develop a sufficiently high strength at lower temperatures, hematite pellets need to be exposed to temperatures above 900°C (marked in figure 2 with H) to develop a strength suitable for their transfer from the preheat grate to the rotary kiln. For this reason, grate-kiln systems have been predominantly installed for plants processing magnetite ores, whereas straight grates can be found for processing every type of raw material, confirming the flexibility of the process.

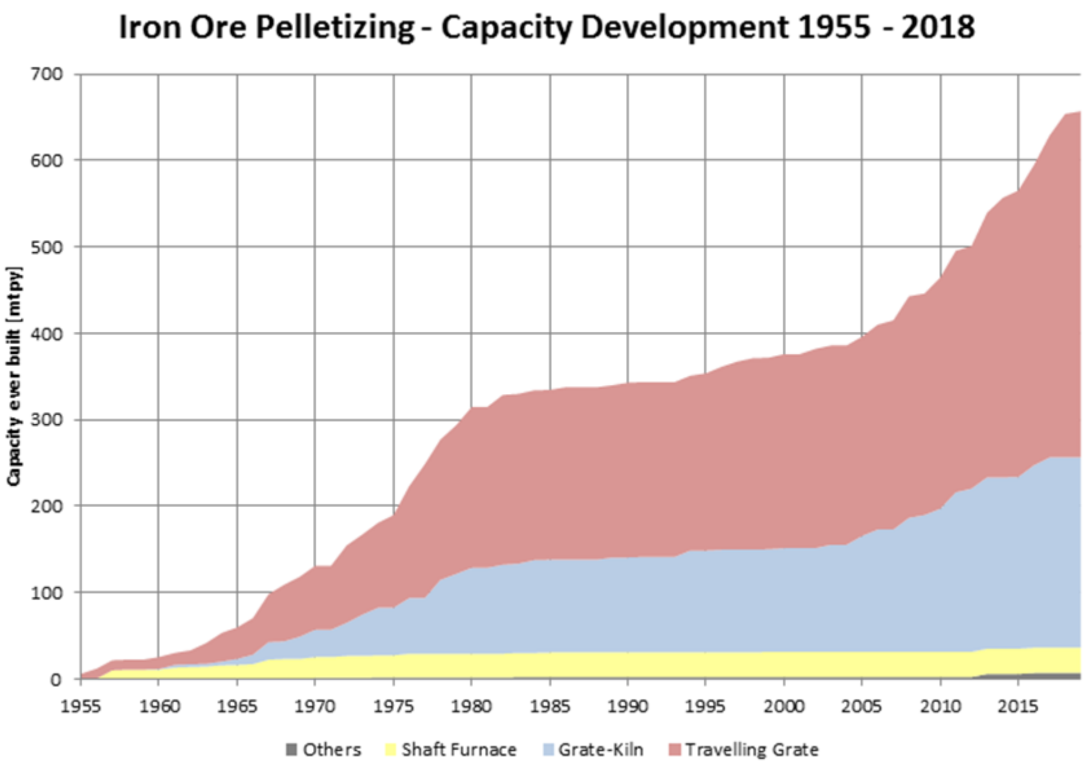

Figure 3: Capacity Development in Iron Ore Pelletizing for various technologies

In the grate-kiln process, the type of pellet transport changes. When on the preheat grate, the pellets rest on the grate plates and are carried through the furnace, whereas they tumble in the rotary kiln and remain stationary again on the cooler.
With the development of the technology, additional burners and adequate cooling systems have been installed in the critical area of the preheat grate, allowing the processing of hematite in grate-kiln plants, e.g. in Bahrain Steel, Vale Sohar or Tilden.
On the straight grate, the pellets remain stationary and are carried by the pallet cars throughout the various process zones. Due to the number of transfer points and tumbling movement in a rotary kiln, most dust is generated in the grate-kiln plant itself, which have to be recycled internally. Such fines are not generated in the straight grate due to the absence of any tumbling action, but straight grate pellets tend to be dustier than grate-kiln pellets. Another factor contributing to dust generation in the straight grate is the use of a hearth layer fraction, which, while being recycled, tends to generate more dust

