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The Use of DEM for Optimising an Industrial Vezin Sampler Operation

Marcus Félix Magalhães [1], Ana Carolina Chieregati [2], Dusan Ilic [3,4,*], Isabella Targino Borges de Carvalho [1], Mariana Gazire Lemos [1], José Gregório da Mata Filho [1] and Homero Delboni, Jr. [2]

[1] AngloGold Ashanti, Mining & Technical, Nova Lima 34000-000, Brazil; mfmagalhaes@anglogoldashanti.com.br (M.F.M.); itcarvalho@anglogoldashanti.com.br (I.T.B.d.C.); mglemos@anglogoldashanti.com.br (M.G.L.); jgfilho@anglogoldashanti.com.br (J.G.d.M.F.)
[2] Department of Mining and Petroleum Engineering, University of São Paulo, São Paulo 05508-060, Brazil; ana.chieregati@usp.br (A.C.C.); hdelboni@usp.br (H.D.J.)
[3] Newcastle Institute for Energy and Resources, School of Engineering, University of Newcastle, Callaghan, NSW 2308, Australia
[4] Centre for Bulk Solids and Particulate Technologies, University of Newcastle, Callaghan, NSW 2308, Australia
* Correspondence: dusan.ilic@newcastle.edu.au; Tel.: +61-2-4033-9010

Abstract: Rotary dividers, also known as "vezin samplers", are widely used in the mining industry to obtain representative samples of particulate streams, and they are used as primary, secondary, or tertiary samplers. Based on Pierre Gy's theory of sampling (TOS), the correct extraction of an increment when composing a sample must give all particles the same chance of being selected. Aiming to comply with the theory of sampling, sampler construction parameters must be considered to avoid increment delimitation and extraction errors (IDE and IEE). In this way, a detailed study of the ore physical properties is necessary before designing sampling systems, which are customised for each application and ore type. Based on ore characterisation studies and combined with Discrete Element Method (DEM) simulations, it is possible to evaluate samplers' dimensions as proposed by the theory of sampling and determine the best design and operational parameters. The present study investigated and optimised the performance of a secondary vezin sampler installed in the feed sampling system of a gold plant in Brazil using DEM.

Keywords: theory of sampling; discrete element modelling; vezin sampler; mineral processing; gold

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1. Introduction

AngloGold Ashanti is a South African company and the fourth largest gold producer in the world. It has several operations around the world, including three in Brazil. The Mineral Metallurgical Complex Córrego do Sítio (CDS) is in the municipality of Santa Bárbara in the state of Minas Gerais, Brazil. The operation sits within the geological context of the Quadrilátero Ferrífero, with 75% of the gold associated with sulphides from underground mines. The sulphide ore processing plant is composed of a comminution circuit with an automatic sampling system in the feed of the mill, with concentration obtained via flotation, pre-treatment of the concentrate by means of acidic pressure oxidation, cyanide leaching, and recovery of gold via electrowinning (Figure 1).

According to Pierry Gy's theory of sampling (TOS) [1], the methodology for estimating grades is divided into three main stages: (1) primary sampling of a lot, (2) secondary sampling or sample preparation, and (3) chemical analysis. Each stage generates one or more sampling errors characterised by their variance, which, when added together, result in the overall estimation error (OEE). Among all the errors that make up the OEE, this study considers only the increment extraction error (IEE). However, to correctly design any sampling equipment, it is essential to guarantee the absence of other systematic errors, such as Increment Delimitation Error (IDE), Increment Weighting Error (IWE), Increment

Preparation Error (IPE), and the minimisation of random errors such as Fundamental Sampling Error (FSE), Grouping Segregation Error (GSE), Quality Fluctuation Error (QFE), and Heterogeneity Fluctuation Error (HFE) to assure that precise, accurate and, consequently, representative samples are selected.

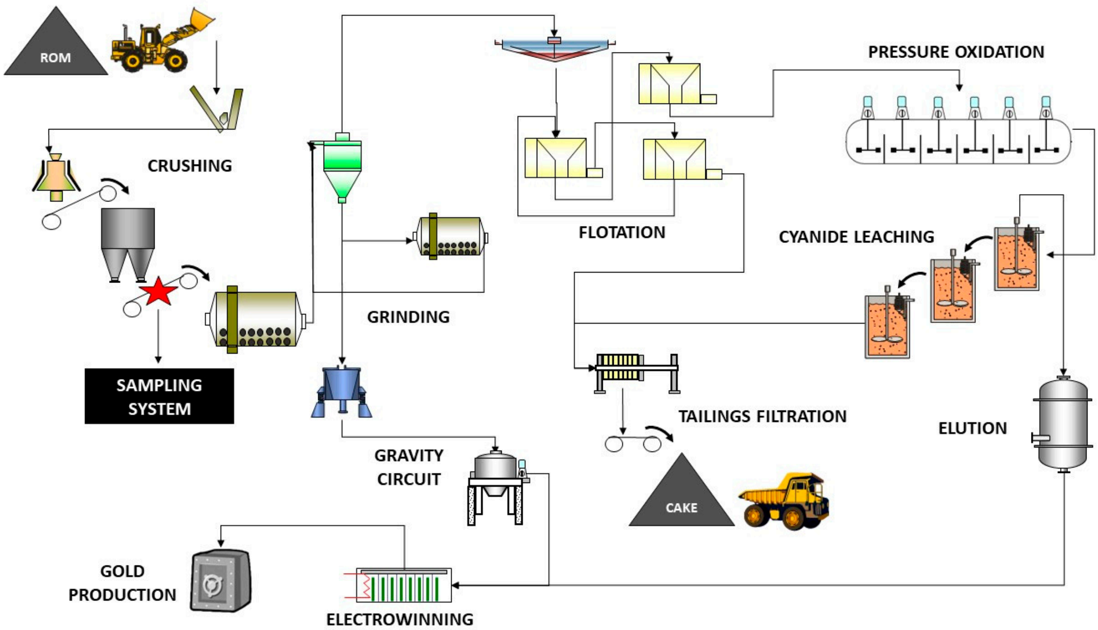

Figure 1. Flowchart of CDS sulphide ore processing plant with the red star showing the location of the sampling system.

Of these errors, the increment delimitation error (IDE) is mainly influenced by the sampling equipment design, and the increment extraction error (IEE) is directly influenced by the physical properties of the ore and by the sampler design, being considered the two biggest sampling bias generators [2,3].

The simulation of discrete particles as individual elements allows the calculation of the movement of each particle in the system within a simulation domain and the interactions between them through the use of contact models. For ores and minerals, the main model parameters include coefficients of restitution, sliding, rolling friction, and adhesion. A few DEM applications for modelling sampling systems of relevance to our study were developed for cross-belt and vezin samplers [4–7]. Despite a few other relevant research works, e.g., refs. [8–12] and our own recent article [13], beyond these studies, the literature on sampling system investigation using DEM remains limited.

At the CDS, the plant feed sampling system was installed in early 2019. The system is composed of a continuous discharge linear cross-cut sampler followed by a secondary vezin-type rotary sampler. Aiming to eliminate the need to install two primary samplers, and to avoid the generation of IWE, the best and most economical solution was to design a single sampling system with two opposing cutters, causing both feeders to discharge the material at the same point. This design eliminated the need for weighting the mass fed by the two feeders when calculating the plant's feed content [12]. Furthermore, the installation of a vezin-type secondary sampler eliminated the need for handling large sample masses in the laboratory and, consequently, the unnecessary generation of additional preparation errors, as the rotary method, among all the sample division methods, generates the smallest deviations [14]. The sampling system was customised and installed in between the feeders located in the feed of the grinding circuit, as shown in Figure 1. The importance of knowing the quality of the plant feed ore is demonstrated by the sampling system's location, which precedes almost all processing stages.

In our previous study, we presented the outcomes of flow modelling and DEM simulation of the primary cross-cut sampler [13]. The present manuscript supplements these findings by disseminating the approach undertaken and outcomes obtained in optimising the operation of the secondary vezin sampler at the CDS processing plant.

