Near infrared spectroscopy sorting in the minerals industry

Mathilde Robben*, Christopher Kleine and Hermann Wotruba

RWTH Aachen University, Department for Mineral Processing, Aachen, 52064, Germany
*Corresponding author: robben@amr.rwth-aachen.de

Introduction

During the past four years the Department of Mineral Processing, RWTH Aachen University has investigated the technical feasibility of implementing near infrared (NIR) spectroscopy as a sorting technique in mineral processing. NIR spectroscopy sorting is one type of sensor-based sorting which can help to overcome problems in some of the most critical areas of modern mining and mineral processing: energy consumption, mineral reserves, water consumption and environmental impact. Sensor-based sorting is applied as an umbrella term for all applications where particles in a material flow are singularly detected and evaluated by a sensor technique and then rejected by a mechanical process. The basic aim of sensor-based sorting is to improve the grade and recovery of the ore stream flowing into subsequent mineral processing operations. This paper is a review of the research performed to evaluate NIR spectroscopy as a sensor-based sorting technique

Pre-sorting of homogeneous material

The research started with basic analyses of homogeneous minerals, and more complex cases were studied for different deposits. The capacity for near infrared spectroscopy to identify minerals was known from several previous applications, particularly exploration of mineral deposits with portable spectrometers, analysis of drill cores and remote sensing (where velocity is not a critical issue). Many minerals can be classified based on their spectral response in the near infrared and typically show diagnostic absorption features between 1300 nm and 2550 nm. Therefore NIR spectroscopy is potentially useful as a sorting technique in the minerals industry.[1]

The potential for sorting was first tested with homogeneous material. Spectral differences between each material were detected with a Tensor 27 desktop spectrometer (Bruker Optiks, Ettlingen, Germany) in the wavelength range 1000 nm–2630 nm. Homogeneous minerals reflect differences between waste and product; hence, if spectral differences can be recovered, then sorting is theoretically possible and bulk sorting tests with a sensor-based sorter are performed. Sensor-based sorting is a single particle separation technique and the throughput and also the operating costs vary linearly depending on the average particle size fed onto the machine. Therefore, in mineral applications, where the throughput in the conventional process is high, it is usually applied as a rougher stage for pre-concentration of coarse particle sizes (+20mm).[2] The main sub-processes of a sensor-based sorting step are shown in Figure 1 and are as follows: material conditioning (1), material presentation (2), detection (3), data processing (4) and separation (5).

PolySort (TOMRA Sorting Solutions, Norway) is a NIR sensor-based sorter which detects 640.000 spectra per second per metre using a high speed conveyor belt operating at 3 $m.s^{-1}$. NIR spectroscopy sorting has its roots in the recycling industry, particularly recycling of plastics; thousands of sorters have already been installed in industry. The knowledge on near infrared spectroscopy in the minerals industry, gained as a result of extensive mineral exploration and deposit evaluation work, can be transferred to sorting algorithms to be used on sensor-based sorting machine systems available from the recycling industry. Also, well-established calibration methods and novel data mining techniques can be applied.

The PolySort instrument first needed to be trained with pre-classified (robust and clearly-identified) samples. Groups were formed by statistical means and applied into the sorting algorithm, referred to as the classifier. The classification result can be improved by various image processing operations which take into account the neighbourhood of a scan point. It is possible to configure sorting applications through the use of filter operations in a fixed neighbourhood (e.g. 4 × 4 filter). By adjusting filters, the software can be configured to, for example, eject at a position only if also a pre-defined number of points in the neighbourhood would have been ejected, or suppress ejection in a neighbourhood if an unwanted material was detected. For high throughput applications, filter operations lead to stable sorting results even if the objects slightly overlap.[4,5,6]

Reference paper as:
M. Robben, C. Kleine and H. Wotruba (2012). Near infrared spectroscopy sorting in the minerals industry, in:
Proceedings of the15th International Conference on Near Infrared Spectroscopy,
Edited by M. Manley, C.M. McGoverin, D.B. Thomas and G. Downey, Cape Town, South Africa, pp. 191-194.