2.3.2 BED HEIGHT AND PRESSURE DROP

Comparing both technologies, the bed height in the straight grate technology is higher. The straight grate technology requires the use of hearth layer, which ranges between 6 and 10cm in height, whereas the green pellet height is typically between 30 to 45cm. In the grate-kiln system, the bed height is 12 to 23 cm on the preheat grate and 60 to 100 cm on the cooler. The tumbling charge in the rotary kiln does not contribute significantly to the overall pressure drop of the system.
The pressure drop across a packed pellet bed can be described with the Ergun equation with the density and viscosity of the flowing process gas across the pellet bed fluctuating with changing process gas and pellet bed temperature. Thus, the velocity of gas differs with the bed height. The higher the bed height, the higher the pressure drop.

2.3.3 HEARTH LAYER

The straight grate requires hearth and side layer in order to protect the pallet cars from overheating and to improve the gas distribution over the cross section of the pellet bed.. Typically between 6 and 10cm of hearth layer are laid on the pellet car prior to the feeding of 30 – 40cm green pellets. Resulting that 25 to 30% of the charged pellets on to the pallet car are hearth and side layer pellets. The hearth layer contributes also to the overall pressure drop of the pellet bed.
The hearth and side layer fraction is separated from the total fired pellet quantity either by screening, segregation bin or by simple splitting of the required quantities from the total amount of discharged pellets. The recycled hearth layer tends to generate more fines and disintegrates with a certain preference.
Experienced operators pay a lot of attention to the separation of a narrow hearth layer fraction and occasionally also employ a rescreening of the hearth layer in order to reduce its fines contents and minimize the pressure drop.

The grate-kiln system does not require hearth layer, since the firing process takes place in a refractory-lined rotary kiln, which, on the other hand, comes with the disadvantage of higher refractory consumption, as he refractory is in direct contact with the hot pellets.
The induration process time is dependent on the raw material and quality requirements and is for the straight grate usually less than for the grate-kiln technology.

2.3.4 HEAT TRANSFER

The form of heat transfer differs in the two technologies. In the grate-kiln process, heat transfer is predominantly by radiation during the firing cycle, and convection plays its role during drying and preheating of the pellets. Whereas in the straight grate process, heat transfer is predominantly by convection only and the role of radiation is negligible. [6]

2.3.5 PROCESS GAS RECUPERATION

In the design of a pellet plant, it is always a challenge to find an optimum balance between the design of operational flexibility, based on the raw material composition, and the project's investment and operating costs.
It can be stated that normally the main process fans and burner systems can be upgraded and additional units can be implemented in the future just using a normal cold shutdown, whereas the implementation of changes and upgrades in the process gas system is much more delicate and difficult. Therefore, the initial process gas recuperation system design is very important for assuring the thermal efficiency in both technologies. There are different designs in the process gas flow scheme for grate-kiln and straight grate technologies. Depending on the raw material and gas composition, the recuperating system and gas flow can be designed differently.
In figure 4, a typical Grate-kiln flow sheet is shown, where the system consists of four-stage preheat grate with two internal recycles and a three-stage cooler:

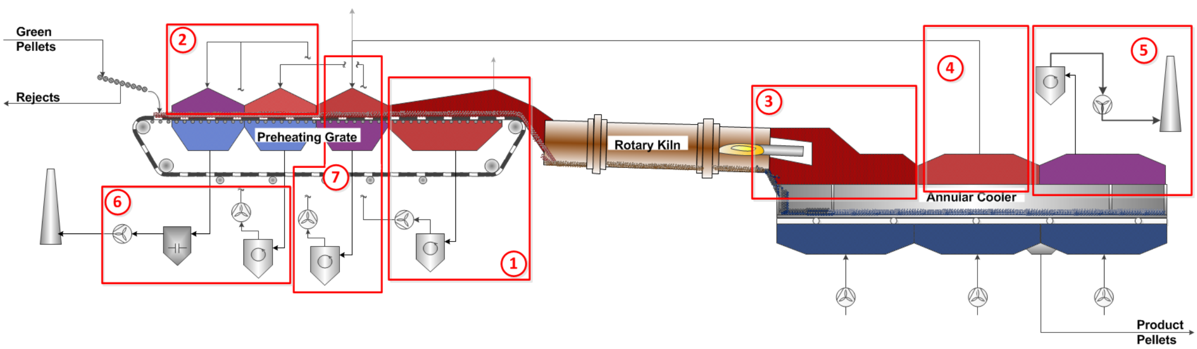

Figure 4: Typical Grate-Kiln Pelletizing System

For the design of the grate-kiln, it is important to identify the requirement of the pellet treatment on the preheat grate.
Standard design of a grate-kiln, the off gases of the last zone of the preheat grate,