2. CDS Sampling System and DEM Simulation

The secondary sampler installed in the CDS plant feed is a vezin-type sampler and receives sample increments collected by the primary sampler, carrying out the second reduction stage to compose the final sample. Following discharge from the primary sampler, the ore loads onto a belt conveyor that then discharges the feed into the vezin sampler's feed chute (Figure 2). The material flow in the equipment is controlled at a constant speed by the feeding belt, and the sampler is activated 2 min after the primary sampler cut. This interval is calculated based on the time spent for a primary increment to go through the entire belt system and reach the vezin sampler feed. The vezin sampler operates continuously for another two minutes and is then stopped away from the material flow by a position sensor.

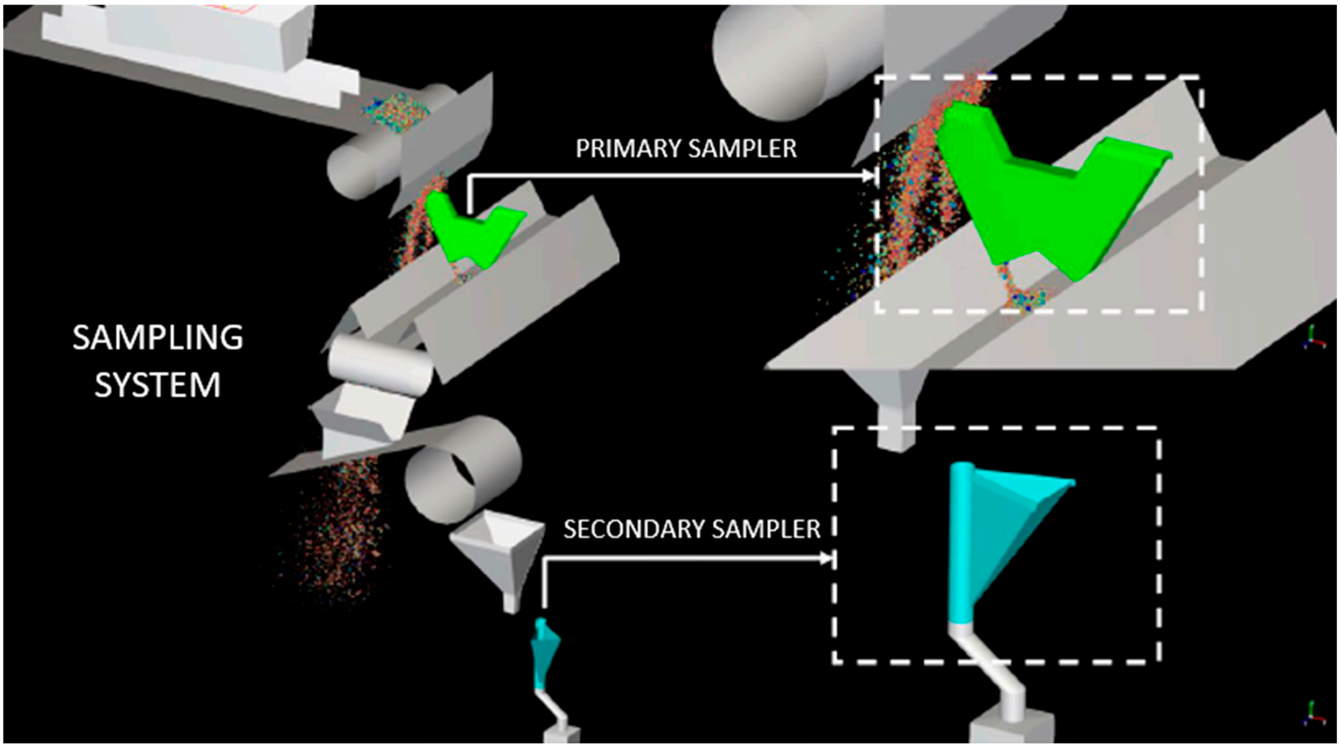

Figure 2. Sampling system (primary and secondary samplers).

The vezin sampler reduces the mass of the primary sampler increments, collecting approximately 10% of each primary increment. The cutter rotates continuously in the horizontal plane, intercepting the material flow with each rotation and collecting a representative portion of the material stream (Figure 3). The number of rotations represents the number of increments in the final sample. The rejects return to the feeding belt of the grinding circuit through a return belt system. The equipment specifications are summarised as follows:

- Model: vezin rotary autosampler;
- Cutter movement: perpendicular to the flow direction;
- Cutter aperture (A): 60 mm;
- Cutter edge angle (γ): 70°;
- Cutter angle (α): 70°;
- Cutter velocity (Vmax): 45 cm/s.

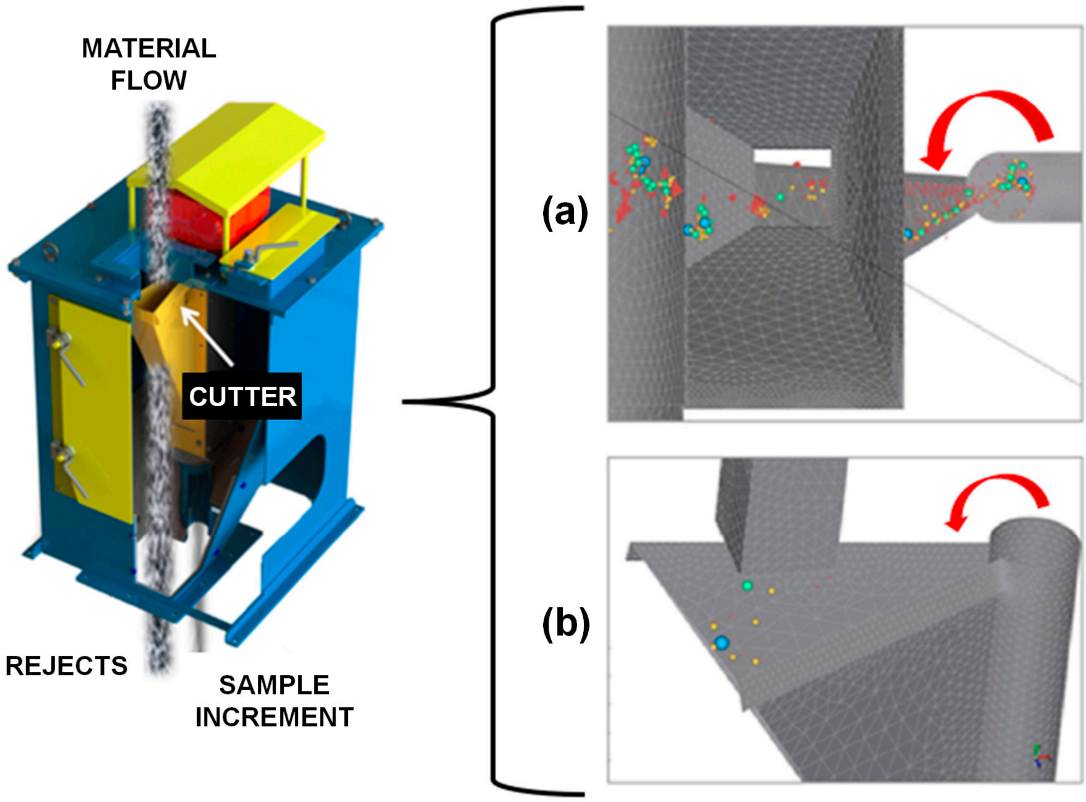

Figure 3. Three-dimensional geometry of the vezin sampler (left): (**a**) top view and (**b**) side view of the sampler in Rocky DEM. The red arrow indicates the rotation direction in the horizontal plane, and particles are coloured according to their size: red (2.5 mm), yellow (6.3 mm), green (10.0 mm), and light blue (13.3 mm).

