automining2020 | August 5 - 7, 2020 · Santiago, Chile
automining@gecamin.com

Ore Sorting Automation for Copper Mining with Advanced XRF Technology: From Theory to Case Study

Jukka Raatikainen[1], Ilpo Auranen[1] and Nicolás Pérez[2]

1. *IMA Engineering, Finland*
2. *Nicolaides Industrial, Chile*

ABSTRACT

Ore sorting is one of the focus areas mining companies are now looking at in improving mining proficiency and becoming ever more sustainable in mining.

For almost a decade IMA Engineering company has been developing sensor applications to better separate ore from the waste from early exploration to modern bulk ore sorting (or particle sorting). To move from theoretical studies to practical evaluation several new concepts have been successfully tested with sensor solutions.

In this article we explain two unique approaches, which have been successfully adopted by mining companies. The one using fast on-line XRF sensor at primary crushed ore to detect amount of waste, which can be separated before the mill (Horizon 2020 ITERAMS project), and the other to estimate sorting potential already during exploration stage by analysing drill cores or drill cuttings accurately and frequently to get practical results for real sorting potential. In both customer cases also economical calculations are explained.

Currently several international full scale bulk ore sorting installations are in progress and planned this year 2020..

INTRODUCTION

Ore sorting is one of the focus areas mining companies are now looking at to improve profitability and becoming ever more sustainable in mining. For almost a decade IMA Engineering has been developing sensor applications to better locate, detect and measure ore and waste rock and separate them in every stage of mining. This is done by analysing drill cores, drill cuttings and ore on conveyor belt and in loader bucket to measure ore grade and to separate ore from waste. The approach has been very consistent and recently we have moved from theoretical studies to practical operation. This article's focus is in bulk ore sorting. Two novel approaches are described in this paper are described in this paper: the first case covering green field exploration sorting study and the second is full scale bulk or sorting pilot.

Sorting is the remedy to minimize waste rock dilution

The root cause of waste rock dilution and ore losses in mining is the limited capability of the used sampling technology to locate accurately ore and waste rock. This defect starts already in drill core sampling where the drilling and sampling costs set limits for practical sampling grid and to the number of core samples and sample lengths to be analysed. This results in analysis averaging on the length of the core and eventually in the ore blocks.

When the mining starts blast benches are mined with big block sizes with sparse sampling and analysis of their grade, which leads to dilution and ore losses at ore waste contact. Mines too easily accept this situation and economic loses, because there are no practical tools to avoid it. Testing has shown that bulk ore sorting could be the remedy to correct and minimize these losses.

METHODOLOGY

Sorting studies during green field exploration

To overcome this fundamental analysis averaging error on drill cores IMA Engineering has developed together with Mine On-Line Service company a new method for analysing drill cores which can also reveal ore sorting potential at an early stage of mining process. This approach includes frequent analysis of drill cores with scanning XRF-method at every from 10 to 20cm length of the core. The method is fast and economic, and it is used for exploration and mine grade control. Practical studies have shown interesting results when we have compared conventional ore sampling and analysis methods with XRF frequent sampling and analysis results. A summary of this study is explained below.

Case silver mine: sorting simulation by Scanmobile from drill core

Evidence of ore/waste heterogeneity is masked by common drill core sampling and analysis practices where analysis technology is setting limits to sample size/length thus averaging the ore grade on core length. Common orebody modelling and mine planning practices involving geo statistics and block modelling which further tend to mask the heterogeneity of the ore. Mining users are therefore often unaware of heterogeneity present within their orebodies which can be exploited to recover ore from waste or alternately reject waste from ore. (Fig.1)

Figure 1 Example of sample averaging: analysis averaging in drill cores dilutes the grade two in a copper ore

Scanmobile (Fig. 2.) ore sorting simulation quickly focuses on marginal blocks within a model and unpacks the geological data to reveal and quantify previously unrecognized ore recovery or waste rejection potential in this material.

