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Performance analysis of the beneficiation process of bauxite from the Juruti Mine. Industrial sampling and performance evaluation

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Abstract

Sampling campaigns were conducted at the industrial bauxite wash circuit of the Juruti Bauxite Mine in Pará, Brazil. The beneficiation circuit consisted of crushing, scrubber washing, wet screening, hydrocyclone classification, and filtration. Considering laboratory processing of samples and statistical analyses of historical operation databases, mass balances were obtained. Integrated analyses of historical databases, mass balances and operating parameters enabled the calculation of performance indices, which constitute the basis for the identification and hierarchy of the bottlenecks in terms of washability efficiency; that is, removal of the fraction below 0.037 mm. Typically, the focus of bauxite ore concentration in the Amazon region is the removal of the 0.037 mm fraction in the concentrate streams via disaggregation and mud washing. Consolidated mass balances indicated consistent values based on the size of the sample particles and percentage of solids, as well as the values obtained from the integrated information systems of the plant; this consistency indicated the stability and representativeness of the process conditions during the sampling campaigns. The base case of the Juruti plant operation, from which the performance indices that allowed the quantification of the efficiency of each process step was calculated, was obtained as a result.

keywords: bauxite, mass balance, performance analysis, process efficiency indexes.

1. Introduction

The degree of complexity of bauxite processing to meet the specifications of alumina refining and processing is a function of the physical and chemical characteristics of each ore. Bauxite processing, which includes washing, is an operation performed only in Brazil, since in other bauxite producing countries such as Australia and China, the ore is sent directly from the mine to comminution stages and then to the refineries. Thus, international refineries are configured to receive bauxite with low levels of available alumina, and also with contaminants and deleterious elements (Chaves *et al*., 2007).

The simulation process is based on the calibration of mathematical models for unit operations constituting the process flowchart. This process starts with detailed planning, minimum mass calculations, field analyses, and execution of sampling campaigns of the input and output flows of each equipment or process stage. Furthermore, a sampling is performed with strict monitoring of circuit stability, and in general, it is performed incrementally for one- to three-hour periods. After careful laboratory treatment of the samples, mass balance routines are applied. A consistent data set is the basis for the calibration of mathematical models of the processing equipment. Such calibrated and flowchart integrated models are used for simulations aimed at local performance improvements and enabling the verification of global impacts on the industrial circuit. One of the great advantages of the simulation is the saving of time and resources in identifying alternatives for the improvement of process performance or even defining new beneficiation routes for projects under development.

This article is Part I of a work on sampling, simulation and optimization. The sampling process, mass balance and quantification of the efficiency of the processes studied in Part I and the model calibration and carrying out simulations are the Part II objective. Therefore, this study aimed to diagnose the performance of the processes of the Juruti Bauxite Mine, based on the samples taken at the industrial plant. The analyses of the samples and mass balances were the bases for the diagnosis of the equipment performance. This diagnosis enabled the identification of operational bottlenecks in terms of improving the washability efficiency, that is, removing the contaminants from the product; this contaminant removal is the main objective of the Juruti bauxite beneficiation plant.

2. Bibliographical review

Bauxite beneficiation consists of a set of unit operations to remove the clay fraction and silica minerals, which are considered contaminants. It generally consists of crushing, grinding, screening, classifying, filtering, and drying (optional) stages. Depending on the mineralogical composition, specifications, and objectives of the enterprise, the sequences of operations are defined to reach the production levels associated with the quality parameters required by customers.

The Juruti bauxite beneficiation plant consists of two parallel lines 1 and 2. Each line consisted of a coarse circuit (scrubber and trommel, a second crusher, and two stages of screens) and a fine aggregate circuit (four stages of hydrocyclones and a belt filter). A material larger than 0.037 mm is considered a product. A 0.037 mm thick material in the product is considered a contaminant. Thus, the coarse product from Juruti is between 76.2 mm and 1.2 mm in size and consists of the combined oversize of the two screening stages of each line, whereas, the fine product has a particle size of between 1.2 mm and 0.037 mm and is made up of the underflow of secondary fine (hydrocyclone of 26 inches) and superfine hydrocyclone (hydrocyclone of 10 inches) batteries. The underflow of the secondary fine battery and the secondary superfine battery goes through the filtration process and is then destined for stacking together with the coarse product. However, the filtering operation has not been studied in the present study. Figure 1 presents a simplified flowchart of the plant.

