Metall. Res. Technol. **119**, 311 (2022)
© A.G. Andrade et al., Published by EDP Sciences, 2022
https://doi.org/10.1051/metal/2022045

Metallurgical Research & Technology

Available online at:
www.metallurgical-research.org

Regular Article

Open Access

Impact of key parameters on the iron ore pellets roller screening performance

Alexandre Gonçalves Andrade[1,*], Steve Beaudin[1], and Maycon Athayde[2]

[1] Metal 7 Inc, 285, des Pionniers, CP 1590, G4R 4X9, Sept-Îles, QC, Canada
[2] Minerai de Fer du Québec, 1100, Boul. René-Lévesque Ouest, Suite 610, Montréal, QC H3B 4N4, Canada

Received: 18 March 2022 / Accepted: 5 May 2022

Abstract. The roller screening process is an important step in the iron ore pellets production. This step is intrinsically linked to the balling production and the induration machine. Improvements to the equipment performance not only promotes benefits to the plant's productivity, but also in the final product's quality. Several parameters influence the equipment's performance, impacting directly or indirectly the screening ratio (ton/m^2 of open screen area). The objective of this work is to provide information regarding the key parameters influencing the roller screening performance through practical expertise and literature review, due to the lack of studies related to this important equipment. It is a review manuscript describing the screen variables and its impact on the iron ore pelletizing process.

Keywords: roller screening performance / roller screen / roller feeder / iron ore pellets quality / plant productivity

1 Introduction

The iron ore pellet is one of the most important raw materials in ironmaking, where the process increases the possibility of high-grade ore utilization, due to the upgrading process of low-grade deposits. As the ore is processed through different equipment with the objective to reduce its size and liberate the desirable mineral from the impurities, different steps of fragmentation, separation by size, concentration, dewatering, etc. are performed [1]. The size distribution is no longer suitable to counterflow reactor, where the right sizing of pellet has a paramount importance. However, ore comminution can also be performed in the pelletizing unit, so the transport of pellet feed is done in a dry or wet basis. The proper moisture level and addition of limestone, coal/coke, dolomite, and binders are also important to promote a better firing process and correct final chemical composition [2]. Therefore, to adjust green pellets sizing to serve as iron burden, a fundamental equipment, the roller screen, is used between the balling disk/drum circuits and the induration furnace to remove the undesirable out-of-spec sizes for the induration process. It is well established that the fired pellet size distribution affects the mechanical resistance with consequent impact in the metallic iron production in the steelmaking plants [2–4].

Originally, in the late 50's, pelletizing plants were designed using vibrating screens, notably the technology promotes a high degradation rate to the on-size pellets and drastically reduces the process efficiency. Then, roller conveyor technology developed in 1958 to solve a specific problem of green pellets handling for International Nickel Co. at Copper Cliffs in Canada [5], provides feasibility for industrial applications later in the 60–70's for roller screening technology in the modern concept based on roller screening, where pellets are submitted to much lower stress compared to the former technology. The roller screen is a machine composed of a group of rollers rotating in the same direction, at a defined rotation speed and arranged in a way to keep a specific gap opening between each roll. Defined by the gap opening strategy [6], it is used to separate the material flow in two different groups; retained and passing. Meyer [5] compared screening efficiency for both technologies, showing 25% more efficiency by using the roller screening technology, with less damage on the green pellets. Besides the fact that vibrating screen technology presents highly intensive maintenance, it can also create structural damages in industrial buildings, depending on the level of vibration used, in terms of frequency and excitation angle. Goncharenko et al. [7] evaluated the performance of the vibrating screen versus

* e-mail: agandrade@metal7.com

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

the roller screen in an industrial unit, proving the benefits of reduction on recirculating loads to the drums by 10–20%, better pellets homogeneity, reduction of fines particles by 0.8–1.2%, inexistence of pellets build-up due to the high moisture level (normally closing the vibrating screens grate meshes), and finally, a possible increase of production by up to 50%, etc. Akbar and Vahid [8], Zhang et al. [9] and Wang and Tong [10] have directed intensive studies of vibrating screen performance depending on different variables, showing screening efficiency levels varying between 5% and 75%, according to the variables applied in vibrating screen and the material processed in the machine.

Current practices in certain plants use the roller screen technology after the disk/drum system and another device just before the entrance of the induration furnace for a final classification purpose. Others use this machine only before the entrance of the induration furnace. Cruz and Santos [11] explain the importance of the correct green pellet's classification for the induration furnace, promoting a better gas flow in the pellet bed through the different stages of the firing process, due to increased and even permeability, therefore contributing to reduce costs related to the furnace's energy consumption. Consequently, producing greater pellet quality and reducing dust generation/emission. The main objective for the screening process is to remove undersized and oversized particles from the pellet production. Nevertheless, an inefficient process may allow on-size pellets in the recirculating load. This undesirable scenario reduces the induration furnace and balling productivity. Athayde et al. [3] demonstrated the impact of different pellet size fractions on performance of operation, improvements on the fired pellets, less fines generation during handling and superior metallurgical behavior during the reduction process, resulting in the production of direct reduction iron (DRI) that consequently add more value to the economic performance of the electric arc furnaces (EAF). A good screening performance is even more important for the pelletizing units using the drum technology for the pellet feed agglomeration step since this technology normally processes a higher quantity of recirculating load for the drums, between 150 to 300% comparatively to 20–30% of recirculating load for the circuits using disks. Consequently, the drums will work with higher loads to be able to promote a good productivity on the process. With that, the screening machine will work at full capacity all the time, reducing its efficiency [12,13].

In regards to furnace benefits, a higher granulometry homogeneity of pellets allows an optimum energy consumption due to the better permeability of the pellet bed profile [14], while a higher pellets heterogeneity negatively affects the grate car permeability [15]. The screen is responsible in guaranteeing a good pellets homogeneity in the induration furnace.

2 Mechanisms of classification

Williams [16] studied in 1976 the phenomenon of segregation in granular mixture relationship with particle size for a bidimensional system. Segregation is greatly relevant in different particle sizes with different densities, shapes, or particle resilience. Mechanisms of segregation are encompassed by 3 stages: trajectory segregation, percolation of fine particles, and the rise of coarse particles at vibration movement.

- Trajectory segregation refers to the horizontal movement of the particles. Where the coarser particles will move further than the smaller particles.
- Percolation of fine particles refers to the movement of fines particles from the top layer to the bottom layer of a granular bed profile in movement or vibration. It is explained by the fact that gaps appear in the granular bed and the fine particles tends to fill these gaps, moving from the top to the bottom layer.
- The rise of coarse particles at vibration movement, refers to the movement of the bigger particles from the bottom to the top layer of a granular bed profile. Coarse particles increase the pressure zone below them, compacting the material and rising the large particles.

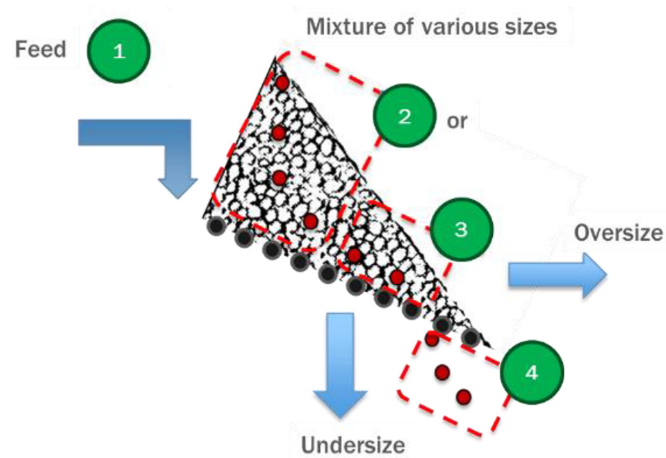

Fig. 1. Pellet's movement over the roller screen process.

Some years later, Drahun and Bridgwater [17] quantitatively studied the segregation in granular materials on an inclined plane depending on the diameter ratio and particles concentration of the mixture, this phenomenon was called free surface segregation. Additionally, it was concluded that the segregation is more evident for different particle sizes and densities.

