Sensor sorting technology – is the minerals industry missing a chance?

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ABSTRACT: The implementation of automatic sorters has substantially changed processing in the recycling industry. In state-of-the-art recycling plants for glass, plastics or metals, sorters are the core of the separation process. In contrast, in the minerals industry sorters are only applied in some niche areas. Sorters can provide solutions in some of the most critical areas of mineral production like energy and water consumption, quality improvement and mineral reserves, but their enormous potential is far from being utilized. Automatic sorters have been successfully introduced for the processing of industrial minerals like calcite, rock salt or talc, as well as for uranium ore sorting, diamonds and other gemstones. Appropriate sensors have to be developed or improved to extend that application of sorters to other minerals like metalliferous ores. To advance sorter development, a much closer cooperation between mining companies and sorter manufacturers is essential.

1 INTRODUCTION

In their fundamental article from the year 1991 with the title “Sorting in the Minerals Industry: Past, Present and Future”, Salter and Wyatt made a remarkable statement:

“When one considers the progress made in the analytical sciences in the last 15 years, it is incredible that so little of this technology has found its way into sorting machines. Little attention has been paid to develop new discrimination systems or detectors. Perhaps there was insufficient incentive, perhaps it was apathy. If sorting is ever to be rejuvenated then the technology available in the scientific world must be applied in sorting machines”.

Cutmore and Eberhardt stated in the year 2002 in another essential article “The future of Ore Sorting in Sustainable Processing”:

“The available sensing technologies include nuclear, optical, electrical, magnetic, acoustic, thermal and various others specific to the ore such as hardness or shape. However, this broad suite of sensing technologies is not represented in current commercial ore sorters…. However, the present absence of other sensing technologies is more a result of insufficient industry interest than any technical barriers to their effective use”.

Not less than 11 years lie between these two nearly identical statements. Has the development in the area of sorting technology for minerals come to a standstill? Is it really apathy, or are the problems with the application of new sensor technologies really insuperable?

Another four years later, this article reviews the present situation.

2 APPLICATIONS AND BENEFITS OF AUTOMATIC SORTERS

It is a fact that the development of automatic sorters has been and is still driven by the recycling industry. Sorters have become state-of-the-art in glass and paper recycling (optical sorters), metal recycling (inductive sensors) and plastics recycling (Near Infra Red, NIR).

For metal sorting alone, more than a hundred machines have been installed worldwide between 2002 and 2005 by the leading manufacturers and since the year 2000, German plastic recyclers have installed about 400 NIR sorters.

Altogether, during the last decade, the implementation of sorters in the recycling industry surpassed the number of sorters which have been installed in the minerals industry by one order of magnitude. It is estimated that during that time about 100 sorters (excluding the number for diamonds) have been commissioned for mineral processing applications around the world (the vast majority for industrial minerals processing). Considering the number of mineral processing plants and the tonnage treated in the whole minerals industry, this is still a
very small number.

It has to be noted that until the sharp rise of commodity prices, the last decade has not been a fruitful time for the mining industry. Investment, if done at all, has been made to keep old plants operable. Few new plants have been built during that time, but even then, considering the advantages of sensor sorting technology, its application could have helped to make operations more profitable or indeed profitable at all.

Hence, a new future for the mining industry is in sight. New mines are opened, old mines are extended, and the planning, design and construction of new processing plants is booming. Order books of companies producing conventional processing equipment are full. With a few exceptions, the minerals industry still shows little interest in sorting. The proven or potential benefits of the use of sorting technology have been described in detail in the two fundamental articles cited above (Salter & Wyatt, 1991; Cutmore & Eberhardt, 2002).

Automation can help to overcome problems in some of the most critical areas of modern mining and mineral processing:

- energy consumption
- mineral reserves
- water consumption
- environmental impact
- quality improvement.

Sorters have been and are currently installed for the following duties (Salter and Wyatt, 1991):  
- pre-concentration of plant feed
- intermediate product production
- finished product production.