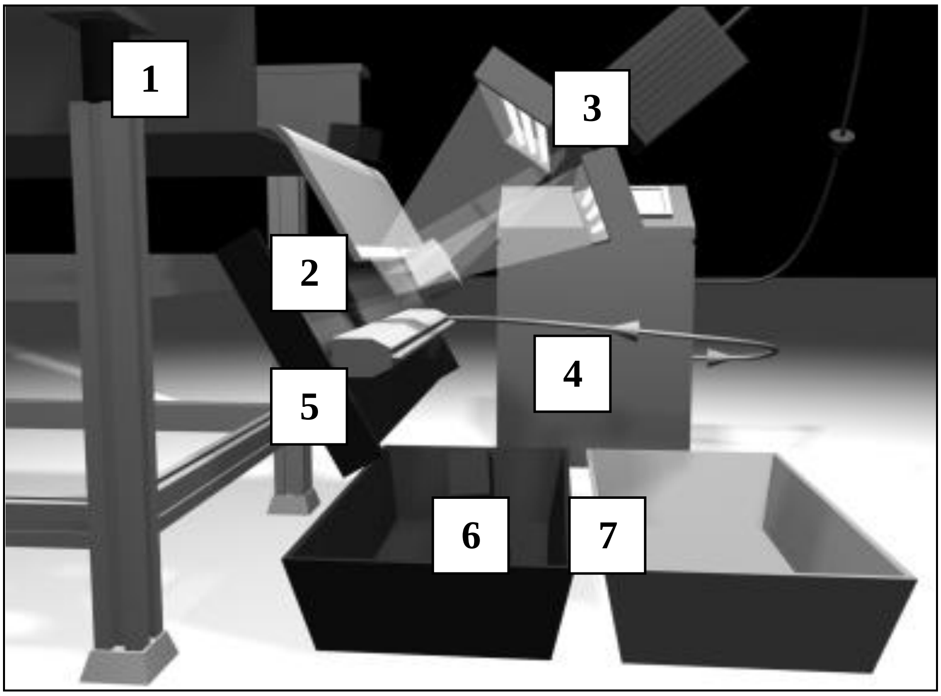

Figure 1. Functional principle of sensor-based sorting.[3]

NIR spectroscopy as sensor-based sorter: homogeneity of material to be sorted

Homogeneous material is preferable for sorting. The spectral response of heterogeneous material, which is the normal situation in mining, is much more complicated; wavelength shifts, overtones, overlapping of the absorption features etc. and mixed spectra occur. All this spectral variation needs to be taken into account during the design of the classifier.[6]

Mixed spectra are caused by diluted minerals, contact zones of different rock types (with different mineral content) and the presence of water (hydroscopic and free pore water). NIR spectroscopy sorting can be used in combination with an algorithm which creates spectral images of the particles. The combination of NIR spectroscopy, object recognition and a high spatial resolution brings the advantage of the possibility to decide for every particle individually in which class it belongs. For the sorting of heterogeneous samples this can be the solution. Because of the possibility of using a large mathematical toolbox to define the limits of the classes (grade, recovery etc), it is not only possible to qualify but also quantify the mineralogical composition of the samples.[6]

NIR sorting of borate

Test work was performed on borate. Borate often occurs together with the contaminant carbonate. Spectral differences between ore (borate) and waste (carbonate) can be seen in Figure 2. The spectra of the product are dominated by NIR activity of colemanite ($Ca_2B_6O_{11}.5H_2O$), or more specifically, by the structural water of colemanite. The spectra of the waste material are dominated by the NIR activity of carbonate-bearing minerals (for example calcite and dolomite). Bulk sorting was performed with the PolySort instrument and Figure 3 shows the classification of borate (purple) and waste (yellow). The feature space has been used for separation during the test work with the PolySort. Each point in the figure represents one spectrum[7] and the preliminary test results are given in Table 1. Tests have shown that NIR sorting has better separation capabilities than optical sorting. The first NIR sorter in the minerals industry implemented for sorting is in Turkey at the company EtiMaden.

More bulk tests with sample sizes as high as 3 tonnes have shown that NIR spectroscopy sorting is technically feasible. The results for sorting barite, fluorite, talc, borate, marble, dolomite, salt and zinc oxide minerals are very encouraging and have led to industrial installations. If the target components do not show specific absorption features, components like alteration minerals could be used as indirect sorting criteria.[7]

Reference paper as:
M. Robben, C. Kleine and H. Wotruba (2012). Near infrared spectroscopy sorting in the minerals industry, in:
Proceedings of the15th International Conference on Near Infrared Spectroscopy,
Edited by M. Manley, C.M. McGoverin, D.B. Thomas and G. Downey, Cape Town, South Africa, pp. 191-194.