A Discrete Element Method (DEM) modelling study and optimisation was undertaken in view of the primary cross-cut sampler system operation previously presented in [13]. DEM simulation involves modelling particles as discrete elements and resolving a series of equations of motion that describe their behaviour. The implemented algorithms calculate individual particle positions according to the resultant between the normal and tangential forces during contact, in each time step, based on a defined contact model. As in the previous study, the simulation in the present analysis was conducted using the Rocky DEM software provided by Engineering Simulation and Scientific Software, Florianópolis, Brazil (ESSS). This software simulates the interaction between particles and other elements, such as the surfaces of sampling systems and conveyors, within a handling system. While informative insights can sometimes be gained by just qualitatively observing flow and particle interactions in a system, quantitative and definitive solutions rely on calibrating the virtual simulation parameters to the actual physical behaviour. This can be performed through different means such as verification according to the actual site performance, given that adequate instrumentation and access is available, and/or through laboratory-scale tests. Our approach used a combination of the two. That is, we implemented a Design of Experiment (DoE) method to systematically calibrate the simulation parameters to the physical laboratory tests, and we supported this through observations during the design, installation, commissioning, and performance evaluation during operation at the CDS plant. DEM is a proven tool for analysing particle flow, detecting inefficiencies, and enabling optimisation of systems, including material handling, manufacturing, logistics, and design processes [15–18]. It is widely applied by many organisations across many industries for different commodities. It helps in making decisions that allow industries, for example, to increase the equipment lifespan and capacity, reduce energy consumption and component wear, as well as minimise downtime [19].

3. Materials and Methods

The adopted methodology includes three steps: (1) characterisation of the material physical properties in the laboratory; (2) calibration of the contact model parameters utilising DoE to model accurate physical particle behaviour via Rocky DEM (v. 4.3); and (3) simulations, analyses, and optimisation of the sampling system. The first two of these steps have been detailed in our previous publication [13]; therefore, only an overview of the approach and the major parameters of relevance to the vezin sampler investigation are presented here.

The first step, i.e., ore characterisation, included the major parameters applicable to any material handling system, namely moisture content, particle density, bulk density, particle-size distribution, angles of repose, and internal friction. An additional parameter, gold grade by size fraction, informed the importance of different size fractions since gold concentration increases as particle size gets smaller [13].

In general, the calibration of DEM simulation parameters requires defining representative values such that the real and accurate behaviour of the granular material is demonstrated [20]. For the sampling system at the CDS plant, several parameters were selected according to previous DEM simulations assessing sampling bias [5] and studies of relevant particulate material flows including our own practical experience, e.g., [21–25]. These parameters relate to the properties of particles and boundary elements (i.e., surfaces of conveyor belts and samplers), including elastic or Young's modulus, coefficient of restitution, and coefficient of sliding friction.

The second step, calibration of DEM parameters, involved determining the interparticle parameters, including the coefficients of sliding and rolling friction and attractive or adhesive force. The DEM simulations adopted the use of spherical particles, with a size of 2.5 mm and above (total of 456,092 particles simulated), matching the granulometric distribution and based on the nominal solid feed rate of the primary sampler of 73 t/h, similar to that of the ore handled in practice at the CDS plant. To reduce computational effort, particle shape was not considered, although, in effect, this is modelled using rolling friction. It is important to point out here that while a shape factor can be used to consider the shape of fragments, the TOS is generally based on calculations that assume spheres [2]. Furthermore, the propensity for irregularly shaped particles, such as those attributed to gold nuggets in ore, is historically low at the CDS plant as gold is generally associated with fine sulphides and arsenopyrite. The rolling friction and adhesive models used in the simulations were the Type-C and constant adhesion, respectively [13]. To reduce the number of simulations in the calibration process, DoE was used. DoE is a statistical optimisation method for determining relationships between factors (independent variables) and responses (dependent variables). The full factorial design was chosen to measure responses at all combinations of the factor levels as it is the most suitable for the analysis of three or more variables [26]. The application of this approach in DEM has been documented by several authors [27–29], and details of our approach can be found in our previous study of the primary sampler [13]. The low and high values used in the DoE were informed by previous studies on the calibration of particulate materials, specifically for the evaluated DEM parameters of friction coefficient, rolling coefficient, and adhesive force [21,22,24]. The number of runs for a 2-level full factorial design is 2^k, where k is the number of factors. Overall, the addition of 1 replicate to the DoE matrix, produced 16 tests for each of the 3 laboratory tests performed (free flow test, box flow test, and central flow test), resulting in a total of 48 DEM simulations used in the calibration. The optimum DEM parameters were then selected, where the simulated parameters best matched the laboratory results, based on ANOVA statistical analysis using Minitab 17.

Following calibration, the third step in the present study involved simulating the sampling system using the calibrated DEM parameters. In a similar manner employed to assess the TOS parameters used for designing the primary sampler [13], using the duly calibrated parameters, 60 simulations were performed to investigate the performance and evaluate four different TOS parameters of the secondary vezin sampler:

- Cutter aperture (A);
- Cutter edge angle (γ);
- Cutter velocity (Vmax);
- Solid feed rate (Q).

In a similar manner to the primary sampler, the values shown in Table 1 were also analysed for each variable for the secondary vezin sampler, although, in the present study, the cutter inclination angle (to the horizontal), α, was fixed at 70°. Triplicate simulations were performed, including simulations considering the original system configuration, with the results representing the averages obtained.

Table 1. Determination of values for each simulated parameter. *D* is the maximum particle size or d_{95}.

Values	Cutter Aperture (mm)	Cutter Velocity (cm/s)	Cutter Edge Angle (°)	Solid Feed Rate (t/h)
1	15 (1D)	45	1	60
2	22.5 (1.5D)	60	20	73
3	30 (2D)	75	35	90
4	45 (3D)	90	50	105
5	60 (4D)	105	70	120

The extraction equation was again used to quantify the percentage of extraction (E_j) for each particle sub-fraction [6]. The extraction was based on the calculation of the percentage of each group of particles from that simulated in the initial size distribution and after sampling. Effectively, the equation compares the mass percentage of a given group of particles that is collected in the sample and the percentage of that same group found in the original lot:

$$E_j = \frac{\left(\frac{m_{g,s}}{m_s}\right)}{\left(\frac{m_{g,l}}{m_l}\right)} * 100 \quad (1)$$

where:

j is the group of particles;
$m_{g,l}$ is the initial mass of the group in the lot;
m_l is the lot mass;
$m_{g,s}$ is the mass of the group in the sample;
m_s is the sample mass.

4. Analyses and Results

4.1. Physical Property Characterisation

The major physical parameters used in this study are summarised in Table 2.

Table 2. Summary of physical properties used in the vezin sampler study.

Property	Unit	Value				
Moisture (w.b.)	%			2.30		
Particle density	g/cm^3			2.83		
Bulk density	g/cm^3			1.70		
Internal angle of friction	°			59		
Angle of repose	°			29		
Draw-down angle	°			67		
Particle groups	n°			5		
Particle size	mm	2.5	6.3	10.0	13.3	15.0
Cumulative passing	%	25	50	80	95	100
Mass distribution	%	25	25	30	15	5

4.2. DEM Calibration

The calibrated parameters obtained using the DoE tests and optimisation, and implemented in the vezin sampler simulations, are summarised in Table 3.

Table 3. DEM simulation parameters used in the vezin sampler study.

Parameter	Value
Young's modulus (particles)	1×10^7 N/m^2
Young's modulus (boundaries)	1×10^{11} N/m^2
Coefficient of restitution	0.30
Coefficient of rolling friction	0.69
Coefficient of sliding friction (particle–belt)	0.70
Coefficient of sliding friction (particle–sampler)	0.50
Coefficient of sliding friction (particle–particle)	0.90
Adhesive force distance	0.00125
Adhesive force fraction	0.58

The validation of the calibrated values is illustrated in Figure 4.