2.1 Basics of Sensor Sorting Technology

Opposed to classical separation unit processes, single particle sensor-based sorting is the only process with a decoupling of material properties from the mechanical separation. After the detection and qualification of one or more properties, all the information is evaluated to decide whether a single particle is discharged or not. The functional principle and main sub-processes of sensor-based sorting for a belt-type sorter.

The basis for any sorting operation is the correct material conditioning (1), which prepares the material to be properly detected by the selected sensor arrangement. Material conditioning comprises screening to appropriate size distribution and, if necessary, washing (scrubbing). The next step is particle isolation and presentation to the sensors (1+2).

2.2 Use of Sorters for Pre-Concentration

Sorting is not the only possible pre-concentration process for plant feed. Apart from selective mining, main competitors are gravity-concentration processes such as dense medium separation and ROM-jigs. Magnetic separation is used mainly for iron ores whereas selective crushing mainly for coal. With the exception of hand-picking, which is still used in smaller plants, these traditional processes make use of (sufficient) differences in density, magnetic properties or hardness/breakability of the particles, which limits their application to certain types of feed.

Even if traditional processes are applicable, the use
of sorters may be beneficial, especially when attempting to limit water consumption and size of the installation.

2.2.1 Benefits of Pre-Concentration of Plant Feed

To understand the untouched potential of sorting technology, it is useful to summarize the benefits of pre-concentration. The principle that “the elimination of waste at any cost less than the total milling cost will show profit”, which was stated by Mathews in 1974, is still valid. Sorting can provide efficient pre-concentration, where traditional techniques fail, or can replace traditional techniques providing a more compact, dry processing method.

According to Salter & Wyatt (1991) and Cutmore & Eberhardt (2002), the separation of waste from plant feed will lead to numerous advantages, such as:

- less overall capital costs for a given product output
- less operation costs per unit of production due to savings in energy and wear (especially for milling), reagents and water
- reductions in disposal costs for fine waste (e.g., flotation and leaching tailings)
- reduction of environmental impact (leaching of fine tailings with large surface areas, acid mine drainage)
- overall improved process recovery (for well-liberated ores suitable for sorting)
- increase in production (of an existing plant maintaining the main process chain adding a pre-concentration step)
- increasing the reserves/the life span of a deposit by including previously untouched blocks (e.g., with dykes or close to the ore body boundaries), which have been excluded due to unavoidable dilution below cut-off grade
- ability to mine by other means uneconomic deposits
- applicability of high-productive, but less selective mining technologies
- application at remote mining sites and transport of pre-concentrated feed to the central main plant and
- possibility to apply pre-concentration near or in the mine in order to leave coarse waste inside the mine (e.g., refill in underground operations).

To analyze the specific cost and benefit of a sorter application, each case has to be evaluated individually.

Even when energy consumption would be considered as the only parameter, the use of sorters can lead to substantial savings. Based on currently available data (mainly from industrial minerals plants), for the elimination of one tonne of waste from plant feed, by using a sorter with conventional air valve ejection about 1-3 kWh/t are used for compressed air depending on size and weight of the particles. This consumption of energy for sorting has to be compared with 12-15 kWh/t, which would be used for grinding this waste to flotation size (energy savings might not be a main issue if materials only have to be crushed to coarser sizes).

2.3 Use of Sorters for Intermediate and Finished Products

Sorters have been used for many years in diamonds processing, mainly with X-ray fluorescence sensors or, recently, with optical sensors such as line scan cameras.

Currently, a small number of optical sorters are used for industrial minerals such as talc, calcite, feldspar, quartz, rock salt, and precious stones. Their acceptance and application in these fields of mineral processing has led to significant improvements in product quality and/or recovery and furthermore in security as in the case of gemstones.

2.4 Sorters in the Minerals Industry

There are two basic criteria for the application of sorters (Schapper, 1976):

1) sufficient liberation of the “accept” and “reject” fraction
2) both fractions must be consistently identifiable by some means (one sensor or sensor combinations) within the time available for examination by the machine.

