AVALIAÇÃO DO USO DE SENSORES DE TRANSMISSÃO DE RAIOS - X DE DUPLA ENERGIA NA SEPARAÇÃO DE CARVÃO E SUA PRECISÃO*

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Resumo

A tecnologia de Sensor-Based-Sorting (SBS) é uma tecnologia emergente aplicada na separação e concentração de minerais. A técnica consiste em usar um método conhecido como separação por transmissão de raio X de dupla energia (DE-XRT). Este trabalho investiga a precisão da medição DE-XRT. A posição da partícula sobre a correia transportadora foi avaliada e, apesar da variabilidade dos resultados, mostra que não há uma posição com maior precisão na leitura do sensor. Os resultados obtidos indicaram que a tecnologia de classificação DE-XRT foi capaz de reduzir significativamente a massa e o teor de cinzas da alimentação, sendo uma opção interessante para redução de custos e melhoria da qualidade do carvão em plantas de beneficiamento.
Palavras-chave: Separação automática; Pré-concentração; Carvão de Moatize.

AN EVALUATION ON DUAL ENERGY X-RAY TRANSMISSION SORTING AND ITS MEASUREMENT PRECISION FOR COAL

Abstract

The Sensor Based-Sorting technology is an emerging technology applied in mineral separation and concentration. The technique consists in using a method known as Dual Energy X-ray Transmission sorting (DE-XRT). The particle's position over the conveyor belt was evaluated and, despite de variability of results, shows that there is no a position with greater accuracy on the sensor's reading. Results obtained indicated that DE-XRT sorting technology was able to significantly reduce the mass and the ash content of the ore feed, being an interesting option for reduction of costs and improvement of coal quality in beneficiation plants.
Keywords: Automatic Sorting; Dry Beneficiation; Pre-concentration; Moatize Coalfield.

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1 INTRODUCTION

Moatize Coal Basin is located in Tete province, Mozambique, at east of the African continent. Recent discoveries of gas and coal deposits made the country a major attraction for investments in large mining projects involving coal mining and natural gas processing [1-2].

Due to coal heterogeneity, particles with low or no content of carbon (wastes) are mixed with particles of high quality coal. These particles can represent a significant part of the *run-of-mine* (ROM) sent to the concentration plant, generating an increment of costs by waste processing and transportation. The decision about the choice of the coal processing plant, grade of concentration and waste removal depends on the market and economic conditions [3-5].

In Mozambique, coal is believed to have an age about 280 Ma. It was formed during the so-called Karoo rifting, which affected the Eastern African Region. The Karoo coal basin, described as Zambezi Basin and Moatize Basin, extends over a distance about 350 km, and probably contains several billions tones of coking coal reserves. This coal basin was considered to be one of the last explored coking coal basins in the world [6-9].

Ten different coal seams have been observed in Moatize Basin, but six of them are the most important. Nowadays, Chipanga is the coal seam explored in Moatize Mine and presents around 30 meters of thickness. Chipanga seam was divided in 4 different layers: UCT, UCB, MLCU and LC456, from the top to the bottom. Each of these 4 layers was processed separately.

In recent years, several authors have studied the use of automatic sorting in pre-concentration of minerals by using different types of detectors known as Sensor-Based Sorting (SBS). This sort of technology has been applied to coal, uranium, gold, diamonds processing, etc. At the mining industry however they were used with uranium, gold and diamonds processing since the 60's. Recently, the improvement of image and data processing velocity brought back this technology to mineral processing area [10-12].

Results published in 2014 by Wotruba et al., about the application of the SBS technology in coal preparation, indicate ash content reduction of about 10%, with feeds around 150 ton/h, for coarse particles. The lower feed rate is still a limiting factor for its application at the mineral industry [13a, 13b].

Even though much has been said about the SBS technology used in mineral separation and concentration, studies involving economical feasibility are still limited. The waste removal at the early stages of size reduction process can decrease production costs, preventing future waste processing and consequently increasing the feed rate [14-17].