Comparatively, Figure 1 represents the screening phases over a roller screening process. The (1) Green balls feed the roller screening deck, starting the classification process. Subsequently, the rearrangement of the green balls in the pellet bed (2) and fine particle percolate happens or free fall processes takes place. Also, large particles may float up in this step. It means that at the same time, fine particles move from the top layer to the bottom layer and the larger particles move from the bottom layer to the top layer. A probability event of undersized pellet achieves the gap opening (3), where in this step, the particles closer in dimension to the gap opening will touch the rolls surface, being able to be accordingly classified. Finally, the separation/classification process (4) after the contact of the fine particles to the gap opening and the separation or classification process takes place.

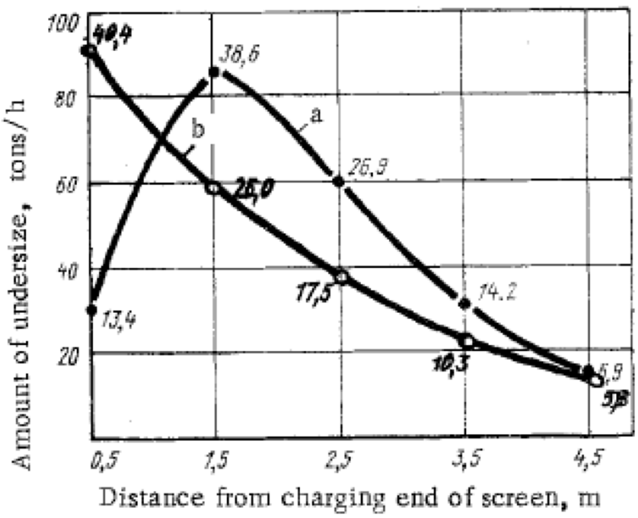

Fig. 2. Screening of undersize along roller screen before (a) and after (b) installation of baffle (numbers next to curves denote fraction of undersize screened on a given section.

The studies carried out by Goncharenko et al. [7] show that the position of the feed in the screen deck may significatively increase the recovery of fines, proving the existence of the percolation or free fall segregation process, described by Drahun and Bridgwater [17]; Williams [16]. Other studies conducted with iron ore stockpiles proved the presence of the segregation and stratification phenomenon [18]. Hogg [19] has also described the segregation processes in the hoppers and bins. Figure 2 is an extract of the study conducted by Goncharenko et al. [7] showing the different undersized pellets screening efficiency according to the evaluation position on the screening machine.

Another phenomenon affecting the screening performance of a roller screening process is the particle shape, considering that the pelletizing process is not 100% efficient in creating spherical green pellets. Figure 3 explains the impact of the pellets shape in removing fine particles. Particle A is too big to be screened in any orientation, therefore, rollers must probably retain the particle. Particle B is smaller than the gap opening, so it will pass throw the gap opening in any orientation. Particles C and D refers to the same particle, but in different orientations. It is possible to see that in the orientation represented in C, the particle will be retained by the rollers gap, while in position D, it will pass through the gap opening. It is also important to note that the rotation movement in the roller screening process will accommodate the travel of the particles between the rolls, but the particles must reach the rollers for this purpose. So, greater feeding for small open screen area (available area for the screening purpose = area calculated by the gap opening) will negatively impact the screening performance.

Characteristics of the pellet feed used to produce pellets are also very important in the evaluation, normally reported by the green pellets' plasticity or fragility, acting as proxy of the combined effect of pellet feed moisture content, particle fineness, binder agent dosage and pellets handling operations, according to [20–25].

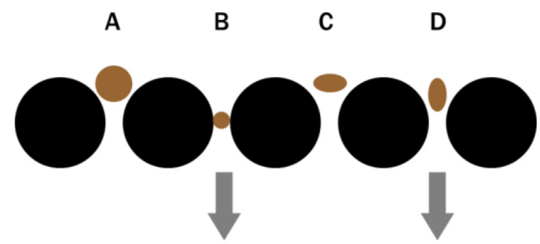

Fig. 3. Particle's shape impacting the roller screen process.

The roller screening process is a probabilistic process depending on the movement of the green pellets over the equipment, screen deck inclination, particles orientation (if not symmetrical), particle size distribution, particle shape, gap opening and the residence time over the screen.

There is a very limited quantity of technical studies related to the roller screening process [24,26–30]. Therefore, the objective of this publication is to provide detailed information about the principal roller screening parameters and their impact on the roller screening efficiency. It is a review manuscript describing the screen variables and their impact on the iron ore pelletizing process.

3 Screening efficiency definition

It is important to set the understanding of the screening efficiency in a roller screening process. For that, we must consider the efficiency of a specific equipment to retain the good size pellets in the final product, and the capacity to remove the undersized and oversized pellets from the process.

$$\%\,SE = \left(\frac{GS_f}{GS_i}\right)\%\,GS_i + \left(\frac{US_f - US_i}{US_i}\right)\%\,US_i + \left(\frac{OS_f - OS_i}{OS_i}\right)\%\,OS_i \quad (1)$$

where, $\%SE$ = screening efficiency, GS_f = good size pellets in final product (ton), GS_i = good size pellets initial (ton), $\%GS_i$ = percentage of good size pellets at feeding point. US_f = undersized pellets in the fines product (ton), US_i = undersized pellets initial (ton), $\%US_i$ = percentage of undersized pellets at feeding point. OS_f = oversized pellets at oversize product (ton), OS_i = oversized pellets initial (ton), $\%OS_i$ = percentage of oversized pellets at feeding point.

Considering a roller screen configured to remove only fines, using a gap opening of 8.00 mm for example. A theoretical process should be able to remove 100% of pellets below 8.00 mm in diameter and retain 100% of pellets above this dimension. But, in real operation conditions, it is not what happens. Usually, screening efficiencies are around 75%, according to equation (1). Considering a process working in 85% efficiency, by the implementation of some solutions covered in this work, the quantity of good size pellets in the final product will be greater and the quantity of fines removed in the screening will be similarly increased. It will provide benefits in the

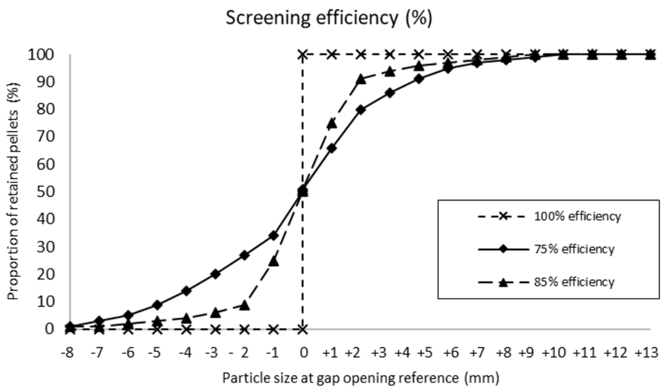

Fig. 4. Screening efficiency.

induration furnace performance and final pellets quality. Figure 4 presents a theoretical comparison of the screening efficiency considering the scenarios above-mentioned.

Thomazini [29] has reported, through discrete element analysis (DEM), the screening efficiency of an iron ore pelletizing plant using a single deck roller screen (SDRS) at the discharge end of a balling disk using a gap strategy of 9.00 mm for undersize removal and 16.00 mm for oversized removal and feed tonnage of 130 ton/h. Additionally, a double-deck roller feeder (DDRF) was simulated also at a gapping of 16.00 mm for the oversized removal screen and 9.00 mm for the undersized removal screen, feed tonnage of 910.00 ton/h.

For the SDRS simulations, Figure 5 represents the mass recovery by size fraction, from a total of 19.4% of material compounding the recirculating load, 14.4% represents good-size pellets (8.00 mm to 18.00 mm). It demonstrates an important inefficiency in the process. For the DDRF simulations, an important portion of pellets between 8.00 mm to 9.5 is discharged in the undersized removal deck, same for pellets over 18.00 mm.

The contamination of good size pellets (8.00 mm to 18.00 mm) in the total return rate in this case was 6.5% of the total feed tonnage. There are different types of screening configurations that can be evaluated and installed in pellet plants, depending on the user requirements.