marked in figure 4 with zone 1, will be recirculated to the drying zone (figure 4, zone 2). Furthermore the cooler off gas of the first cooling zone will be directly diverted to the kiln (zone 3), whereas the second cooling zone off gases are recirculated to the preheat grate (figure 4, zone 4). The recovery of the remaining off gas from the cooler (zone 5) will be defined, depending on the utilization of the off gases from the preheat grate (zone 6 and 7), otherwise these off gases will be released to the atmosphere.

The recirculation design of preheat grate off gases will be defined by resulting process off gas temperature and flow of zone 1. Further, the concentration of SOx in the off gas of zone 1, is of great relevance, to define the recirculation design and utilization of the preheat off gases of zone 1. When operating a grate-kiln with iron ore having a high sulphur content, it´s important that the off gas temperature exiting the gas treatment system of zone 6 above 140°C, in order to avoid the condensation of sulphur oxide. Typically the temperature of the off gases of zone 6 are lower, in the range of 60 to 110°C, thus the addition of hot process gas from zone 7 is required. This relation impacts in a much higher process gas volume to be cleaned. An alternative is to recirculate off gas from the last cooling area (zone 5), which mostly leads to certain thermal penalties during drying.

In figure 4, a standard design of straight grate technology is shown. The recuperation system of a straight grate consists of direct recuperation (figure 5, zone 1), an off gas recirculation from second cooling zone (figure 5, zone 2) to the first drying stage (figure 5 zone 3) and the windbox recuperation (figure 5, zone 4) recirculating hot process gas to the second drying zone (figure 5, zone 5). In some plants the hot process gases are recirculated to a distribution header (figure 5 zone 9), allowing the adjustment of the preheating temperature profile, as per process requirement.

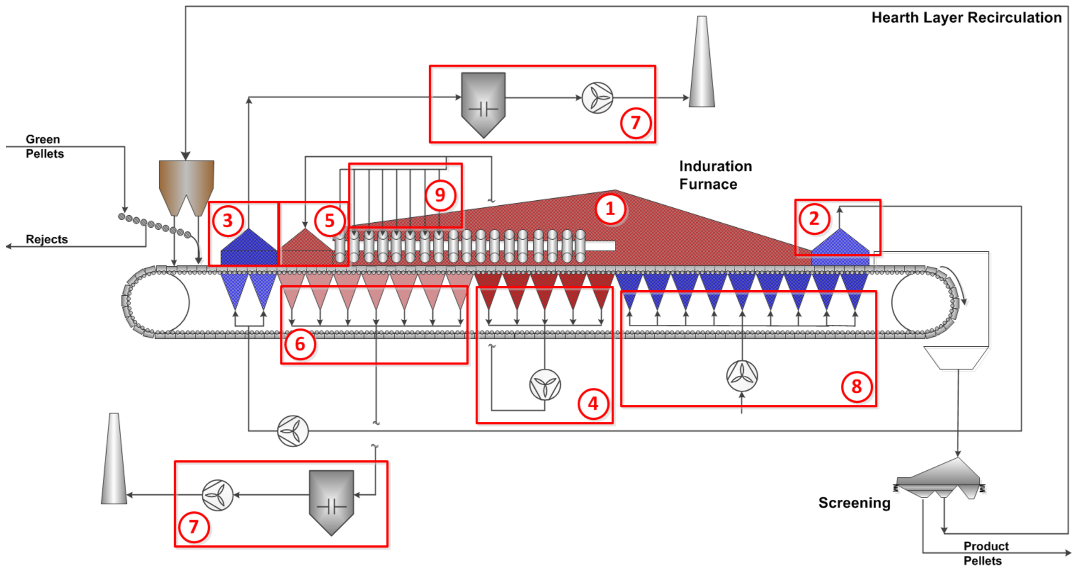

Figure 5: Standard design of straight grate

One great advantage of the straight grate is that the configuration of windboxes can be easily be changed to define off gas conditions, ideal for recirculation or gas cleaning equipment (figure 5 zones 7). Owing to this flexibility, various different recirculation concepts were implemented in the past by various technology providers, designing tailored solutions for the unique raw material characteristic and plant operation.

