Minerals Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Bridging the gap: Understanding the economic impact of ore sorting on a mineral processing circuit

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ARTICLE INFO

Article history:
Received 15 June 2015
Revised 21 August 2015
Accepted 24 August 2015
Available online xxxx

Keywords:
Ore sorting
Capital expenditure (CAPEX)
Operating expenditure (OPEX)
Copper
X-ray transmission

ABSTRACT

Automated, continuous ore sorting is a mature technology that has only been used to a limited extent in the hard rock mining industry. However, sorting has been applied in many industries ranging from food preparation and recycled scrap recovery, to diamond mining, industrial minerals, and precious metals processing. A major barrier to widespread implementation in hard rock mining is a knowledge gap: sorting equipment manufacturers have made modest footholds in the mining industry, while miners and plant operators are largely unaware of recent developments and the state-of-the-art technology. Most importantly, a widespread understanding of how ore sorters can be implemented and their significant economic impacts is lacking. The impacts of ore sorting on the economics and the process flow sheet of an existing semi-autogenous milling circuit of a US copper mine are discussed.

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1. Introduction

The hard rock mining industry faces rising energy costs, falling ore grades, tightening environmental regulations, and shrinking access to resources. Compounded by global recession, the industry has seen mines close due to their inability to compete on a global scale. Largely in response to this trend, several new technologies have been developed. This work will evaluate one technology in particular: ore sorting.

In typical hard rock mining operations, the ore that is collected for processing, the run-of-mine (ROM), contains both the metal values (ore) and waste rock (gangue). Depending on the metal being mined, and its specific mineralogy, grades of the ROM vary widely. Therefore, a majority of the ROM stream is material that has no economic value and is essentially an energy and resource sink, costing the producer money to process and eventually separate from the ore through physical or chemical means. Ore sorting is a class of technology that identifies those stones in a ROM stream that contain economically viable levels of ore for further processing and separates them from the gangue (Newton, 1959; Wills, 1992). By separating the ROM stream into ore and waste fractions, downstream processing is positively affected (Allen and Gordon, 2009; Dalmijn and de Jong, 2004; Harbeck, 2004; Lessard et al., 2014; Riedel, 2006). The ore fraction is a higher grade material than the original ROM feed. This in turn reduces the energy consumed in comminution, reduces resource and reagent consumption, and improves performance in downstream processes.

Introduced in the 1930s and 1940s, sorting technology first took root in mining applications with relatively simple sorting criteria, low throughput, and/or high value minerals and metals (Anon., 1971; Coulson, 2012; Salter and Wyatt, 1991; Sivamohan and Forssberg, 1991; Wills, 1992). At the time, sensor limitations in the state-of-the-art sorters prevented application of the technology in more diverse mining sectors. The sensor resolution and ore throughput were simply too low for widespread adoption of the technology. While the benefits of sorting have been enumerated in the literature for years, ore grades continued to fall and production tonnages dramatically increased at hard rock mining sites. Those mining companies initially interested in the technology during the late 20th century quickly became disillusioned with commercial-scale ore sorting when it could not process the streams they were typically handling. However, relatively recent advances in detector technology coupled with high speed computing capacity have made sorting viable for many hard rock applications.

The manner in which the ore sorting is performed is largely dependent on the metal(s) and ore mineral(s) to be sorted. To date several different technologies have been investigated, including X-ray fluorescence, X-ray transmission, radiometric sorting, and optical sorting (Knapp et al., 2014; Manouchehri, 2003). The economic impact of ore sorting has been studied by several authors,

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http://dx.doi.org/10.1016/j.mineng.2015.08.019
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to varying degrees. de Jong (2005) outlined many of the qualitative benefits of the technology as applied to various minerals or ores through pilot studies. Another qualitative approach taken by Ballantyne et al. (2012) identified the practical limitations to ore sorting from a particle size versus power savings perspective. Lessard et al. (2014) examined a specific case involving molybdenum mining to show that savings potentials amounted to nearly 60% reduction in comminution energy per tonne of molybdenum produced. However, the scope of these works was narrow. A patent application by Harding and Stoiber (2014) has identified the need to incorporate ore sorting with mine planning, but no method to determining the economic impact of sorting technology was taught. The current paper hopes to expand upon these ideas by incorporating an understanding of how sorting technology works and how it will affect production economics.

The economic viability of hard rock sorting is currently limited to discrete applications, but as sorter capacity increases, the viability in additional operations increases. Coal operations were one of the earliest adopters for DE-XRT sorting because it could be used to de-stone coal (to reduce ash content and create streams with different heating values) and to desulfurize coal (by identifying and rejecting pyrite inclusions). Therefore, sorting as applied to the coal industry is a powerful example of how throughput has increased nearly ten-fold over the past decade (Fig. 1; de Jong et al., 2003; de Jong, 2005; von Ketelhodt and Bergmann, 2010; Kleiv, 2012; Bartram et al., 2013). Sorter capacity is largely determined by belt width and speed, and the ability by which a monolayer of stones can be established on a rapidly moving belt. Today, typical belt widths, speeds and coverages are 2–3 m, 3 m/s and 10–20%, respectively. Steinert is currently developing equipment to boost throughput to several hundred tons per hour across its standard ore sorters. Therefore, in light of recent sorting technology improvements, ore sorting must be re-introduced to the hard rock mining community from an economic perspective: namely, capital payback and dollar-for-dollar process improvement.