The first criterion is dependent on the ore characteristics. Sorting is a one-by-one particle separation process, where the overall throughput of a machine is related to the size and limited by the number of the individual particles. Even if sorting is possible down to a particle size of 1 mm using high resolution line scan cameras, the low resulting throughput restrains the use of sorting at this size to special tasks, e.g. removal of impurities from industrial minerals.

A common rule is that sorting becomes more economic with larger feed size (currently, a maximum feed size of about 300 mm is possible). This is not only due to reduced costs for previous liberation, but especially due to the higher achievable specific throughputs. State-of-the-art sorting machines for minerals can process up to 250 t/h on a 1,200 mm wide machine, for a feed size between 100 and 300 mm.

Especially for smaller feed sizes, the resulting lower throughput of sorters can limit their application. To enable economic sorting, a minimum particle size of about 10-20 mm is often required. There are, however, applications where sorters are used for much smaller feed sizes down to 1-2 mm (e.g., diamonds, gemstones, rock salt). If a sufficient liberation cannot be achieved at an economically, not technically suitable size, sorting of the respective feed will not be appropriate.
Even if very large mines do not make use of sorters for sorting their ROM, sorters could be applied there in specific applications as well, e.g. in AG mill circuits to prevent barren pebbles from going back to the mill. Sorters are lightweight and compact and therefore especially well suited for underground and mobile installations. Parallel installations of sorters (treating different size fractions, if necessary) are well established in the recycling industry to achieve higher throughputs.

The second criterion, the recognizability of accepted and rejected material, is the real challenge. A lot of test-work has been done and some installations have been realized using inappropriate discrimination techniques, sometimes accompanied by inappropriate feed preparation and materials handling. Such failures have been grist to the mill of notorious skeptics. Indeed, automatic sorting does not solve all the problems of modern mineral processing but it can solve some of them.

Beyond sufficient liberation and consistent recognizability, all other difficulties to the use of sorters in the minerals industry can be overcome. The lack of expertise and knowledge among plant designers and plant operators is one of the most pressing issues. Compared to the relative young recycling industry, which has repeatedly demonstrated its ability to adapt and use new technologies, the minerals industry is a very traditional one.

Generally speaking, the minerals industry relies on proven technologies, not least because the banks financing mineral projects require this. A sorter is definitely more delicate than a screen or another heavy piece of equipment but if well maintained and operated, it will last as long and work as reliable as any dense-medium vessel. Any service which is more than changing wear parts will certainly require qualified service personnel.

Currently an important drawback is that most manufacturers of sorters are smaller companies not offering 24h worldwide services. So either the plant personnel is sufficiently qualified (e.g. to adjust the sensors), or the sorter is accessible via e.g. the internet so that the manufacturer can help solving problems (mainly with the software) from remote, or the manufacturers built their own maintenance and service networks, or they cooperate with larger equipment companies which already have their service points installed in or close to the main mining areas.

Who ever visited an automobile shredder knows that the conditions in this environment are as dirty and dusty as in a mining environment. The only challenging difference in the handling conditions of the feed material is the greater abrasiveness of minerals, but this problem can be overcome with appropriate wear protection or a higher level of maintenance.

The argument that in mineral processing plants the available personnel is not capable of being trained on sorting machines is weak compared to the situation in the recycling and waste treatment industry, where the amount of academically trained personnel is the lowest of all sectors of industry.

It is somewhat surprising that an industry using highly complex process control systems, still pretends that a sorter is too complicated and therefore not appropriate for their needs. A re-thinking is here necessary. The recycling industry did so within the last decade turning from a low-tech hand-picker level to its present high technology and productivity standard, at least in industrialized countries.

3 SORTER DEVELOPMENT

The highly efficient sorters used in the recycling industry are the result of an intensive and long-lasting relationship between recycling companies and the manufacturers of sorters. This concept of mutual learning and joint development is not so well established in the minerals industry. After a certain learning curve, the recycling companies got what they needed for their sorting tasks and appropriate for their environment, why should the mining companies not do so as well?

As stated before, manufacturers of sorters are usually smaller companies, who have to plan carefully how to spend their resources. Even if most hardware parts of the machines can be bought on the market, especially the sensors usually have to be adapted or even newly developed. The software for processing the immense amount of data produced by high-throughput operation needs to be developed individually and up-dated constantly.