Figure 2 Scanmobile drill core analysis laboratory

In the Silver Mine project ore Silver and Zinc have a strong correlation. The ore sorting simulation was made using two 80meter long drill cores samples and using Zinc as the Silver indicator element. The cores were analysed with Scanmobile with scanning XRF method using 10cm and 100cm analysis

lengths. The potential recovered (=sorted) core (i.e. ore) length was registered with 1 000, 2 500, 5 000 and 10 000ppm cut off grades and the length and average grade of the sorted core (ore) was measured and computed. (see Table 1.)

Table 1 Silver Mine Zn-ore sorting simulation with different cut of grades as a function of the analysis length

Zn cut-off grade (ppm)	Length of core sorted as ore		Core (ore) length difference	Ore average ore grade		Relative head grade increase XRF 10cm vs XRF 100cm
	XRF 10 cm (m)	XRF 100 cm (m)	XRF10cm vs 100cm	XRF 10cm (ppm)	XRF100cm (ppm)	
1.000	61	89	-31%	6.138	4.987	23%
2.500	28	40	-31%	11.691	8.365	40%
5.000	14	19	-26%	19.612	13.897	41%
10.000	6	8	-25%	36.741	23.918	54%

The simulation results in 23% to 54% increase in mill head grade and from 25 to 31% decrease to core length indicating the tonnage reduction of the ore to be processed in milling and in concentrator. The mine made the following press release after further studies: "In comparison with the previous ore-reserve estimate, the average content of silver in Proven and Probable reserves have increased with 22%. The amount of ore-reserve tonnage has been reduced by ore-sorting with 17%, which reduce the treatment cost at the concentrator further per produced ounce". (press release February 8th 2016-www.silver.fi)

As a result of the study the project got financing for the Silver Mine and the mine is operating today. With the inexpensive and quick ore sorting simulation study from drill cores at an early stage of the mining process the company was able to increase the value of their mineral deposit.

From laboratory pilot to full scale bulk ore sorting

IMA uses a small lab-scale and full-scale piloting with IMA FCA XRF sensor aka. Fast Conveyor Analyser. IMA has done several FCA Lab-scale studies with mini pilot bulk ore sorting system (Fig.3.) in iron, in base metal and in gold ore cases.

In case of the elemental composition of the targeted element is below 50 ppm the sorting is applied via analysing proxy elements having higher grades e.g. Arsenic in for Gold, Lead and Zinc for Silver and Copper for PGMs.

The FCA version has been applied in applications with top size at 400mm including fines. Naturally big lump sizes and fractions make calibration more challenging. Methods have been applied to overcome calibration challenges.

Figure 3 IMA XRF mini pilot bulk ore sorting system (IMA BOSS)

The mini pilot tests have resulted into piloting with full-scale production with 150ton/h and 3000ton/h capacities. Below is an example of such case.

RECOVERING ORE FROM WASTE – INCREASING HEAD GRADE IN MILL FEED – PILOT STUDY IN A NI-CU MINE

Ima Engineering conducted a pilot study for a Nickel-Copper mine to upgrade their low grade ore. First a mini pilot bulk ore sorting study with customers' samples was done in our laboratory. The next step was a full scale sorting study at the mine. For that a mobile sorter with a capacity of sorting 140 tons per hour was built on a mobile screen carrier. Four dump truck loads, total 600tons, of low grade and high grade ore and waste rock from the pit was hauled a mobile primary crusher. There the feed material was crushed to minus 150mm of size and the crushed ore was fed by a wheel loader to the IMA mobile bulk ore sorting system (IMA BOSS). (Fig. 4 and 5) An IMA FCA XRF analyser was installed on top of the main conveyor. The IMA BOSS XRF analyser analysed the Ni% and Cu% and Fe% contents of the ore on the moving conveyor. A bulk ore sorting chute principle was used; i.e. in every 15 seconds the continuously analysed material on conveyor was sorted using a flop-gate principle diverting the ore to left and waste to right by a chute located in the end of the blocked screen mesh. The screen deck was blocked to facilitate a 15 second delay between the sorting chute and the FCA analyser. The cut-off grade for sorting was set to Nickel equivalent (Ni EQV%) 0,23%. The results showed that 50% of the low grade ore (average NiEQV 0,24%) feed material was below the cut-off grade. By sorting out the below cut off waste the mill head grade was increased from original 0.24% to 0,3% resulting in 25% increase in mill head grade. Analysis performance is based on analyser calibration with static samples of same materials, which were analysed in the laboratory (Fig. 6).