The SBS process starts in the feeding of particles. Particles need to be feed in a monolayer, as a requirement so the particle can be recognized individually and unwanted extractions can be minimized. The particles passed through a detection area where sensors measure individual properties. The analyses results in a color picture that supply an pixel-based information about the particle. The false color picture is resulted of the measured intensity at each pixel is an average resulting from the X-ray attenuation as a function of the thickness of a particle. The scale of color used for relative density of particles is from 1 to 255. The relative density is function of atomic density of the particle main constituents, in this specific case, quartz and carbon. Particles can be recognized and their relative densities compared and they are selected or rejected when a specific criteria is satisfied.

Many mineral properties could be use in that kind of separation process, i.e. color at visible light, magnetism, light reflectance, x-ray absorption, etc.. It is estimated that the SBS technique could be used at Mozambique coal pre-concentration to reduce wastes sent to the concentration plant.

2 EXPERIMENTAL

Coal samples from Moatize Mine were provided by Vale. Samples obtained from 4 different coal layers were manually prepared, homogenized and divided as the ASTM Standards recommend [18]. Due to detection limit of the device, particles size range was fixed in 100x25 mm.

In order to evaluate the accuracy, three particles of UCB coal layer were used. They were identified as A, B and C. The influence of the geometry interactions among sample, emitter and detectors was investigated. Twenty-four histograms and pictures were collected for each particle, resulting seventy-two histograms and pictures. Results were evaluated by mathematical indices applied for grouped data into class intervals. The range of product concentration, or relative density, varies from 1 to 255 in a color scale. In the histogram, provided by the software, a product concentration is presented as percentage (0 -100%). The mean values and standard deviation were calculated for data grouped into class intervals are presented in equations 1 and 2, respectively. Finally, the variation coefficient (VC) was calculated for analysis of each particle, as the equation 3 [22-24].

$$\dot{X} = \frac{\Sigma xifi}{\Sigma fi} \quad (1) \qquad s = \sqrt{\frac{(\Sigma fixi^2)}{n} - \left(\frac{\Sigma fixi}{n}\right)^2} \quad (2) \qquad CV = \frac{s}{\dot{X}} \times 100 \quad (3)$$

The repeatability of the measurements was evaluated for samples of UCB layer. Samples were separated by sink-float tests according to ASTM standards [19], in three different density ranges: -1,4 g/cm³, -1,8+1,9 g/cm³ and +2,2 g/cm³. Particles in each of these ranges were analyzed in three different positions over the conveyor belt, left, center and right in the belt flow direction.

Particles in these three different density ranges were analyzed in the SBS to identify a criterion able to promote the selective separation of coal and waste. The histograms obtained were compared and the criteria of selective separation was defined.

One hundred particles were selected from each coal layer and submitted in the SBS technique. Different tests were performed for each layer in order to obtain the best results for the separation selectivity. After separation tests, particles densities were identified by sink-float tests, from 1,4 g/cm³ to 2,2 g/cm³. Samples with same densities were grouped and analyzed in terms of ash content using the ASTM Standards D3174 [21]. In the coarse fraction of the run-of-mine coal, for each coal layer, the potential of waste removal was calculated.

3. RESULTS AND DISCUSSION

For coal samples identification, the calibration curve used was Quartz-Carbon. Samples with densities -1,4 g/cm³ and +2,2 g/cm³ were submit to SBS analysis (see figure 1). The difference between the particle colors is due to differences in composition and relative densities identified by the equipment software. Figure 2 also presents a color scale for relative densities. Lighter particles, or high quality coal, are presented mainly in blue color while low quality coals (or wastes) are presented in orange and yellow colors. From the images, it is possible to set up intervals of relative densities that makes possible a selective separation between coal and waste. In this case, it was identified the set up of relative density interval to separate coal in 1x60 and 61x255 for waste, by considering a color scale from 1 to 255.