In comparison to the grate-kiln, the straight grate has in the past generated more development in the recirculating concepts, resulting in a continuous increase of the thermal efficiency. It is worthwhile mentioning that the development of a recirculation of hot off gases from the 2nd cooling zone to the first windboxes of the cooling zone (see zone 8) with a dedicated process fan. This change increased the cooling temperature from 25°C to above 200°C, which lead to a decrease of the cooling rate of the bottom layer pellets, improving ther compression strength of the bottom layer. Further such process contributes with small increase in the direct recuperation temperature (zone1).

Another development is the implementation of a split direct recuperation zone (zone 1), aiming at a more tailored recycling of off gases from the 1st cooling zone to all suction process zones.

2.4 RAW MATERIAL

2.4.1 IRON ORE

Straight grates are used for the induration of virtually any kind of iron ore, suitable for pelletizing. The ores do not need to develop a minimum strength for intermediate transfers and, due to their design with multiple lateral burners; virtually any heat profile can be implemented in the furnace.

This allows the processing of high grade magnetite, ensuring the full oxidization of the magnetic iron contents during preheating, as well as the oxidization of sulphidic ores and the reduction of sulphur below the limits required by downstream direct reduction processes. Especially for the production of acid pellets, sulphur reduction from up to 1% feed concentration to below 0.05% product concentration is known from operations in Iran and China.

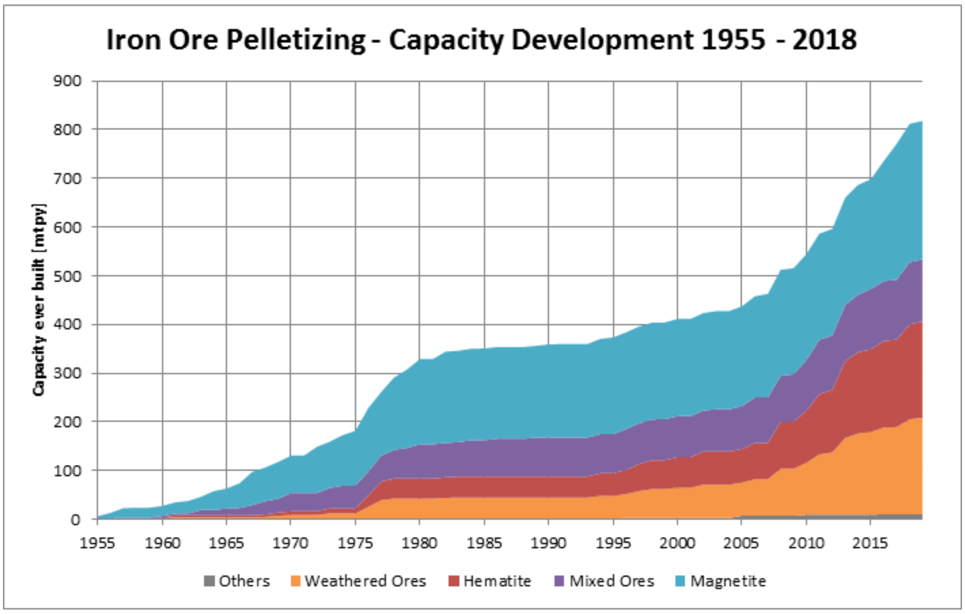

Figure 6: **Pelletizing capacity with ore mineral**

The flexibility of straight grates for the implementation of temperature profiles was

used in Australia, where pellet feed with a loss on ignition of up to 10% was processed to LOI-free product pellets, simultaneously increasing the iron content of the product.
For many years, grate-kiln systems were used almost exclusively for the processing of magnetite ores, but with technological advancement, they found more recently also their way in high capacity hematite plant, such as in Oman and Bahrain.
A certain process flexibility, e.g. for the processing of hematite, can be achieved by the installation of additional burners at the grate–kiln.