Figure 4 Primary crushing the ore

Figure 5 IMA BOSS Pilot bulk ore sorter system

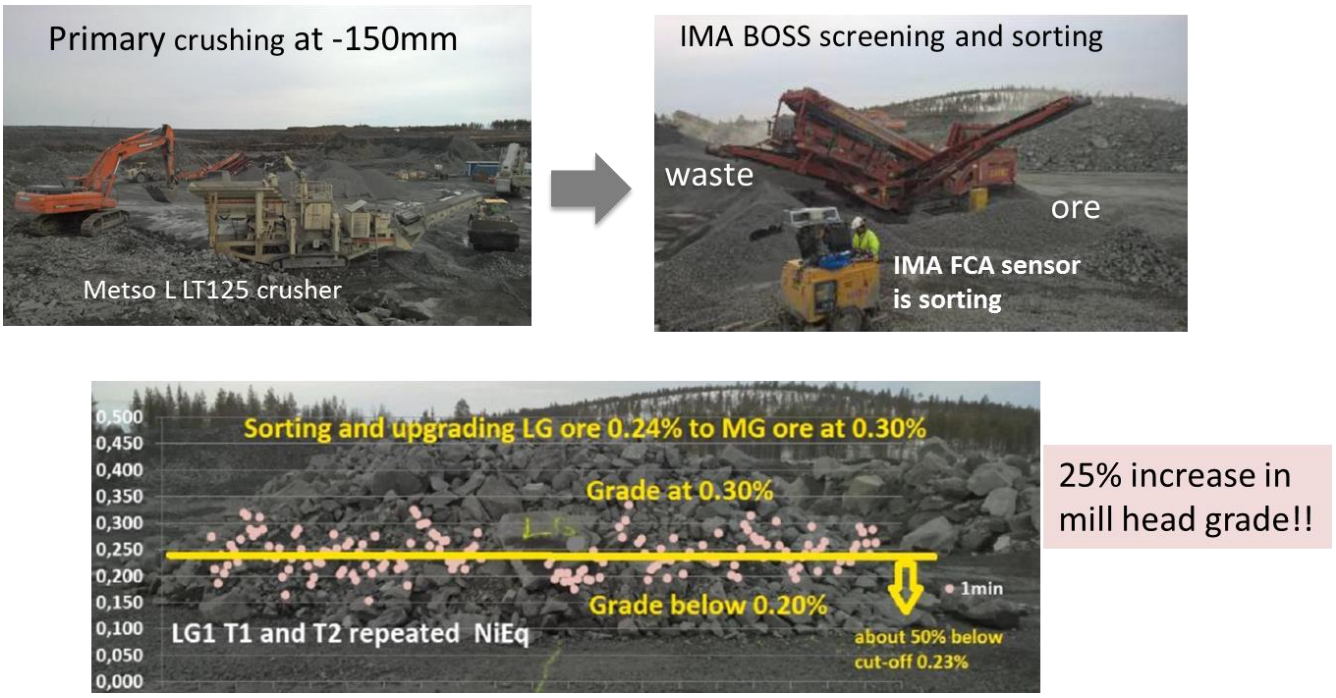

Figure 6 At cut-off grade 50% of ore was recovered to Middle Grade

IF YOU CAN'T MEASURE YOU CAN'T IMPROVE.

