

AVALIAÇÃO DA DISTRIBUIÇÃO DE GASES EM FORNO DE PELOTIZAÇÃO DA SAMARCO MINERAÇÃO ATRAVÉS DE CFD E VALIDAÇÃO EXPERIMENTAL

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Resumo

A Samarco Mineração produz pelotas de minério de ferro processadas termicamente em fornos de grelha móvel. Este processo é fundamental para que se obtenha a adequada resistência mecânica dos aglomerados para o transporte e operação dos reatores de redução. Todas as propriedades mecânicas dos aglomerados são obtidas durante a etapa de queima, sendo etapa decisiva, para a qualidade da pelota. Portanto, a distribuição de velocidade do fluxo gasoso no interior desta zona deve ser homogênea ao longo do leito. Para tanto, foi desenvolvido um modelo matemático em CFD objetivando caracterizar o escoamento dos gases na zona de queima, aplicando as equações de conservação de quantidade de movimento, massa e energia. A validação do modelo proposto foi obtida através de medições de temperaturas no interior do forno. Foi desenvolvido um sistema de comunicação wireless de forma a acompanhar de forma contínua a evolução de temperatura do forno.

Palavras-chave: Modelagem; CFD; Pelotização; Leitos porosos.

EVALUATION OF FLOW DISTRIBUTION IN THE PELLETIZING FURNACE THROUGH CFD AND EXPERIMENTAL VALIDATION AT SAMARCO

Abstract

Samarco produces iron ore pellets thermally processed in Travelling Grate furnaces. This process is essential in order to obtain adequate mechanical strength to the pellets transportation and operation in the reduction reactors. All the mechanical properties of the agglomerates are obtained during the stage of firing, being a decisive step to pellet quality. Therefore, the velocity distribution of gas flow within this zone must be homogeneous. For this reason, it was developed a mathematical CFD model to characterize the gas flow in the burning zone, applying the equations of conservation of momentum, mass and energy. The validation of the model was obtained by measuring the temperatures inside the furnace. It was developed a wireless communication system in order to monitor continuously the evolution of the temperatures in the furnace.

Keywords: Modeling; CFD; Pelletizing; Packed beds.

I INTRODUCTION

One of the strategic objects of Samarco Mineração S/A is to “ensure quality products and services”. The iron ore pellet quality is attained when mechanical resistance is added to the agglomerates. This property is obtained by thermal treatment of the pellets in the Travelling Grate furnace. In order to achieve this goal, the furnace processes the pellets in three steps: drying, firing and cooling. Accord-

ing to Meyer [1], all properties of the agglomerates are obtained during firing, and therefore this step is crucial to ensure the quality of the pellet.

Travelling Grate furnaces are thermal equipment based on intense heat transport by convection. Through recovery of the heated air due to the cooling of the pellets at the discharge of the furnace, firing of the new agglome-

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rates is performed by adding heat to the pre-heated air via burners positioned along the firing zone. Despite the importance for the quality of the product, thermocouples placed above the pellet bed indicated unbalanced gas flow along the firing zone. Additionally, thermographic images of the furnace discharge have shown a large temperature variation along the bed cross section. Uneven gas flow distribution may lead to higher variability of the final physical quality of the agglomerates.

The decrease of pellet quality increases the risk of degradation during transport [2]. Additionally, in industrial practice, the irregular hot gas flow distribution along the cross section of the furnace may generate premature and non-uniform mechanical parts wearing especially in the firing zone where the highest temperature occur. Despite the high temperature of the process and the process air rate that can be higher than 1500 Nm³/dmt, the dominant mechanism for energy transport is convection, different from other industrial and common pellet beds where radiation is more important.

Fluid dynamic and geometric factors may be associated with non-regular profile of the heated gas flow, which is unwanted to the process. The geometric asymmetry of furnace windboxes, which conduct the gas flow from the firing zone to the exhaust fan, seems also to be critical and is also pointed out as the reason of the preferential wearing of the pallet car at the south side.