4 Types of screening equipment

There are different configurations of roller screening equipment, presented in Figure 6. The first type presented is called the Single-deck Roller Screening (SDRS) represented by the Figure 6a. This configuration is applied at the discharge end of the balling process, pelletizing disks or drums. This device normally uses smaller diameter rolls, improving the screening surface for a specific footprint. This configuration can be set to remove just undersized pellets or to remove undersized and oversized pellets.

The Single-deck Roller Feeder (SDRF) represented by Figure 6b used at the furnace entrance for a final sizing classification. It has the same configuration as a SDRS, therefore the main difference is related to the screen inclination angle and the rollers diameter, length, and velocity. These modifications are necessary to handle greater quantities of green pellets feeding the equipment.

The next equipment is the Double-deck Roller Feeder (DDRF) represented by Figure 6c, which is also applied at the furnace entrance, and is composed by two decks with different objectives. The first deck is designed to remove the oversized pellets, the second deck is designed to remove fines and retain the good size pellets. Normally, the first deck uses a lower inclination angle and the second uses a higher inclination angle to be able to handle all the material without creating a process bottleneck. This configuration can also be used to create the segregation concept in the pellet bed, by using a different gap strategy, which is obtained by using smaller gap opening in the first part of the lower deck and a larger gap opening at the end part of the deck.

The following equipment is the Triple-Deck Roller Feeder (TDRF) patented by Metal 7 Inc and represented by Figure 6d. The particularity of this configuration is related to the addition of an intermediate deck between the upper and lower decks. It was specifically designed to promote an increase of the screening surface for the same footprint and additionally boost the segregation concept in the pellet bed over the grate cars feeding the induration furnace. The segregation concept aims to properly distribute the larger diameter pellets in the top layer of the pellet bed and the smaller diameter in the bottom part of the pellet bed. It improves the overall firing process, since the downwards air flow inside the furnace will first encounter the bigger pellets, which require longer exposition time at higher temperature for a proper induration process. Using the higher temperatures for the bigger diameter pellets and lower temperatures for the smaller diameter pellets, which requires shorter time for the heat transfer process reaching the pellet core and promoting the induration reaction, it will increase the furnace productivity and/or reduction on the thermal consumption according to Beaudin and Godin [31].

To facilitate the explanation of the different parameters impacting the performance of the roller screen process, the paper was divided in two groups, presented in the next chapters. The first group refers to the parameters directly impacting the screening ratio, in other words the quantity of material feed divided by the total open screen area (ton/m^2 of open screen area). The second group refers to general factors impacting the screening efficiency.

5 Screening efficiency impacted by the screening ratio (ton/m^2)

The screening ratio is the relation between the total quantity of material feeding the machine divided by the total area available for screening the material, normally presented in ton/m^2. It is important to have enough open screen area to process the total feeding material, otherwise part of the pellets will not touch the gap opening to be properly classified.

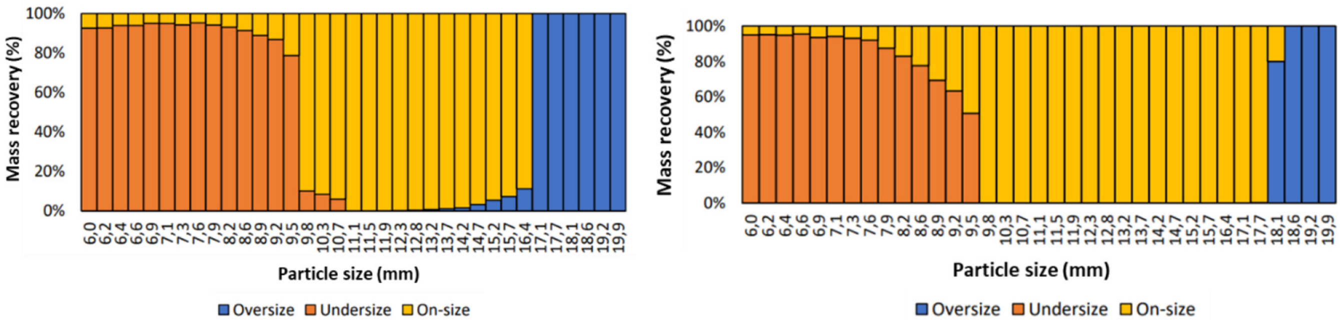

Fig. 5. Mass recovery in DEM simulations for a double-deck roller feeder (DDRF) [29] (translated).

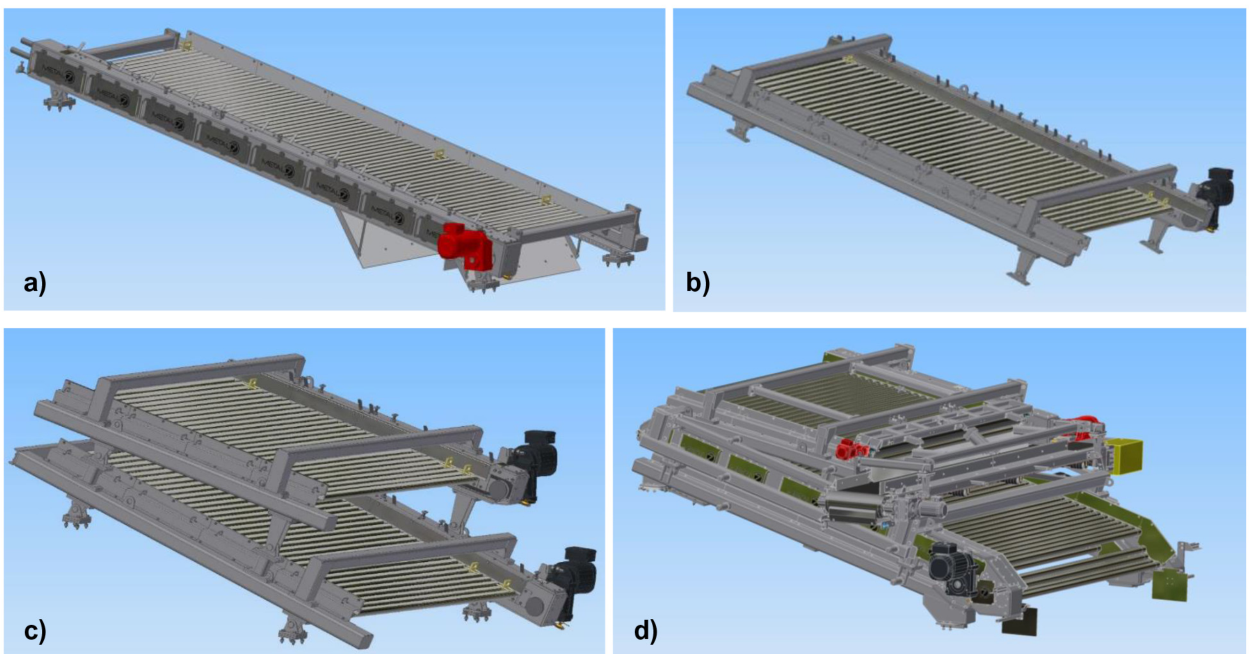

Fig. 6. Roller screening equipment models. (a) Single-deck roller screen, (b) single-deck roller feeder, (c) double-deck roller feeder, (d) triple-deck roller feeder.

5.1 Quantity of rolls

The quantity of rolls has a major impact on the screening ratio. In other words, the higher the quantity of rolls for the same feed tonnage, lower will be the screening ratio, in ton/m^2. This configuration will provide more screening surface for the same feed tonnage, increasing the probability of the particles reaching the gap opening between rolls, improving the screening efficiency. On the other hand, the higher the quantity of rolls, higher will be the plant footprint and higher CAPEX and OPEX are required. A high quantity of rolls can present a negative effect on the pellet's transportability perspective. A low pellets load can create the "cigarette effect". This phenomenon occurs when some pellets get stuck between rollers, turning over its axe, without moving them out to the next rollers, this rotational movement deforms the sphere-like pellets into small cylinders of iron ore. The "cigarette effect" closes the roller gaps destined for pellets screening. So, the correct load of material is important to force the movement of pellets over the roller screening machine. Some machine configurations can help solve this problem: changing the gap strategy or rollers rotational speed, promoting positive impact on the roller screening performance.