Mines today can only measure the average grades of the mill and concentrator feed i.e. of the ore and waste rock they are processing. The ore and waste are homogenized in the intermediate stockpiles and especially in the grinding mills. Samples taken after the homogenization process do not reveal the amount of waste being processed. Samples taken on belt or from slurry for laboratory or for on-line analysis represent only the average grades of their feed. Ore grade variations can be seen only by continuous fast and representative analysis of the primary crushed mill feed material.

CASE: ORE GRADE ANALYSIS AFTER PRIMARY CRUSHER:

FCA on-line XRF analyser (Fig. 7.) was installed on a conveyor at a Ni-Cu mine right after the primary gyratory crusher to analyse the ore going to the intermediate stock pile located before grinding mills. The production capacity varied from 1200tph to 2000tph. Analysis time one was minute which gives typically 5 analyses from a 250ton dump truck load when the ore is being crushed. For more details see at the end References (1) and (2)

Figure 7 IMA FCA installed after primary gyratory crusher

To verify the analysis performance and calibration FCA analysis results were compared to the mines Outotec Courier on-line slurry analyser in the concentrator. The Courier analyses samples typically once in every 15 to 20 minutes from the mill discharge to flotation feed flow. In this FCA vs Courier comparison the time delay variation from 6 to 8 hours which was due to the production feed and the ore volume variation in the in primary crushed ore stockpile was eliminated. Using longer time averages and time shift allow to see how the two analysers give similar trend curves of low grade Cu-ore. FCA 1min analysis values are used to calculate one-hour average, then the IMA FCA and the Courier one hour averages were compared. (see Fig 8.)

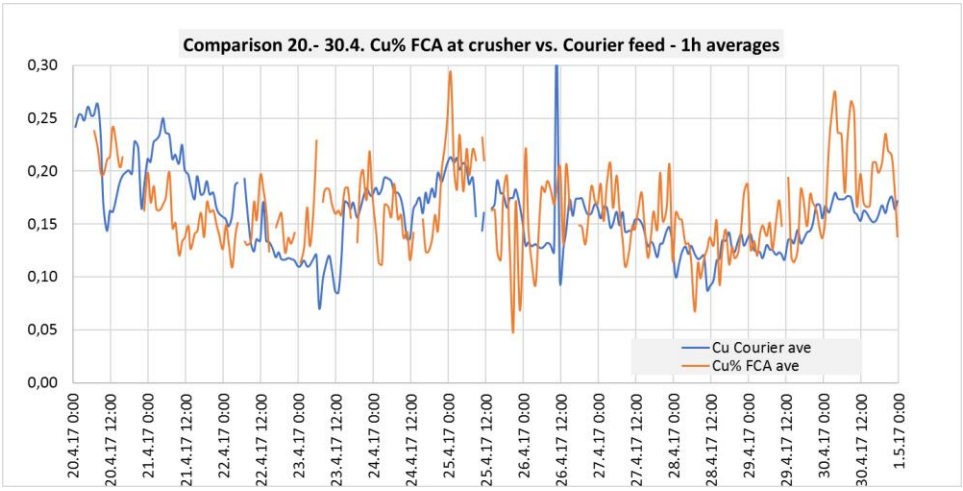

Figure 8. Here is 11day Cu% grade comparison between the FCA on-line XRF analyzer on primary crushed ore discharge conveyor belt and Outotec Courier analyzer analyzing concentrator slurry feed after grinding. There is typically 6h to 8h delay between the two analysis points which has been corrected accordingly.

The FCA gives the results from 6 to 8 hours earlier than the ore is fed from milling to flotation. This helps the concentrator operators in optimizing recovery at the concentrator by reacting to the coming changes of the ore grades by adjusting beforehand flotation chemicals to the process.

However, the main benefits of primary crushed ore analysis are to be gained by sorting out the undesired below cut off waste rock or deleterious elements before they enter the mill and concentrator.

FCA system is composed of on-line XRF Probe installed on a level above the conveyor. The Probe is connected to the Control unit (PES) and the PM-station mainframe computer all parts located inside a climate controlled cabins. System has also connection and Control Junction with the conveyor system and signals to Flop -gate sorting system. Remote access has made remote commissioning possible (used during covid-19 epidemic).