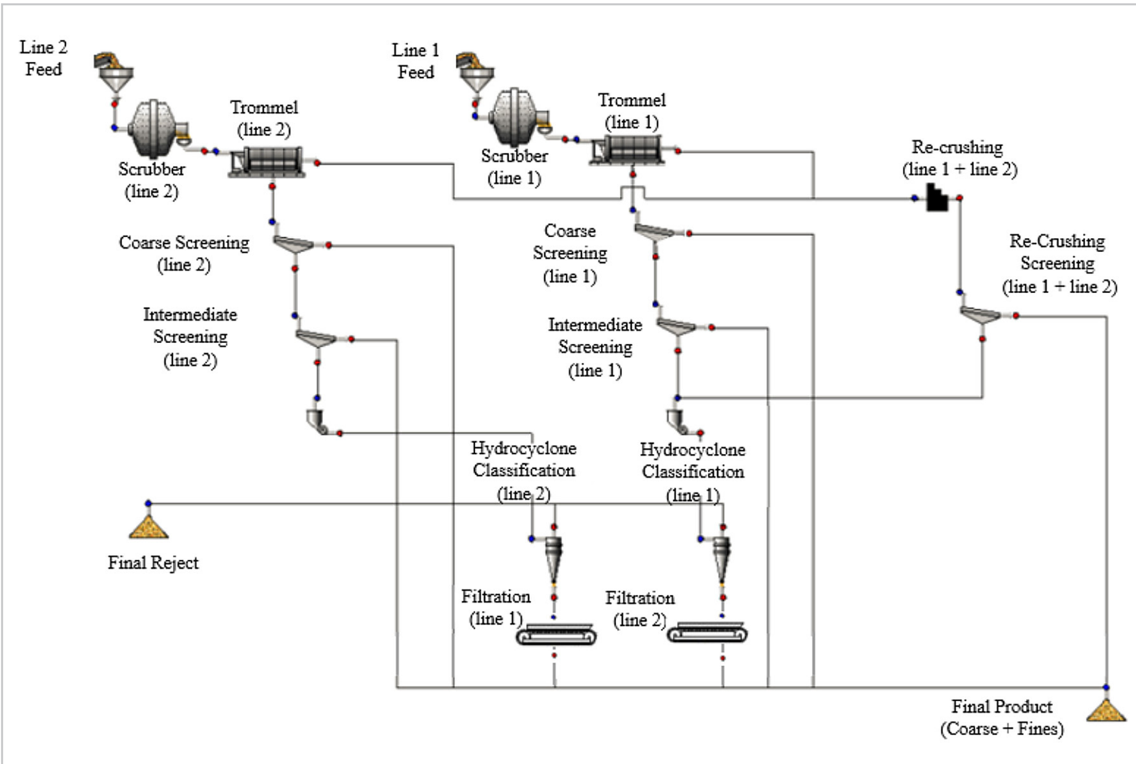

Figure 1 - Simplified flowchart of the Juruti bauxite beneficiation plant.

Sampling represents the first step in the development of mass balances and calibration of representative models of the unit operations of a plant. This step consists of collecting quantities of material in increments at different times and a series of operations to construct an overall sample that represents the entire population of interest. An analytical result with several decimal digits is futile if the analyzed sample is biased or insufficiently representative. The sampling process becomes even more complicated in processes with high feed mass flow and becomes critical with increasing thickness of the particle size distribution of a given flow. Nappier-Munn *et al.* (1999) stressed that important factors, namely, stability of the process operation, type of samplers, and processing of samples, must be managed carefully in industrial sampling to ensure the collection of a representative sample.

After evaluating the data, the mass balance of the entire sample can be initiated in an attempt to investigate, in greater detail, the inconsistencies in the data obtained during taking the samples in the field and treating them. In this stage, programs are used to carry out the mass balance, which seek to minimize the difference between the measured values and the estimated values, according to the deviation attributed to each measurement. The magnitudes of the deviations must be related to the difficulty of obtaining specific samples, or even to problems with data measurement systems in the field. In the present study, JKSimMet was used. In the specific module for performing mass balances, the user can insert up to 30 components in a flow to then perform mass balances according to all the information entered. Errors can be attributed to any particle size or flow determined experimentally, since some data extracted from the sample can be more reliable than others, due to the difficulty of taking the sample or even due to a problem without a measuring system installed in the field. In the procedure, a flow should be taken as a reference, that is, consider a flow with zero error to perform the mass balance.

3. Method

In order to generate experimental information to establish the base case, two sampling campaigns were carried out at the Juruti bauxite processing plant, one on each production line. In the two campaigns, 23 flows from the plant were sampled, as described: 1 washing plant feed; 2 trommel oversize; 3 re-crushing screen oversize; 4 re-crushing screen oversize underize; 5 primary screening oversize combined of two screens decks; 6 secondary screening oversize combined of two screens decks; 7 hydrocyclones feed/fine primary; 8 hydrocyclones underflow/fine primary; 9 hydrocyclones overflow/fine primary; 10 hydrocyclones feed/fine secondary; 11 hydrocyclones underflow/fine secondary; 12 hydrocyclones overflow/fine secondary; 13 hydrocyclones feed/superfine primary; 14 hydrocyclones underflow/superfine primary; 15 hydrocyclones overflow/superfine primary; 16 hydrocyclones feed/superfine secondary; 17 hydrocyclones underflow/superfine secondary; 18 hydrocyclones overflow/superfine secondary; 19 reject global; 20 reject from each line; 21 coarse product; 22 fine product; 23 fine product combined from two lines.