5.2 Rolls' diameter

Pellet plant operators can decide to improve screen capacity by reducing the rolls' diameter and adding more rolls in the same existing footprint, significantly increasing the open screen area. Figure 7 presents a comparison between a roller screen using rolls of 155 mm diameter versus 115 mm diameter. The final quantity of rolls for the case using 155 mm is 28 rolls and 38 rolls for the case using 115 mm rolls. An increase of 10 rolls for the same footprint. This configuration change represents an increase of 35% on the open screen area.

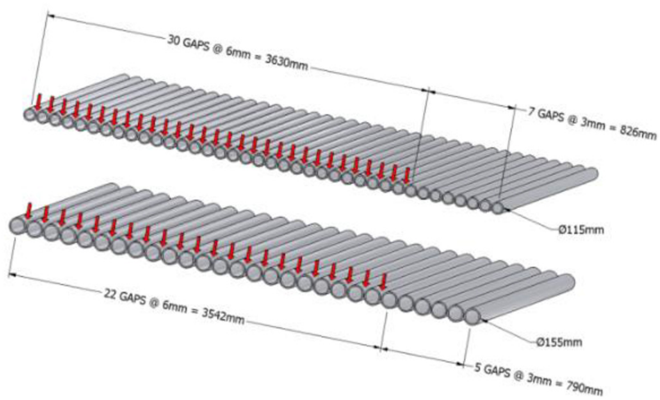

Fig. 7. Comparison between a roller screen using diameter rolls of 155 mm and 115 mm.

Silva et al. [28] studied the impact of changing the roller screening parameters in the screening efficiency using discrete element method (DEM). One of the parameters studied was the reduction of the roll's diameter from 75.0 mm to 57.8 mm. Therefore, increasing the quantity of rolls for the same footprint. The parameters used in this study is presented in Table 1. The optimum configuration described by Silva et al. [28] was able to increase the global screening efficiency from 85.6% to 91.5%. This improvement was mainly impacted by the greater ability of the screen to remove undersized particles. As observed, the rolls' diameter was one of the modifications done in the original screening configuration, but the final benefits achieved represent a multifunction relation between parameters.

5.3 Rolls' length

The impact of the rolls' length in the screening surface is clear, it will impact the total screening width, promoting an increase of the open screen area. For a better understanding of the screening length, comparing two different screening configurations using the same parameters, excepted by the roll's length. As an example, using a Single-deck Roller Screen with 60 rolls of 75 mm on diameter and gap opening of 8.00 mm. The only difference is related to the rolls' length (L), the first configuration uses rolls with 1600 mm on length and the second uses 2300 mm. The open screen area, represented by the area available for the screening process, was increased from 7.96 m^2 to 11.45 m^2. If only the gap opening area is considered for the calculations, the increase is from 0.75 m^2 to 1.08 m^2, both calculations represent an increase of approximately 44%.

5.4 Feed tonnage

A higher amount of material feeding the roller screening process will negatively impact the equipment efficiency if the screening surface is not enough to handle it. In other words, if there are excessive quantities of material feeding the device, the screening ratio will be higher and the probability of part of the particles not touching the gap opening will increase, reducing the probability of particles to be correctly classified.

Table 1. Parameters used by Silva et al. [28] (modified).

Parameters	Base case	Optimum configuration
Rolls diameter (mm)	75.0	57.8
Rolls rotation frequency (rpm)	80	140
Deck inclination angle (°)	15	9
Undersized gap opening (mm)	8.75	8.40

Yang et al. [32] studied through discrete element analysis (DEM) the effect of different parameters in a coal roller screening efficiency, including the feed tonnage. They also studied different particles shapes, comparing the performance of non-spherical and spherical shapes. The feed rate has a direct impact on the roller screening efficiency for equipment at 6 degrees of inclination angle and rolls speed rotation at 100 rpm. The same behavior was observed for both non-spherical particles and spherical particles. The results are presented in Figure 8. As presented in the results, greater the feeding rate, lower will be the screening efficiency for the same equipment configuration. This is explained by the excessive quantity of material over the screen, in which a part of the material does not reach the gap opening to be classified. Resulting in a reduction of the screening efficiency, or in other words, higher quantities of undersized and oversized pellets in the final product. The parameters used in the study was: Single Deck Roller Screen with 15 rolls of 1800 mm length and 240 mm diameter, using 80 mm of gap opening. Feed rate varying between 500 and 900 kg/s (or 2340 t/h).

6. Screening efficiency impacted by other factors

There are other parameters impacting the roller screening efficiency not directly related to the screening ratio (ton/m^2). It will be explained in more details in this chapter.

6.1 Particle size distribution

Particle size distribution, or PSD, is a characteristic of the green pellets, being impacted by the balling process, moisture content and binders added. The PSD represents the percentage of each range of the product leaving the balling machines. The studies from Goncharenko et al. [7] shows that use of up to 11–11.5% moisture in the pellet charge does not lead to spontaneous pellets accretion on the roller screen, as it inevitably occurs on the vibrating screens. Dias et al. [14] has proposed an automatic water addition at the drums based on the growth rate of pellets, due to the importance of this parameter at the final pellets quality and homogeneity. The surface of pellets unloaded from the roller screening is more uniform and contains practically no aggregated charge particles. The particle size distribution will impact the pellet's average diameter. The roller screen gaping strategy will depend on the particle

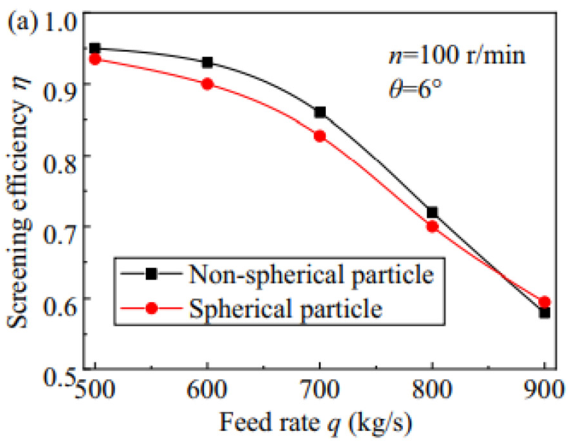

Fig. 8. Parameters used by Yang et al. [31] (modified) and screening efficiency depending on the feed rate.

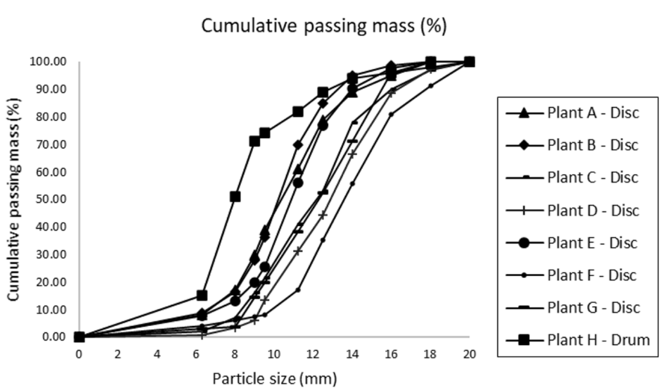

Fig. 9. Particle size distributions on pelletizing plants around the world.

distribution provided by the agglomeration area. If it is not linked, the recirculating load will be highly impacted, promoting a negative performance on the plant's productivity. Each plant has its own strategy to increase or to reduce the pellet's diameter, either screen gaping strategy to improve the equipment's throughput and reduce the recirculating load.

Figure 9 presents some different distributions found in plants around the world, considering plants using both balling disks and drums devices to produce green pellets.

6.2 Gap opening uniformity

The gap opening uniformity is the represented by the uniformity of space between rolls over the entire screening machine. It is directly impacted by the wear effect on the rolls' surface, increasing the gap opening over time. It is also impacted by the incorrect preventive maintenance practices.