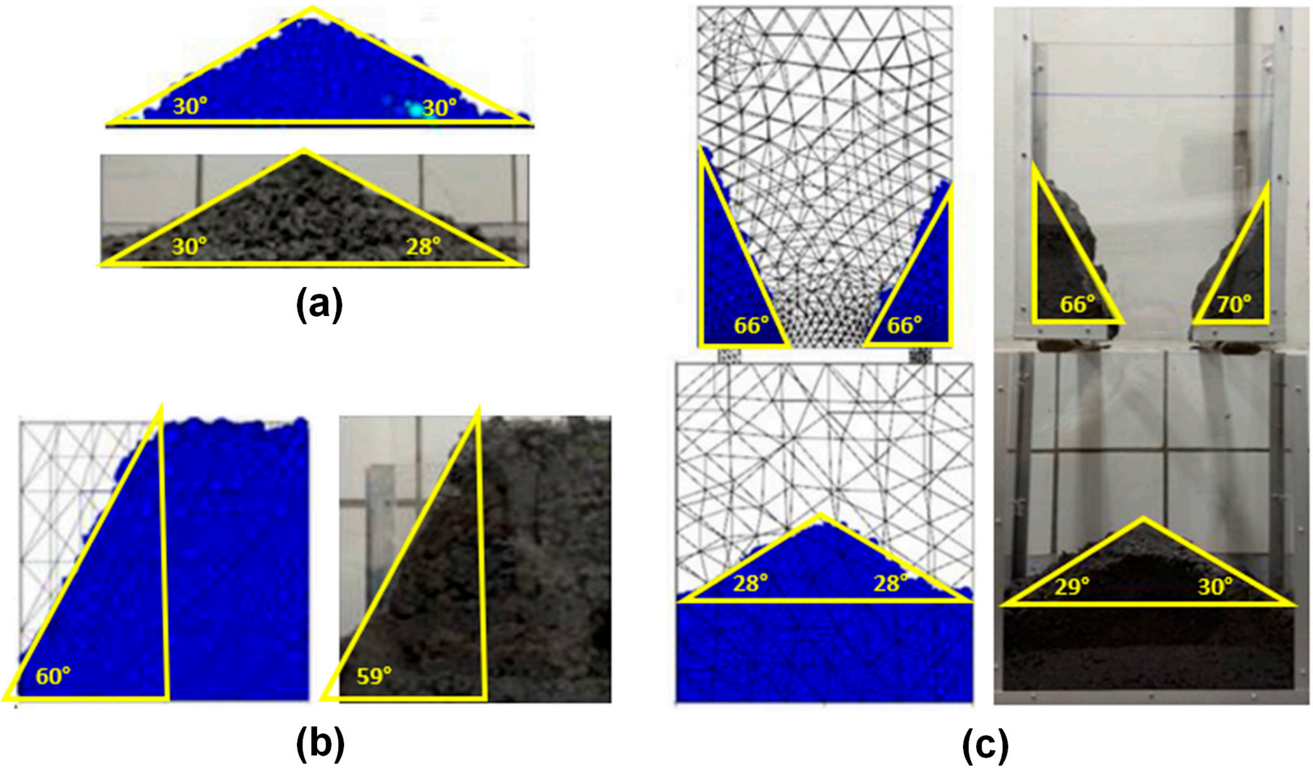

Figure 4. Comparison between experimental laboratory tests and calibrated DEM simulations: (**a**) angle of repose; (**b**) slump plane; and (**c**) draw-down angle (adapted from [13]).

4.3. Cutter Aperture

The theory of sampling parameterises the minimum opening of the cutter aperture as 1 cm or, for fragments larger than 3 mm, as at least 3 times the diameter of the largest particle in the lot, i.e., *D* or d_{95} or "top size". Figure 5 shows the extraction for the vezin sampler as a function of the opening of the cutter aperture.

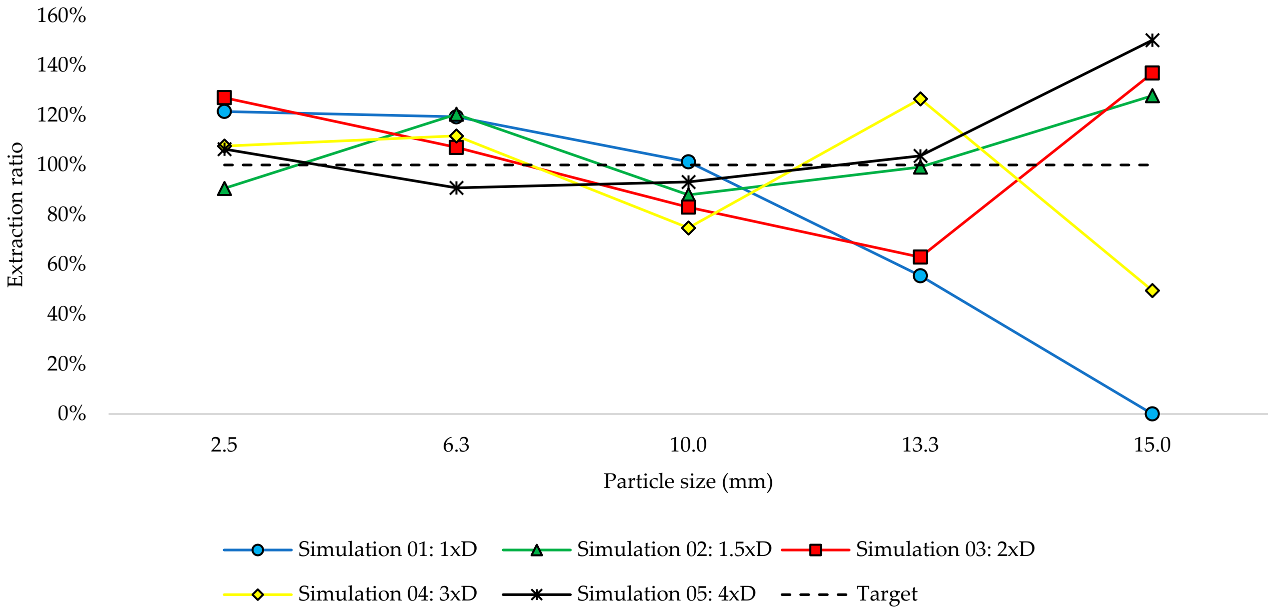

Figure 5. Extraction of the vezin sampler as a function of cutter aperture. *D* is the top size or d_{95}.

The behaviour of the vezin sampler shows low extractions for a cutter blade's opening equal to the diameter of the larger particle group. The extraction was 55.49% for the 13.3 mm particle group and 0% for the 15.0 mm particle group.

4.4. Cutter Edge Angle

Although no significant variations were observed for extraction in the particle groups between 2.5 and 13.3 mm, a reduction in extraction for the 15.0 mm particle size group could be noted (Figure 6).

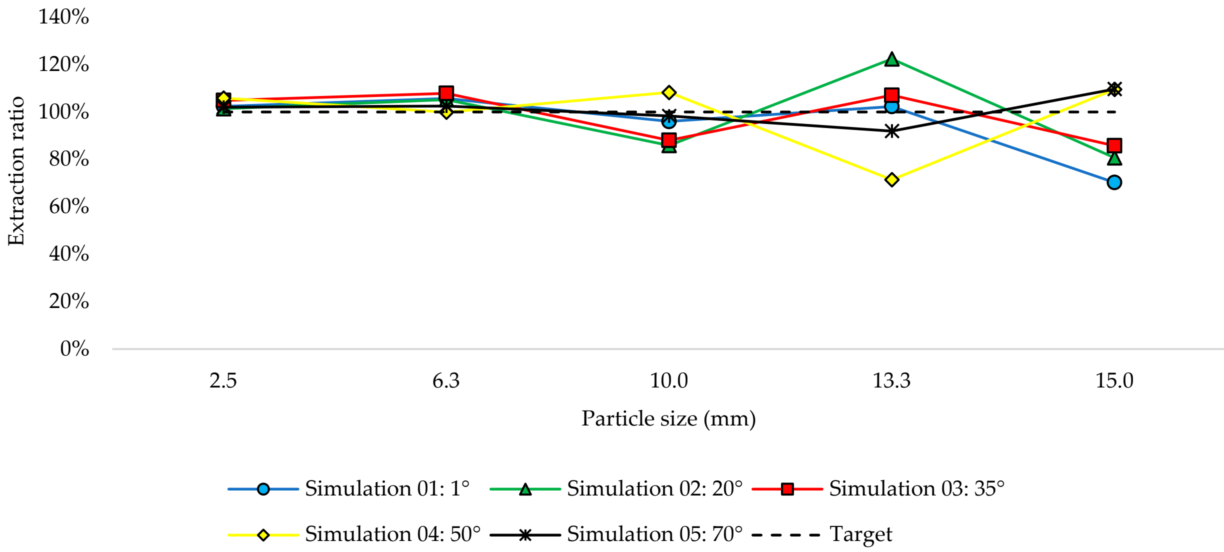

Figure 6. Vezin sampler extraction as a function of the cutter edge angle.