The samples from points 1, 2, 3, 5, 6 and 23 (coarse and fine) were collected in belt conveyors, while samples 7 to 18 (slurry) were taken in the feed, overflow and underflow pipes, by means of valves installed in them. The samples from points 19 and 20 (tailings) were also obtained manually, that is, using a manual sampler (mug type), the samples were taken in the transfer chute that receives the tailings from the production lines. The samples from points 21 and 22 were obtained using linear samplers operated automatically. The taking of samples at each selected point was conducted incrementally, during a stable period of operation, with feeding considered typical.

The samples were obtained following the minimum mass criteria established by Pierry Gy's sampling theory (1992). The samplers used to take the samples met the rule of having an opening at least three times the size of the largest particle for material above 10 mm, and at least 10 mm for flows with particles smaller than 3 mm. The coarse flows were sampled on the belt conveyors, delimiting a sufficiently large length for removing the material, in order to guarantee the obtaining of the minimum representative mass for each flow. The slurry flows were taken using mug-type samplers. To increase the degree of sampling redundancy, during the sampling period, the values of all instruments installed, in operation and calibrated in the circuit were recorded. The physical characteristics of the bauxite fed to the plant were also recorded during the two sampling campaigns.

The screens series used in the treatment of coarse, fine and slurry samples in order to obtain the samples particle size distributions representative of the sampled flows were: i. Coarse samples: 4”, 3”, 2”, 1”, ½”, ¼”, 8#, 16#,30#, 70#, 100#, 140#, 200#, 270#,400#; ii. Fine and slurry samples: ¼”, 8#, 16#,30#, 70#, 100#, 140#, 200#, 270#,400#.

Square screens (400mm x 400 mm) were used for the coarse samples and circular screens (220mm x 50 mm) for the fines and slurry samples. The entire screening process was carried out in the wet, just as performed in the sampled plant.

The samples were also processed to determine the percentage of solids and total chemistry. Each increment was opened, and all its contents were unloaded in trays and dried in greenhouses at 105 °C. The dry mass of each tray was measured on scales. The sum of the masses of the trays and the ore constituted the dry weight of each increment. The tare of each increment includes the weight of the plastic bags and clamps used to store the samples. After drying, the dough was ground in roller mills to disaggregate the material, allowing adequate quartering for chemical analysis. The ground material was homogenized by an elongated pile, with the objective of gathering the mass of all the increments of the referred sample, later quartered in a Jones-type splitter, respecting the criterion of the opening of each riffle being greater than 3 times the size of the largest particle of the flow. At the end of this procedure, an aliquot of approximately 80 g was obtained, which was pulverized and then destined for chemical analysis, to determine the levels of available alumina (Av-Al_2O_3), reactive silica (Re-SiO_2), and iron oxide (Fe_2O_3) via digestion of bauxite in alkaline medium, atomic absorption spectrometry and titrimetry, respectively.

From the information obtained in the sampling campaign, data obtained from the field sampling and information from the physical and chemical processing of the samples, it was possible to prepare the mass and metallurgical balances for the two production lines of the bauxite beneficiation plant, that is, line 1 and line 2. The mass balance and performance analyses for each individual equipment were performed with the help of JKSimMet 6.0.1, a simulator developed by Julius Kruttschnitt Mineral Research Centre (JKMRC), University of Queensland, Australia.

The Table 1 shows the models selected in the JKSimMet software for each unit operation.

Table 1 - models applied for each unit operation, as presented in the JKSimMet model list.

Unit Operation/Equipament	Model Name (JKSimMet v6.0.1)
Washers	Variable Rates - AG Mill (adapted)
Trommels	Efficiency Curve - Water & Fines
Re-crushing	Crusher (Andersen-Whiten)
Screening	Efficiency Curve - Water & Fines
Cyclones	Nageswararao Cyclone

4. Results and discussion

4.1 Analysis of plant stability during the sampling period

The stability of the plant operation during the sampling period was evaluated by analyzing the feed flow of the plant (Figure 2) and the feed flow of the fine circuit (Figure 3 and 4), which receives the undersize from the coarse circuit.

