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Development of ore sorting and its impact on mineral processing economics

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ABSTRACT

Several factors contribute to an often bleak outlook for mining and mineral processing projects in the current market: rising energy costs, falling ore body head grades, and lower profit margins on added value products have all made it more difficult to operate economically. Ore sorting is a class of technologies that offers potential solutions to these problems by identifying the metal values in a run-of-mine stream and separating the stones containing valuable mineralization from barren stones. This separation reduces the amount of material that must be processed to produce a given amount of value added metal, which has significant impact on the total mine and plant economics. To date, ore sorting has been studied extensively and several technologies have been identified as suitable for industrial application; however, very little quantitative discussion has been made about the impact of these technologies. Dual-energy X-ray transmission has been used to sort ore from different mines, and an analysis identifying the economic impact of these results is presented. Significant energy savings in milling have been realized, and capital and operating cost advantages to using ore sorting have been identified.

1. Introduction

The energy costs required to refine metal values contained in ore to concentrates constitute the majority of the cost to produce metals. On average across the mining industry, 44% of the total electricity consumption is dedicated to crushing and milling activities (Fig. 1). Size reduction operations, nearly 150×10^9 kW h, are the largest single consumer of energy during mineral processing activities. Furthermore, because the energy required during crushing and milling increases as the inverse square root of the product size per the Bond equation (Bond, 1961), the majority of the power during comminution is dedicated to the high energy milling operations used to produce feed for froth flotation operations and subsequent separation steps (de Bakker, 2014). In many specific metal industries (e.g. the refractory metals), milling can account for as much as 60% of the total energy cost to produce value added metals (Gupta, 1992). Falling ore head grades and rising energy costs are making it increasingly expensive to produce metal from ore. Therefore, an intensive effort is currently underway in the industry to identify energy saving measures to address these issues.

It was outlined in U.S. Department of Energy and U.S. Energy Information Administration reports that current size reduction practices are highly inefficient (BCS, Incorporated, 2002, 2007). The use of best practices crushing and milling operations was predicted to reduce energy consumption during comminution by over 15%; however these savings pale in comparison to the potential savings with improved technologies and practices. While it is important to understand how current crushing and milling practices can be improved, and new size reduction technology seeks to address these issues (de Bakker, 2014), a more pertinent question might be: why crush and mill at all? Base metal ore bodies often have head grades below 1%; and as will be outlined below, many refractory metal ore head grades fall well below 0.1%. Bearing this in mind, >99% of the material processed in a comminution circuit contains no economic metal values. The energy invested in the majority of the material processed, therefore, is wasted; the waste material, or gangue, is usually rejected shortly after milling by froth floatation or other separation methods. In addition to wasted energy, the gangue now represents a waste material that must be disposed of in a tailing impoundment. The presence of waste material during processing also consumes valuable capital and operating expenses, all for material that cannot be sold to the customer.

Ore sorting as a class of technologies addresses these issues by reducing the amount of material fed to the milling circuits,

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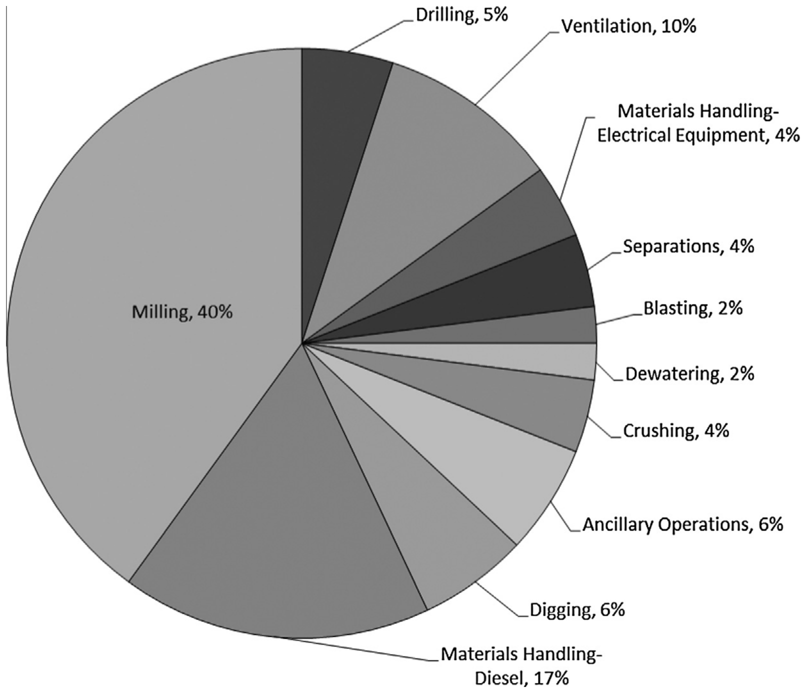