The histogram of pixels count by product concentration for particles in figure 1 is presented in figure 2. The comparison between the pixels count histogram for each sample could indicate a selective separation. Histograms were generated from the software, where the vertical axis present the units of pixels count and abscissa is the product concentration in percentage. In figure 2, blue data refers to high quality coal, or less dense particle, while the yellow data refers to low quality coal or high dense particle.

The difference between relative densities of high and low quality coal indicates the possibility of a selective separation for particles -1,4 g/cm³ and +2,2 g/cm³.

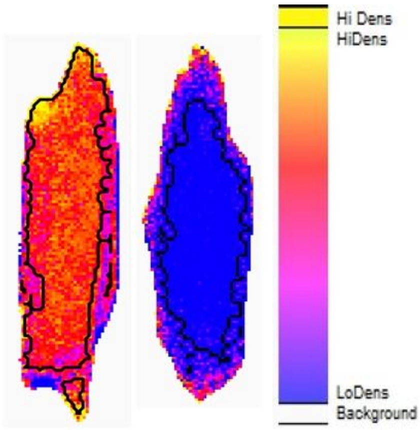

Figure 1. Images generated in calibration process.

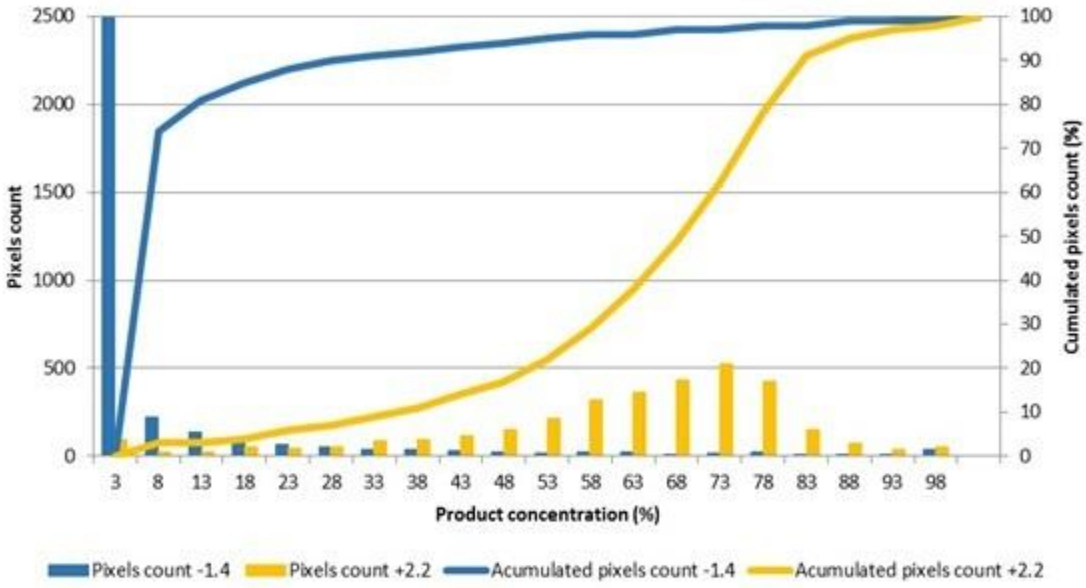

Figure 2. Coal and waste histograms.

3.1. SBS reading accuracy

Aiming to evaluate the occurrence of image distortion, tests were developed in order to verify the role of the geometry interactions among sample, emitter and detectors.

First, the influence of particles relative position over the conveyor belt was evaluated. Three particles of coal were set in six different positions, across the conveyor belt. The particle positions used in this test is presented in figure 3. In figure 3 numbers from 1 to 4 in vertical axis indicates the particle position in terms of particle side facing the sensor. For each of these positions, the particle was rotate from the position before. Numbers from 1 to 6 in horizontal axis indicates the particle position across the conveyor belt, where the position 1 is at left and 6 at right in the flux direction of the conveyor. For each one of these particles, positions were extracted their colored picture and histogram.