These companies spend a large percentage of their turnover on research - usually far more than other machine manufacturers and do not benefit from selling many spare parts due to the usually low wear on sorters. Currently most of the research spending is targeted to the recycling industry, as this is their actual main market.

Mineral companies currently benefit from the developments in sorter technology that have been made for (and paid by) the recycling industry. But after all, they are dealing with quite different materials and this means that specific research in sorter and especially in sensor technology has to be carried out.

It is interesting to briefly highlight the role of universities or other non-private research institutions in the development of sorters. Does the small number of academic publications on sorting mean that there is a similar lack of interest? The reason for this might probably originate from another issue.

Even the most common sensor, a high-speed, high-resolution line scan camera, is an expensive piece of hardware. A sensor test rig with various types of
sensors, peripheral equipment, air-valve array and CPU can cost several hundred thousand dollars, which is far too expensive for a normal university budget. For this simple reason, sensor and sorter development will possibly never be carried out on such a broad basis like, for example, research on flotation.

The lack of hardware in the form of sorters and/or sensors not only makes it difficult for universities to do research in this field, but also limits especially the possibility of appropriate training of the students on sorters. Even if sorting technology has already found its way into the curricula, few mineral processing students have the chance to do hands-on studies on sorters. It is obvious that mineral processing engineers who already had experiences with sorters during their study, will have fewer problems later in using this technology in their professional career. Here, more engagement of the minerals industry would be extremely helpful and ultimately pay off.

3.1 Sensors and Sensor Development

As mentioned before, the crux of the matter for the successful application of sorters in the minerals industry are appropriate sensors.

Discrimination of ore and waste rock by optical sorters is always possible, when the “accept” and “reject” fractions have sufficient optical differences, for example, bright gold bearing quartz veins from dark waste rock, translucent rock salt from opaque anhydrite or black chromite from grey-green host rock. Optical sorting becomes very difficult, if not impossible, in case the differences in the mentioned optical characteristics are too small or, even worse, erratic.

With the exception of radiometric sorters, X-ray fluorescence sorters for diamond sorting and very few metal detector sorters, most applications of sorters in the minerals industry make use of optical cameras for visible light. Sorters based on visible light sensors are already successfully being applied in the field of industrial minerals, such as calcite, rock salt, quartz, feldspar, talc etc. For these applications, sorters have proved to be reliable under mining conditions, and there is no doubt that the number of installations for the processing of industrial minerals will increase further.

Sorting of massive sulphide lumps or larger gold nuggets is an easy task for metal detector sensors/sorters. A much more difficult objective is posed when the dark host rock of the above mentioned example, usually waste, is impregnated with gold close to the contact with the vein and should therefore be allocated in the ore product. Gold concentrations in the ppm-range cannot be directly detected by either an optical or any other present sensor.

A similar problem is encountered when instead of sorting massive sulphide lumps, the aim is to sort optically indifferent low grade sulphide ore from waste rock or to sort by ore grade (metal content) in order to pre-concentrate the mill feed. In most cases, the sulphide particles are small (<1 mm); only in rare cases, the coloring of the rock matrix might correlate with the metal content. Much more often there is a variety of colors and brightness in both ore and waste rock, so even experienced mine geologists are not able to achieve an exact identification of a single rock without prior chemical analysis.

The objective of separating ore from waste in a range from 0.1-3 % metal content is the real challenge for the application of sensor-based sorters in the processing of metalliferous ores.

In the following sections state-of-the-art sensors as well as exploratory sensors which will be soon ready for industrial usage will be described.

3.1.1 Optical Sensors

Line scan cameras are state-of-the-art optical sensors which can easily be applied when ore and waste can be differentiated by color, brightness, reflection or transparency. Incident light is suitable for most ores and depending on the application double sided camera systems can be employed. Using optical sensors with incident light, only properties visible on the particle surface can be determined whereas the distribution of minerals inside the particles themselves remains unknown.

Transmitted light is applied with good results for translucent and/or transparent minerals like diamonds or rock salt.

