New high definition X-ray sorting system based on X-MINE detection technology

J Kolacz
Comex Polska Sp. z o.o., 30-644 Krakow, Poland

jacek.kolacz@comex-group.com

Abstract. The new sorting system has been developed to achieve efficient separation at low mineral content levels. The system employs high sensitivity X-ray sensors providing multi-energy analysis, thus giving maximal information about processed materials. It makes it possible to analyse the internal structure of the particles and directly detect intrusions of minerals and metals like copper or gold. The paper describes sorting application examples for copper ore with metal content under 0.5% Cu. The sorting system still allows high efficiency analysis, quantification and removal of rock particles representing waste fraction with no metal or a negligible amount, being uneconomic to process. This brings a huge advantage, where almost no losses of valuable minerals in the waste fraction are achieved. The presented sorting system has been developed by Comex and X-MINE EU Project Consortium.

1. Current technology and potential new solutions

Processing of metal ores including copper and gold, is mainly based on complex mineral separation. It often includes several processing stages including crushing, grinding, flotation, leaching etc. The processing equipment provides an efficient grinding and separation, however, the operating cost is very high. The main reason is related to very low metal concentration, so the main material steam from the processing plant consists of fine ground waste particles and a very small amount of the metal concentrate fraction. The input material has to be ground to fine sizes to liberate different minerals, separated in complicated flotations circuits, and often treated by complex leaching. The water involved in the process must be recycled. The waste materials often contain toxic elements and compounds, which are problematic for simple landfilling. All these factors generate a very high cost of processing, which in addition indicates increasing tendency due to more and more restrictive environmental regulations.

Pre-concentration of such ore types by sorting, has a huge potential in reducing the processing cost and gaining important environmental benefits. Application of the sensor based sorting is very attractive when compared to other separation technologies. It provides the following advantages, when compared to the traditional systems:

- Possibility to apply in small capacity production lines
- Small space requirement
- No use of water (it is completely dry technology)
- No complicated additional equipment like, pumps, mixers, conditioners, recuperation devices, instrumentation, etc.
- No requirement of high density powder (ferrosilicon in DMS systems)
- Lower investment cost (about 50%)
- Very low operating cost (about 10 times lower)

Sorting process is very neutral for the environment, does not require water and reduces the cost by about 10-20 times when compared to the traditional mineral processing operations [2],[6]. Ideal pre-concentration means separation of particles containing 0% of ore and providing this with high stability through the severe mining conditions. However, there is always a certain loss of ore particles in such processes, which makes this sorting technology less attractive. Therefore, the sorting process must be carried out with the best possible precision to reduce these losses in the waste fraction. It is only possible by applying technology, which allows detecting the fine ore particles disseminated in the rock material. Currently used XRT sorting technology is often based on dual energy analysis (XRT-DE), which has a resolution of 0.4-0.8 mm. It means, potential ore particles, which have sizes under 400 µm, are not detected at all or they are detected with much lower accuracy, providing significant ore losses in the waste fraction. New technology described in this paper, gives a possibility to detect particles under 50 µm, which provides a significant breakthrough in sorting. An example of copper ore pre-concentration shows the efficient separation of waste particles, practically without any losses.

2. X-ray sorting technology
Application of the sensor based sorting systems, without any doubt, brings a lot of possible advantages in many mineral operations. The main advantage of the new system is related to its universality and at the same time very sophisticated image processing functions, which can be carried out in the same processing unit [1]. Figure 1 shows the CXR system from Comex, in the configuration where many different analysed parameters can be used to provide particle separation. The image analysis system includes a camera installed either over the transport belt conveyor or at its discharge end. The system includes the X-ray attenuation analysis realized by the XRT system in the central part of the conveyor belt. The sorting system can be used with both optical and XRT analysis or separately depending on an application.

![Figure 1. Comex CXR sorting system – configuration with the X-ray and the optical analysis.](image)

Particle recognition used to separate different materials is based on a complex shape and colour analysis where the particles can also be identified by over 20 parameters used for shape description. Some of them are: diameter in different orientations, perimeter, centre of mass, moment of inertia, particle elongation factor, edge sharpness, etc. Additional combinations of these parameters can also be used for distinguishing particles of interest. The surface of particles where different colours or contours vary in intensity and frequency can be analysed by FFT filtration (Fast Fourier Transformation) to recognize differences in texture and structure of the processed particles. This analysis brings much more
complex information about the analysed particles rather than colour recognition alone. Finally, the XRT picture is integrated into the optical analysis, which provides a lot more information about the particle surface properties and its internal structure. All these sophisticated analysing functions require a lot of computation power and they have to be optimized to allow high capacity sorting. This is done by special program architecture and algorithm solutions allowing efficient management of the calculation routines and sorting priorities. This allows achieving still high separation capacity and extremely high efficiency (Kolacz, 2014), where the product purity can reach even 99.9%. Such results can be achieved in different production scale depending on the process requirements [3]. Current sensor based sorting systems with standard sensors are already successfully tested and applied in the metal ore processing like iron ore [1] including Zn/Pb ore [5] and coal [2].