2 MATERIALS AND METHODS

2.1 Mathematical Modeling of Flow in the Burning Zone

A numerical code based on finite elements method was applied [3] for solving continuity and Average Reynolds Navier-Stokes equations (RANS). The energy conservation equation was also included in the model. The study was conducted with resources from LaSiP - Process Simulation Laboratory, in the Department of Metallurgical and Materials Engineering of the Engineering School at UFMG. The discretization of the fluid domain was carried out through a mesh of 118,225 elements (the mesh independence test showed less than 2% variation doubling the number of elements, which was considered acceptable). Regarding the boundary conditions, the combustion was taken into account based on the assumption of non-reactive approach injecting a stream of combustion products (CO₂, H₂O, N₂ and O₂) at the adiabatic flame temperature, considering a multicomponent flow. The pressure at the windbox outlet was set up as the static pressure measured in the pellet plant and the furnace walls were considered adiabatic. The flow regime was considered permanent. This latter simplification was assumed to minimize the computational cost due to the high mesh refinement achieved. It may fit the industrial practice as the gas flow is roughly fully developed

crossing the pellet beds, however, the pellet bed movement is transient regarding the furnace production line. This assumption is valid considering the purpose of the present work which is the evaluation of the flow profile of the gases (many studies have evaluated the pellet bed temperature profile after Thurlby *et al.* [4]). The κ - ϵ model turbulence was used. This model is largely used in industrial cases according to Seshadri *et al.* [5]. One more assumption needed to the travelling grate furnace is the effect that the porous bed on the pressure drop of the fluid through the furnace. This effect may be modelled adding a source term on the momentum equations. This source term can be defined by Equation 1 which is similarly to the Ergun's equation for pressure drop in the particle bed [6].

$$\frac{\partial p}{\partial x_i} = \frac{\mu}{K_{perm}} U_i + K_{loss} \frac{\rho}{2} U_i |U| \quad (1)$$

$$\text{Where, } K_{perm} = \frac{1}{150} \frac{\phi d^2}{(1-\epsilon)^2 \left(\frac{1}{\epsilon^3}\right)} \text{ and } K_{loss} = 1,75 \frac{(1-\epsilon) \left(\frac{1}{\epsilon^3}\right)}{\phi d}$$

μ : Dynamic Viscosity (kg/m.s); ρ : fluid density (Kg/m³); ϕ : Roundness (-); ϵ : void fraction; U : Fluid Velocity (m/s)

2.2 Development of Temperature Measurement System in Pallet Cars

It was developed in partnership with INSAUT Instrumentation a continuous and on-line measurement system for temperature profile of the pallet cars along the furnace to evaluate for a long term the temperature profile of the pellets and grate bars. Grate bars with points for insertion and support of thermocouples were used. In order to establish a system for data communication, temperature transmitters and signal repeaters composed a wireless HART network, non-structured. In this developed device, the signal is constantly optimized as the network tries to communicate the temperature information. This system enables to determine the location of the pallet car across the furnace. The whole system consists in 15 signal repeaters, which can communicate with each other in order to amplify and ensure the highest possible signal strength for the network. The reception of these signals from the repeaters strategically positioned along the furnace was carried out through a gateway positioned on the side of the furnace with the function of sending the signal to the record data system for remotely monitor the process. Every four thermocouples installed in the pallet cars operate in groups of temperature transmitters that had the communication function, the wireless HART network, yet transmitter electronic temperature was also monitored, creating a safety parameter for the equipment integrity.

3 RESULTS AND DISCUSSION

3.1 Characterization of the Fluid Flow in the Firing Zone

Figure 1 shows the velocity and the flow pattern of the gases in the region of the firing zone. The velocity contours show the existence of areas with high velocities, especially close to the grate bars and burner.

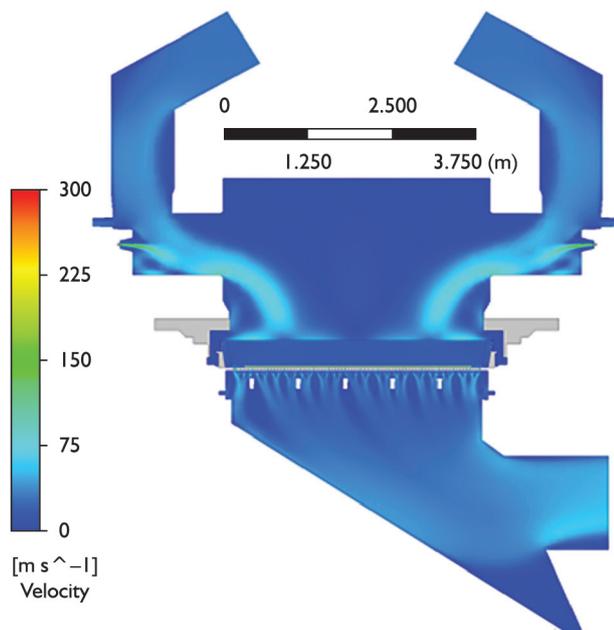


Figure 1. Velocity contours inside the firing furnace zone.