The test were carried out with three coal particles, identified as A, B and C. Twenty-four pictures and histograms for each particle were obtained. For three particles, seventy-two pictures and histograms were obtained. Figure 4 presents the graph containing twenty-four histograms of particle A

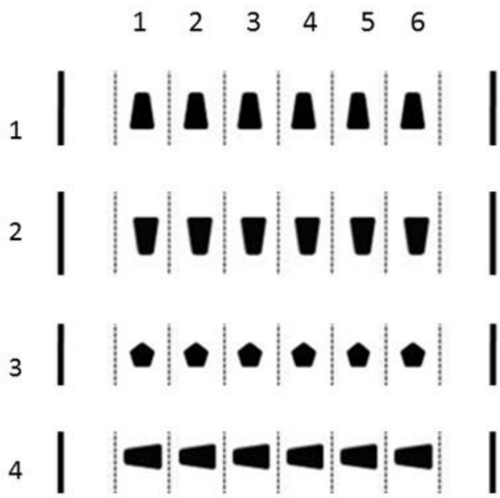

Figure 3.Imaginary grid over the conveyor belt.

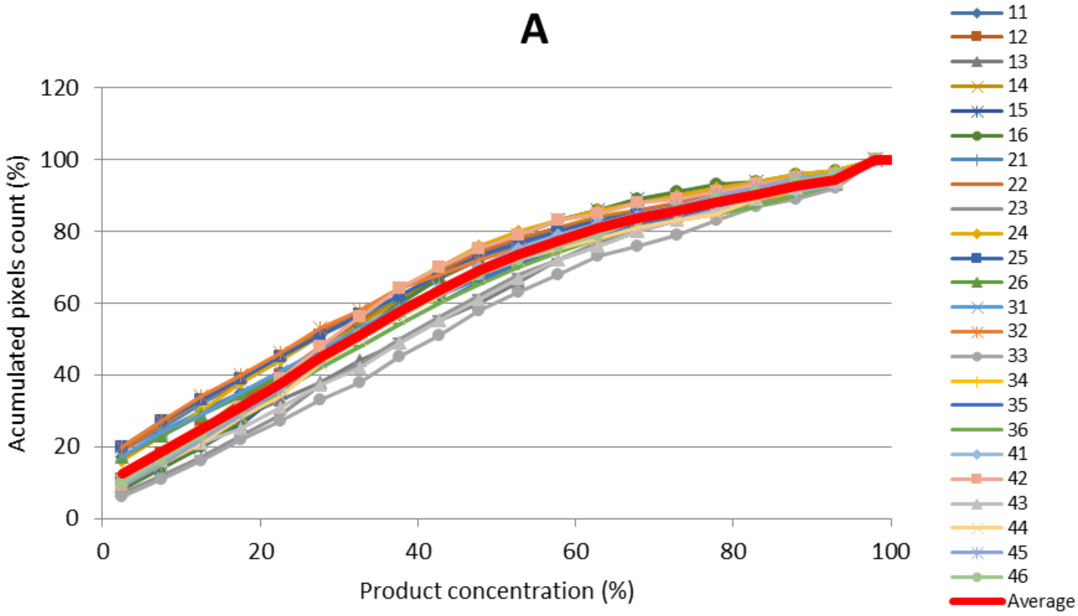

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Figure 4. Graph of twenty-four histograms of particle A.

From the figure 4, it is possible to observe that a single particle could present different numbers of pixels for each range of product concentration, according its relative position over the conveyor belt. The red line was obtained by a simple arithmetic mean of pixels count. The dispersion around the mean can be also observed. Similar results were found for particles B and C. The figure 4 does not indicate a position on the conveyor belt with major accuracy. The mean value and standard deviation were calculated, as well as the variation coefficient.