Re-gaping procedure is an important item to keep a good gap opening uniformity over time. The utilization of a good wear resistant coating on the rolls will improve the gap opening uniformity, reducing the costs related to re-gaping procedures and the loss of the plant's productivity. If a poor wear resistance coating or uncoated rolls are used, it will reduce the quantity of good-sized pellets feeding the furnace during operation, and even if the maintenance is effective, the quantity of intervention on the equipment will be higher, requiring longer shutdown time to adjust the gap openings.

Figure 10 exemplifies the impact of wear on the rolls' surface and the impact of a poor maintenance of the screening equipment. The figure shows an irregular wear in the rolls, increasing gap opening in some parts of the screen that will represent a loss of good-sized pellets to the recirculating load and in other parts the reduction of gap opening by incorrect adjustments of the maintenance team. The second representation is a regular wear over the rolls' surface, increasing on the gap opening uniformly, this case represents a lack of re-gaping procedures during the normal operational basis. Both scenarios will represent loss of production and degradation on the final pellets size distribution.

According to Silva [6] through several parameters studied using DEM analysis, the most important one impacting the undersized removal efficiency in the iron ore balling circuit is the gap opening strategy, followed by the rolls speed (rpm). So, confirming that a correct gap opening over the screen machine has a major impact on the recirculating load. Figure 11 presents this effect.

Still, according to Silva [6] the impact of the gap opening uniformity is even more apparent in the good-sized particles screening efficiency, representing by far the major factor to keep good size pellets on the downstream steps. It is linked to the correct understanding of the balling product, in terms of pellets sizing, and the correct gap strategy according to the pellets' diameter feeding the screen. Figure 12 presents this effect.

6.3 Rolls' straightness

Differently to the gap opening uniformity, the rolls' straightness is related to the rolls' fabrication quality used on a screening machine. The rolls' straightness is the capacity of a roll to receive the load of the particles on the feed tonnage without bending elastically or even plastically. The bending effect, or also called run-out effect, will affect the gap opening set up on a screen. The bending will appear more evidently in the central part of the roll since more load is applied in this section. This characteristic is normally neglected by the operational team, due to the difficulty to measure this parameter. The bending effect will negatively impact the screening efficiency, since the screen will run in a different gap opening than originally set-up, normally increased in the central part of the rollers. This parameter is related to a poor or incorrect base metal used in the rolls' fabrication, impacted by the selection of a low mechanical resistance base metal. It can be also related to the use of higher run-out tolerance in the rolls' fabrication. Therefore, metallic or ceramic coatings on the rolls will improve this characteristic, since the coating will improve the straightness and mechanical resistance of the rolls. The wear on the rolls according to the normal operation process tends to increase the

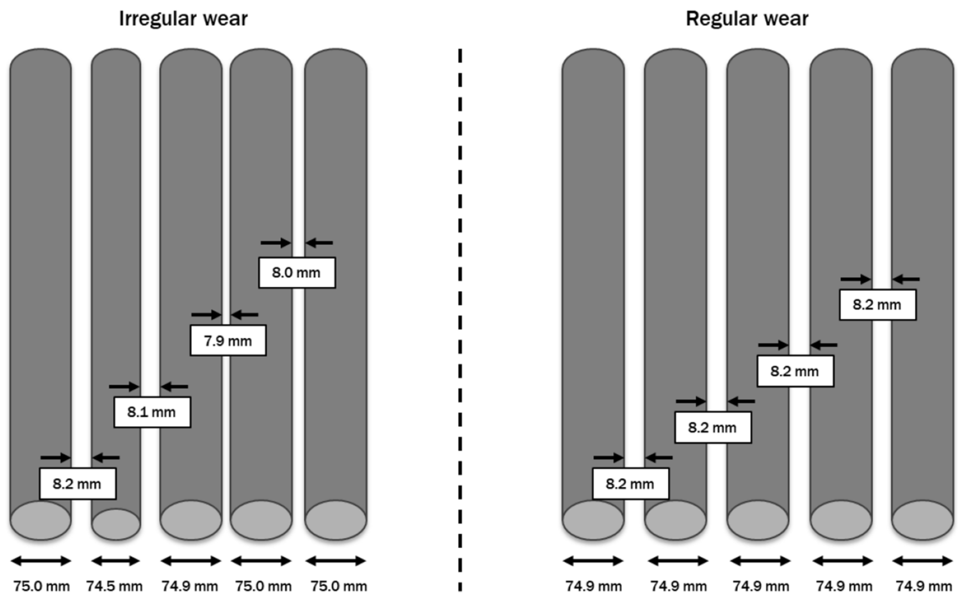

Fig. 10. Examples of impact of rolls uniformity due to the wear and lack of maintenance.

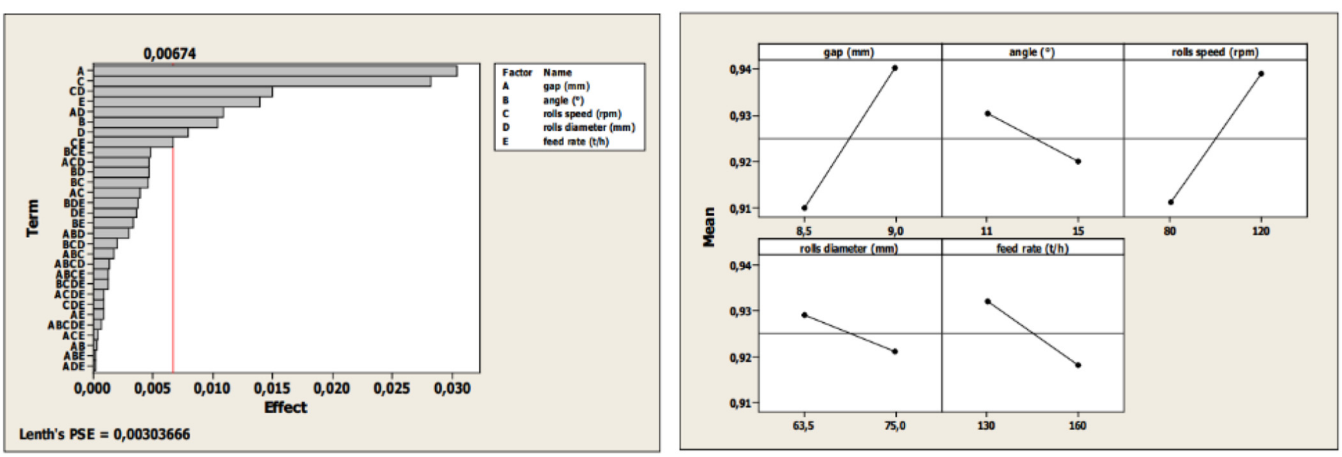

Fig. 11. Factor impacting the undersized particles' removal efficiency, by Silva [6].

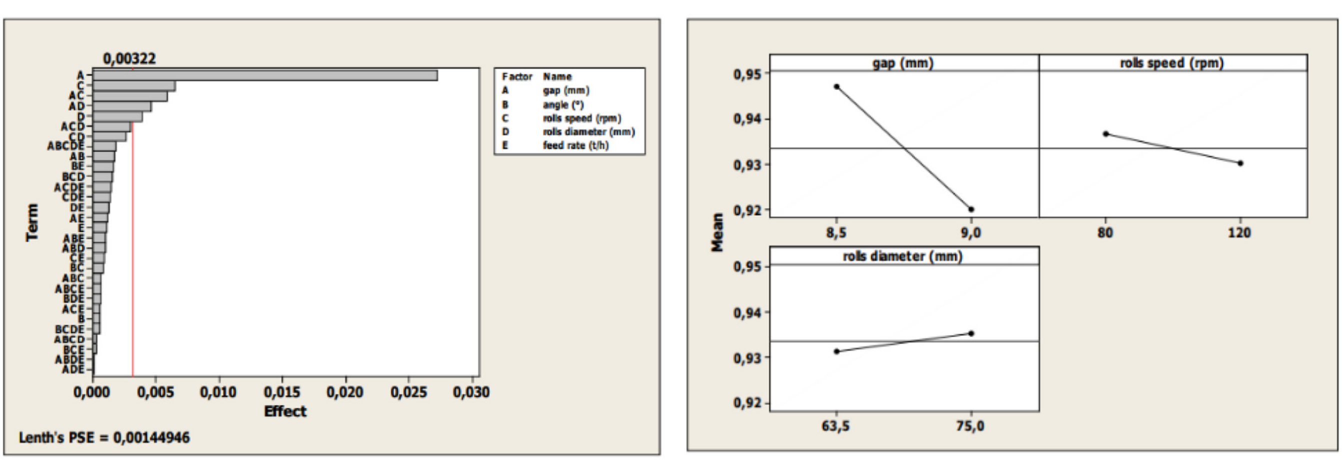

Fig. 12. Factor impacting the good size particles' efficiency, by Silva [6].