Despite the high resolution on the object (~0.1 mm) mineral particles of too small size (<1 mm), e.g. sulphides, are hard to detect in the overall mineral matrix; because the difference in color between target minerals and associated minerals is often too small. Nevertheless, the excellent results achieved with optical sorters for industrial minerals indicate potential for use in other mineral applications.

Optical sensors are and will be the backbone of sensor sorting technology, either alone or in combination with other sensors. Low-resolution sensors, such as metal detectors, have often to be combined with optical sensors to enable the delimitation of particles in a random feed stream.

In the case when waste and ore show similar color and brightness distributions but differ in their distribution pattern, the use of texture recognition methods seems very promising, e.g. for the sorting of Witwatersrand gold ore dumps, and is objective of current investigation.

For most optical camera applications the surfaces of the particles have to be clean, usually implicating the use of water for washing/scrubbing which can be combined with screening off undersize. Moist surfaces do not cause problems - in contrary in most cases they
enhance the recognizability by optical cameras.

3.1.2 Optical Sensors for Ultraviolet Applications (High-Sensitivity Optical Sensors)

A number of minerals are fluorescent in long and especially in shortwave UV light. The strength of the fluorescence depends on the mineral itself, but also on the power and spectrum of the exciting UV light source. In many cases, normal optical line scan cameras are not sensitive enough for this application, so the use of high sensitivity cameras will be necessary. The fluorescence in minerals is caused by so called activators which can be rare earths, titanium, vanadium, chromium and a variety of other elements. A typical application is the sorting of scheelite ores.

Table 1 shows the percentage of minerals in each mineral group that are known to react to excitation by UV light.

<table>
<thead>
<tr>
<th>Mineral Groups</th>
<th>Percentage with Fluorescence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Sulfides</td>
<td>5%</td>
</tr>
<tr>
<td>Sulfosalts</td>
<td>0%</td>
</tr>
<tr>
<td>Oxides/Hydroxides</td>
<td>5%</td>
</tr>
<tr>
<td>Halides</td>
<td>15%</td>
</tr>
<tr>
<td>Carbonates</td>
<td>30%</td>
</tr>
<tr>
<td>Borates</td>
<td>30%</td>
</tr>
<tr>
<td>Sulfates</td>
<td>10%</td>
</tr>
<tr>
<td>Phosphates/Arsenates</td>
<td>10%</td>
</tr>
<tr>
<td>Tungstates</td>
<td>15%</td>
</tr>
<tr>
<td>Silicates</td>
<td>20%</td>
</tr>
</tbody>
</table>

Table 1: Percentage of known fluorescing minerals in each group (Robbins, 1994)

Discrimination by fluorescing color is not possible at the moment since high-sensitivity cameras only produce grey scale images. Furthermore, as with other optical sensors, fluorescent minerals can only be detected on the surface of particles.

Recently, the first pilot sorter using this type of camera has been commissioned.

3.1.3 Infrared Sensors (Infrared Cameras)

Infrared cameras measure the temperature of minerals after previous energy input by heat radiation or microwaves. Temperature differences of below 1°K can be detected. Especially microwaves heat up minerals selectively and differently. Even very small sulphide particles can be heated extremely fast by microwaves and thereby be detected.

On the one hand, a fast infrared camera has a resolution on the object of only about 2 mm, which makes the separate detection of small sulphide particles impossible. On the other hand, this circumstance will be partially compensated by the effect that even small sulphide particles will heat up the whole ore particle which will experience a slight overall increase in temperature. That way, infrared sensing can be used for detecting sulphide minerals inside an ore particle itself, provided a certain "reaction" time between microwave heating and detection so the heat emitted from the sulphide particles is possible to reach the particle surface through the associated minerals.

Table 2 shows the microwave heating behavior of various minerals after Walkiewicz et. al. For each mineral heating time and temperature reached are stated for heating with 1 kW at 2.45 GHz.