2.4.2 FUEL

Almost all thermal energy is introduced into the grate-kiln system via the central burner, installed at the discharge end of the rotary kiln. This burner can be operated on gaseous, liquid or solid fuels. There are various references where grate-kiln systems are operated exclusively with solid fuel (e.g. in Sweden and Chile), which, depending on the fuel prices, can give significant operational cost advantages.
Due to the installation of multiple, multiple smaller sized lateral burners, the operation of straight grates is typically limited to the use of gaseous or liquid fuels. Attempts to directly use solid fuel in straight grate furnaces failed, but today a number of straight grates operate in India where the solid fuel is gasified prior to its combustion in the furnace.
For hematite processing plants, the "magnetite equivalent" (maximum up to 1.2% C_{fixed}) is added to the pellet feed to generate thermal energy inside the pellet. This improves the thermal efficiency of such plants and also helps in increasing the porosity of the fired pellets, which supports a better pellet reducibility.

2.5. PRODUCT QUALITY

It is generally stated that grate-kiln systems produce pellets which are more homogeneously indurated, compared to pellets from a straight grate. The main reason is that in a kiln, the pellets are evenly and exposed longer to the firing temperature. In addition, the tumbling of pellets in the kiln gives better pellet surface conditions. It is also reported that the reducibility of grate-kiln pellets is affected. It seems there is a certain relation between reducibility and the pellet exposure to temperature during firing, meaning that, although the cold compression strength of pellets from grate-kilns is higher, and its reducibility can become less. As depicted in the figure below, with an increase of the pellet compression strength, the porosity drops, and therefore the reducibility characteristics deteriorate [8].

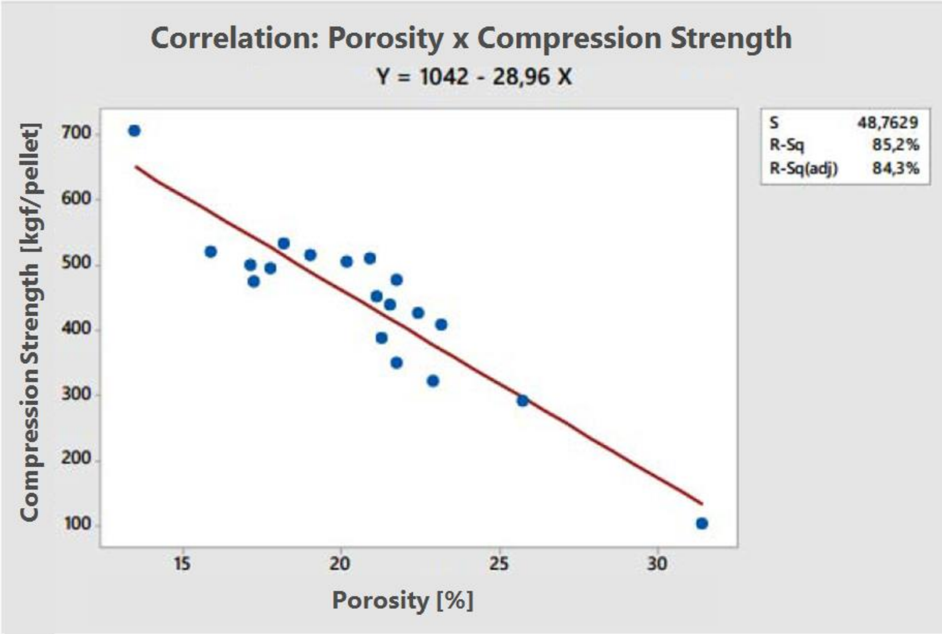

Figure 7: Relation between cold compression strength and porosity of pellet [8]

Owing to the characteristics of the grate-kiln technology, especially the exposure of pellets to the firing atmosphere, it is symptomatic that the grate-kiln generates a slightly higher number of pellets with high compression strength, which will have an impact on the overall reducibility. Furthermore the tumbling effect in the kiln, has a positive impact on the pellets tumbling strengths, which is better than in the straight grate technology.