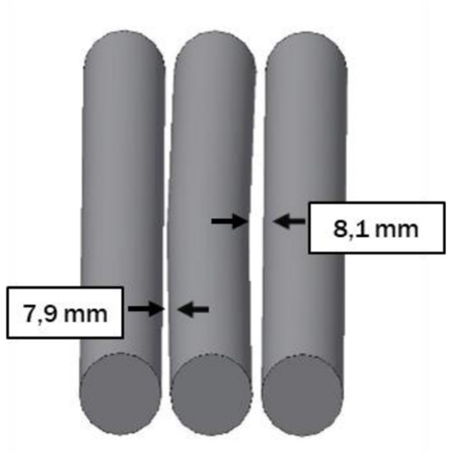

Fig. 13. Bending effect on a roller screen.

bending effect, mainly for the rolls working at the end-of-life cycle. Figure 13 exemplifies the impact of a single roll bending in the gap opening, taking as example a gap opening of 8.0 mm.

6.4 Pellet bed distribution

The pellet bed distribution on a roller screen is essential to promote a good distribution of particles to fulfill the entire screen surface, maximizing its utilization. In that way, the particles will have more probability to reach the gap openings and consequently to be properly classified.

A good pellet bed distribution over the screen starts by the correct pellet distribution by the wide belt feeding the equipment, impacted by the reciprocating, oscillating or shuttle equipment. Or by the good distribution of pellets in the balling chute. It will also prevent the increase of bending effect on the rolls, due to the lower load on the central part of the rolls. Figure 14 brings examples of different pellet bed distribution over the screen.

6.5 Rolls transportation capacity

The screen transportability is the capacity to move the pellets over the machine. This parameter is influenced mainly by the rolls surface roughness and the rolls' velocity (that will be discussed in more details in Sect. 6.7). It is also impacted by the tonnage load on the equipment since there is a push effect from the pellets in the feeding discharge point to the screen discharge point. The rolls' surface roughness also plays an important role in the iron ore build up on the rolls, reducing the gap opening. Another undesirable effect of an incorrect pellets' transportability is "cigarette effect", it is observed when the near-size pellets to the gap opening are trapped between rolls without transporting, reducing the equipment productivity and the gap availability. Figure 15 is a schematic representation of different rollers's roughness. Therefore, the correct roughness application in the rolls' fabrication is a key parameter for good transportability. Normally, the rolls coated by a thermal spray process are set to produce roughness ranging between 30 and 50 microns, to provide a good transportability and to avoid iron ore build up. A smoother rolls surface will promote a weak transportation characteristic and will create a "cigarette effect" on the pellets, deforming the pellets' shape. A rougher rolls surface will attach the fines particles over the rolls surface, creating a layer of iron ore over the rolls surface, reducing the gap opening and impacting the screening efficiency. A second effect of a rougher rolls surface is the creation of contact between pellets and iron ore adhered in the rolls surface, making it difficult to transport the pellets. The correct roughness choice, with a good rolls' velocity application, will promote a good pellets transportability.

6.6 Screen inclination angle

The screen inclination angle is the inclination applied to the roller screen on the horizontal plane. In a horizontal roller screening device, the pellets' transportation is given exclusively by the rolls' rotation speed. But in an inclined roller screen, the equipment throughput is given by the rolls' velocity and the gravity force applied in the pellets. The inclination angle also impacts the screening efficiency, since the gap opening set up does not represent the available gap opening in an industrial machine. For example, if the gap opening is set up to 8.0 mm in a horizontal screen, the available gap opening will be 8.0 mm, but if the same gap opening is set in a screen at 16°, the available gap opening will be around 7.7 mm. Calculated by the Cos Theta = projected gap/ real gap. Figure 16 represents this effect, for illustration purposes.

Goncharenko et al. [7] has performed tests on roller screen at different inclination angles to the horizontal plane. The undersized content of the pellets exceeded norms at an angle of 11°, so the angle was reduced to 9°. The use of roller screen technology, in replacement of vibrating screens originally designed for the operational unit, promoted an increase on productivity of the 36 m drum in 150–180 tons/h without harming the quality of pellets. The impact of the screening inclination angle modification is explained by the fact that in lower inclination angles, the pellets' residence time is increased (for the same rollers rotation speed), therefore increasing the possibilities of each individual pellet to reach the gap opening and consequently be screened.

It is important to apply some inclination angle to the screen to ensure a good pellet transportability and desired throughput. Normally, balling circuits screenings use inclination angles around 10–15°, due to the lower tonnage feeding rate over the roller surface area. For the screening devices applied at the furnace entrance, inclination angles are normally between 19 and 23°. This higher inclination angle is required to promote good pellets transportability, considering the higher feed tonnage (ton/m^2 of open screen area).

The increased screen inclination angle requires corrections in gap opening to promote the correct undersized and oversized pellets range removal.

Yang et al. [32] simulated through DEM the impact of different inclination angles in the percentage of material passing the gap opening in an industrial coal roller screening process. The screening was divided in 4 parts

Fig. 14. Examples of pellet bed distribution over the roller screen.

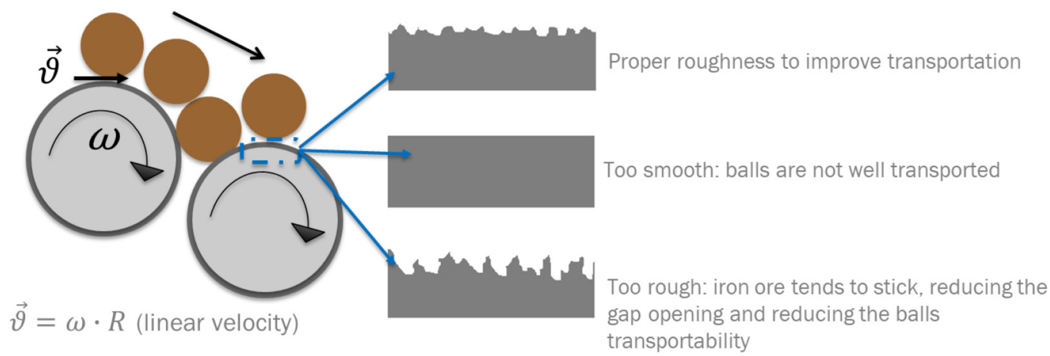

Fig. 15. Impact of different rolls' surface roughness in pellets' transportability.

