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Testing a new laboratory-scale high-frequency screen for continuous trials with smaller samples

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ABSTRACT

Laboratory devices are key to modeling processes and allowing scale-up simulations to assess industrial scale performance. This study presents the development of a laboratory-scale high-frequency screen for continuous trials and initial modeling assessment using two different approaches. The models are assessed according to accuracy and precision for the data set considered. Additionally, the sensitivity of their parameters to changes in process conditions is analyzed for variations in solids concentration, feed rate and screen aperture. For both modeling accuracy and parameter sensitivity, Mwale et al. model presented better results, indicating a more suitable model for dataset description and process simulation.

1. Introduction

Development of reduced scale devices is important to assessing new technologies designed specifically for industrial application. Laboratory devices allow modeling novel processes and simulating their adoption in industrial circuits, estimating potential techno-economic benefits, while using reduced size samples [1].

High frequency screens are an example of industrial equipment that have been adopted in grinding circuits, but assessment trials of applied studies have been reliant on only industrial size devices. This strategy has the benefit of having a real scale result, but with the downside of requiring tons of material for assessment [2,3]. This sample size is not frequently available, especially for greenfield projects, or limits the process parameters evaluated in tests due to the sampling complexity.

Laboratory-scale high-frequency screens are commercially available, but not continuous processing devices with special screens designed to have higher open area and better efficiency in fine separation [4–6].

These are the qualities that contributed to the adoption of high-frequency screens in industrial processes, replacing hydrocyclones in grinding circuits for classification, particle dewatering and determination of final product size. High-frequency screens offer better efficiency than previous technologies, reducing energy consumption and costs, while increasing productivity and quality [7–9]. Their downside is their large footprint, which can create a bottleneck in high-throughput plants, especially in brownfield projects [3–6].

Thus, this research describes the development of a novel continuous lab-scale high-frequency screen representing the key features observed for an industrial size screen. In addition, a magnesite ore sample is used to assess the new device, and experiments were run under multiple process conditions, and the results were analyzed with different screen models. Finally, the models are compared according to their fitness to describe trial data and simulation capability.

2. Materials and methods

Firstly, the main aspects of the development of the lab scale device are described, considering design features and limitations for a full comparison with an industrial scale screen. Additionally, the stand-alone experimental set-up is described for a continuous screening test. Finally, the interconnection with upstream and downstream components is detailed if a continuous pilot plant trial is needed.

After the development of the scaled-down screen is detailed, an experimental dataset is analyzed for process modeling and parameter analyses, establishing the basis for comparison with industrial size equipment.

The tests were conducted with the novel lab screen in a stand-alone mode, using samples produced in a continuous pilot-scale ball mill calibrated to replicate the particle size distribution of industrial scale magnesite ore processing.

With the feedstock prepared, three different feed solids concentrations (50, 40 and 30% in weight) and two feed rates were assessed

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(500 and 300 kg/h). In addition, for each experimental condition, two different screen apertures were tested (300 and 250 μm). Finally, for each test, each stream (feed, oversize and undersize) was sampled three times to improve the robustness of the data analysis.

These conditions were selected to reproduce the variables present in a magnesite ore processing plant located in Brumado (Brazil) [10], the base-case selected for this study.

For each of the 36 sampling campaigns, the mass accounting was balanced using the BILCO™ software from Caspeo. The balanced data was modeled and analyzed using Mwale et al. [11] and Hatch & Mular [12] models, which were selected according to an assessment carried out by Moraes, Galery and Mazzinghy [3] due to their good data modeling and simplicity for implementation. The models were set using Microsoft Excel, with a minimization of the objective function, based on the sum of squares, selected as the parameters estimation method. In conclusion, the model's accuracy in representing experimental data and their parameters' sensitivity to process variables were analyzed to assess simulation capability.

2.1. Laboratory-scale high-frequency screen

The centerpiece of the laboratory device developed was the frame that was set-up to receive the special screen used in the industrial equipment, while reducing the screening area when compared to the base-case device for this development, which is the Derrick® Stack Size® high-frequency screen [13]. Thus, a frame was assembled for the screen installation and with the flexibility to allow choosing portions of the original screening area, controlling the inclination angle and maintaining the screen tension necessary for proper operation. Fig. 1 illustrates the frame set-up and screen installed.

Subsequently, the screen set was placed on an existing pilot-scale dewatering screen, which can operate at a high-frequency range (1800 cycles per minute) controlled by a variable frequency drive. This screen was modified for use on the frame developed without limiting its vibrating mechanism. This pilot device was selected to take advantage of existing equipment in the laboratory and facilitate other developments, since this is a commercially available device supporting the hereby developed screen frame.