Table 2: Heating behavior of various minerals (Walkiewicz et al., 1988)

<table>
<thead>
<tr>
<th>Category</th>
<th>Mineral</th>
<th>Temperature [°C]</th>
<th>Time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easily Heated</td>
<td>FeS₂</td>
<td>1.019</td>
<td>6.75</td>
</tr>
<tr>
<td></td>
<td>PbS</td>
<td>956</td>
<td>7.00</td>
</tr>
<tr>
<td></td>
<td>CuFeS₂</td>
<td>920</td>
<td>1.00</td>
</tr>
<tr>
<td>Very Little Heating</td>
<td>SiO₂</td>
<td>79</td>
<td>7.00</td>
</tr>
<tr>
<td></td>
<td>Al₂O₃</td>
<td>78</td>
<td>4.50</td>
</tr>
<tr>
<td></td>
<td>KAl₆Si₄O₁₈</td>
<td>67</td>
<td>7.00</td>
</tr>
<tr>
<td></td>
<td>CaCO₃</td>
<td>74</td>
<td>4.25</td>
</tr>
</tbody>
</table>

Regarding the extremely different heating velocities of e.g. pyrite and chalcopyrite, the differentiation between various sulphides does not seem to be out of reach.

The potential of microwave excitation and IR-camera measurement is just beginning to be explored. First tests showed very promising results for coal and low-grade sulphide ores. Contrary to expectations, moist surfaces have shown little influence on the practicability of this method.

The use of microwave attenuation with a microwave transmitter and detector has already been successfully applied by De Beers for kimberlite discrimination (Salter, 1989). However, this particular project never exceeded the pilot plant stage due to a lack of sensitivity of the sensor set-up at the time.

Another type of sensor is the NIR (Near Infra Red) sensor, which is used successfully for plastic sorting in the recycling industry. NIR sensors have been introduced for core-logging (where velocity is not a critical issue). Minerals can typically be detected in a range of wavelengths above 2 µm, being just above the wavelengths of sorters used for plastics, which are therefore not applicable without modification. At the moment, no commercial ore sorter using NIR or MIR (Medium Infra Red) technology exists, but first tests are currently carried out.
3.1.4 X-Ray Sensors

The particles to be sorted are penetrated by X-ray radiation at certain energy levels and the intensity of the remaining radiation after having passed the particle is measured by sensitive and fast sensor arrays with line resolutions below 1 mm. Minerals with elements of high atomic order absorb the X-rays more than minerals with elements of lower order.

Given a sufficient energetic radiation, a significant advantage is the penetration of the particles as a whole and the projection of contained metalliferous (e.g. sulphide) particles onto a two-dimensional area where they produce a grey-scale image differing locally and by intensity.

In addition, oxide metalliferous minerals can be measured this way. The influence of different particle thicknesses can be eliminated by applying the so-called dual-energy X-ray method. So far, tests with oxide zinc minerals have been carried out successfully; an investigation with sulphide nickel and copper ores is ongoing (Harbeck, 2004). X-ray sensors work well for distinguishing coal and waste and can even distinguish different coal qualities (de Jong, 2006).

In many cases particles do not have to be washed before being measured by X-ray sensors enabling a completely waterless process. One disadvantage of X-ray sorters is that particle thickness using conventional (and save) X-ray sources is limited to about 60 mm thus limiting the possible throughput of a sorter.

3.1.5 Metal Detectors

Metal detectors measure conductive minerals and metals. They can be employed for the detection and measurement of elemental metals (mainly for recycling) and of sulphides.

Their sensitivity for small particles depends on the frequency, usually between 2 and 200 kHz, and decreases with increasing distance between detector and particle. Penetration depth and sensitivity for fine conductive particles are in a reciprocal relationship in the sense that the higher the frequency the smaller the size of the particles that can be detected but the lower is the penetration depth into a particle.

Metal detectors are able to detect sulphide particles distributed in a larger particle, but the detection depends on their size and their distance to the detector coil. With about 10 mm, the resolution of metal detectors is reasonably low. They provide good results at high metal grades while measurements become inexact at low grades and/or small sulphide particle sizes. A coarse interlocked sulphide particle, for example, gives a measurable response whereas finely interlocked sulphides of the same total mass often cannot be measured (Wotruba and Riedel [1], 2006).