While FCA with XRF probe has limiting performance of light elements from coarse ore material, PGNAA method could be applied to analyse them, however, it is limited with the analysis speed and with material bed variations Other fast on-line sorting technologies such as LIF (laser Induced Fluorescence) or IR spectroscopy could be used parallel to get mineral compositions of the ore and waste.

BULK ORE SORTING ECONOMICS

Waste rock dilution results in significant economic losses. The main reason being that waste rock replaces ore in the concentrator and reduces thus the mine's concentrate production. Waste rock is often harder and more abrasive than the ore. The waste rock stays longer than the ore in the grinding mills which are often the bottle neck of the production. It reduces the mills processing capacity more than the waste mass would indicate. Waste rock abrasiveness causes also extra wear on grinding mill and crusher liners and reduces the overall availability of the plant.

Horizon 2020 ITERAMS project has shown how without doubt the volume of sortable material can be detected and used to calculate obvious economic benefit, which can be achieved with bulk ore sorting. To calculate economic losses in feeding waste into concentrator should be done by using the average ore value which is negative in case of waste. It is to be noted that the waste rock often contains below cut-off grade elements the value of which should be considered in the calculations. Naturally the value loss per ton of ore processed varies from mine to mine depending on the grade and value of the ore and for instance rock hardness. A rule of thumb is a value loss ranges from 20USD to 50USD per ton of ore processed in open pit mining when "pure" waste rock bearing no value elements.

In this case mill feed was analyzed with FCA. The below curve (Fig. 9) show typical primary crushed ore variation at a Cu-Ni mine when processing low grade ore. A 24 hour follow up reveal that about 12.825 tons of below cut off material has been fed to grinding mills representing 36% of the total mill feed during that period.

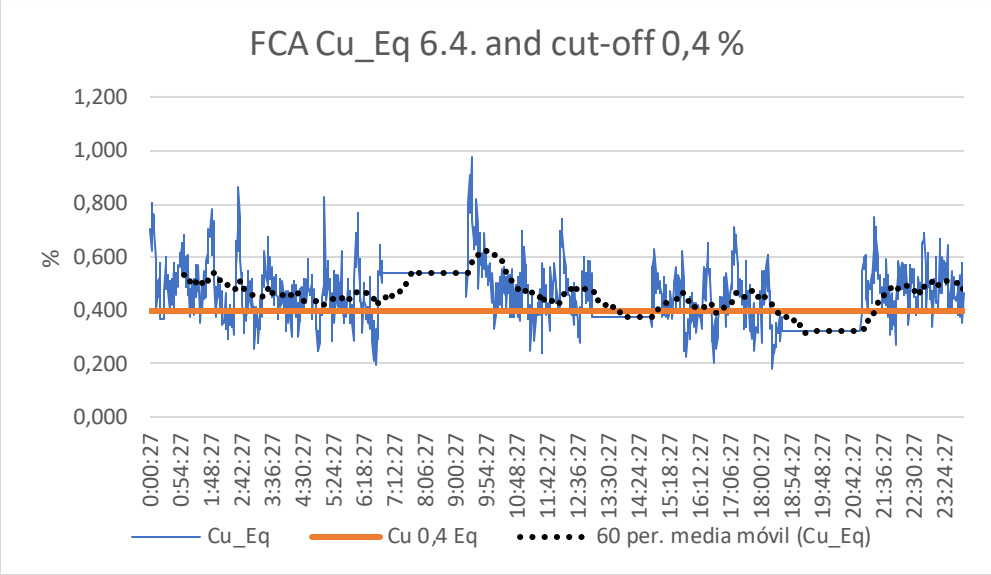

Figure 9. April 6th 24hour mill feed measurement (Cu% Eqv) by IMA FCA; One-minute analysis time (blue line), Cut-Off grade (orange line) and 60minute sliding average (dotted line …….)