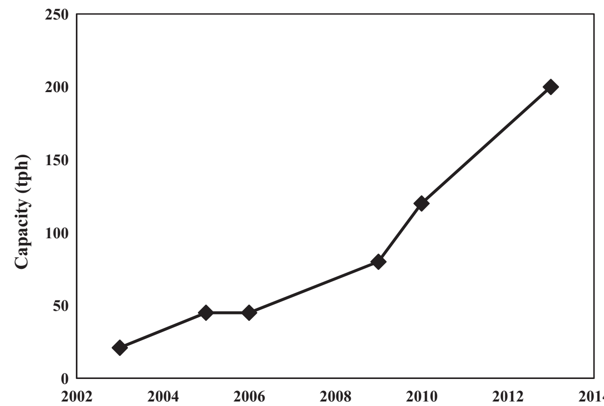

Fig. 1. Approximate sorter capacity over time in coal de-stoning and de-shaling (de Jong et al., 2003; de Jong, 2005; von Ketelhodt and Bergmann, 2010; Kleiv, 2012; Bartram et al., 2013).

2. Modern ore sorting equipment

The goal of ore sorting technology is to differentiate between ore and waste. Sorting is an age-old practice, with documented examples of hand-picking in the medieval workshops of alchemists (Agricola, 1556) through to modern picking tables at coal mines and fluorescent picking at tungsten deposits. Modern sorting is done mechanically in an automated fashion using electronic sensors (Wills, 1992). By examining how minerals interact with different wavelengths of the electromagnetic spectrum, sensors can detect the presence (or absence) of the minerals of interest in the stone being examined. In a commercial installation the sensor array is mounted such that the ore is fed continuously pass the sensor, allowing for real-time, continuous, automated sorting. In these applications, the signal detected by the sensor is interpreted by a computer processor that decides whether or not to identify the stone as waste or as ore. Based on this decision, the trajectory of the stone is adjusted at the end of the belt by an actuator (normally pneumatic or mechanical) to send the stone either to the waste fraction or the ore fraction (Fig. 2).

For many hard rock applications, including the ones presented here, X-rays provide the necessary interaction with the minerals of interest. X-ray transmission (XRT), which analyzes the energy of X-rays that transmit through a sample, is particularly useful in sorting stones (Lessard et al., 2014). As X-rays pass through a material, they are absorbed, reflected, or transmitted; the extent to which X-rays transmit through a material is largely dependent on the atomic density of that material. Therefore, denser elements (usually ore) absorb more X-ray energy than lighter elements (typically gangue). Collecting the signal of the transmitted X-rays at two different energy levels allows a sensor to mitigate the effect of material thickness on X-ray transmission. Such sensors, which are the ones used to sort ore, are known as dual energy X-ray transmission (DE-XRT) sensors.

Because DE-XRT sorters examine the full contents of the individual stones, the ROM material does not need to be exceptionally dry or clean, and no particular orientation is required in order for the sensor to detect the ore. Much like the X-ray scanners at airport security checkpoints, DE-XRT instruments see through the stones being examined. Unlike many surface techniques used in the industry (*e.g.* X-ray fluorescence, laser induced breakdown spectroscopy, etc.), DE-XRT sorters do not need to rely on stochastic methods in the hopes of sampling enough of a stone's surface to get an adequate representation of its contents.

Identifying the appropriate point in a process to implement ore sorters is critical. Because they reject waste, sorters should be installed as early in the flow sheet as possible so as to minimize the energy, reagents, and capacity investments in gangue that should otherwise be eliminated from the circuit. Current DE-XRT sorters can process a maximum size on the order of 200 mm (Steinert US, 2015a); Ballantyne et al. (2012) showed that the capacity of a sorter increases with larger stone sizes. Therefore, sorters are best installed downstream of primary and/or secondary crushing (or handling similarly sized streams, *e.g.* the pebble circuit in semi-autogenous grinding circuits) and upstream of milling operations. While comminution can account for 40–60% of the total energy costs in mineral processing (Gupta, 1992; BCS, Incorporated, 2007), Lessard et al. (2014) showed that primary and secondary crushing constituted only 10% of that total cost, with milling consuming the remaining 30–50%. Thus, the energy spent crushing ore and waste is *de minimis* compared to the savings realized by reducing the amount of waste processed in the mills.

Ore sorting affects nearly every point in the mineral processing flow sheet. At the front end, because sorting allows a mine to either increase throughput at the same cost per ton or reduce costs while maintaining production rates (Lessard et al., 2014). Additionally, because sorters essentially increase the head grade of the ROM, engineers can alter the strip ratio and mine lower grade areas of the pit. The impacts on comminution have already been discussed in detail elsewhere by Lessard et al. (2014). The waste rejected upstream of milling can be handled differently from tailings, increasing capacity of existing ponds while reducing overall rates of hazardous waste generation. Furthermore, by reducing the amount of tailings generated per ton of mineral produced, water

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