As a metal detector detects only the amount and size of conductive material in a particle, but gives no information about the grade, it is necessary to co-measure two-dimensional size or, better, tridimensional size (volume) of the ore particle. This can be achieved using optical cameras or laser/optical cameras.

For an application in the minerals industry, especially for low grade sulphide ores, the currently available sensors, which have been developed for detecting metals in the recycling industry, have to be further improved.

3.1.6 LIBS (Laser Induced Breakdown Spectroscopy)

A LIBS detector system measures the elemental composition of a single spot on a surface by producing a plasma by a focused pulsed laser. The emitted photons of the plasma are measured by a spectrometer which can be calibrated to element specific spectral lines.

This technology is already used for grade control of feed material on belt conveyors (Gaff, 2006). To be able to measure individual particles on a moving belt, the laser beam has to be diverted by a scanner to the exact position of the particle, demanding a preceding detection of the position of the particle on the belt by an optical line scan camera.

So far, LIBS sorting technology is applied in a pilot sorter for aluminum alloy sorting (Mutz et al., 2003). Several groups around the world are looking at the adoption of the LIBS technology for online minerals analysis and sorting. The potential of the LIBS technology is enormous; by a direct assay at the particle surface it makes sorting by primary properties possible.

Anyhow, the drawback is the low resolution in terms of scanning frequency (~100 Hz) and the small surface detected by each laser pulse (~1 mm²). As a result, fine, homogenous distributions of elements can be analyzed with high accuracy whereas typical disseminated ores, e.g. sulphide ores, are difficult to be measured (if the laser beam hits a sulphide inclusion, the reading will be high, and if it hits the matrix, the reading will be zero).

Providing multiple measurements on a particle, e.g. by splitting the laser beam into several sub-beams, it is possible to improve this issue but the problem cannot be eliminated in general, indicating the necessity of a combination with other sensors like LIF.

3.1.7 LIF (Laser Induced Fluorescence)

LIF analyzers are used for the online analysis of bulk streams. They operate on the basis of an ultraviolet laser exciting the fluorescence on a particle surface and detecting this event time resolved with resolutions of down to 1 ns with spectrometers or photomultipliers. The same disadvantages as with the LIBS detectors apply here with the exception that the
surface detected is larger.

It is possible to widen up the laser beam to diameters of up to 80 mm and still induce enough energy to excite fluorescence. The advantage of a LIF system is its ability to produce fluorescence even in minerals currently not known to fluoresce by the use of standard UV lamps.

The signal measured is not a primary characteristic as with a LIBS system, but rather a fingerprinting technique where the signal has to be calibrated and matched with rock types separately for each deposit; the fluorescence here depends on activating elements as with regular fluorescence which is already visible with UV hand lamps (Nienhaus et al., 2003).

Currently, the Department of Mineral Processing of RWTH Aachen University coordinates a collaborative research project where a pilot sorting unit including LIF and LIBS detectors is developed, mainly for the detection/separation of magnesium content in carbonate rocks for cement production. An expansion to certain types of metal ores is planned during the next stage of the project.

3.1.8 Sensor Combinations

After considering the various advantages and disadvantages of the different currently available sensors, the obvious question is: What might a combination of two or more sensors achieve regarding the accuracy of the recognition process?

Different sensors are different not only in the nature of the detected particle characteristics. They have different resolutions, acquisition times, scanning velocities, scanning widths, and they need different lighting, background and feed presentation conditions. Some of them have analogue and some of them digital outputs, which seems to be the least problem, but any conversion needs time. If the task is to identify up to 10,000 particles per second per meter width of sorter, and to blow out up to 2,000 particles in the same time, it is clear that one of the outstanding problems is velocity.

This requires advanced computing algorithms for data processing and filtering already for only one sensor. For sensor combinations the complexity of sensor calibration, adjustment, coordination, integration and data processing is much higher (Wotrub and Riedel [2], 2006).