Finally, a slurry feeding mechanism was designed and manufactured to ensure good distribution throughout the screen surface and reduce the stream speed, which is detrimental to process efficiency. Fig. 2 shows the final set-up, with the screen frame and slurry feeder installed on the pilot vibrating screen.

In this set-up, a sample size of 30 kg is enough to run modeling trials that can be increased to 100 kg if a multi-process condition analysis is desired as presented in this study.

2.2. Alternative circuits for continuous trials

The lab-scale high-frequency screen was designed to work for continuous processes either isolated (feedstock coming from a sampling campaign carried out before the screening test) or interlinked to a grinding operation. Fig. 3 shows the alternative circuits that can be operated with the screen developed.

For the experiments presented in this study, the screen was operated in isolation, processing the sample generated previously in the pilot ball mill.

3. Results and discussions

The tests results are divided in two sections, one to evaluate model accuracy and precision, followed by an analysis of the model's parameter according to process variables.

3.1. Efficiency curve modeling

The screening process models are developed to represent the efficiency curve, which is defined experimentally by the percentage of particles of size class *i* retained on the screen surface (oversize) in relation to the total mass of the size class [14].

$$E_i = \frac{O}{F} = \frac{f_i - u_i}{o_i - u_i} \tag{1}$$

To model the experimental results, Mwale et al. [11], and Hatch & Mular [12] models were selected, represented by Eqs. (2) and (3) respectively.

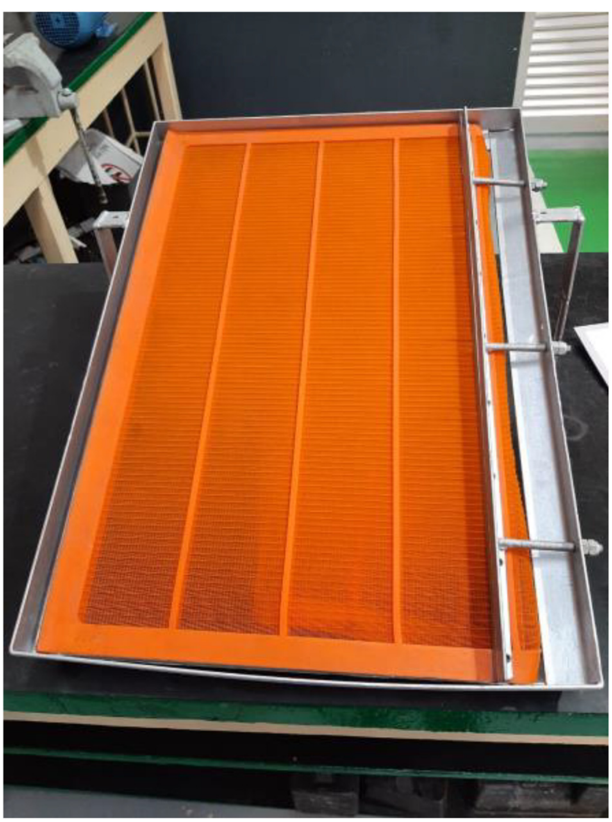

Fig. 1. Laboratory screen frame with adjustable processing area.

Fig. 2. Laboratory screen installation with slurry feeder and vibrating mechanism.

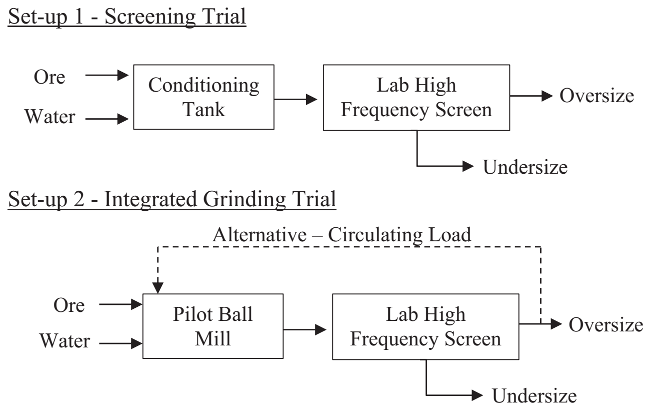

Fig. 3. Alternative circuit configurations for screening trials.