This map also highlights the effect on the inlet flow from the burner of the downcomer, which generates a deflection of the flames leading to a change in velocity pattern inside the combustion chamber. That seems to influence the entire velocity profile in the firing zone of the furnace. According to Athayde *et al.* [7], this effect can increase the risk of obstruction of the combustion chamber due to accumulation of particles carried out through the downcomers to the combustion chamber bottom.

The flame deflection occurs in the combustion chamber due to the ratio between the cross momentum flow rates of the air stream and natural gas coming out of the burner. Figure 2 shows a front view of the combustion chamber where the configuration of the flame is captured in four moments. As shown, the “tail” of the flame is always displaced downwards, as predicted by the model.

In the present work, it has been identified that the high jet velocity from the burner is intensely deflected by the flow coming from the downcomers, even after the combustion chamber length. Afterwards, the flow goes towards the pellet bed with higher intensity near the sides of the furnace, and not in the center, as expected. One possible cause for this effect might be the differences in the void fraction between pellet bed and the hearth layers, which has great impact on the flow pattern. A simulation carried out, shown in Figure 3, shows the influence of the void fraction in the pressure drop across the pellet bed. This influence is more significant than the increase of the pellet mean size. Indeed, the amount of voids between the pellets seems to be more critical and it is strongly linked to the heterogeneity of particle size distribution. At this

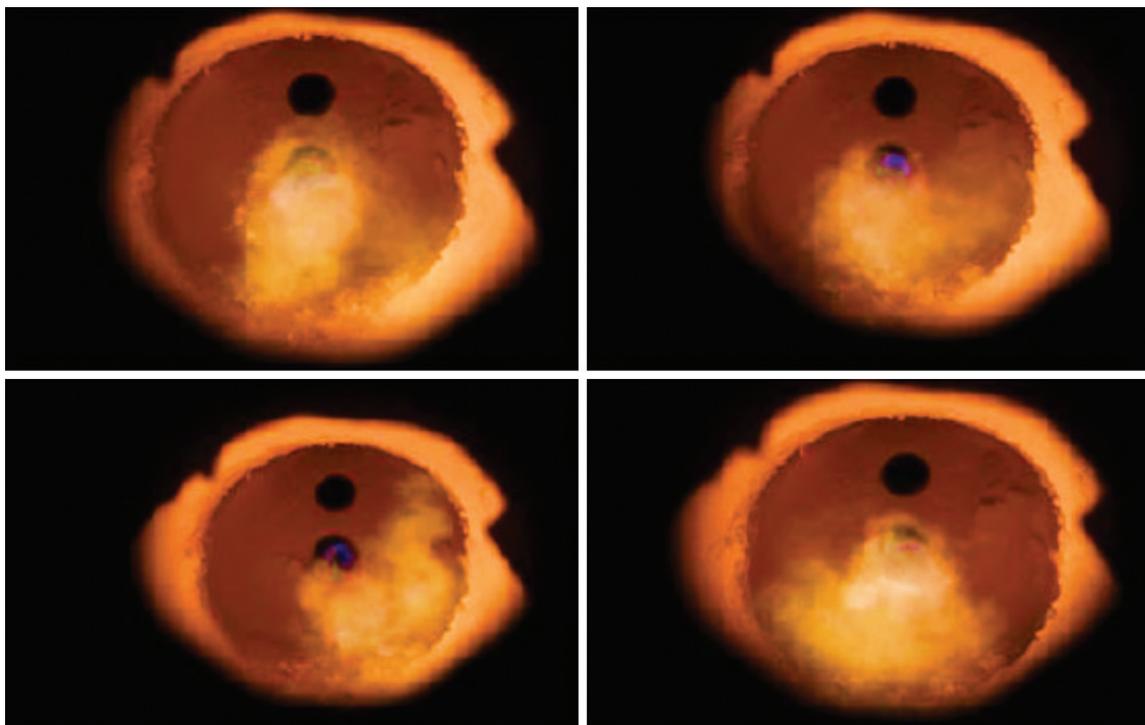


Figure 2. Flame deflection inside the combustion chamber.

point it is important to highlight that the small pellets are screened out of the hearth layer (burned pellets) in order to attain better gas flow into the bottom hearth layer of the pallet car. A pressure drop of 400 mmWG was found between the hearth layer side wall of the pallet car and the green pellet, shortcutting the gas flow closer to this region.