Fig. 1. Electricity consumption in the mining industry from mine to comminution (BCS, Incorporated, 2007).

eliminating much of the waste before any further capital or operating expenses are invested into its processing. In the simplest sense, ore sorting constitutes a sensor, a processor, and a sorter (Fig. 2). Ore sorting has been done by hand for centuries by identifying mineralization on the surface of individual stones (Newton, 1959; Wills, 1992). However, modern technology affords the opportunity to look deeper than the surface, and in spectral ranges invisible to the naked eye. As outlined in Fig. 2, stones pass through a sensor mechanism, which operates on one (or more) of several principles. The signal from the sensor is sent to the processor, which decides whether the stone contains metal values and whether the values are present in economically recoverable amounts. This decision is passed to the sorting mechanism, which takes action to create two classes of stones: ones that contain metal values and ones that do not. The goal of ore sorting is to reduce the total amount of material sent to the high energy milling circuit, while not significantly impacting total metal recovery. In general, ore sorting operates on the run-of-mine (ROM) stream after it has gone through preliminary, relatively low energy, crushing operations. This reduces the size of material from >1 m to ~5 cm, at a fraction of the energy used during milling. Therefore, by rejecting waste stones from the ROM stream after a minimal energy investment, the total impact on energy (and capital and other operating expenses) can be maximal. It has been estimated

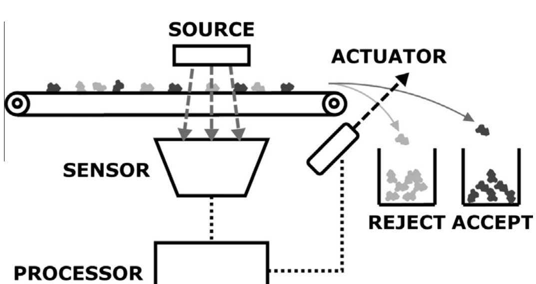

Fig. 2. Simplified ore sorter featuring source, sensor, processor, actuator and accept/reject piles.

that ore sorting post-crushing and pre-milling has potential annual economic impact on the order of hundreds of millions of dollars across the industry (Buxton and Benndorf, 2013).

In addition to the reduction in energy used during milling by implementing ore sorting, capital savings in equipment sizing, tailings impoundment and extended mine life can be realized. Furthermore, reagent consumption is reduced and the feed to unit operations downstream of milling is smoothed by eliminating variations in the feed head grade. The impact of ore sorting is wide reaching (Allen and Gordon, 2009; Dalmijn and de Jong, 2004; Harbeck, 2004; Riedel, 2006). But to date, very few impact studies have been performed to identify some of these advantages offered by implementing the technology. The purpose of this study is to highlight recent advances in ore sorting as it pertains to two refractory metal ore bodies. However, the effects of these findings will be extended to the entire mine and plant operation, and generalized to identify the savings or operational improvements made possible thanks to ore sorting.

Ore sorting has been extensively used in the mining industry, with some of the earliest applications finding use in high value products like diamond and gem mining (Tomra, 2013; Von Ketelhodt, 2009). In such applications, the minerals that host the gems are sought using X-ray fluorescence and X-ray transmission as a proxy to identifying the gem. Radiometric sorting has been applied in the processing of uranium ores. The Lodève mine in France has seen successful implementation of ore sorting on the 30–100 mm fraction of ROM material (International Atomic Energy Agency, 2000). Work performed by the International Atomic Energy Agency has achieved >98% uranium recovery with rejection of 52% of the ROM stream on Indonesian deposits in Northwest Kalimantan (International Atomic Energy Agency, 2000). Refractory metal deposits have also been the beneficiary of ore sorting with installations at the Wolfram Bergbau tungsten deposit in Austria and the Wolfram Camp tungsten property near Cairns, Australia. The latter deposit has reported that X-ray sorting has recovered 80–85% of the tungsten value while rejecting 90–95% of the ROM stream; implementation of the technology has doubled the annual production rate (Wolfram Camp Mining,