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X-ray transmission sorting of tungsten ore

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Abstract The Deutsche Rohstoff AG, TOMRA Sorting Solutions|mining and the RWTH Aachen University have performed a study on the applicability of sensor-based sorting in the process of tungsten ore for the Wolfram Camp Mine in Australia. The aim of this project was pre-concentrating of tungsten ore by removal of barren material. The pre-concentration can lead to energy and water savings, decrease of reagent input in downstream processes and increase minerals reserve utilization by lowering the cut-off grade. A comprehensive research programme concluded that the best suited sensor-technology for this material was X-Ray Transmission (XRT). The XRT sensor provides a highly efficient system for classifying and sorting different materials based on their atomic density. XRT sorting is already applied as well in the recycling as in the minerals industry. The results of the test runs have shown that XRT sorting can effectively remove and reduce barren material and that it is an effective technology for the pre-concentration of tungsten ore.

1 Introduction

One of the challenges for the minerals industry is the economization of the most important resources energy and water. Other challenges like increasing demand for resources, decreasing ore grades, reducing accessibility to resources and meeting the sustainable development also need to be faced. This requires research and implementation of innovative, dry and energy efficient technologies. Sensor-technology in connection with intelligent data processing systems is playing a key role facing those challenges. The recognition of diagnostic material properties and machine control by innovate sensor-technologies cause higher automation levels, higher recovery and better quality (purity) of resources [1,2].

X-ray sensor-technologies are well developed and already wide applied covering all steps in the resource process chain from exploration through grade control to process control and product quality assurance. X-ray sensor-technologies are key technologies for characterizing elements and crystalline phases of material.

X-ray Transmission (XRT) can recently also be applied as a scanning method for sensor-based sorting (SBS). SBS involves the detection of single particles and the rejection of those single particles out of a material flow that do not warrant further treatment. This way SBS can help to face the above described challenges. Most of the solutions are based on the fact that SBS is a dry and energy efficient sorting technology which allows a pre-concentration step (waste removal at an earlier stage) [3]. Pre-concentrating increases the plant efficiency, because gangue material is rejected prior to the mineral processing plant and therefore improves the downstream processes. Pre-concentration can tip the balance for otherwise nonviable resources. This way potential reserves can be turned into reserves, the cut-off grade reduced and the reserves and life time of the mine increased [4]. The benefits of pre-concentration are well documented in the literature (e.g. [5]). By pre-concentration close to the mining face, the capacity required for transport is decreased. The removal of gangue from the ROM (run-of-mine) ore enables an increase in the ore throughput rate and therefore a better utilization of the installed processing unit with decreased specific costs and increased productivity. This means for the milling process an increase in capacity and reduction in the Bond Work Index, wearing and energy requirements. Furthermore by pre-concentration the quantity of the material is reduced but the grade of the ore increased. With the smaller quantity, but higher grade of concentrate feed, other savings can be achieved, such as reagent costs, costs for water, tailings dewatering and disposal of fine tailings. Pre-concentration can also open up opportunities for the introduction of alternative mining methods. Low-cost mining methods that are associated with a higher percentage of gangue can be used due to effective pre-concentration [2].

In this paper, the XRT sorting technology and the results of a number of test runs conducted on tungsten ore, from Wolfram Camp Mine, are described. The aim of the test work was pre-concentration of the ore.

2 The functional principle of XRT-sorting

Sensor-based sorting is introduced as an umbrella term for all applications where particles in a material flow are singularly detected and evaluated by a sensor-technology and then rejected by a mechanical process [4]. A wide variety of sensors are currently available within the electromagnetic spectrum, which can be utilised individually or in combination to identify properties such as conductivity, response to optical and near-infrared light. Sensor-based sorters can be implemented in different mineral processing stages to fulfil various tasks [6,7], which is in more detail described later in this article. Typically sorters can process materials within the size range $-300mm + 6mm$ at a throughput of around 150 tons per hour. Smaller size ranges can be processed for specialised applications, but at reduced throughput.