The variation coefficient (VC) measures the dispersion of data in relation to the mean value. The smaller is the variation coefficient, the smaller is the dispersion of data. In this case, more accurate is the reading in some position over the conveyor belt. The variation coefficients calculated for each position over the conveyor are presented at table 1.

Table 1 shows the VC for particles A, B and C, in each position on an imaginary grid. Highlighted are the smaller VC values for each relative position of the particle. Position 3 has more frequency of smallers VCs. Positions five and six also appear with small VCs values for A, B and C particles. A relevant aspect observed over the VC calculations is in positions 3 and 4. They are equally distant from the conveyor border, or equally centered. If the geometry between particles, emitter and detector were considered, could be expect a higher accuracy in the center of the conveyor belt, or small variation at pixels count by product concentration in positions 3 and 4. In this case, the results for positions 3 and 4 could be similar and have better accuracy then positions 1, 2, 5 and 6. Higher VC values were expected for positions with larger distance from the center of the conveyor belt. If this argument is correct, smaller values of VC should be on 3 and 4 positions. In the whole, it is not possible to indicate a preferential position in which a higher accuracy of particle measurements could be obtained.

Table 1.Variation coefficient for particles A, B and C.

	1						2						3						4					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
A	79	74	68	72	66	66	82	82	64	78	83	78	78	85	61	73	71	71	72	71	66	70	69	70
B	91	92	69	85	81	95	103	100	82	87	88	91	102	103	86	88	92	92	97	100	86	91	96	95
C	89	94	83	87	83	86	91	90	78	85	82	78	90	86	85	84	82	82	94	91	82	88	87	87

Another important variable to be investigated is the repeatability of the measurements. In order to evaluate the repeatability, coal particles in three different densities -1,4 g/cm³, +1,8-1,9 g/cm³ and +2,2 g/cm³ were investigated in three different positions on the belt conveyor. Each particle was measured at center, right and left positions in the belt flow direction. Successively, ten measurements were obtained at same positions for each particle. Histograms showed good repeatability, since the curves are partially overlapped. However, when the measurements in different positions are compared by the use of pixels count, the results were very distinct for the three ranges of densities studied. The results were very similar for densities -1,4 g/cm³ and +1,8 -1,9 g/cm³ in the center and left position, respectively. There were similarities in the shape of the curve and pixels count, showing the difficulty in separating these 2 particles.

Also, it was observed a significant variability in the identification of coal particles density from Moatize Mine in the device used in that research. Industrial processes for coal preparation present different imperfections.

3.2. Evaluation of SBS technique application for pre-concentration of Moatize Coal

In order to evaluate the separation of coal from waste by SBS technique, samples in three different density ranges were used. Sink-float tests were used to select samples. Particles in each densities range, -1,4 g/cm³, +1,8-1,9 g/cm³ and +2,2 g/cm³, were selected and identified one by one.

Figure 6 presents pixels count curves of low density coals, -1,4 g/cm³, in blue lines with the average curve in a thicker line. In pink are presented the pixels count curves of intermediary density coal (middlings), +1,8-1,9 g/cm³, with their respective average curve in thicker line. The pixels count curves for waste(+2,2 g/cm³) are presented in yellow.

Although the average curves are distant from each other, it is possible to observed that some middlings (density +1,8-1,9 g/cm³) show similar characteristics of light coals (density -1,4 g/cm³), indicating a difficult separation between these two classes. This behavior was presented previously, when the repeatability was investigated for the same samples. Particles of middlings (density +1,8-1,9 g/cm³), identified as M2 and M10 shows a larger pixels count at the first intervals of product concentration, even larger than pixels count for particles with density -1,4 g/cm³.