With the reduction in the cutter edge angle to values lower than 50°, an accumulation of fine material on the top of the blade was also observed (Figure 7), showing an inadequate sampling condition.

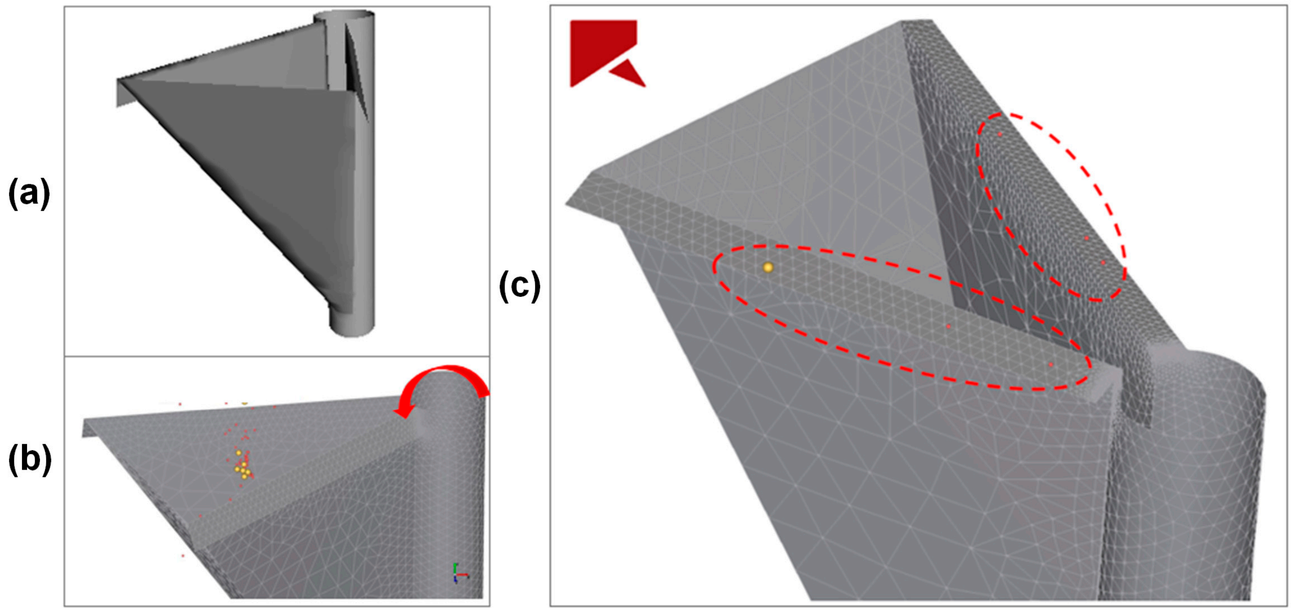

Figure 7. Schematic illustrating (**a**) cutter edge angle; (**b**) cutter rotation direction; and (**c**) representation of a 35° angle of the cutter blades, showing the accumulation of fine particles on the top of the blades (circled in red). Red particles shown represent the 2.5 mm group and yellow particles represent the 6.3 mm group.

These results highlight the relationship between the angle of internal friction of the ore sampled and the minimum cutter edge angle. This also relates the angle of internal friction to the angle of the cutter discharge chute and the design of sampling systems. Due to the relative increase in the extraction of smaller particle-size groups for lower blade angles (1°, 20°, and 35°), relatively low extractions were observed in the coarser fraction.

4.5. Cutter Velocity

Cutter speeds above 75 cm/s favoured the extraction of the 15.0 mm particle group (Figure 8). This is due to the greater number of increments collected, consequently increasing the probability of collecting large particles that are fewer and segregate in the lot. This could be due to the larger mass of bigger particles, which are still able to flow down the sampler chute rather than rebound due to impact. Considering particulate solids, the state of segregation is transient and may drastically change from one instant to another, or from one point to another; in this case, it occurs in the discharge from one conveyor belt to another that feeds the vezin sampler. The effect of segregation is influenced by the simulation parameters, such as sliding and rolling frictions, particle size, and adhesion. Thus, if this effect is specifically investigated in future research, additional calibration tests and/or a scheme would need to be adequately designed and implemented. For example, a scheme could involve assessing the particle-size distribution of physical samples with varying operating conditions in a specific location on site at the CDS and using this information to fine-tune the DEM model. As shape and particle size also influence segregation, these parameters may also require attention as they are likely to also influence the simulated behaviour. Segregation is discussed further in Section 5.

4.6. Solid Feed Rate

The solid flow rate in the vezin sampler is directly related to the speed with which particles enter the cutter. The extraction for the simulations with variations in solid flow rate in the vezin sampler is shown in Figure 9.

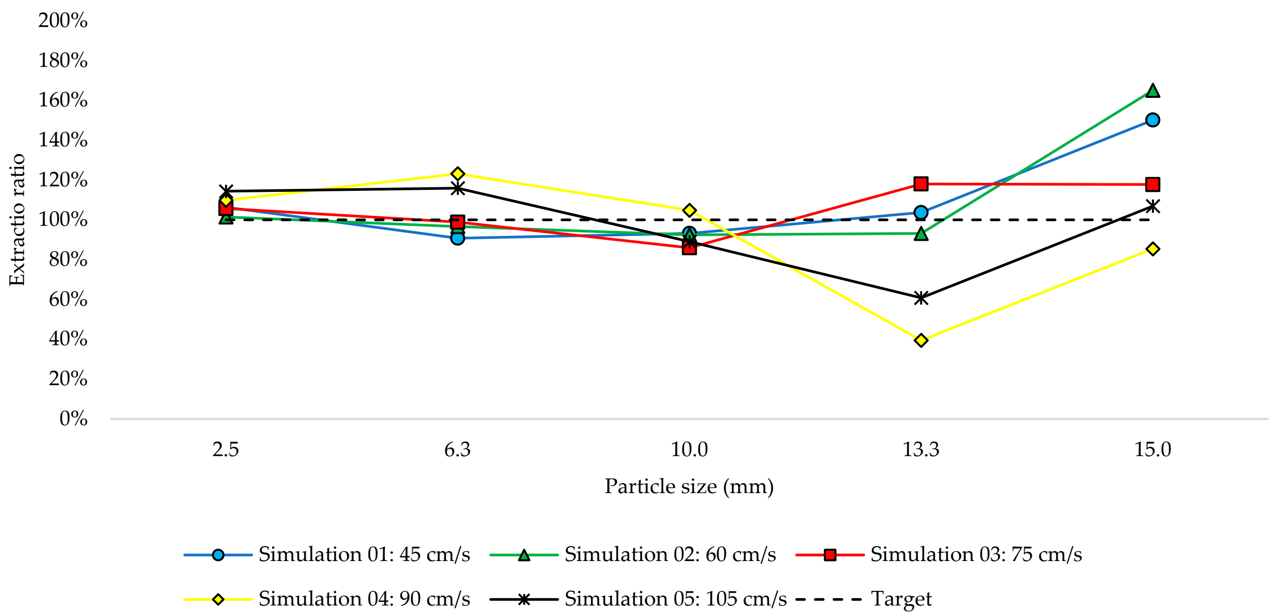

Figure 8. Vezin sampler extraction as a function of cutter velocity.