The functional principle of SBS can be divided in five sub-processes; material preparation, material presentation, material sensing, data processing and material separation. The critical stage of examining the particle and determining whether material is valuable or barren, is done by a combination of sensor and data processing unit. A valve bank with high pressure jets makes the physical separation possible.

The XRT sensor in sorting works according to the airport baggage security inspection applications. The sensor system has been developed further suitably adapted to minerals sorting. A radiation source, an electrical X-ray source with the energy range between 90 and $200keV$ (depending on the application), is placed on top of the unit, as indicated in Fig. 22.1. The radiation penetrates the particles that are presented on a conveyor belt running at $3m/s$ or on a chute. The residual radiation is registered by the detector, a line scan camera with a spatial resolution of approximately $1mm$, beneath the travelling path (Fig. 22.1). The sensor consists of an array of scintillation crystals that capture the number of counts on each element for the array. Figure 22.1 shows the schematic setup of a belt-type XRT-based sorter.

X-rays are transmitted through material at varying degrees, depending on the atomic density of the material and the thickness of the ma-

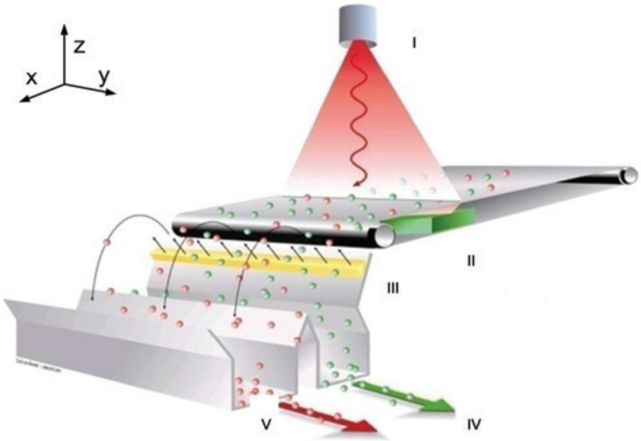

Figure 22.1: Schematic set-up of XRT sorting system. I) X-ray source/tube, II) X-ray detector, III) Valve bank with high pressure jets, IV) Ejected fraction, V) Rejected fraction [3].

terial. In other words, material absorbs a proportion of the radiation resulting in a reduction in the intensity of the X-ray. The detected intensity is an exponential function of the thickness of the irradiated material. As long as variations in particle thickness are restricted and the difference in atomic density is large enough, the use of a single energy wave to classify the material is accurate enough. By conditioning the material, the influence of particle thickness can partly be levelled out. The feed material needs to be prepared by screening this way that the ratio between the largest and the smallest particle is around 3 or 4, also due to mechanical restrictions of the sorter.

Observing the effects of two or more different wavelengths would eliminate the effects of particle thickness completely. Dual energy XRT involves the use of a high energy and low energy X-ray beam (or two detectors one with a filter and the other one without). In Fig. 22.2, the difference between single and dual energy X-ray detection is presented.

If the influence of particle thickness can be levelled out, the sorting criteria or discrimination is thus only based on the atomic density of

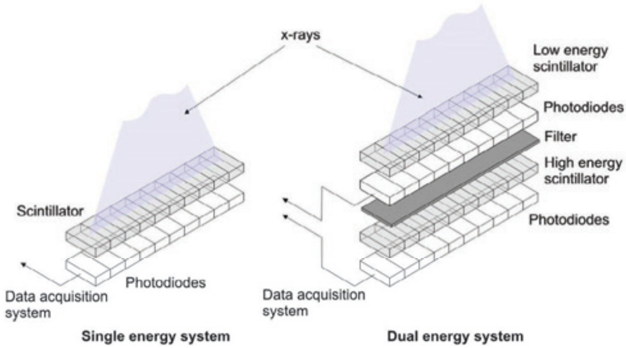

Figure 22.2: Single-energy vs. Dual-energy X-ray sensing principle [8].

the particle. In the below mentioned application example only a single energy X-ray wave is applied.