For example, the line scan camera image of a mineral inclusion of 1 mm size in a particle, which moves with 3 m/s has to be combined with an image of an X-ray sensor, which base line is 20 cm apart. Both images have to be made absolutely congruent to enable a sorting decision. The main data processing unit receives information of different types and localities, scanning speed and resolutions. The "decision time" available to acquire, synchronize and evaluate all data and to actuate or not the air valves, is only a fraction of a second.

Considering this challenging task, it is impressive how far sensor sorting technology has already been advanced in the last years. Current sorters are able to handle a combination of two high-resolution and one low-resolution sensor in "near-real-time" velocity. Nevertheless, there is still plenty of room for further improvements in "multi-sensing technology". This is especially important, if the enormous amounts of data from spectral resolve sensors like LIBS or NIR have to be processed and integrated in suitable speed. Here, the crucial point is the reduction and filtering of data by not using the whole spectrum of a response, but only characteristic peak areas.

The application of sensor combinations is already state-of-the-art in the recycling industry, where for example sorters working with a combination of metal detector and optical cameras are used for metal sorting.

3.2 Other Fields of Sorter Development

A sorter comprises more parts than one or more sensors. Other components influencing the performance of a sorter as a whole include the excitation of the feed material (e.g. lighting), data processing, the mechanical construction, the mechanical rejection mechanism and the feed presentation.

Illumination methods are under constant development, especially for applications using optical sensors where, for example, LEDs have come forward during the past couple of years.

In data processing progress is made on an annual basis where processing frequencies are increasing and better algorithms for data reduction, filtering and operation are being developed. The potential limits, for example, in intelligent and fast pattern recognition are by far not reached.

In regard to its robustness and ease of maintenance, the mechanical engineering of belt and chute sorters is in constant development as well. Sorters can still be optimized, regarding their footprint and loss of height, potentially resulting in even more compact machines.

Currently employed air valves are of the fastest kind in their class of volume flow. Still, there is enough potential in the optimization of activation and coupling of air valves to significantly reduce the pressurized air consumption and exactness of rejection. To minimize the energy consumption of compressed air (especially for coarser size ranges), the application of water jets could be reconsidered.

Sensor-based sorters are highly specialized for each application and require an in-depth examination and integration into existing processes, even altering these processes to the sorters' needs. Responsibilities are limited not only to the machine suppliers, but in a large extend rely upon the operator side who cannot.
expect to receive an off-the-shelf product. Sorters are ultimately not testable in a laboratory environment. Only embedded in a process sorters can be tested with statistically significant feed rates, under realistic feed characteristics and relevant environment.

4 CONCLUSION

The example of the recycling industry shows impressively how the use of automatic sorters revolutionized the technology of a whole industry sector. Contrary to that, the enormous potential of sorters in the minerals industry is far from being exploited. The advantages of sorters for various steps of mineral processing, from pre-concentration of plant feed to finished product applications are so convincing that the industry should have greatest interest in their further development and application. With more machines being implemented year by year, the industry-wide experience with sorters will increase, and sorters will be constantly improved on the basis of industry practice. For some industrial minerals, sorters using state-of-the-art sensors have already been successfully implemented.

New specific sensors for minerals and ores exist in the form of prototypes and pilot plants. Nonetheless, the current practice in the minerals industry is to use automatic sorters only as a last resort and only if traditional methods cannot be applied.

Regarding this attitude, a re-thinking has to take place. Sorter application has to be taken into consideration in the earliest planning stage of new projects or plant extensions. There will always be cases in which traditional coarse separation techniques are preferable, but in the future, there will be more and more cases where sorters will be definitely the better - or only - option.

The availability and qualification of necessary personnel for trouble free operation (operator as well as machine manufacturer service personnel) will increase with more and larger installations of sorters in the minerals industry.

Sorter and sensor development for mineral applications has to be promoted by providing sufficient financial means. Sorter manufacturing companies cannot carry this burden alone. Substantial engagement of the minerals industry and a much closer cooperation between mining companies, machine suppliers and research institutions is essential. Many mining companies are still lack the risk propensity that is necessary to enter new grounds. But there is some light on the horizon.

5 REFERENCES