The average curve for particles in density +2,2 g/cm³ is more distant from the others average curves, indicating that this class of particles can be separate more easily. However, the particle identified as M4 (density +1,8-1,9 g/cm³) presents a similar pixels count curve of particles with density +2,2 g/cm³.

The identification of coal from Moatize Mine by SBS technology in three different classes of densities indicates that is possible to separate coals (middlings and low density) from wastes (higher densities).

Coal from UCB layer were beneficiated in order to obtain high quality coals (lower densities; -1,4 g/cm3). A Quartz-Carbon curve was used with a relative density scale from 1 to 255. The criteria to define high quality coal was from 1 to 60 at the relative density scale and selection of particles with 35% of pixels in that range of relative density. Eleven particles of coal at density -1,4 g/cm³ were submitted to the separation with the SBS. Ten of these particles were selected (correctly separated by the equipment) independent of their position on the conveyor belt (left, center or right). Eleven particles of coal with density +1,8-1,9 g/cm³ were also beneficiated by the SBS. Eight of them were selected (correctly separated). They were in different positions on the conveyor belt. Only three particles were not correctly selected because they do not show the established criterion. No particles with density +2,2 g/cm³ were separated by the SBS, independent of their position on the conveyor belt.

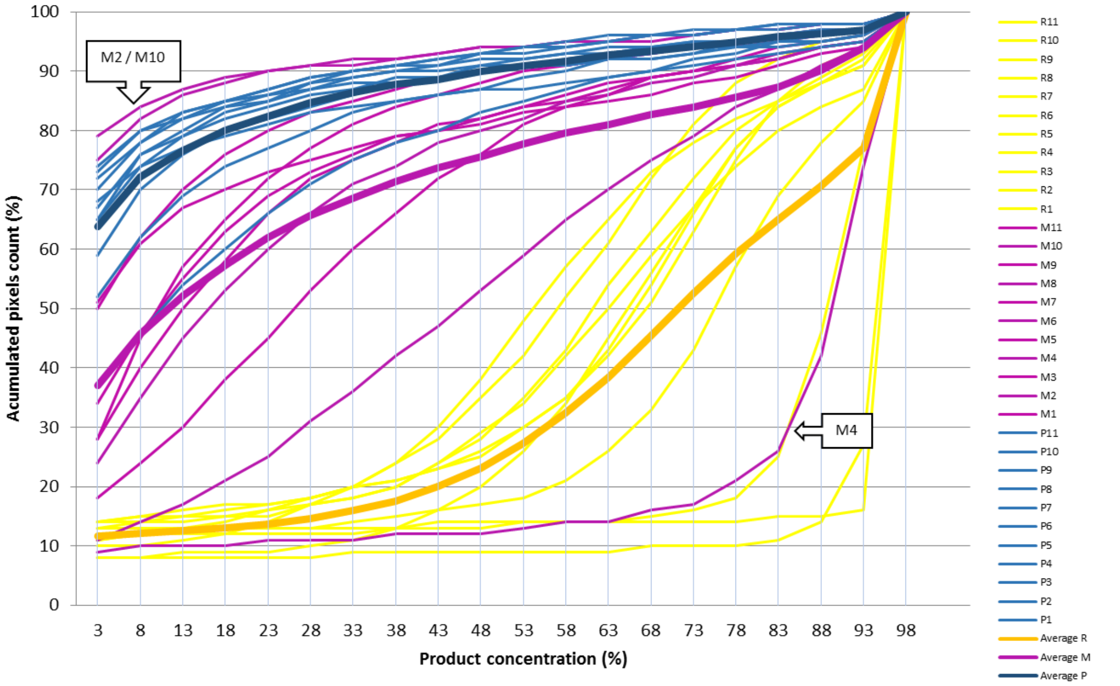

Figure 6. Graph of accumulated pixels count by product concentration.