Nevertheless, it case of the grate-kiln operation, the average product compression strength is control and defined by the kiln off gas temperature. In the other hand, the preheat grate operation and process condition, has a strong influence in the physical quality distribution of the pellet product. This means, in some cases, it is not unusual, that straight grate and the grate-kiln produce pellet quality with the same or very similar characteristics.

Iron ore pellets in both technologies are suitable for the use in direct reduction and blast furnaces. For the straight grate technology, the remaining FeO in the product pellets is typically less compared to the grate-kiln. This is because the heat transfer in the straight grate is predominately by convection, which allows a continuous air flow through the bed, and exposes the pellets to higher oxygen partial pressure, improving the oxidation reaction during firing. In the grate-kiln, the oxidation of magnetite gets interrupted in the kiln, and continues during the cooling phase.

2.6. MAINTENANCE AND OPERATION

In operation and maintenance, there are two key differences between the two technologies. Contrary to the straight grate, the kiln and cooler of the grate-kiln has moving refractory, which is in direct contact with the pellets. This results in more refractory damage. In the cooler, high refractory wear occurs in the rotary kiln discharge area. In the straight grate, product is transported below the refractory lined hood, but refractory wear occurs in burner ports.

The second key difference is that in the straight grate, contrary to the grate-kiln,

short plant stoppages are only needed to execute pallet car changes, for preventive maintenance.
These two features have a main impact on the overall plant availability and consequently, the maintenance strategy. Typically, grate-kiln plants have longer cold shutdowns than straight grates. On the other hand, straight grates are subject to a higher number of planned short stoppages.
In grate-kiln systems, only during major cold shutdowns can repair works be executed at the preheat grate, the rotary kiln and the cooler. In case of the straight grate, a pallet car exchange system allows to perform an overall maintenance of a pallet car off-line. A short daily stoppage of up to 5 minutes is typically enough to exchange one pallet car.
Therefore, it is quite common that grate-kiln plants operate with a lower yearly availability than the straight grate, i.e. up to 330 days per year. This is similar to the design availability of a straight grate; however it is not unusual for the straight grate plants, to achieve plant availability substantially higher than 330 days per year.
Apart from the availability, plant operators are making continuous efforts to achieve longer life cycle of the major plant units, requiring longer shutdowns. In case of the grate-kiln, it is reported that the rotary kiln requires a major repair cycle up to every five years, the preheat grate every two years and up to three years for the cooler. For grate-kiln maintenance, it is important to have a strategy in place not to execute all major repair works in the same shutdown. This is owing to the fact, that several repair works cannot be executed at the same time, as the major plant units intersect with each other, not allowing a safe execution of simultaneous works.
In the straight grate technology, typically every year a main cold shut down takes place allowing major repair works. But in recent past, great efforts were done, to extend the intervals of a main cold shutdown by more than one year. Some straight grate plants have established safe procedures allowing the repair of critical refractory items, such as the combustion chamber, during a short hot shutdown. This kind of procedure, allows extending the cold shutdown interval by more than 5 years. This means that in such cases, the straight grate can operate for 8 years without a cold shutdown, assuring constant yearly availabilities.
When it comes to the operation of grate-kiln plants, the fines generated in the process are of constant concern as it can cause chunk formation build up at the preheat grate, the rotary kiln and also in the cooler. The most critical are the chunks formed in the rotary kiln and cooler. At the rotary kiln, the generated fines result in ring formation (chunk), leading to backflow of hot pellets to the preheat grate, and to accretions at the hot grizzly of the kiln discharge. An accretion at the hot grizzly causes the flow of pellets to deviate, resulting in improper cooler charging, leading to insufficient cooling and the formation of larger clusters.
In the straight grate, the generation and accumulation of dust is only critical for the burner chambers, as they cause the risk of slagging and infiltration into the refractory, reducing the refractory life. Unlike the grate-kiln, the straight grate fines generation will not compromise the plant operation and its availability.
Considering how the burner systems are applied in the two technologies, the straight grate operates with a higher number of individual burners (up to 50 burners in big plant), giving it great operational flexibility, whereas the grate-kiln plant has only one main burner at the rotary kiln, resulting in very low maintenance, but providing less operational flexibility.
A grate-kiln plant normally operates with more process gas fans, than a straight grate plant. Typically, a straight grate plant has 5-6 fans and a grate-kiln plant 7-11.