The non-uniform distribution of gas flow can lead to heterogeneity of the final physical quality of the agglomerates in the central region of the furnace, as it can reduce the residence time at certain reaction temperature, defined by Batterham *et al.* [8] as the isothermal pellet trajectory.

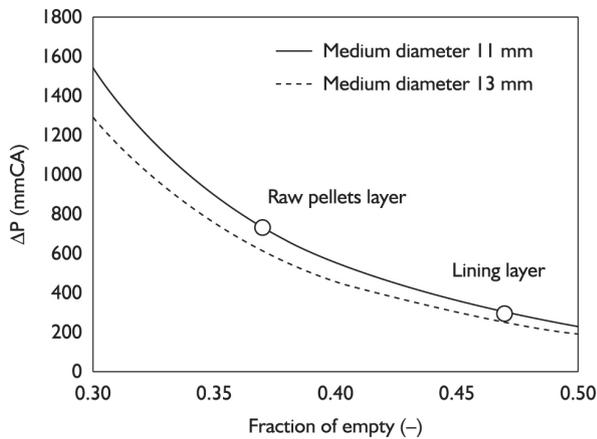


Figure 3. Influence of the void fraction and divisions of the pellet beds fall pressure in the pellet beds.

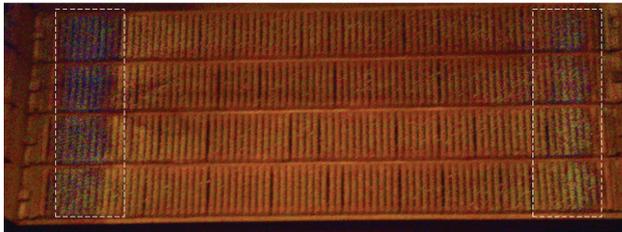


Figure 4. Abrasive wearing due to intense flow in the region.

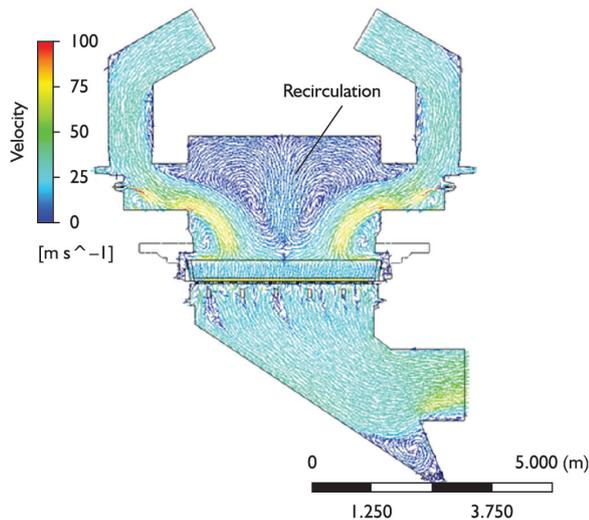


Figure 5. Velocity profile inside the furnace highlighting the temperatures gradient.

In the industrial practice, the heat input is increased to guarantee the quality, on another hand this may have a side effect as this singularity along this flow pattern may promote premature and not uniform wearing of mechanical parts as the pallet car grate bars and side walls. It is shown in Figure 4 an industrial example of the the side bars of the furnace damaged due to the intense gas flow in the region of the extremities of the pallet car.

Furthermore, other geometric factors of the furnace can also be associated with the uneven flow distribution. For instance, the lack of symmetry plane on the windboxes has been pointed as a critical issue for the gas flow distribution. It is associated with the differences between the two sides of the furnace. It is also remarkable the higher south side degradation compared with the north side. Although there is a plane of symmetry in the firing zone hood, there is no symmetry at the bottom of the pellet bed, in the windboxes. This geometry leads to a gas flow that may cause premature and accentuated wearing of the furnace south side or specifically the side near the outlet duct towards the exhaust fan.



Figure 6. Example of slag reaction on the refractory due the iron ore fine inside the furnace.