It is to be noted that in these average grades the 60 min floating average stays almost constantly above the cut-off grade limit which highlights the fact that on an average everything looks fine – however, the mine is losing money in waste rock dilution. For one week follow up the results showed that 11% of mill feed was below cut of ore and the lost value due to dilution was 293 044 USD per week and annualized loss about 15 million USD. (Table 2)

Table 2. Economical calculation of losses due to waste rock dilution in case above

Below cut-off grade (0,4%) mill feed waste daily value loss		
Date	Tons of waste in mill feed	Value loss (USD)*
4.4	2.825	19.768
5.4	4.425	37.339
6.4	12.825	179.470
7.4	4.300	25.358
8.4	3.025	21.615
9.4	600	5.481
10.4	350	4.014
One week loss total		293.044
Annualized loss total		15.238.302

Waste rock dilution remains undetected at many mines today. This happens because on-line slurry analysis or sampling is from feed which has been homogenized in stockpiles and in grinding mills. Real quantity of waste rock dilution and the economic improvement potential remains hidden without continuous and fast belt analysis and bulk ore sorting.

FCA XRF analysers can be installed as described above on existing conveyors to measure and quantify the improvement potential at any mine. When the sorting volumes and economics and are known then the optimum solution for bulk ore sorting and sorted material handling can be designed.

Sorting is reducing carbon footprint in mining by reducing the amount of waste rock and related higher energy consumption. It has positive impact on ore reserves and mine lifetime and it lowers mining and processing costs.

DISCUSSION

Our case study using frequent analysis from drill cores was used in new ore reserves calculations by the Silver mine and has led to plans to take sorting as pre-concentration method in production. Recently same method is tested in another mines in Finland. These findings may also lead to modifications in the mining method.

The same principle can also be applied for sorting out scats from SAG mill recirculating load. Further, bulk ore sorting can be applied for separating Non Acid Forming (NAF) and Potentially Acid Forming (PAF) waste on conveyor for environmentally safe storage of mining waste rock.

Pilot testing in Horizon 2020 have convinced several mines with different ore types to start applying bulk ore sorting as pre-concentration method. Current plans include mines with capacities varying from 100tons/h to 8000tons/h.

CONCLUSIONS

Ore sorting is a new mining trend, which has been reported during last years in various technical reports and articles. It has become obvious that bulk ore sorting where the ore and waste can be separated on conveyor with simple chute arrangements is the high capacity solution to big base (copper) metal and ferrous metal mines.

The newly developed methods show how sorting potential can be studied at exploration phase or before mining starts adding value to the mineral deposits. Case study with frequent drill core analysis led to increase in ore reserves estimate and plan to start sorting as pre-concentration method.

Horizon 2000 sorting and other sorting studies have convinced international mining companies to take the next step towards full scale bulk ore sorting. Several full scale and pilot studies are in progress.

.

When the production starts or when developed mines want to study ore sorting fast on-line conveyor analysis right after the primary crusher can be utilized to study how waste or low-grade material appears in the mill feed or already in the mine next to muck pile.

We are sure that within next five years mines will ask themselves; Why didn't we do this already years ago?

NOMENCLATURE

FCA fast conveyor analyser
XRF fluorescent x-ray technique
USD American dollar
Cu copper mineral
tph ton per hours
ppm parts per millions, is the number of units of mass of a contaminant per million units of total mass.

REFERENCES

1) A. Perälä ; J. Alli, J; Raatikainen; I. Auranen; 2015 On-line Analyser optimizing mill feed at FQM Kevitsa Nickel-Copper-PGE mine. 15.8.2015 IFAC Seminar Oulu.

2) K. Heiskanen*; M. Talikka *; J. Rohleder *; P Takalo *; J. Raatikainen **; I. Auranen
Outotec (Finland) Oy **IMA Engineering Oy, DEVELOPING REAL GRADE- RECOVERY CURVES FOR SORTING, 2018 SME Annual Conference & Expo and 91st Annual Meeting of the SME, February 25, 2018 - February 28, 2018. South Minneapolis, USA