In general, the process gas fans are exposed to similar conditions in both technologies.
Nevertheless, one difference is the configuration of the process gas fans, recuperating the heat from the last process zone of the preheat grate. That process zone has particularly highly exposed to the fines from the rotary kiln off gases, making it mandatory to be de-dusted before entering into the process gas fan, and even having a wear protected fan impeller, whereas in the straight grate, low rotating and wear protected fan impellers, are sufficient.
Sensitive and critical operation phases in both technologies that are unplanned can result in sudden plant stoppages. In case of such a stoppage of the straight grate, it is fundamental to maintain the furnace temperature and the process gas fans in a condition to avoid overheating and damaging the pallet cars inside the furnace. This can be done, by reducing the process gas flow through the firing zone. In the case of the grate-kiln, it is not possible to completely reduce the process gas flow through the rotary kiln. As the rotary kiln cannot be promptly stopped due to its inertia, the preheated pellets at the kiln feed end, would quickly cool down in the kiln firing zone, exposing the kiln refractory to a critical condition. So, to safeguard the kiln refractory it is crucial to maintain a constant heat exposure throughout the entire kiln circumference, by maintaining the kiln burner in operation and the kiln in rotation. Such conditions leads to, in some cases, one major disadvantage of the grate-kiln during an emergency stop, in which the process off gases of the rotary kiln burner have to be released to the atmosphere via an emergency stack, without any gas cleaning treatment. Contrary to that, all process gases from the straight grate at any condition and time will be released to the atmosphere always via the gas treatment system.

2.7. COMPARISON OF CONSUMPTION FIGURES

In the daily routine of the operation of both technologies, the following consumption figures play an important role for the control of the operational expenses of the induration furnaces: the electrical, thermal consumption, addition of additives and binder in the iron ore concentrate.
A direct comparison between both technologies can be difficult, as they are mostly not conclusive. If the differences are due to the installed technology, the raw materials used in the process or the utilization rate of the operating companies. Even the location of the installed technology can greatly influence the specific consumption, e.g. if the installation is at sea site, or at 1000m above sea level.
The consumption figures of additives, primarily related to the target specification of the fired pellet product, are not considered in this comparison. But, it is needed to emphasize, that different target specification of fired pellet, greatly influences the consumption figures, due to variations in the plant productivities for both the technologies.
In the case of the straight grate, the consumption figures for binders, are mainly influenced by the binder quality itself and the specific surface of the raw material mix used in the process. In the grate-kiln technology, it is necessary to differentiate the binder consumption, when processing hematite or magnetite ore. While processing a magnetite ore, the binder consumption will be similar to the straight grate, or can be even lower [8], due to the lower bed height in the grate-kiln travelling grate. However, when processing a hematite iron ore, and using bentonite as a binder, the

consumption is greatly influence by the specific surface of iron ore mix. This is attributed to the fact that the bentonite works also in increasing the strength of the preheated pellet, before being charged into the kiln. The same positive effect is also of significance, when considering the thermal consumption of a grate-kiln processing a hematite ore. This means, when applying hematite ore into a grate-kiln, it is recommended to operate with a significant higher specific surface, when compared to the straight grate, in order to operate with lowest thermal and binder consumption figures.
Considering same process and mechanical conditions for both technologies, i.e. pellet feed moisture, chemical and physical quality and type of pellet quality produced, the thermal energy consumption in a straight grate tends to be lower than in grate-kiln [7] [8] [9] [10]. The main difference between the two technologies is that the design of the straight grate technology allows the recovery of mostly all of the heat introduced to the pallet car and hearth layer. Where as in the grate kiln the grate plate temperatures of the preheat grate, is fully lost to the atmosphere. Another difference is that the grate-kiln shell temperature of the rotary kiln, is operated with an outer plate temperature of approximately 300 °C, whereas in the straight grate the furnace plate temperature is mostly below 100°C.
The main consumers of electrical energy are the process gas fans. Comparing the electrical consumption figures between both technologies is often not inconclusive, as many parameters influence the efficiency of the process gas fans, such as fan impeller blade shapes, efficiency of the motor drives, plant location above sea level, the use of variable speed drive and the nominal operation against the design value in case of a fix speed drive. But, considering the same process gas fan design condition, the electrical energy consumption tends to be lower in the grate-kiln. [7] [10]
Further, when comparing different consumption figures for the two technologies, it is necessary take into consideration at which productivity level the plant is being operated.