$$E_{io} = 100\exp\left(-\frac{A_oK}{Fs\left(\frac{d_i}{x_a}\right)^{\alpha\prime}}\right)+\frac{\delta F}{1-s}\left[exp\left(-\frac{d_i}{x_a}\right)\right]^{\alpha\prime} \quad (2)$$

$$E(x) = \frac{1}{\left\{1+\exp\left[\propto\left(1-\left(\frac{x}{x_{50}}\right)^3\right)\right]\right\}} \quad (3)$$

For the first analysis, the modeled data is plotted against the experimental results, represented in Fig. 4 for modeling according to Mwale et al. [11] and Fig. 5 for Hatch & Mular Model [12]. The mean square error of prediction (MSEP) and bias are considered for accuracy comparison, while variance is the parameter assessed for precision [3,14,15].

Comparing the results achieved for both models, Mwale et al. [11] presented better accuracy and precision as observed in Moraes, Galery and Mazzinghy [3], represented by the lower MSEP, bias and variance of MSEP (σ^2_{MSEP}). This model presented a good compromise of model fitness for coarse and fines representation.

Hatch & Mular's model [12], in turn, better reproduced the finer portion of the efficiency curve, but lost adherence to the coarse part, leading to the lower accuracy represented by a higher bias and MSEP. Nevertheless, it is still a good model for reproducing the dataset analyzed.

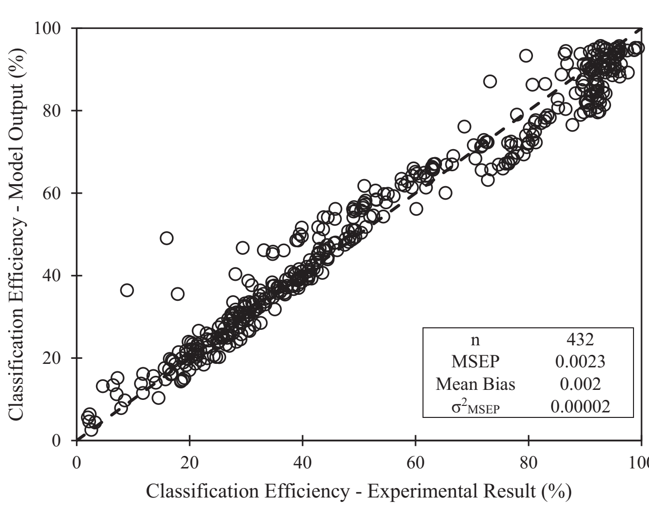

Fig. 4. Adherence of the Mwale et al. model [11] to the balanced experiments' results.

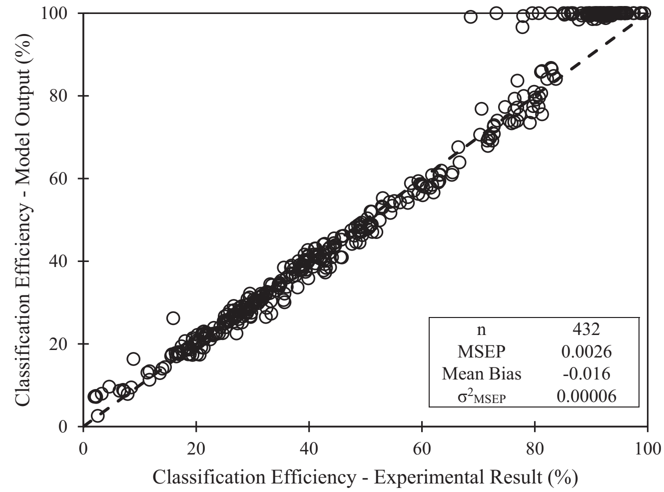

Fig. 5. Adherence of the Hatch & Mular's model [12] to the balanced experimental results.

3.2. Sensitivity of the parameters of each model to process conditions

Finally, the parameters of the models are assessed according to each test condition, evaluating their variability as an indication of the simulation accuracy when a process condition is changed.

For Mwale et al. model [11], K represents the kinetic parameter, α the sharpness of separation and δ describes the by-pass and fish-hook effects. Fig. 6 shows variation in parameter k according to test variables, while Fig. 7 presents this comparison for parameter α. Parameter δ is not analyzed since it is intrinsically dependent on the process condition and varies accordingly.

Analysis of the results indicates that parameter K increases with higher solids concentration and screen throughput, while it decreases with an increase in the aperture. The change in performance with the changing value of K in the model presents a limitation for simulation using the model. For example in the phenomenological analysis using this model, the higher value of K leads to more particles reporting to the oversize stream. Thus, if experiments are carried out under a single condition and K is not estimated for the modified parameter, the model and, consequently the simulation, would have lower accuracy. Nevertheless, the variation is relatively low when compared to Hatch & Mular [12].