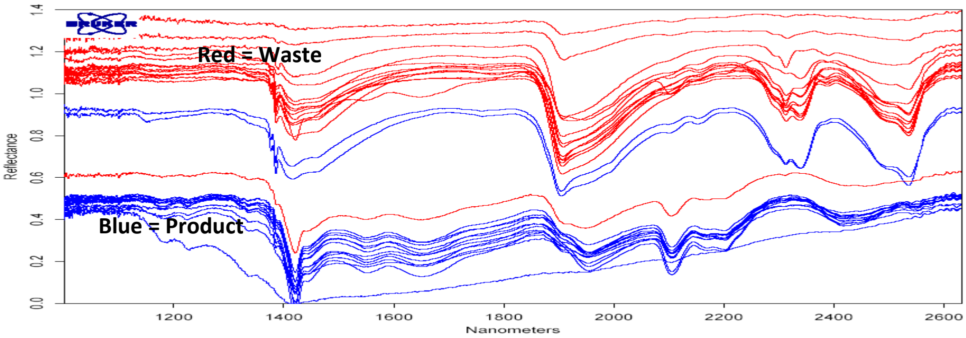

Figure 2. Diagnostic spectra of the gangue material (red) and the product, borate (blue).[7]

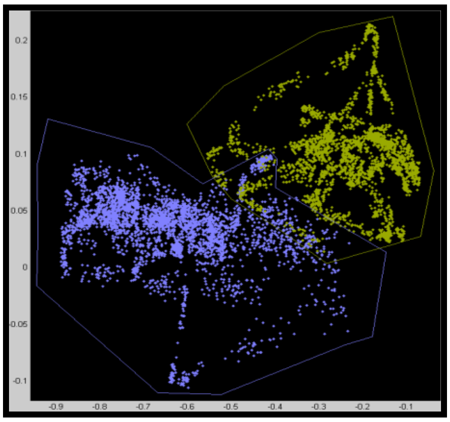

Figure 3. NIR spectral feature vector chart. Yellow is the gangue material and purple is the product.[7]

Table 1. Preliminary test results on NIR and optical sorting of Borate.[6]

	Send	Received			
Test	B2O3 (%)		Weigth ratio's (%)	B2O3 (%)	Recovery (%)
NIR Test 1	39,6	product	71,9	46,61	84,63
		waste	28,1	21,97	15,59
Color Test 1	39,6	product	71,2	42,06	75,62
		waste	28,8	32,28	23,48
NIR Test 2	44,85	product	84	47,42	88,81
		waste	16	27,73	9,89
Color Test 2	44,85	product	82,1	45,63	83,53
		waste	17,9	33,27	13,28

Conclusion

If differences in spectral responses are large enough for detection, then identification and classification based on mineralogical composition is possible. Differences in absorption features allow materials to be sorted with NIR spectroscopy. NIR spectroscopic sorting is a proven and sustainable technology which can be transferred from other industries to unfold its technical and economic potential.

Acknowledgements

I would like to thank TiTech, and in particular Dirk Balthasar, for giving access to their sorters and instrumentation and for support during the research.

References

1. H. Wotruba, M. Robben, and D. Balthasar. *Near-infrared sensor-based sorting in the minerals industry*. Conference in Minerals Engineering 2009. Lulea, Sweden (2009)
2. H. Wotruba and H. Harbeck, Sensor-Based Sorting, in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag Gmb&Co. KGaA (2010).

Reference paper as:
M. Robben, C. Kleine and H. Wotruba (2012). Near infrared spectroscopy sorting in the minerals industry, in:
Proceedings of the15th International Conference on Near Infrared Spectroscopy,
Edited by M. Manley, C.M. McGoverin, D.B. Thomas and G. Downey, Cape Town, South Africa, pp. 191-194.

3. H. Wotruba and T. Preetz, “State of the art in sensor-based sorting”, in *Proceedings of sensor-based sorting conference*, Aachen, Germany (2006).
4. M. Robben. *Feasibility study on the use of NIRS sorting in the process of Skorpion zinc ore*. Master Thesis, unpublished. RWTH Aachen/TuDelft. (2009).
5. TiTech, www.titech.com
6. M. Robben, H. Wotruba, D. Balthasar and V. Rehmann, *NIR Spectral Imaging in the Minerals Industry, Conference 15.* Workshop Farbbildverarbeitung. Berlin, Germany (2009)
7. M. Robben and H. Wotruba, *Near-infrared Sorting for Minerals*. Conference Proceedings- Sensor Based Sorting. Aachen, Germany (2010).

Reference paper as:
M. Robben, C. Kleine and H. Wotruba (2012). Near infrared spectroscopy sorting in the minerals industry, in:
Proceedings of the15th International Conference on Near Infrared Spectroscopy,
Edited by M. Manley, C.M. McGoverin, D.B. Thomas and G. Downey, Cape Town, South Africa, pp. 191-194.