The X-rays penetrating the material are converted into digital image data. An image of the object is generated in a "line by line" fashion, similar to optical sorting. A typical example of such and image is presented in Fig. 22.4. Images, with different shades of grey, provide a great deal of information regarding the density of the objects i.e. an object of low density appears brighter than a denser object. The analysis of images in order to facilitate separation is conducted using different algorithms. It is for example possible to eject objects based on their percentage of high density material. Suitable values for the minimum percentage of high density material in one object are usually determined through process optimization based on final product specifications.

Information regarding particle shape, size and texture is also used for evaluation. The decision to accept or reject a particle and the position of particles on the conveyor belt is passed from the data processing system to the control unit of the valve bank (Fig. 22.1). The sorter's control unit activates the respective high pressure jets. This burst of compressed air diverts the direction of flow of selected individual particles so that they get separated to the reject-fraction (Fig. 22.1). The amount of rejected material has therefore a direct relation to the compressed air consumption; the more rejected particles, the higher the usage.

It can be concluded that the XRT sensor provides a highly efficient sensor system for classifying and sorting different materials based on their atomic density.

3 Potential of XRT-sorting

As mentioned, a multitude of different sensors is applicable for sensor-based sorting. The choice is generally driven by the mineralogy of a given ore. Optical sensors are the most common sensor type, and have been very successfully used in the industrial minerals industry [2]. In 2007 the RWTH Aachen University started research on the applicability of near-infrared spectroscopy (NIRS) sorting in the minerals industry. This sensing technology has high potential and the first sorters are implemented [2].

One of the advantages over surface sensing technologies like optical and NIRS, is that XRT-sorting is insensitive to surface conditions, because instead of surface layer, particle volume is detected. This means that no surface conditioning like washing/scrubbing is necessary and XRT-sorting can therefore be operated completely dry. Additionally the composition of the surface does not have to be representative for the composition of the whole particle. The images produced provide information on the internal structure, texture and shape of the particle.

The absence of water in the process does not only result in highly reduced effort during the licensing procedure, or to the absence of a tailings pond and costly dewatering process and therefore reducing disposal costs, environmental and footprint of the plant, but also decreases the amount of units and space needed for the plant. It finally leads to high flexibility where whole plant setups can be moved to a new position within days when applying a modular plant design [3]. Dry processing is of course also advantageous in climatic dry regions.

The space saving design of the plant with only four units enables the flexible application of XRT-sorting in the optimum position in the process chain – ideally in close proximity to the mining face. The four main units needed are crusher, screen, XRT-sorter and compressor. The environmental impact can be significantly decreased when applying XRT-sorting close to the mining operation. The reductions of carbon emissions in the transport process as well as in the comminution process do not only limit the environmental impact but also lead to high specific cost reductions [3].

SBS is an innovative technology, which, as mentioned before, can be implemented in different mineral processing stages to fulfil various tasks. SBS can, for example, be implemented in the processes as a pre-concentration or waste removal step for coarse size particles (up to 300 mm), for ore type diversion into different processing streams, (final) product quality improvement, marginal dump retreatment and waste dump retreatment. SBS can turn waste dumps and diluted mining blocks into reserves. As mentioned in the introduction, the implementation can also cause a decrease in specific operating costs of mill and mine when for example replacing selective mining by bulk mining methods with subsequent sorting. SBS can be implemented for simple sorting tasks where hand-sorting was used before, with the advantages that they are more stable, based on objective sorting criteria, higher security standards, applicable for smaller size ranges with higher throughput and lower operational costs. Additional it is possible to combine different sensors contrary to traditional unit operations, in this way multiple sorting criteria can be used in one processing step [2].

The economic evaluations show that the capital costs of XRT-sorting installations are at least 25% cheaper and the operating cost low in comparison to competing technologies like dense-medium-separation. Harbeck [9] indicates that operating speeds of the XRT sorting units are comparable to standard optical sorting units.