In contrast, parameter α' presented similar values for different apertures and feed rates but showed an increase with higher solids concentration. Thus, the simulation will present good accuracy if this parameter is estimated for a determined condition, especially for fixed solids concentration. Since α' represents sharpness of separation, it should vary with alternative process conditions, however, this model individualizes variables for those conditions precisely to reduce their influence on the parameter modeled.

Hatch & Mular present different parameters in their model [12], with α controlling the sharpness of separation and by-pass, while x_{50} is the size class in which 50% of the particles report to oversize. In this case, only α analysis is presented in Fig. 8 since x_{50} is inherently dependent on the process condition.

According to α parameter dependency on process conditions, Hatch & Mular's model [12] would present a very low accuracy for simulations, since there is a considerably high variation for α independent of the condition assessed. This parameter decreases at higher feed rates and apertures, which is conflicting from a process perspective. There is no clear trend to the correlation of α with solids concentration, but it presented independence for some experimental conditions.

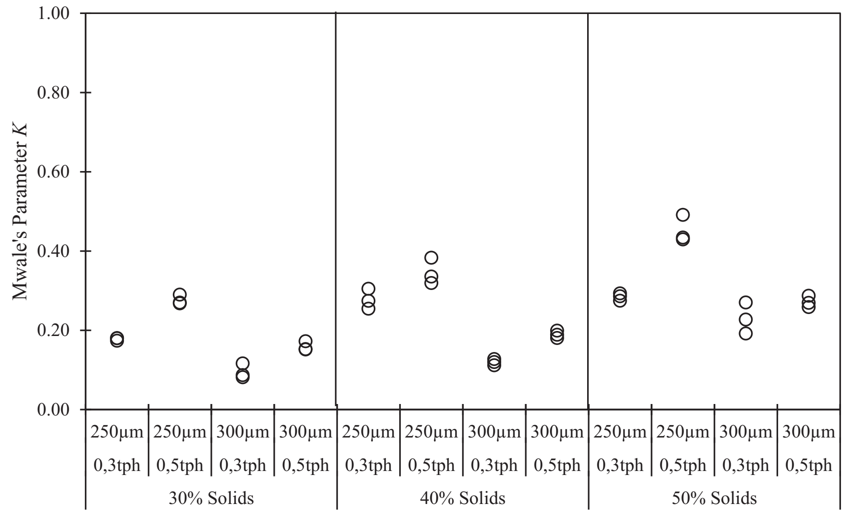

Fig. 6. Mwale et al. model [11] parameter K variation according to trials' parameters.

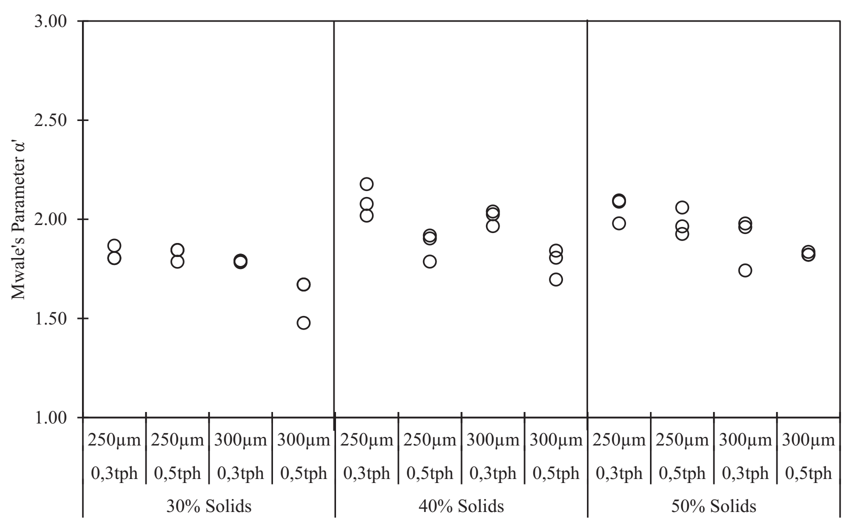

Fig. 7. Mwale et al. model [11] parameter α variation according to trials' parameters.