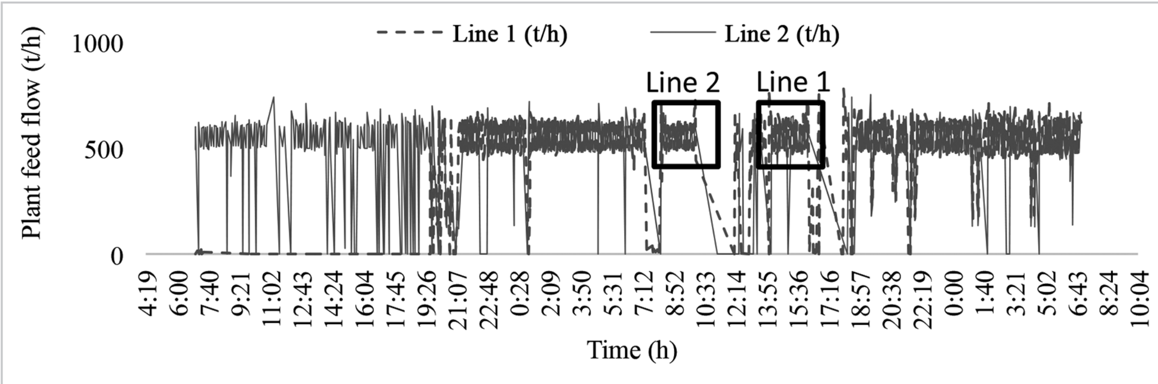

Figure 2 - Time series of lines 1 and 2 mass flow readings within the 48 h operation.

The data from the integrating scales installed in the belt conveyors feeding lines 1 and 2 were used for the 48-hour operating period (from 07:00 a.m. on the day before the sampling day until 07:00 a.m. on the day after the sampling day). Figure 2 shows the graph for the feed mass flow of lines 1 and 2 for this period. At the beginning of the sampling in line 1, as well as during the sampling in line 2, anomalous readings were recorded; such readings were considered as outliers and were excluded from the analysis through the evaluation of the data box plot.

From the data presented in Figure 2 and considering the highlighted areas that refer to the sampling period of each production line, we obtained the flow values for line 1 as follows: mean feed flow of 549 t/h on a wet basis, standard deviation of 13 t/h, coefficient of variation of 2.4%, minimum flow of 522 t/h, and maximum flow of 585 t/h. For line 2, the flow values were as follows: mean feed flow of 549 t/h, standard deviation of 12 t/h, coefficient of variation of 2.2%, minimum flow of 512 t/h, and maximum flow of 582 t/h. This information validated the stability of the circuit feeding, which indicated that the operational flow was constant during all samplings.

Figures 3 and 4 show the graph of the slurry volumetric flow from the four hydrocyclone batteries in lines 1 and 2 during the sampling period. No significant disturbances were observed in the volumetric flows, which remained within the normal operating range for line 1 hydrocyclone operations of the plant (Figure 3).

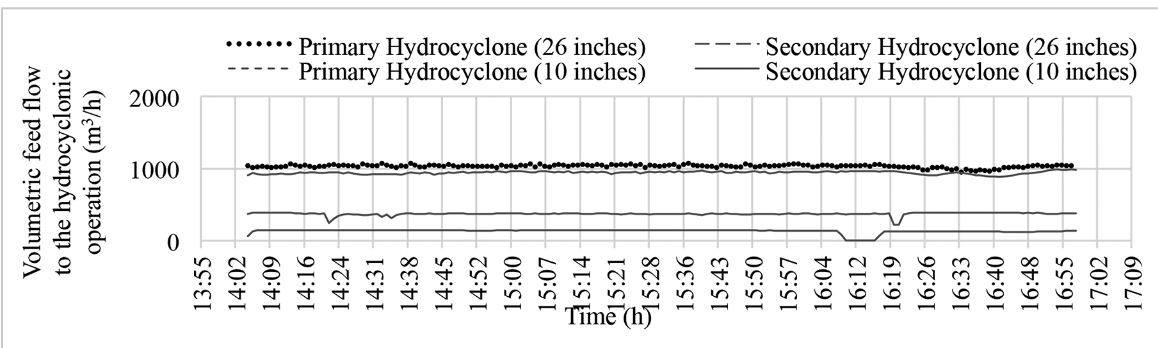

Figure 3 - Time series readings of slurry feed volumetric flow to line 1 hydrocyclone operation.