3. New generation sensors
The new sorting system has been jointly developed by Comex, Advacam [4] and X-MINE partners in relation to the X-MINE EU project. The X-ray unit, as shown in Figure 1, sometimes called X-ray gate, contains the complete system for analysis like: X-ray source, detectors, air conditioning, communication devices, etc. It is therefore possible to install different sensors in different configurations inside the unit. The new sensors, developed in X-MINE project, include the highly sophisticated technologies involving high resolution XRT, collimated XRF and 3D imaging, as shown in Figure 2.

Figure 2. New complex sensor system – configuration with the XRT, XRF and 3D optical analysis.

The XRF detector (Figure 3) provides multi-energy analysis of the transmitted photons with about 50 µm resolution. The XRF sensor provides the collimated analysis of strictly defined areas allowing
spectral analysis. Finally, the 3D camera provides the information about the topographic particle structure. The signals from the sensors have a very complex form and contain huge amount of information about each analysed pixel. This requires teraflop GPU based computing systems to analyse the images and provide the digital separation of product and waste particles. It is necessary that this computation sequence is finalised within very limited short time period, typically 5-10 ms. This short computation time is necessary to obtain a reasonable sorting capacity in industrial applications.

![New XRT sensor with high resolution.](image)

**Figure 3.** New XRT sensor with high resolution.

Applying the new XRT system alone, without XRF and 3D imaging, already allows a very sophisticated analysis, as shown in Figure 4. The high density intrusions having very small sizes, would never be registered by the traditional detectors. The new sensor is able to make the quantification and material differentiation in the micrometre range. Figure 4 shows the spectral response from the sensor indicating different X-ray attenuation characteristics. It allows direct identification of disseminated ore types like gold, copper, zinc, lead, tungsten, chrome, iron, etc.

![New sensor response indicating high density intrusions in the low density rock material.](image)

**Figure 4.** New sensor response indicating high density intrusions in the low density rock material.

Figure 5 shows even more sophisticated analysis. In this case, the high density particles (red colour) like gold or mercury ore, can be identified from medium density particle (yellow) like iron or copper
ore, and both types of materials can be differentiated from the regular low density rock (blue). Spectral analysis shown for both materials indicates the differences in X-ray attenuation for both high and medium density particles.

Figure 5. New sensor response indicating medium (yellow) and high (red) density intrusions in the low density rock material (blue).

4. Sorting results
The CXR-1000 X-ray sorting unit with 1 m belt width and the new XRT sensors, has been used for testing of the copper ore. In this case the other sensors as XRF and optical 3D cameras, were not applied. The feed material was fed with the low quality copper ore, where the average metal content varied from 0 to about 2%. Such ore was completely impossible to sort by using the standard XRT-DE detectors. However, using the new XRT sensors, the low copper content areas in the rock material, could be detected as shown in Figure 6 (right side).

The separated particles were further analysed in terms of chemical composition. Table 1 shows the result from this separation test. The particles containing copper, were identified with very high variations of metal content from 0.01 to 8.96%. This is not unexpected since the copper ore is highly disseminated and very differently concentrated in the rock structure. However, the waste particles were identified with almost no copper content, which is the extremely important factor. This allows much more efficient application of sorting for metal ores, where the metal content is low or very low, and where very low losses in metal recovery can be achieved in the overall process.
Figure 6. New sensor response indicating waste fraction (left) and disseminated copper ore (right).

Table 1. Sorting results for copper ore.

| Batch no. | Unit | Product | Waste |
|-----------|------|---------|-------|
| B1        | %    | 2.67    | 0.01  |
| B2        | %    | 0.14    | 0.01  |
| B3        | %    | 0.02    | 0.01  |
| B4        | %    | 1.82    | 0.02  |
| B5        | %    | 8.96    | 0.02  |
| B6        | %    | 0.30    | 0.01  |
| B7        | %    | 0.02    | 0.01  |
| AVR Cu content | % | 1.99 | 0.011 |
| Yield     | %    | 68      | 32    |
| Cu recovery | % | 99.7  | 0.3   |

The same new equipment with new XRT detectors has been tried for gold ore sorting. The sorting results indicate the similar advantage of identifying the ore particles even at the level of 1 ppm, by direct detection of the gold ore. This research work is still not finalized and current results are confidential, thus they cannot be published in this paper.

5. Conclusions
The new XRT sorting detectors can provide a very efficient pre-concentration of most of the metal ores like: Zn-Pb, Cu, Au, W, or other types, before further processing. The detection system allows identification of high density particles being smaller in size than 50 µm. This brings an enormous advantage over the current sorting equipment, where the recovery losses in processing of disseminated ores are limited to the absolute minimum.

Detection of particles smaller than 10-20 µm is not possible in the new detection system, however, this may even help to eliminate particles being uneconomic for further processing. Currently applied mineral processing systems for e.g. copper ore, are not able to separate so fine particles (mainly by flotation). Therefore, the mentioned sorting system can pre-concentrate the particles of metal ores being in the optimal size range for further processing. This brings another advantage to reduce the processing cost and gain the important environmental benefits of pre-concentration. Further development work is carried out in the X-MINE Project Consortium and further new technologies like collimated XRF sensors and 3D imaging, will be possible to combine with the described XRT system. This will bring even more possibilities for further material identification and more efficient sorting of complex minerals or materials. This can make many current mining operations more economic or bring new possibilities for new potential mines, where the current economic or environmental restrictions hinder their start or planning.
6. References

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