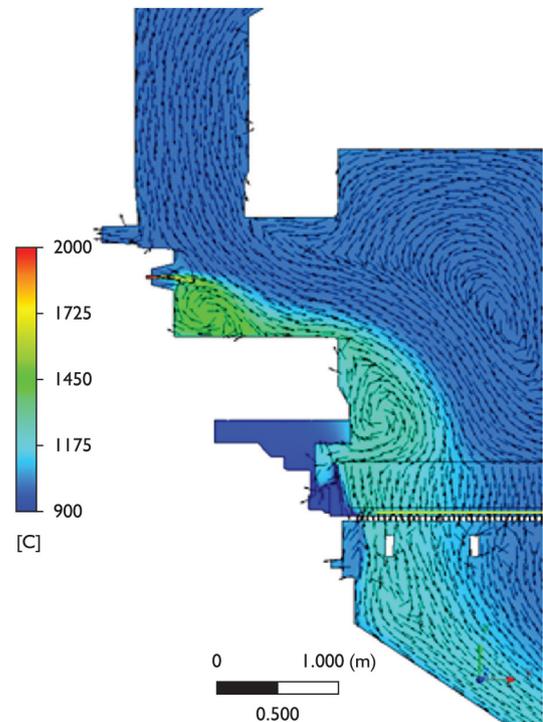


Figure 7. Temperature Contours at the furnace cross section.

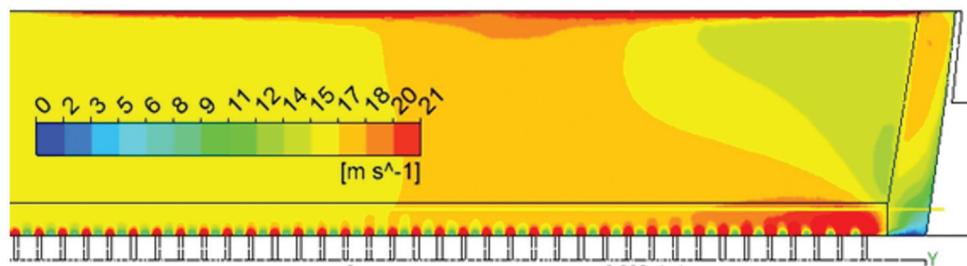


Figure 8. Velocity distribution on the pellet bed, showing intensity on the grate bars.

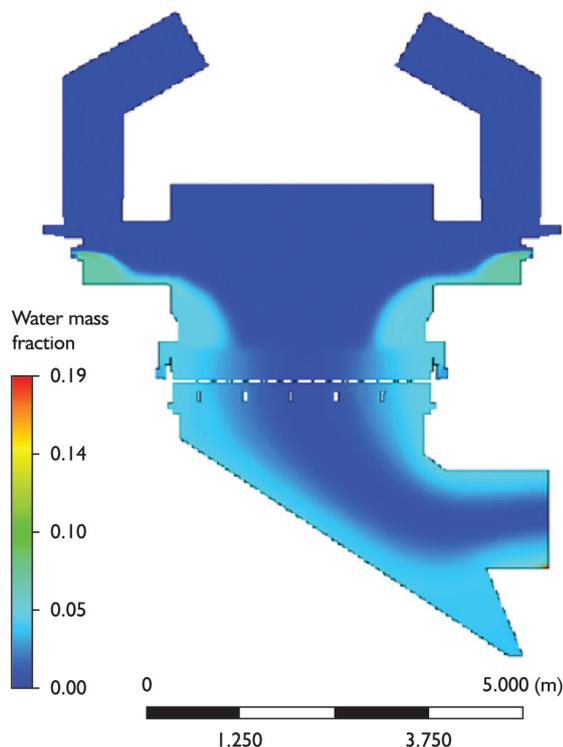


Figure 9. The concentration of water vapor along the furnace.

The most important final effect of this uneven flow distribution was observed in the temperatures in the furnace. Figure 5 shows the velocity profile across the furnace. The higher velocities are further the hood furnace centerline and similarly the high temperature streams concentrated closer to the sidewall. This has an important implication on the process (side hearth layer).

The main factor to determine the pressure drop in the furnace is the pellet bed itself. A remarkable feature of the previous map of velocity is the strong recirculation of the gases in the central region of the furnace, which carries iron ore fines to the hood, causing a slag reaction with the refractory hood (Figure 6).

The resulting effect of the gas stream is previously demonstrated directly in the temperature profile inside the pellet bed and even on the grate bars, that, as a consequence, will exhibit overheat and also the higher temperature cycles, resulting in excessive abrasive wearing in this region. The temperature profile is presented in Figure 7.