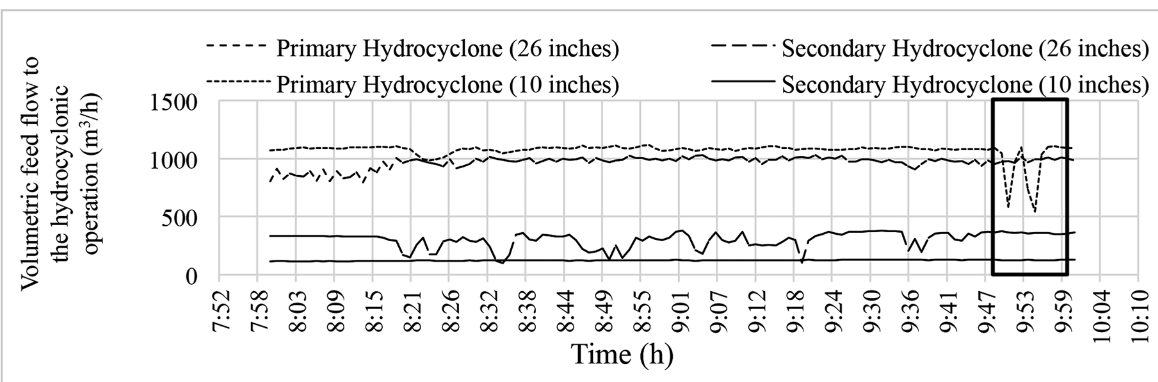

Figure 4 - Time series readings of slurry feed volumetric flow to line 2 hydrocyclone operation.

Figure 4 shows the feed to line 2 hydrocyclone operation where an instability in the feed of the superfine primary battery was observed from 09:49 to 09:57; this instability also caused a disturbance in the superfine secondary hydrocyclone operation. Different sensors detected the fluctuation in the circuit from 09:49 to 09:57; thus, these data were included in the outlier analysis.

4.2 Model calibration

In calibrating the representative model of the bauxite beneficiation operations at the Juruti plant, the efficiency curve models (Napier-Munn *et al.* (1999) were used for the screening operation and Nageswararao (1978 and 1995) for the cyclone classification operation. Tables 2 and 3 show the constants and parameters obtained for the calibrated model, considered the base case in the present study.

Table 2 - Parameters of the efficiency curve model applied to the screening.

Efficiency Curve Parameters	Trommel	Primary Screening	Re-crushing Screening	Secondary Screening
Efficiency curve - Alpha	13.82	9.72	80.51	6.92
Efficiency curve - Beta	0.00	0.00	23.38	0.00
Water Partition - Fine Product	99.51	97.70	92.34	98.43
D50 corrected - d_{50c} (mm)	54.45	8.66	1.10	2.09
Beta calculated	1.00	1.00	1.10	1.00

Table 3 - Parameters of the Nageswararao model applied to the five cyclone stages.

Model Parameters	Primary Fine Ore	Secondary Fine Ore	Primary Super-fine Ore	Secondary Super-fine Ore	Tertiary Super-fine Ore
K_{D0} (D_{50} - total)	0.00022	0	0.00015	0.00013	0.00013
K_{Q0} (capacity)	686.01	412.41	599.03	361.51	361.51
K_{V1} (volume partition)	4.61	11.11	2.23	19.87	19.87
K_{W1} (water partition)	15.59	26.45	13.84	109.86	109.86
Efficiency Curve - Alpha	0.01	0	1.81	3.74	3.74
Efficiency Curve - Beta	0.84	0.23	0	0	0

To evaluate the calibration quality, the particle size distributions of the coarse and fine product obtained from the sampling process were plotted, together with the distributions obtained in the calibrated base case, as shown in Figure 5. Good adherence of the experimental and simulated curves can be observed, indicating that the calibrated model is representative of the operations that compose the bauxite beneficiation process at the Juruti plant.

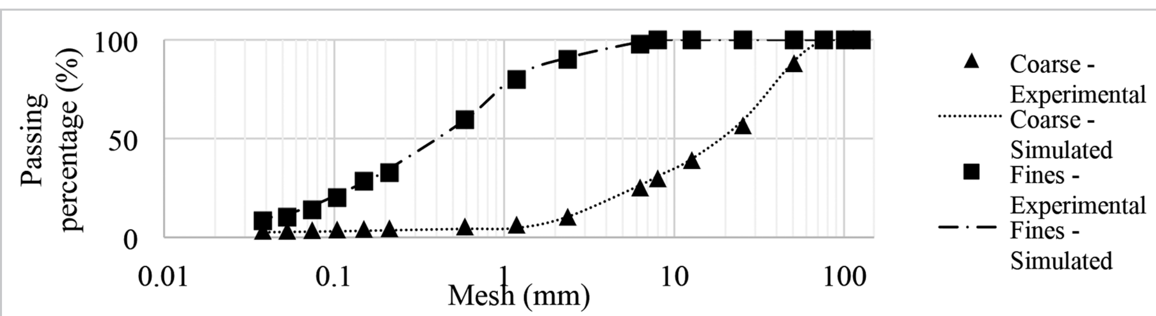

Figure 5 - Experimental and simulated particle size distribution of the coarse and fine product for the base case.