Some new tests were carried out with the same particles. However, different separation criteria were used to promote coal reverse concentration. Reverse concentration is a term used to indicate coal concentration by removing wastes (the SBS selected the wastes instead the coal particles). In this way, the main objective is the waste segregation. Quartz-Carbon calibration curve was used again, but separation criteria were modified to 61-220 at the relative density scale. The particle selection used was particles with at least 85% of pixels count in the range of density (+2,2 g/cm³). In this case, samples with densities -1,4 g/cm³ were not selected, but only samples with densities +2,2 g/cm³, independent of their position on conveyor belt. For the particles with density +1,8-1,9 g/cm³, only one was removed with the waste, M4. However, it presented the number of pixels count in the range of density separation higher than 85%.

3.3. SBS technique to beneficiate coal from Moatize Mine

Several tests were carried out to separate wastes from coal. The separation criteria pixels count higher than 85% of the relative densities scale upper than 61. When wastes were separated (removed by SBS), there were lower coal particles in the waste stream in comparison to separate coal particles form the wastes.

The tests were performed with four different coal layers, separately. Particles were beneficiated individually. About 80% of particles selected (separated by SBS) presented densities higher than 2,0 g/cm³. The 20% of the selected samples presented densities lower than 2,0 g/cm³. Table 2 presents mass balance and ash content of the tests carried out.

Table 2. Separation tests results.

Seam	Ashcontent of coarse fraction (%)	ROM Mass Size over 2.54 mm (%)	Separated waste mass (%)	Ash content of separated waste mass (%)	Ash content after waste removal (%)
UCT	63.08	30.36	16.00	80.97	43.02
UCB	53.10	34.80	9.70	78.72	43.14
MLCU	60.07	26.90	13.50	75.55	44.58
LC456	58.01	20.40	11.00	74.62	38.62

UCT coal presents 30.36% of the ROM with size over 25.4 mm and 63,08% ash content. This was the minimum size used in all tests. The mass of particles separated was 16% with about 81% ash content. The rest of the particle (not separated by SBS) represented 84% of mass. Ash content of these particles were of 43.02% and represented 20% reduction in the ash content, from 63.08% to 43.02%.

UCB coal presents 34.80% in the size over 25.4 mm, with 53.10% ash content. The separation resulted in 9.7% of mass removal with ash content reduction of about 10%, from 53.10% to 43.14%.

MLCU coal presents 26.90% in the size over 25.4 mm, with 60.07% ash content. The waste mass removal was 9.7% of with ash content reduction ofabout 15%, from 60.07% to 44.58%.

LC456 coal presents 20.40% mass of the ROM at size over 25.4 mm, with 58.01% ash content. The waste mass separated was 11% with 75% ash content, approximately. The ash content reduction was about 20%, from 58.01% to 38.62.

The feed rate of Moatize concentration plant was 8,000 ton/h, in 2016. The reduction of 10% of mass in the early stages represents 800 ton/h less in the waste removal with high ash content. The waste removal, in the coarse fractions, indicates a reduction in 10% of ash content in the feed. That represents reduction in production costs and improvement in the coal quality. Next to these, the feed rate of the concentration plant can be increased in 11%, i.e. 8,880 ton/h.

4 CONCLUSIONS

Tests were performed in order to evaluate the technical feasibility of using sensor-based sorting technique for destoning coal from Moatize Mine. Results obtained indicated that SBS technology was able to significantly reduce the mass and the ash content of the feed, being an interesting option for reduction of costs and improvement of coal quality in beneficiation plants.

Tests for evaluation of accuracy and repeatability of coal beneficiation by SBS demonstrated a significant variability. However, separation tests conducted with coal seams from Moatize Mine show the possibility to reduce ash content in the beneficiation plant feed by removing wastes.

All coal layers studied showed different ash content reductions. It was observed a waste mass removal from 10% to 16% and an ash content reduction from 10% to 20%. It is important to emphasize that this research was conducted at a SBS equipment developed for different materials. Bests results are expected with an equipment properly dimensioned for coal separation.

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