SBS is nowadays a proven technology that has been successfully implemented in recycling and mineral processing industry. This limits the technical risk for new applications. XRT systems are for example applied to the aluminium heavy metal separation in the metal scrap industry and the estimation of calorific value of packed mixed and sorting of shredder residue. The use of XRT sorting is also successfully demonstrated for number of mineral applications as well. For example, an XRT-sorter is implemented at a tungsten mine, owned by the company Wolfram Bergbau und Hütten AG, near Mittersill, Austria. This mine is only still in operation because XRT sorting is lowering the cut-off point. The sorting is based on the difference in densities of scheelite ($6.0 g/cm^3$)

and the tailings ($2.8 g/cm^3$) [10]. Another successful application is large diamond recovery from primary kimberlitic run-of-mine (ROM) before crushing stages. Other research examples with a positive outcome are separation of metal sulphides from gangue (e.g. [9]), sorting of nickel sulphide ores (e.g. [11, 12]), sorting of copper sulphide ore [13], pre-concentration of gold ores (e.g. [3]), de-shaling and de-stoning of coal and the separation of different coal qualities [3, 8, 14].

The potential of any ore sorting venture is highly dependent on the liberation of the material to be examined. It is therefore important to evaluate the validity of sorting on a case by case basis. Because the sorting criterion is based on atomic density the reliability of the applicability is high, for the life of mine but also for other deposits.

4 Tungsten sorting

In collaboration with the Deutsche Rohstoff AG and CommodasUltrasort, RWTH Aachen University has performed a feasibility study on the applicability of SBS as pre-concentration step in the process of tungsten ore for the Wolfram Camp Mine in Australia. The aim of this project was pre-concentration by removal of barren material. The pre-concentration of the tungsten ore cannot only lead to energy and water savings but also to a decrease of reagent input in downstream processes and increase mineral reserve utilization by lowering the cut-off grade.

A pre-screened sample suite of around $340 kg$ from the mine site was available in two different size fractions $16 - 50 mm$ and $10 - 20 mm$. This sample suite was taken after the secondary crusher in the process of Wolfram Camp Mine. The sample was handled dry.

Out of this sample suite a training set of 20 single samples was used for preliminary laboratory test work to test the applicability of NIRS and optical sorting and to train the XRT sorter and to possibly build up a sorting algorithm (Fig. 22.3). Of all 20 samples, chemical information was available.

To test the applicability of optical sorting, pictures and false colour figures were made. The figures were treated with special developed sorting analyzing-software tool from CommodasUltrasort to simulate the sorting test. Optical sorting is technical feasible if detectable differences in colour, brightness, transparency, form or texture are present

Figure 22.3: Picture of the training set (left).

between ore and waste material. No correlation between the occurring different colour classes (dark grey, light grey and orange) and the tungsten content exist for this sample suite.

To test the applicability of NIRS sorting, the 20 samples were measured with a desktop spectrometer. The spectra of product and waste were compared and different spectral processing steps were conducted. Spectral differences in the near-infrared region of the electromagnetic spectrum make material sortable with NIRS sorters. No reproducible spectral differences between the product and the other samples exist for this sample suite.

Another outcome of the comparison of the X-ray fluorescence surface analysing measurements and the chemical analyses of milled samples was that surface measurements are not convenient for this sample. The tungsten content measurement on the surface did not correlate with the tungsten measurement of the crushed sample. This means that the surface is not representative for the whole particle.

The same 20 samples were also used to train the XRT-sorter. Figure 22.4 displays line scan images of tungsten bearing and tungsten barren material. The images appear to be bright where density is low and it appears to be dark where the density is high. The atomic density of tungsten bearing minerals is depicted as a dark grey in the X-ray image (speckled appearance in the images). Figure 22.4 also illustrates clearly that the sample suite can be sorted in ore bearing and waste material with the XRT line-scan camera.

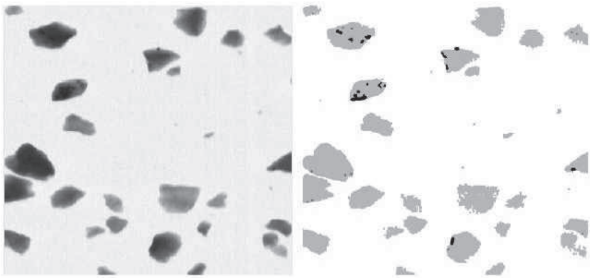

Figure 22.4: Left: Line scan images of tungsten bearing and tungsten barren material. Right: Contrast filter based on different densities.