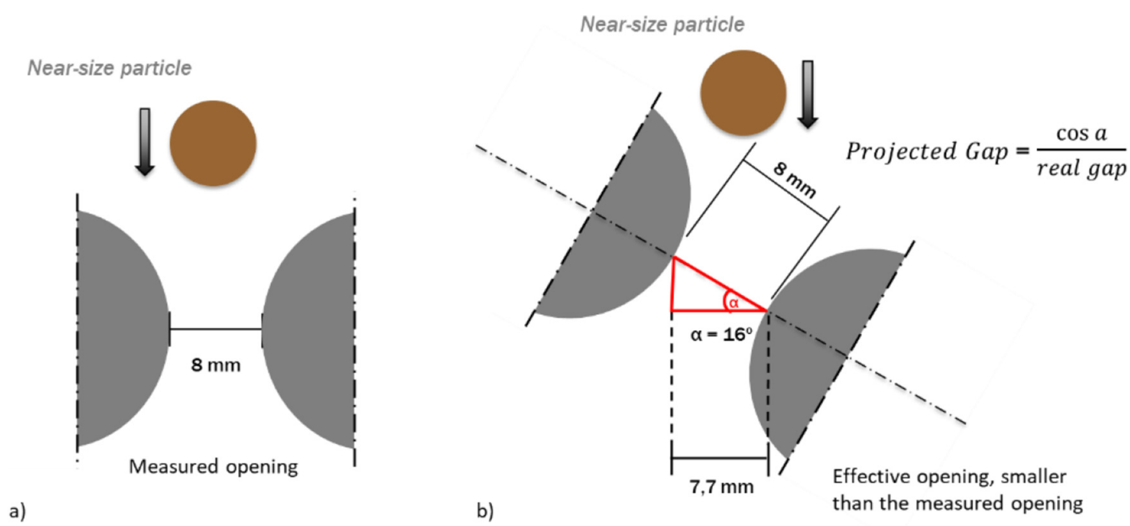

Fig. 16. Impact of inclination angle in the real gap opening. (a) Horizontal screen; (b) inclined screen.

on the screening deck, called screen numbers, in which 1 represents the first part of the screen and 4 represents the final part. As can be seen in Figure 17, more inclined angles will reduce the efficiency of removing fines (20–40 mm) and near-size particles (60–80 mm) in the beginning of the process, but it increases the efficiency at the final part of the equipment. Near-size particles (60–80 mm) are screened at the second part of the roller feeder due to the percolation effect. The most different results were performed at 24° on inclination angle, which increases the efficiency at the 4th deck. This result is not clear for the author.

6.7 Rolls' rotation speed

Rolls' rotation speed is very important for the pellet's residence time at the equipment, impacting throughput. Silva et al. [27] explains that as the rolls' rotational speed is raised, the quantity of undersized pellets removal increases due to the superficial interaction between pellets and rolls surface and the higher torque at gaps throat, which increase pellets deformation. In other words, the increase in roll's velocity will increase the traction of material inside the gap opening. On the other hand, the efficiency to retain

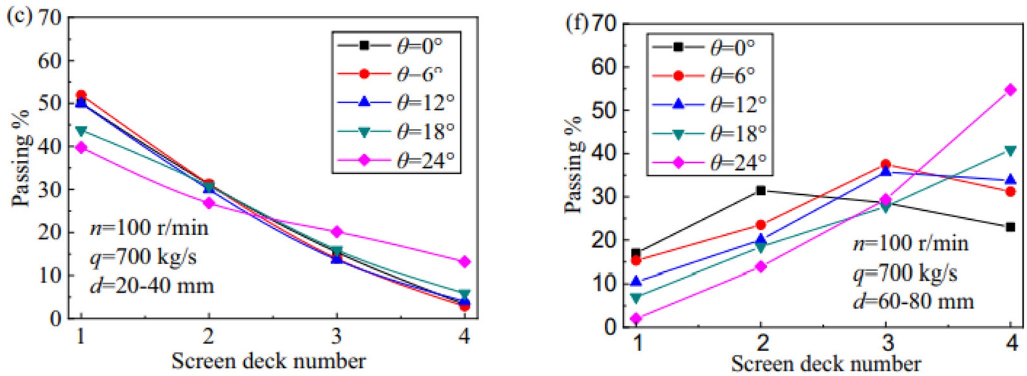

Fig. 17. Impact of inclination angle in the screening efficiency for fines particles (20–40 mm) and particles with size closer to the gap opening (60–80 mm) [32].

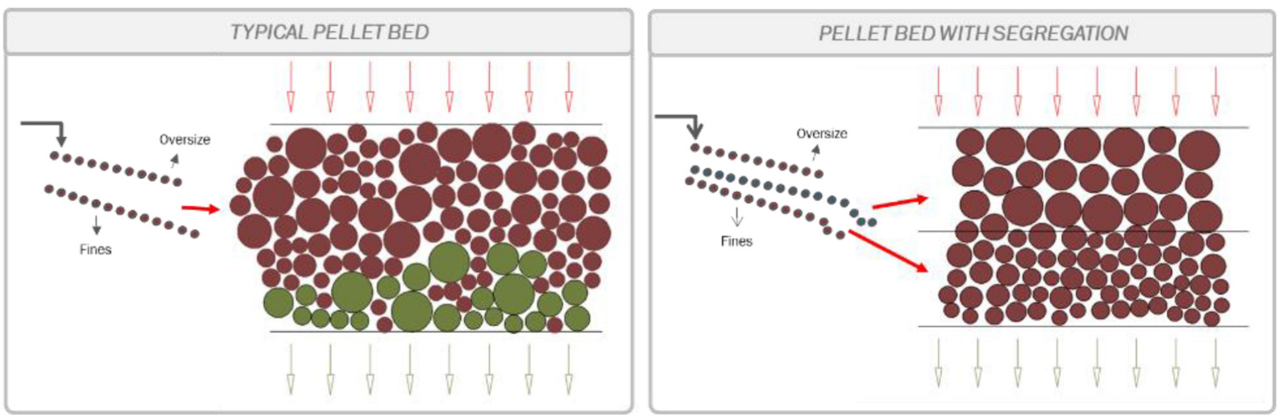

Fig. 18. Comparison schematic of a DDRF without segregation concept x TDRF with segregation concept [31] [modified].

the good-sized pellets is reduced by the fact that the near-sized pellets are pulled to the gap opening due to the sticky interaction between these solids' surfaces.

Yang et al. [32] also studied the effect of the rotational speed on the screening efficiency using a SDRS at 6° of inclination angle. According to this study, no significant effect was noted for this screening configuration, considering a very low inclination angle, and the particles' residence time is defined basically by the rotational speed of rolls.

Javaheri et al. [33] have proposed a different approach related to the rolls' speed. In this study, using discrete element analysis (DEM), the use of different rotational speeds between rolls was proposed, starting by the lower speed with increments on speed with the objective of reducing the quantity of pellets trapped between rolls and finally improve the screening efficiency. A slight increase on screening efficiency was observed by the method proposed by the author compared to the uniform speed regime.

7 Benefits of using a better screening efficient equipment

The benefits of using a high-performance roller screening are evident, since the pellets' production chain will produce a narrower green pellets size distribution feeding the furnace, it also promotes an increase on the pellet bed void fraction over the pallet car, therefore reducing the energy consumption in the induration furnace and improving the fired pellets quality. The benefits of the void fraction in a packed particle's bed are explained by Ergun [34]; Kozeny [35].

$$\Delta P = \left[\frac{150(1-\varepsilon^2)\mu_g}{\varphi^2 d^2 \varepsilon^3 \rho_g} G + \frac{1.75(1-\varepsilon)}{\varphi d \varepsilon^3 \rho_g} G^2\right] \Delta Z \tag{2}$$

where ΔP = Pressure differential through the bed, ε = void fraction, μg = gas viscosity, ϕ = pellets sphericity, d = pellets mean diameter, ρ_g = gas density, G = gas flowrate and ΔZ = bed height.

A more efficient roller screening process will also benefit the balling production. It will be able to remove more undersize and oversized pellets from the process, while keeping a higher quantity of good size pellets on the downstream process. With that, the balling disks or balling drums will work with lower load of good size pellets, increasing the particles' residence time inside the agglomeration units, improving the final pellets mechanical resistance, and producing a narrower particle size distribution.

Silva et al. [24] studied, through the application of DEM, the impact of a double-deck roller feeder (DDRF) configuration applied by the segregation process compared to a standard equipment (without segregation concept configuration). The formation of a segregated bed in the pallet cars was observed, while the smaller pellets are placed the bottom layer of the cars and the bigger particles are deposited on the top layer. An increase between 3 and 5% on the bed void fraction was noticed compared to the base case scenario. It can represent a reduction of the furnace energy consumption, maintaining the same level of productivity or by the increase of the pellets cars' velocity, considering the easier air flow rate over the pellets bed (reduction of the pellet bed pressure differential), improving the plant productivity.