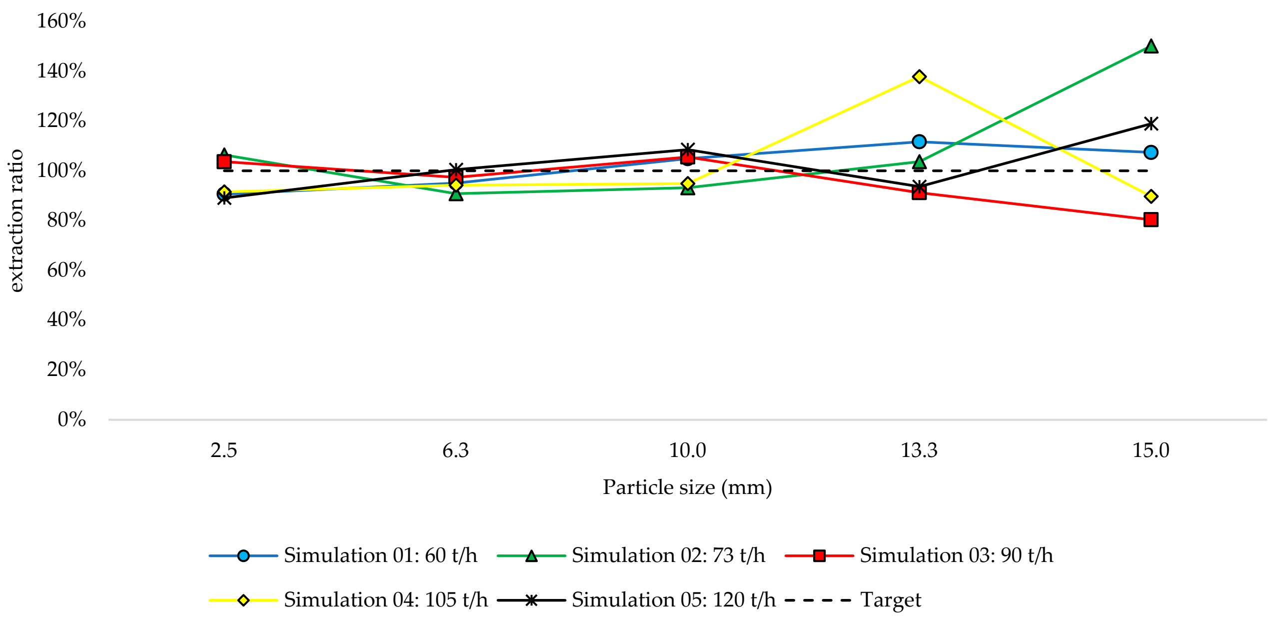

Figure 9. Vezin sampler extraction as a function of solid flow rate.

In general, no biases or significant variations were observed in the extraction of particles with an increase or a reduction in the solid flow rate, showing that the sampler was well designed. There is a bit of fluctuation for larger particles (13.3 and 15.0 mm), but it is not associated with an increase or a decrease in the feed rate. So, there is no evidence of any corresponding bias.

5. Improvements Implemented from Simulations

One of the main observations in all simulations was the great extraction variability regarding the representation of the mass percentage of each particle-size fraction. This variability is greater for the coarser-size fractions. Table 4 summarises the simulation values for the sampling system based on its original design settings. Considering these settings, the sampler collects eight increments per sampling cycle to compose the final sample. When analysing the average extraction of the three tests performed for each group separately, it is noted that, from the fourth increment on, the extraction of coarse particles drops abruptly, reaching 0%. In addition, the first increment extrapolates four times the target in the same coarse fractions (Figure 10). In this instance, the sudden change in behaviour appears to cut off with the 13.3 mm size fraction. This is mitigated by taking more increments, thus reducing variability in the secondary sampling stage. Despite the great variability between cuts, the average extraction is very close to the lot reference, thus not characterising a bias. It is important to emphasise that the tests were performed in triplicate.

Table 4. Statistical analysis of extraction in the vezin sampler.

Data	Particle Size (mm)				
	2.5	**6.3**	**10.0**	**13.3**	**15.0**
Test 1	100.0%	97.1%	86.7%	99.7%	195.0%
Test 2	112.4%	76.8%	89.6%	100.3%	215.8%
Test 3	110.1%	96.5%	101.5%	119.4%	0.0%
Target	100.0%	100.0%	100.0%	100.0%	100.0%
Deviation (95% confidence level)	16.0%	29.0%	20.0%	28.0%	296.0%
Inferior limit	123.9%	118.8%	112.1%	134.2%	432.7%
Average	107.5%	90.1%	92.6%	106.5%	136.9%
Upper limit	91.1%	61.4%	73.1%	78.7%	−158.8%
Standard deviation	6.6%	11.6%	7.9%	11.2%	119.0%
Variance	0.4%	1.3%	0.6%	1.3%	141.7%

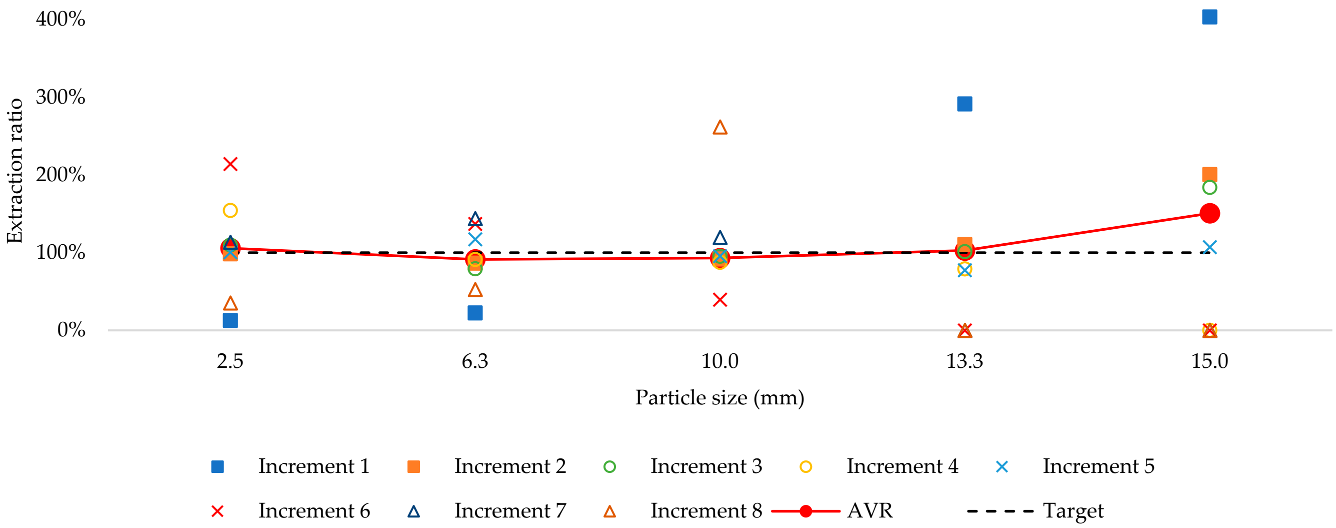

Figure 10. Vezin sampler extraction per increment.

The low extraction of coarse particles in the last cuts is due to the particle segregation on the first conveyor belt and the transport that takes the primary sample to the vezin sampler. Particle distribution is an important factor that is greatly influenced by the gravitational forces affecting the system, which create segregation. The fine particles segregate and concentrate at one extremity of the burden or pile, which causes only the fine material to be collected in the last cuts (Figure 11). Coarse particles of the same density as the fine ones can segregate in the same lot. If the speed of the stream is substantially reduced, a circular type of segregation may be seen, with the fine particles sifting through the larger fragments and agglomerating in the upper part of the pile, while the large fragments roll down on the fine particles to segregate at the bottom of the pile, as shown in Figure 11. This phenomenon is amplified as the slope of the pile becomes steeper [30].