The conclusion of this comprehensive research programme was that the best suited detection technology for sensor-based sorting of this ore is XRT. The outcome of this test work is encouraging. However, it is recognized that a more detailed examination on a bulk sample is required to determine the performance of this technology. Laboratory scale test work cannot provide data regarding the performance of the sorting process, such as product purity and associated mass yields.

5 Sorting test work

Because a sorting algorithm was successfully established, bulk sorting tests are run on a CommodasUltrasort Pro Secondary XRT belt 1200 sorter, which can handle the required size range at a throughput of around 40 to 50t/h. A 55kW compressor with an operating pressure of 8 bar is used. For adjusting the sorting algorithms, the XRT pictures are uploaded into specialized software where simulations and the applications of filters and object detection are possible. A contrast filter is used for the sorting of the sample suite. The filter enhances the contrast between colour differences in pixels. In Fig. 22.4 the result of this can be seen. The sorting program can be adjusted by defining various percentages of inclusions. The setting of the sorter was changed three times. The first time the sorter opens the high pressure jets if at least 0.5% of the pixels in one particle are dark (tungsten), the second time with 1% and the third time if 2% are dark. Those percentages are labelled as "sensitivity" in Table 22.1. Table 22.1 shows the test run on the XRT sorter.

During the analyses of the training set it became clear that in every waste rock particle at least a small amount (average 0.0105%) of tungsten was present. This means that with a single particle sorting technology only a certain amount of the tungsten can be recovered (the recoverable recovery). The "recoverable recovery" takes into account the average grade of tungsten in the waste rock samples. This grade is calculated for the sorting test as well (table 22.1).

Table 22.1: Sorting results of bulk tests.

Size fraction	Selectivity/Setting	Recovery (%)	Rec.Rec (%)	Masspull to waste (%)
$10-20mm$	0.5	75	83	82
	1	68	82	93
	2	54	64	95
$16-50mm$	0.5	83	89	72
	1	59	72	76

Samples from each run are taken for assay. The results clearly show that XRT sorting can effectively remove and reduce barren material and that X-ray transmission is an effective technology for the preconcentration of tungsten ore. With an increase of sensitivity the recovery decreases and the masspull increases. This is a positive development.

The product of every test is re-sorted to decrease the difference between detection and sorting. A two step sorting does not change the recovery much (the recovery at the second step is around 95%), but it increases the masspull to waste again.

It can be concluded that the sorter application is ideally suited for coarse tungsten beneficiation. A pilot plant is currently operated in production mode to prove its robustness and reliability in a real operational environment.

6 Conclusions and recommendations

The use of dry and energy efficient methods will be more important in the future. Sensor-based sorting, including XRT sorting, is already gaining more and more significance in the minerals industry. XRT-sorting is applicable for a large variety of sorting tasks. While being technically feasible, XRT-sorting is offering side effects that underline its sustainability. It is a dry separation technology that needs little energy when compared to other coarse particle separation technologies. This also means that it needs little infrastructure and can be applied in semi-mobile separation units that can be erected in strategic locations close to the mining face, minimizing mass movement and costs and avoid unnecessary crushing of barren material while increasing downstream productivity [3].

This article describes a successful application of XRT-sorting in tungsten processing. The XRT sorting technology has good potential to become a fundamental component of future processing of tungsten ore. A pilot plant for the pre-concentration of tungsten ore is currently operated in production mode to prove its robustness and reliability in a real operation environment.

Until today, sensor-based sorting machines have only been used as separation units. The potential that lies in the huge amount of data generated is not yet unfolded. Sensor-based sorters cannot only be integrated online into mine-wide information systems to improve downstream processes, but can also be used as analytical tools for sample assaying. The possibility to scan high amounts of mass in real time improves the correctness and representativeness of the data generated when comparing to conventional sample taking, splitting and essaying procedures [3].

XRT-sorting is believed to be a powerful addition to the portfolio of processing machinery and therefore must be considered in early test work and plant planning stages.

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