Beaudin and Godin [31] had described in more details the benefits of a segregated bed profile in the iron ore induration furnace, resuming the benefits in terms of pellet plant productivity and pellets' quality. Figure 18 schematically represents the differences from a typical pellet bed formation to a segregated pellet bed formation.

8 Conclusion

There are very limited studies related to the roller screening process performance. The available studies are always linked to discrete element method (DEM) simulations. Therefore, there is a lack of knowledge regarding how each individual parameter affects the equipment performance. This paper has the objective to fulfill this deficiency by bringing practical and literature review understandings.

Some parameters directly related to the screening ratio (ton/m^2 of open screen area) impacts the screening efficiency, such as feed tonnage, quantity of rolls, rolls length and rolls diameters. Other parameters, not directly linked to the screening ratio also play an important role in the screening efficiency, like the particle size distribution, rolls uniformity, rolls straightness, pellet bed distribution over the screen, rolls transportability capacity, deck inclination angle and rolls rotational speed.

Improvements on the different parameters of the roller screening process provide benefits for the agglomeration and firing processes, such as producing pellets in a narrower size distribution, improvements on pellets' mechanical resistance and increase on the pellet bed's void fraction in the induration machine. Such benefits increase industrial plant productivity and/or reduce furnace energy consumption.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. S.L. Moraes, J.R.B. Lima, T.R. Ribeiro, Iron ore pelletizing process: an overview, in Iron Ores and Iron Oxide Materials,
2. S. Forsmo, Influence of Green Pellet Properties, Lulea University of Technology, 2007
3. M. Athayde, S.F. Nunes, M.C. Bagatini, A case study of pellet size fraction influence on pelletizing operation, Mineral Process. Extract. Metall. Rev. **39**, 276–283 (2018)
4. A.M.R. Nyembwe, D. Cromarty, A.M. Garbers-Craig, Relationship between iron ore granulation mechanisms, granule shapes, and sinter bed permeability, Mineral Process. Extract. Metall. Rev. **38**, 388–402 (2017)
5. K. Meyer, Pelletizing of iron ore fines. Springer-Verlag, Frankfurt, 1980
6. B.B. Silva, Modelling and Optimization of Green Pellets Classification on Roller Screens Using the Discrete Element Method UFRJ, 2017a
7. V.A. Goncharenko, V.G. Balandin, V.N. Peretyaka et al., Roller screening for raw pellets, Plenum Publishing Corporation, 1982
8. J. Akbar, S.N. Vahid, Employing DEM to study the impact of different parameters on the screening efficiency and mesh wear, Powder Technol. **297**, 126–143 (2016)
9. B. Zhang, J. Gong, W. Yuan, J. Fu, et al., Intelligent prediction of sieving efficiency in vibrating screens, Shock Vibr. **2016**, 1–7 (2016)
10. G. Wang, X. Tong, Screening efficiency and screen length of a linear vibrating screen using DEM 3D simulation, Mining Sci. Technol. (China) **21**, 451–455 (2011)
11. A.F.F. Cruz, J.M. Santos, Estudo das causas do fenômeno de agregação de minério em rolos de mesas classificadoras do pelotamento, 7° Simpósio Brasileiro de Aglomeração de Minérios **7**, 302–315 (2019)
12. G.C. Carter, F. Wright, Analysis of Sintering and pelletising including laboratory investigations, Inst. Mining Metall. Soc., 89–113 (1967)
13. P.E. Wellstead, M. Cross, N. Munro, et al., On the design and assessment of control schemes for balling-drum circuits used in pelletising, Int. J. Mineral Process. **5**, 45–67 (1978)
14. I. Dias, F. Guimarães, M. Souza, Sistema de controle granulométrico de pelotas de minério de ferro: um estudo de caso, 2018. https://doi.org/10.20906/CPS/CBA2018-0709
15. A.P. Matos, Influência da Temperatura, Pressão, Produção e Granulometria no Processo de Secagem das Pelotas Cruas. Universidade Federal de Ouro Preto, Ouro Preto, 2007
16. J.C. Williams, The segregation of particulate materials: a review, Powder Technol. **15**, 245–251 (1976)
17. J.A. Drahun, J. Bridgwater, The mechanisms of free surface segregation, Powder Technol. **36**, 39–53 (1983)
18. D. Zhang, Z. Zhou, D. Pinson, DEM simulation of particle stratification and segregation in stockpile formation, EPJ Web Conf. 140, 2017
19. R. Hogg, Mixing and segregation in powders: evaluation, mechanisms and processes, KONA Powder Particle J. **27** (2009)
20. F. Bérubé, M. Dubé, Green ball screening on roller decks, in 3rd Symposium on Iron Ore Pelletizing, 2013
21. D. Cherepakha, J. Johnson, A. Kulchitsky, Examining roller screen performance to categorize iron ore green pellets to optimize pellet induration, in Proceedings of the 8th international conference on discrete element methods (DEM8), 2019
22. S.P.E. Forsmo, P.O. Samskog, B. Björkman, A study on plasticity and compression strength in wet iron ore green pellets related to real process variations in raw material fineness, Powder Technol. **181**, 321–330 (2008)

23. A.B. Kotta, A. Patra, M. Kumar et al., Effect of molasses binder on the physical and mechanical properties of iron ore pellets, Int. J. Miner. Metall. Mater. **26**, 41 (2019)
24. B.B. Silva, E.R. Cunha, R.M. Carvalho, et al, Modeling and simulation of green iron ore pellet classification in a single deck roller screen using the discrete element method, Powder Technol. **332**, 359–370 (2018)
25. L.M. Tavares, R.F. de Almeida, Breakage of green iron ore pellets, Powder Technol. **366**, 497–507 (2020)
26. G.K.P. Barrios, R.M. de Carvalho, A. Kwade, et al., Contact parameter estimation for DEM simulation of iron ore pellet handling, Powder Technol. **248**, 84–93 (2013)
27. B.B. Silva, E.R. Cunha, R.M. Carvalho, et al., Modelamento da classificação de pelotas verdes de minério de ferro em peneiras de rolos pelo método dos elementos discretos. 5° Simpósio Brasileiro de Aglomeração de Minério de Ferro, São Paulo, SP, Brasil, 2017b
28. B.B. Silva, E.R. Cunha, R.M. Carvalho, et al., Improvement in roller screening of green iron ore pellets by statistical analysis and discrete element simulations, Mineral Process. Extract. Metall. Rev. **41**, 323–334 (2019)
29. A.D. Thomazini, Modelagem e simulação da degradação de pelotas verdes de minério de ferro em operações de pelotização pelo método de elementos discretos [Master Thesis, UFRJ/COPPE], 2020
30. D. Wang, M. Servin, T. Berglund, et al., Parametrization and validation of a nonsmooth discrete element method for simulating flows of iron ore green pellets, Powder Technol. **283**, 475–487 (2015)
31. S. Beaudin, E. Godin, Triple Deck roller feeder, a positive impact on pellet production, fired pellet quality and energy savings MinExpo, 2021. Available at https://img.minexpodirectory.com/files/base/ascend/minex/document/2021/07/GroupM7_Booth655_Metal7_TDRF_A_positive_impact_on_pellet_production__fired_pellet_quality_and_energy_savings.60fd058f735d2.pdf
32. X.-D. Yang, L.-L. Zhao, H.-X. Li, et al., DEM study of particles flow on an industrial-scale roller screen, Adv. Powder Technol. **31**, 4445–4456 (2020)
33. M. Javaheri, A. Jafari, G.H. Baradaran et al., Effects of rollers speed regime on the roller screen efficiency, Mineral Process. Extractive Metall. Rev. 1–8 (2021)
34. S. Ergun, Fluid flow through packed columns, Chem. Eng. Progr. **48**, 89–94 (1952)
35. J. Kozeny, Ueber kapillare Leitung des Wassers im Boden, Sitzungsber Akad. Wiss. **136**, 271–306 (1927)

Cite this article as: Alexandre Gonçalves Andrade, Steve Beaudin, Maycon Athayde, Impact of key parameters on the iron ore pellets roller screening performance, Metall. Res. Technol. **119**, 311 (2022)