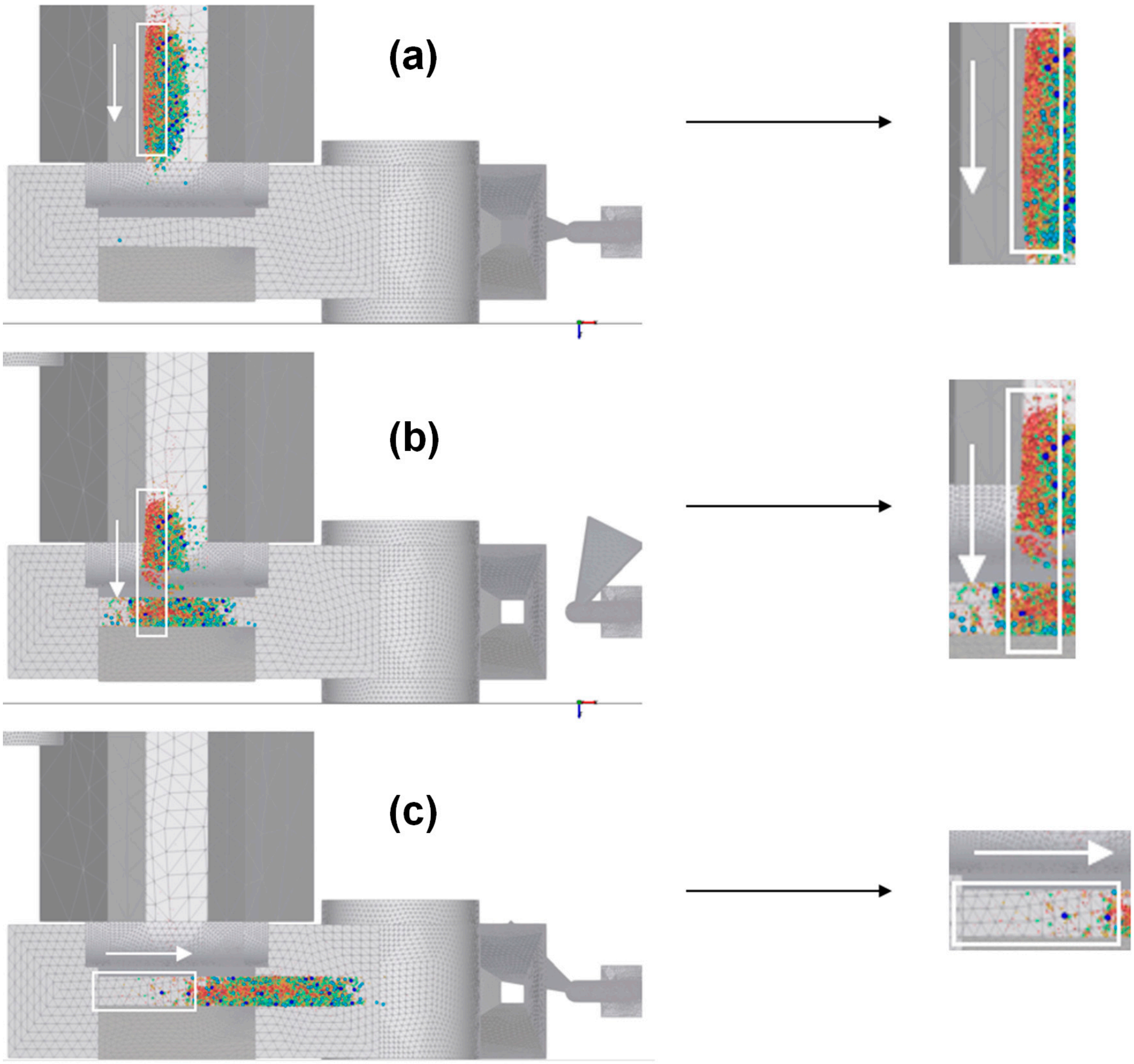

Figure 11. Segregation of fine particles on the belt: (**a**) primary sample; (**b**) primary sample being transferred to the second conveyor belt; and (**c**) primary sample feeding the vezin sampler. Particles are coloured according to their size: red (2.5 mm), yellow (6.3 mm), green (10.0 mm), light blue (13.3 mm) and dark blue (15.0 mm). The arrow indicates the material flow direction.

Based on Pierre Gy's theory of sampling, this observed variability can be reduced by increasing the number of increments. The number of increments depends on the interval between cuts and, according to Gy [1], geostatistical tools can be used to determine the ideal cut interval. With the greater stratification of the material by the conveyor belt, the number of increments can be increased and, therefore, the effect of fine particle segregation can be reduced, thus improving the performance of the equipment and minimising the grouping and segregation error (GSE). Due to the possibility of directly simulating the cut and evaluating variability, direct modifications were applied to the sampling system to investigate the effects of reducing variability. The changes were as follows:

- A 25% reduction in the primary sampler speed (45 cm/s to 34 cm/s);
- A 50% reduction in the speed of the primary conveyor belt (3 cm/s to 1.5 cm/s);
- Feeder flow rate reduction to a maximum of 60 t/h.

The purpose of the changes was to increase the mass of the primary sample and increase the material stratification on the secondary conveyor belt, which feeds the vezin sampler, allowing the collection of a greater number of increments by the vezin sampler.

Figure 12 illustrates the default configuration before and after the improvements made to the system.

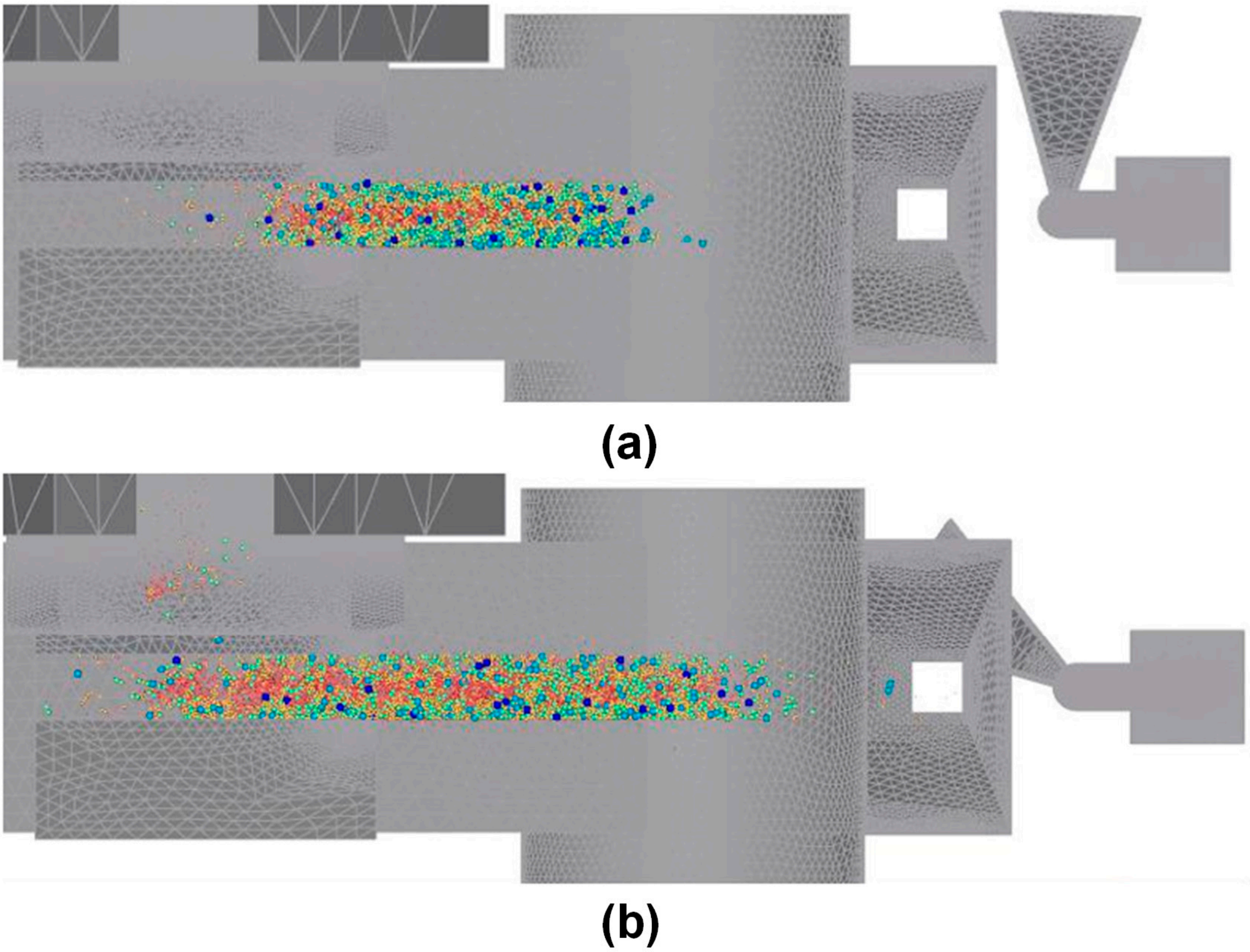

Figure 12. Primary sample stratification on the secondary conveyor belt before (**a**) and after (**b**) modifications. Particles are coloured according to their size: red (2.5 mm), yellow (6.3 mm), green (10.0 mm), light blue (13.3 mm) and dark blue (15.0 mm).