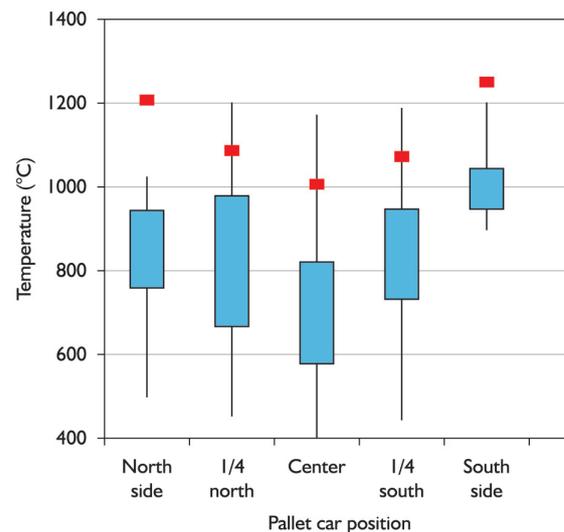


Figure 10. Industrial Validation of the proposed model and mapping temperatures of pallet car.

Figure 8 shows the combined influences of the mass flow passing through the pellet bed and the temperature of the grate bar. A broad distribution of flows along the pellet beds occur and, therefore, the unbalance in the flow of the furnace hood leads to heterogeneity in this region. It is important to state that regions with more intense gas flow also exhibit higher temperatures. This effect occurs especially in the region comprised of the 8 grate bars from the first “blind bar”, which presents excessive wear.

The flow of the combustion products coming from the burners also concentrates near the furnace wall (Figure 9). The multicomponent gas flow should be analyzed. The high concentration of super-heated steam (molar fraction from 0.04 to 0.07, at temperatures above 1,000 °C) in the region becomes a powerful agent of great importance in the generation of wear on grate bars.

3.2 Validation of the Proposed Model and Analysis of Temperature Measurements

Thirty days of continuous monitoring of the temperatures of the pallet car was performed in order to establish the “burnthrough” temperature of each cycle. Figure 10 shows a Box-Plot representing the temperature distribution in the bottom layer in different pallet car positions.

This figure also includes the temperatures predicted by mathematical model. As shown, the variation is similar to the average data measured at the end of the firing zone of the furnace, where steady state condition is attained.

The data were collected directly on the industrial plant and a good fit to the predicted values was obtained. The shift between the measured and calculated curve it is attributed to steady temperature profile achievement within the bed pellet and to the large response time of the thermocouples as the pallet car is suddenly cool down due the cooling zone.

4 CONCLUSION

It was possible through a two-dimensional model to characterize the fluid profile in a pelletizing furnace. The

model helped on the identification of an uneven velocity and temperature profiles which may be the main cause to the mechanical parts wearing due to the high temperatures required in the process. A robust measurement system and reliable temperature measurements were developed which enabled the validation of the mathematical model.

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REFERENCES

- 1 Meyer K. *Pelletizing of iron ores*. Düsseldorf: Springer-Verlag mbH; 1980.
- 2 Nunes SF. *Influência da carga circulante do pelletamento na qualidade física das pelotas cruas e queimadas da Samarco Mineração* [dissertação de mestrado]. Ouro Preto: Redemat/UFOP; 2007. 133 p.
- 3 Patankar SV. *Numerical heat transfer and fluid flow*. Washington: McGraw Hill Book Company; 1980.
- 4 Thurlby JA, Batterham RJ, Turner RE. Development and validation of a mathematical model for the moving grate induration of iron ore pellets. *International Journal of Mineral Processing*. 1979;6(1):43-64. [http://dx.doi.org/10.1016/0301-7516\(79\)90031-0](http://dx.doi.org/10.1016/0301-7516(79)90031-0).
- 5 Seshadri V, Tavares RP, Silva CA, Silva IA. *Fenômenos de transporte: fundamentos e aplicações nas Engenharias Metalúrgica e de Materiais*. São Paulo: ABM; 2010.
- 6 Niven KR. Physical insight into the Ergun and Wen & Yu equations for fluid Flow in packed and fluidised beds. *Chemical Engineering Science*. 2002;57(3):527-534. [http://dx.doi.org/10.1016/S0009-2509\(01\)00371-2](http://dx.doi.org/10.1016/S0009-2509(01)00371-2).
- 7 Athayde M, Nunes SF, Silva GAL, Sousa FDA, Arima MN. Novel burner design supported by cfd to minimize deposits inside combustion chambers of samarco pelletizing furnaces. In: *Associação Brasileira de Metalurgia, Materiais e Mineração – ABM. Anais do 6th International Congress on the Science and Technology of Ironmaking*; 2012; Rio de Janeiro, Brasil. São Paulo: ABM; 2012. p. 100-105.
- 8 Batterham RJ. Modeling the development of strength in pellets. *Metallurgical and Materials Transactions. B, Process Metallurgy and Materials Processing Science*. 1986;17(3):479-485.

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