4.3 Mass balances

From the information obtained during the sampling campaign and from the physical and chemical processing of the samples, it was possible to elaborate the mass balances for the two production lines of the Juruti bauxite beneficiation plant. Table 1 shows the details of the results for line 1 for the washing, screening, and re-crushing circuits and Table 2 shows the details of the results for the hydrocyclone circuit of line 1. It is important to note that the mass balance for line 1 and line 2 is presented separately, as samples were taken on each line separately, each with its characteristic feed and its operating parameters. And yet, although the rebranding step is the same for both lines, when receiving ore with different characteristics, coming from the oversize of the trommel, its performance results will also be different, as was proven with the sampled and balanced information presented in the Tables 4, 5, 6 and 7.

Table 4 - Mass balances for the washing, re-crushing, and screening of the base case of line 1 (F is feed, O/S is oversize, U/S is undersize, P is.

Variables	Plant Feed	Trommel			Primary screening			Re-crusher		Re-crushing screen			Secondary screening			Coarse product
		F	O/S	U/S	F	O/S	U/S	F	P	F	O/S	U/S	F	O/S	U/S	
Solids flow (t/h)	453	453.0	28.7	424.3	424.3	110.4	313.9	28.7	28.7	28.7	23.9	4.8	313.9	72.1	241.8	206
Solids density (t/m³)	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
Water flow (t/h)	96.2	453.0	2.2	451	562	12.7	550	2.2	2.2	35.1	2.7	32.4	646	10.2	636	25.5
Percentage of solids	82.5	50.0	92.8	48.5	43.0	89.7	36.3	92.8	92.8	45.0	89.9	12.9	32.7	87.7	27.5	89.0
Slurry density (t/m³)	2.01	1.44	2.30	1.42	1.36	2.21	1.28	2.30	2.30	1.38	2.21	1.09	1.25	2.15	1.20	2.19
Slurry flow (m³/h)	273	630	13.5	616	728	55.8	672	13.5	13.5	46.3	12.0	34.3	769	38.3	730	106
P_{80} (mm)	41.1	16.1	75.3	11.5	11.5	31.5	2.26	75.3	51.0	51.0	53.7	0.24	2.26	6.4	0.571	29.1

Table 5 - Mass balances for the hydrocyclone operation of the base case of line 1 (F is feed, O/F is overflow, U/F is underflow).

Variables	Hydrocyclones - Fine primary (1st 26")			Hydrocyclones - Fine secondary (2nd 26")			Hydrocyclones - Superfine primary (1st 10")			Hydrocyclones - Superfine secondary (2nd 10")			Reject	Fine product
	F	U/F	O/F	F	U/F	O/F	F	U/F	O/F	F	U/F	O/F		
Solid flow (t/h)	246.6	108.0	138.6	108.0	103.1	4.9	143.5	19.1	124.4	19.1	15.6	3.5	127.9	118.7
Solid density (t/m³)	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
Water flow (t/h)	1247.7	53.2	1194	234.8	50	185.0	1451	16.2	1435	93.4	13.2	80.2	1514.9	63
Percentage of solids	16.5	67.0	10.4	31.5	67.4	2.6	9.0	54.1	8.0	17.0	54.2	4.2	7.8	65.3
Slurry density (t/m³)	1.11	1.69	1.07	1.24	1.70	1.02	1.06	1.49	1.05	1.12	1.49	1.03	1.05	1.66
Slurry flow (m³/h)	1344	95.4	1249	277.0	90	186.9	1507	23.7	1483	100.9	19.3	81.6	1564.9	109
P_{80} (mm)	0.56	1.19	<0.010	1.19	1.21	0.00	0.000	0.145	<0.010	0.145	0.163	<0.010	<0.010	1.115

Tables 6 and 7 present the mass balance details for line 2 for the washing, screening, and re-crushing circuits and for the hydrocyclone circuit, respectively.

Table 6 - Mass balances for the washing, re-crushing and screening of the base case of line 2 (F is feed, O/S is oversize, U/S is undersize, P is.

Variables	Plant Feed	Trommel			Thick primary screening			Re-crusher		Re-crushing screen			Secondary screening intermediaries			Coarse product
		F	O/S	U/S	F	O/S	U/S	F	Product	F	O/S	U/S	F	O/S	U/S	
Solid flow (t/h)	462.0	462.0	39.0	423.0	423	148.8	274.1	39.0	39.0	39.0	32.3	6.7	274.1	60.7	213.5	241.8
Solid density (t/m³)	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
Water flow (t/h)	87.1	494.4	2.7	492	609	20.2	588	3	2.7	57.4	4.1	53.3	588	12.3	576	36.6
Percentage of solids	84.1	48.3	93.6	46.2	41	88.0	31.8	93.6	93.6	40.5	88.8	11.1	31.8	83.1	27.0	86.9
Slurry density (t/m³)	2.05	1.42	2.33	1.39	1.33	2.16	1.24	2.33	2.33	1.33	2.18	1.07	1.24	2.03	1.20	2.12
Slurry flow (m³/h)	268	675	17.9	657	774	78.4	696	18	17.9	72.6	16.7	55.9	696	36.0	660	131
P_{80} (mm)	64.2	32.0	86.6	22.0	22	44.1	1.74	86.6	46.8	46.8	50.1	0.250	1.74	5.6	0.432	39.6

Table 7 - Mass balances for the cyclonic operation of the base case of line 2 (F is feed, O/F is overflow, U/F is underflow).