2.8. Environmental Aspects:

In reference to the environmental aspects, the following emissions are of interest: Dust, SOx, CO2 and NOx. Generally the environmental impacts are controlled and mitigated by the correct selection of the gas cleaning equipment's installed in both of the technologies. Nevertheless, both technologies have different potential in reducing the emission at the source, impact the capex and opex cost of the installed gas cleaning equipment, independently of the raw material quality.
In the previous chapter, it was stated that a grate-kiln plant generates more dust, when compared with a straight grate. As the stack emission will depend only on the dust cleaning equipment (ESP's, bag houses, scrubbers, multiclones/cyclones), the main difference between both technologies is that a grate-kiln requires a greater number and variety of dust cleaning equipment than a straight grate technology. Typically, a straight grate incorporates 2 to 3 main gas cleaning equipment for the process exhaust gases, whereas the grate-kiln has dust cleaning systems for the preheat grate and cooler gases and also a dust cleaning system in the process gas recuperation system to protect the fans. This fact, can lead to higher capex cost, in case of the grate-kiln.
The emission of SO_x depends solely on the quality of raw material and fuel used in

the operation, but in case of NO_x and CO_2-emissions, this is not completely the same case.
The emission of CO_2 goes along with the thermal energy consumption and tends to be lower in the straight grate [11], but is also influenced by the type and quantity of additives and fuels.
In the case of the NO_X emissions, there is an influence of the thermal and chemical NO_x generation. Comparing both technologies, the thermal NO_X is of importance, as chemical NO_X, is depending on the fuel used in the process. The thermal NO_x can be influenced by the burner design, primary and secondary burner air temperature and operating temperature of the firing zone. Design considerations to reduce the thermal NO_x, can be summarized as “primary abatement measures” at the source. In case the design modifications are not sufficient to meet legal requirement, the need of “secondary abatement measures” or “end of pipe”-systems are to be installed.
Considering the primary abatement measures, several systems were already tested and successfully operated in both of the technologies. The main burner of the grate - kiln benefits from solutions, developed for the cement industry. But, the thermal NO_x reduction potential at the main kiln burner is somewhat limited in comparison to the burner system in the straight grate. As the straight grate consists of many smaller burners, it is possible to isolate every single burner and create a separate combustion chamber providing the best condition to oppress the thermal NO_x formation. Such a system was successfully implemented at a modern plant in the USA.

4 CONCLUSIONS

Straight grates build bigger units compared to grate-kiln and grate-kiln has lower plant availability.
Straight grates are more flexible with different type of iron ore (hematite, magnetite and a mixture of the two), while in grate-kiln technologies the number of plants installed with hematite ore is limited.
Solid fuel cannot used in straight grate technology only in limited quantities as an additive to the pellet feed, here the grate-kiln is more flexible, since the main burner of the kiln can operate on solid fuel.
Straight grate facilities tend to be lower in thermal energy consumption while grate-kiln facilities tend to be lower in electrical energy consumption.
The consumption of refractory is significantly higher in the grate-kiln due to the direct contact of pellets with refractory in the kiln which increases maintenance.
For straight grate, the burner systems are more sophisticated.
In the grate-kiln, the physical product quality is more even, but the porosity and consequently the metallurgical quality of pellets seem to be better in straight grate.
Due to its better thermal efficiency, straight grates emit less CO_2 than grate-kiln systems.
Both technologies have been successfully used for the production of oxide pellets for blast furnace and direct reduction use. The success of installation and operation depends on the specific boundary conditions of the project, the diligent design of the systems and the careful and predictive operation and maintenance of the plants during their cycle.

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