By making these system changes, the burden or pile on the conveyor belt feeding the vezin sampler was effectively elongated and spread. Table 5 shows the statistical summary of the extraction after the modifications. Again, the tests were performed in triplicate.

Table 5. Statistical analysis of extraction in the vezin sampler after the implemented improvements.

Data	Particle Size (mm)				
	2.5	**6.3**	**10.0**	**13.3**	**15.0**
Test 1	94.7%	94.0%	101.7%	115.4%	110.0%
Test 2	108.9%	93.9%	90.6%	120.1%	84.3%
Test 3	98.8%	104.3%	101.7%	87.2%	113.9%
Target	100.0%	100.0%	100.0%	100.0%	100.0%
Deviation (95% confidence level)	18.2%	14.8%	15.9%	44.2%	39.9%
Inferior limit	119.0%	112.2%	113.9%	151.7%	142.6%
Average	100.8%	97.4%	98.0%	107.5%	102.7%
Upper limit	82.7%	82.6%	82.1%	63.4%	62.8%
Standard deviation	7.3%	6.0%	6.4%	17.8%	16.1%
Variance	0.5%	0.4%	0.4%	3.2%	2.6%

Figures 13 and 14 show, respectively, the comparison of the extraction averages before and after the modifications and the extraction for each group of particles per increment collected.

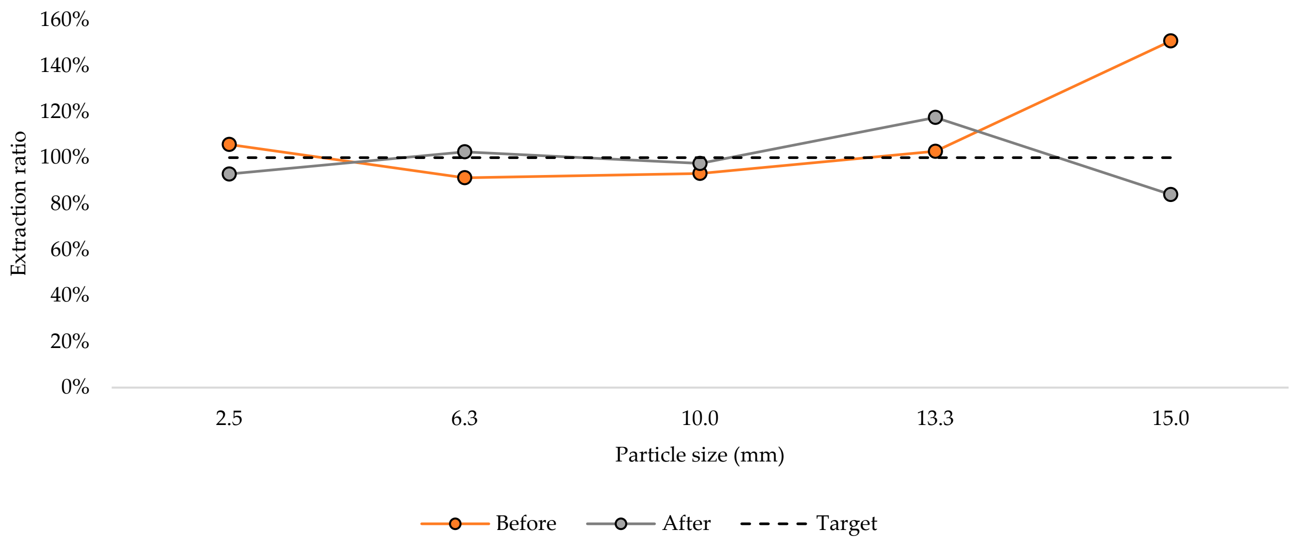

Figure 13. Comparison between extractions by the vezin sampler before and after improvements.

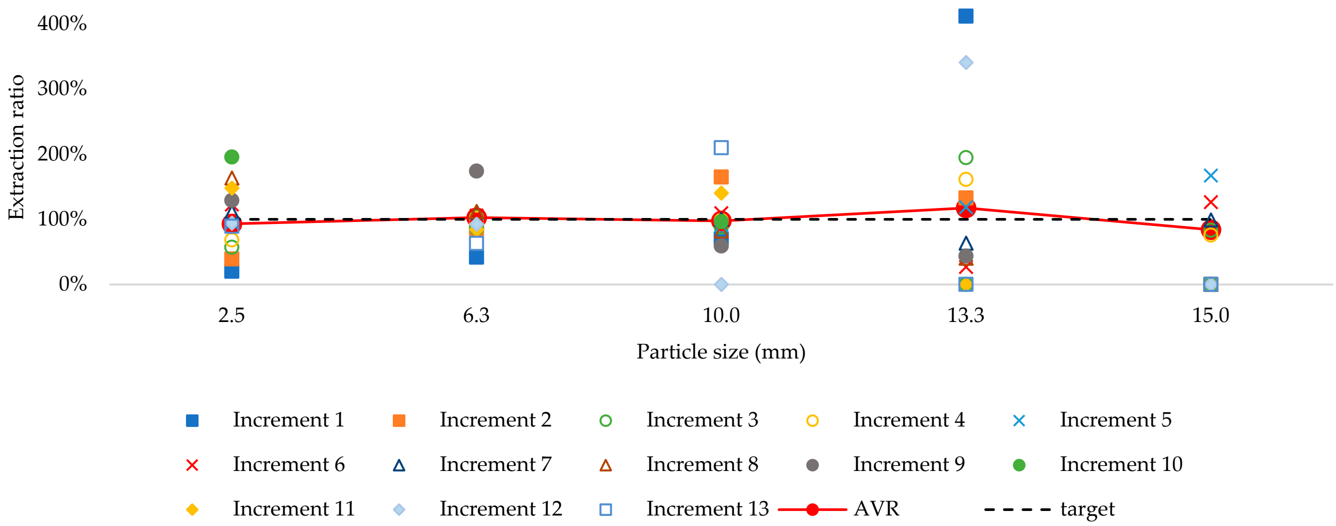

Figure 14. Vezin sampler extraction per increment collected after system improvements.

After implementing the improvements, it was possible to reduce the extraction variance in the coarse fractions and maintain the averages around 100% extraction for all groups of particles, with minimal deviations, considering the average extraction of the composite increments.

It is worth mentioning that, in addition to observing the correct design of the sampling equipment, it is essential that sampler feeding systems are also correctly designed to avoid systematic errors that may result in biased samples.

6. Conclusions

The methodology for simulating the CDS plant's secondary vezin sampler was successfully applied, validating all simulations while considering the quality of the particle contact model calibration using DEM (ESSS Rocky 4.3 software), and obtaining physical parameters extremely close to those obtained in the laboratory tests.

It was observed that the number of increments taken by the vezin sampler has a direct influence on the variance in the extraction percentage between groups of particles for each of the collected increments. Due to the segregation effect on the conveyor belt, collecting a greater number of increments reduces the granulometric variability between increments and increases the final sample's representativeness. While the practical changes made to the implemented system showed improvement, it is worthwhile to note that other changes not investigated may also lead to improvements. When making any changes, it is important to not affect the efficiency and operation of the primary sampler. Unfortunately, additional stream cuts or increments were not possible in practice at the CDS plant due to constraints associated with the speed of the installed conveyor and the sampling system and were, thus, not investigated further. It is also important to point out that the selection of eight increments aligned with the rule of thumb of at least seven cuts from a primary sample [30].

In general terms, no significant biases were observed in the CDS plant's sampling system, validating its correct dimensioning and operation. It is worth emphasising that the correct design of samplers and sampling systems must consider the physical and chemical properties of the ore sampled and, consequently, customised systems must be developed for each application.

Finally, it is important to point out that this study was carried out using a specific gold ore from a certain region of Brazil and, therefore, the results should not be applied to other types of gold ore with different physicochemical characteristics. The recommendations for dimensioning sampling equipment according to Pierre Gy's theory of sampling are, in practice, a reference guide and should be used with caution. Each sampling equipment or sampling system design should be based on the recommendations of the theory of sampling and, ideally, on the results of physical characterisation tests.

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