Variables	Hydrocyclones - Fine primary (1st 26inches)			Hydrocyclones - Fine secondary (2nd 26 inhces)			Hydrocyclones - Superfine primary (1st 10 inches)			Hydrocyclones - Superfine secondary (2nd 10 inches)			Reject	Fine product
	F	U/F	O/F	F	U/F	O/F	F	U/F	O/F	F	U/F	O/F		
Solid flow (t/h)	220.2	98.4	121.8	98.4	95.9	2.5	124.3	22.3	102.0	22.3	18.9	3.3	105.0	114.8
Solid density (t/m³)	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
Water Flow (t/h)	994.0	46.0	948	174.9	48	127.4	1272.0	14.6	1257.3	83.7	13.7	70.0	1327.3	61
Percentage of solids	18.1	68.1	11.4	36.0	66.9	1.9	8.9	60.3	7.5	21.0	58.0	4.5	7.4	65.2
Slurry density (t/m³)	1.12	1.71	1.07	1.28	1.69	1.01	1.06	1.58	1.05	1.15	1.55	1.03	1.05	1.66
Slurry flow (m³/h)	1080	84.0	996	213.0	85	128.0	1320.5	23.3	1297.2	92.4	21.1	71.3	1368.5	106
P_{80} (mm)	0.425	0.904	<0.01	0.904	0.920	<0.01	<0.010	0.11	<0.010	0.11	0.12	0.04	<0.010	0.813

The balances were consistent, thereby offering the basis for evaluating the performance indexes of the plant and for calibrating the mathematical models of each equipment. These balances were also used for integrating the models to configure the industrial washing and classification circuits, thus forming the base case representative of the typical operation of the Juruti plant for the ore processed during the sampling campaigns.

4.3 Diagnosis of plant performance

Table 8 presents the selected efficiency indexes for each screening and classification step, which were calculated from the sampling conducted in lines 1 and 2. The efficiencies were calculated from the sampled and balanced data, in order to constitute the base case of the study that reflects the real condition of plant operation. The fine removal efficiency was considered as the percentage ratio of the fines flow in the undersize (or overflow) to the fines flow in the feed of the considered step. For each step, a specific reference mesh was defined.

Table 8 - Efficiency indexes for the base cases of lines 1 and 2.

Unit operation	Reference mesh (mm)	Line 1 efficiency (%)	Line 2 efficiency (%)
Trommel	76.2	95.2	94.4
Coarse Screening	8.0	95.7	94.7
Intermediate Screening	1.2	98.1	98.1
Re-crushing Screen	1.2	94.4	93.4
Primary Fine Hydrocyclone (26 inches)	0.037	90.1	93.0
Secondary Fine Hydrocyclone (26 inches)	0.037	32.3	29.2
Primary Superfine Hydrocyclone (10 inches)	0.037	95.9	95.3
Secondary Superfine Hydrocyclone (10 inches)	0.037	64.3	50.9

Based on the results in Table 8, the calculated screening efficiencies for the coarse circuit were considerably high for both production lines, ranging from 94.4% (line 1) and 93.4% (line 2) for re-crushing to 98.1% (line 1) and 98.1% (line 2) for secondary screening. The primary fine and superfine classification stages exhibited an excellent efficiency at mesh 0.037 mm, with values of 90.1% (line 1) and 93.0% (line 2) for the primary hydrocyclone of 26 inches and 95.9% (line 1) and 95.3% (line 2) for the primary hydrocyclone of 10 inches. For the secondary batteries (26 inches and 10 inches), the efficiency values were low at 32.3% (line 1) and 29.2% (line 2) and 64.3% (line 1) and 50.9% (line 2), respectively; this result indicated a low performance in the removal of the passing fraction at the 0.037 mm mesh.

As shown in Table 8, only the secondary hydrocyclone of 10-inch operation showed a significant difference between the efficiencies for lines 1 and 2. A detailed analysis of the balances showed that the two lines had almost the same performances. It is important to emphasize that the differences observed may be related to the operating conditions of the equipment, such as the condition of the lifting bars of the washers with different wear from one line to another, operating condition of the screening sprays and the first and second decks, and re-crushing flow direction to line 1 only. These factors may have had an impact at the time of sampling.