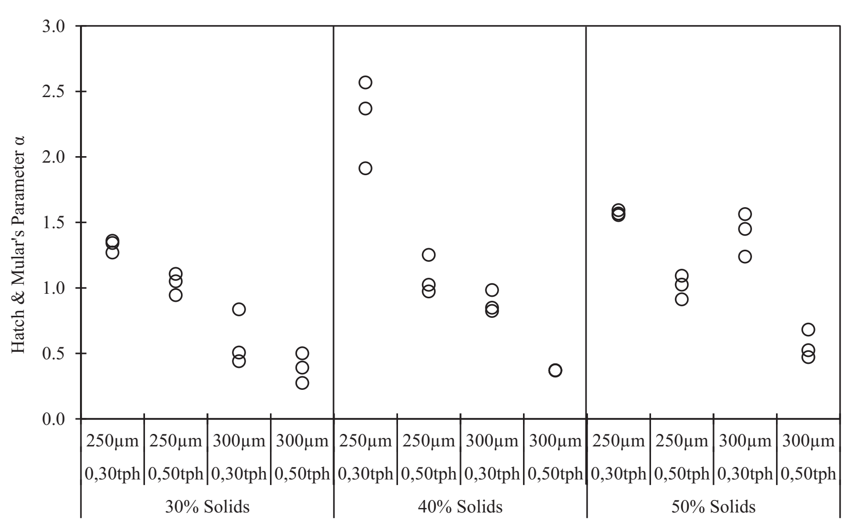

Fig. 8. Hatch & Mular's model [12] parameter α variation according to trials' parameters.

This result is expected for this model, since it is a purely empirical development and combines several process conditions to be described by only two parameters without individualizing any process variable. Therefore, if simulation is required, the use of Hatch & Mular's model [12] is recommended when the parameters are estimated for each desired condition to achieve a reasonable accuracy.

4. Conclusions and recommendations

The laboratory-scale high-frequency screen was developed and implemented with features that allow downscaling this industrial device and changing the key process variables and screening area. Considering this development, it is now possible to model this process with samples starting from 30 kg for estimating simple parameters and 100 kg for analyzing multiple process conditions as presented in the dataset.

Additionally, tests carried-out in a continuous process in the lab generated a dataset for modeling and parameters assessment according to the Mwale et al. [11] and Hatch & Mular [12] models, selected from the screening models review and comparative analysis carried out in Moraes, Galery and Mazzinghy [3].

Firstly, these models were assessed according to their accuracy and precision to describe the dataset generated in the experiments. Mwale et al. model [11] had higher accuracy and precision. Hatch & Mular's model [12], in turn, presented a bias to overestimating the overflow stream for the coarse size fraction, but with still acceptable results. The latter model offered a good description for the linear portion of the efficiency curve and by-pass region.

Lastly, each model had their parameters assessed according to their sensitivity to the variation of process conditions (solids concentration, feed rate and screen aperture).

Mwale et al. model [11] K parameter presented low variation and with good relation to phenomenological explanation, which increased with the solids concentration and throughput, yet declined with a larger aperture. On the other hand, α' had lower sensitivity to process condition variations, only increasing for higher solids concentration. Hatch & Mular's [12] parameter α not only presented higher variability according to process conditions but also does not capture phenomenological trends, which is expected since this model combines different process responses in a single parameter. According to these results, Mwale et al. model [11] is better suited for process modeling and provides higher accuracy in simulated process conditions, due to its lower sensitivity to the model's parameters.

The next recommended step in this development is the comparison between laboratory and industrial results, finding correlation and scale-up parameters for the laboratory-scale high-frequency screen developed.

Notation

A_o	Screen open area
d_i	Size class
$E(x)$	Fraction of particles of size class x reporting to oversize
E_i	Fraction of particles of size class i reporting to oversize
E_{io}	Fraction of particles of size class d_i reporting to oversize
F	Feed mass flow rate
f_i	Fraction of particles retained in size class i in the feed
K	Kinect constant
O	Oversize mass flow rate
o_i	Fraction of particles retained in size class i in the oversize
s	Solids concentration in weight
u_i	Fraction of particles retained in size class i in the undersize
x	Particle diameter
x_{50}	Size at which half of the particles report to oversize
x_a	Screen aperture
α	Model parameter reporting to the sharpness of separation and apparent by-pass
α'	Sharpness of separation
δ	By-pass parameter

CRediT authorship contribution statement

Matheus Naves Moraes: Conceptualization, Methodology, Formal analysis, Writing. **Gustavo Geraldo Rezende Nogueira:** Data curation. **Roberto Galery:** Supervision, Writing – review & editing. **Douglas Batista Mazzinghy:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.powtec.2022.117286.

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