Specifically, in evaluating the impact of the washing machine liners and lifting bar conditions on the generation of the 0.037 mm passing material, the condition of the liners (or lifts) of line 2 was better than that of line 1 during the sampling campaign (Figure 6). These differences associated with the combinations of the operational conditions of the equipment and the characteristics of the ore fed to each line during the sampling period contributed to the differences in performance observed between the two plant production lines.

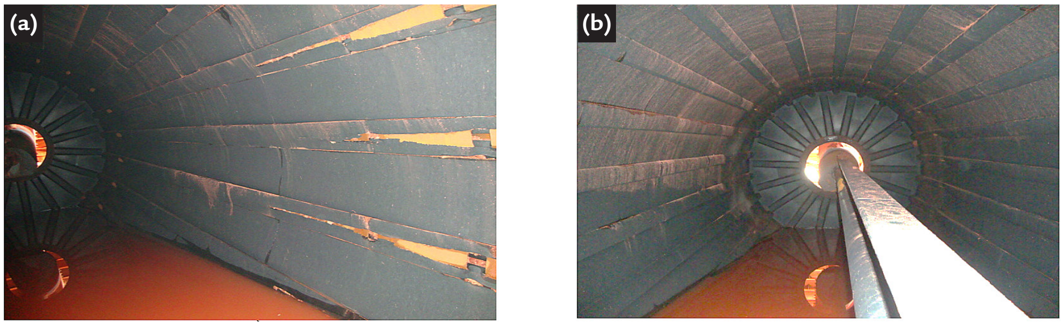

Figure 6 - Internal liner (or lifts) of the washer of a) line 1 and b) line 2.

Table 9 presents the analysis of the 0.037 mm passing fractions in the product flows of plant lines 1 and 2.

Table 9 - Analysis of the 0.037 mm mesh passing fraction for line 1 and line 2.

Product Streams	Line 1	Line 2
Underflow - Secondary Hydrocyclone (26 inches)	55,6	38,6
Oversize of Coarse Screening	19,1	26,4
Oversize of Intermediate Screening	13,0	15,7
Underflow - Secondary Hydrocyclone (10 inches)	11,4	17,1
Oversize Re-crusging screening	0,9	2,1

As shown in Table 9, the two major sources of contaminants (0.037 mm passing material) in the final product for both production lines originate from the underflow of the secondary hydrocyclone battery (55.6% in line 1 and 38.6% in line 2) and from the oversize of the coarse screening (19.1% in line 1 and 26.4% in line 2). This result demonstrated that the performances for the removal of fines are almost identical. This analysis allows the identification of the equipment or process stages that can considerably increase the quantity of contaminants in the product. Consequently, the areas that have the utmost impact on the process quality can be alerted.

4.4 Assessment of equipment capacity

Considering the base case of line 1 as the reference, the relationships between flows and equipment capacities were evaluated, taking into consideration the capacities indicated by the equipment manufacturers. The trommel used 91.6% of its active area. The re-crusher utilized 62% of its capacity. For the screens, in terms of layer thickness in the feed, only the re-crushing screen was within the limits specified by the manufacturer; all the others extrapolated the maximum thickness limit. However, in terms of percentage of area used, all screens were within the specifications. In particular, the first deck of the re-crushing screen exhibited a utilization of only 15.6% of the total useful area, whereas the second deck of the secondary screen presented a utilization of 84% of the useful area. The percentage of area used is a significant operating condition that contributed to the high screening efficiencies presented in Section 4.3. The four hydrocyclone batteries in operation had enough hydrocyclones, including the backup hydrocyclones, to meet the required production capacity.

5. Conclusions

The main conclusions of this study are as follows:

- The stipulated strategy and sampling criteria were confirmed to be adequate for the study conducted at the Juruti plant, thereby providing a consistent basis for the later stage of mass balances, process diagnosis, and performance simulations.
- The conducted mass balances indicated consistent values based on the results of sample granulometry and solid concentration, as well as the values obtained in the data base system of the Juruti plant.
- The base case provided an essential reference for detailed performance analyses, thereby allowing for quantification of the efficiency of each process stage, where high efficiencies of passing portions in screenings and hydrocyclone operations were observed; however, the exception in the latter are the secondary stages of fines, which represented the ultimate area for interventions to enhance the quality of the product.
- The evaluation of the balances enabled the identification of the critical stages in terms of final product contamination, thus indicating the need for performance improvement of the fine secondary hydrocyclone operation and primary screening of coarse particles.
- The base case resulting from the integration of mathematical models was a suitable platform for further works on washing circuit process simulations in the Juruti plant.

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