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The relevance of water recirculation in large scale mineral processing plants with a remote water supply

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ABSTRACT

Water and energy are essential requirements for mineral processing plants, and they can be either scarce or expensive. In the present paper, the implications of a remote water source location (typically the seashore) are analyzed in terms of a definition for the combined water and energy operational cost required to transport ore concentrate using long distance pipelines. A typical process route is defined to expose the relevance of key process variables, including source remoteness and water reclamation both from tailing storage facilities and thickeners. Both mass and energy balances have been made to give an estimation of specific energy consumptions for a typical large scale Chilean mineral processing operations, considering a number of realistic hydraulic design criteria to make a comparative analysis of different plant processing capacities. In the present cost function definition, an account has been made on whether the water is either makeup or has been recirculated on the plant, and a distinction has been made on whether tailings are conventional or thickened, which allowed to analyze the relevance of in-plant water recovery compared to water recovery from the tailing disposal site. This has allowed to express the cost of water in terms of the various energy cost terms, thus showing in this case that the cost of water is ultimately the cost of energy, and therefore all cost components become proportional to the unit cost of energy. A piecewise constant pipeline diameter analysis scheme has been defined to allow studying the implications of water recovery on widely different plant sizes. Results show that for fixed water recovery rates, increasing plant throughput tends to cause a decrease on the specific energy for water transport. On the other hand, for fixed pipeline diameters, increasing the throughput causes an increase on the specific energy consumption, but such increase rate becomes milder at higher throughput rates. This suggests the advantage of the existence of common makeup water supply systems for mining districts with more than one mineral processing plant. On the other hand, for constant pipeline diameters, increasing the water recovery from the tailing disposal site or from thickeners generates a decrease of water specific energy consumption, where in the case of the water recovery from the tailing disposal site such decrease rate becomes stronger with the amount of water recovered. Results also shows that, except for very high solid concentrations, water makeup costs dominate over recirculation ones, supporting that producing thickened tailings is a more efficient option than conventional ones in the sense of specific energy consumption, in spite of the additional energy costs due to slurry transport that this option implies.

1. Introduction

Water is ubiquitously used in mineral processing plants. While in the plant it is required for valuable mineral extraction, often *via* flotation, it is also used as a vehicle for both the transport of the commercial product (ore concentrate) and the residue (tailing). In either case water acts as a vehicle both for separation and transport, and is subject to losses in several stages in the process. It is therefore important to note that water, just like energy, acts as a raw material. Water and energy supply have been treated in the past as two separate problems the mining industry faces. Common approaches to the efficient use of resources have been focused on either efficient water management or life cycle analysis (LCA) to

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both use less water and maximize recycling. Examples include Boger (2009), who focuses on the value of thickening and rheology to reduce water footprint, Norgate and Haque (2010), who suggests, using LCA, the need to improve the efficiency of major energy consuming equipment such as mills in the context of iron ore, copper and bauxite production. On the other hand, Dunne (2012) enhances the value of planning and the use of a system-level approach for water management, and Norgate and Haque (2012), using again LCA, expose the high environmental footprint of the gold extraction process. Only recently efforts have been devoted to treat the integral problem of efficient combined use of both. Indeed, only in recent years the notion of decision making after trade-off values related to water and energy has received attention in the literature. An example is the Mine Water Network Design (MWND) approach (Gunson et al., 2010) where, after the identification of the water balance and potential water sources, an optimization of the water consumption based on minimizing energy requirements *via* linear programming has been applied to water cooling of mills and compressors in a mineral processing plant. In the coal industry, the impact of the mine plan on potential decisions to optimize pumping capacity for dewatering has been depicted in terms of both the specific energy and water consumption in India (Sahoo et al., 2014) and. The opportunities to use alternative water sources increasing global efficiency is discussed by (Nguyen et al., 2014, and references therein). This has included the potential to use another mine's acquifer. The concept of water transfer between plants has been exploited in the hierarchical system model that has been proposed and applied to an Australian plant network to minimize water contamination due to overflow in plants during extreme events (Gao et al., 2016). In these cases, the explicit metric of interest is either energy or water consumption.

The interplay between water and energy use has been only relatively recently identified as a plant efficiency driver. Conceptual approaches have been proposed to expose trade-offs between water and energy consumption in mining. Donoso et al. (2013) have identified, in light of a simulation of a copper concentrator, the relevance of particle size through comminution and water recovery. They observed that larger particles are bonded to reduced energy consumption, and increased water recovery at the thickeners. However, this optimum does did not match the highest copper concentrate throughput, making this approach strongly copper and energy cost-dependent. Assuming comminution and flotation as process data, a water energy index, corresponding to the ratio of available water volume and energy demand (Nguyen et al., 2014) and a dimensionless parameter for water-energy cost in slurry transport systems, including ore concentrate and tailings (Ihle et al., 2014) have been defined. These approaches have in common the requirement of a site-specific assessment (including cost and location) for a best combined use of both resources. Apart from desalination, water supply cost and associated greenhouse gas emissions is strongly tide to delivery distances (Hiam-Galvez et al., 2012; Ihle, 2014). To account for a metric of the ore concentrate transport cost, an energy/water cost formulation can be used to measure how energy- and water-intensive is the transport process (Ihle, 2013; Ihle et al., 2013a). This approach requires a water and energy cost separately. The result after an optimization procedure is a set of optimal concentration and flow conditions given both the unit costs of water and energy. Adiansyah et al. (2016) have worked an example taking into account the combined relevance of water and energy in a coal plant using a hierarchical system model (HSM) software to seek for the best tailing transport and disposal option for thickening solids concentrations between 30% and 60% by weight. They conclude that considering water recovery rates and energy consumption there is an optimum close to 50% (in their study the most water saving option was not the best due to the high energy consumption). Although their computation did not add a metric for the cost of water and they took a qualitative valuation of the use of water based on recovery, they reinforce the point made in previous works (e.g. Ihle, 2014) regarding the relevance of considering both water and energy in plant assessment, with emphasis on the impact of water slurry transport.

The Chilean copper industry is massive on both water and energy consumption and faces several challenges involving water that range from economical to environmental aspects. While it shares the common water scarcity and/or competition with other stakeholders (Cochilco, 2008), it also needs to minimize the use of energy in the especially high energetic Chilean cost scenario (on the order of 100USD/MWh as reported by Utreras et al., 2016), that implies CAPEX can be as high as 19USD/m^3 and OPEX 3.5USD/m^3 (Soruco and Philippe, 2012). On the other hand, in Chile, the water scarcity close to many mineral processing plants in arid regions, even when compared to other mining countries with present and potential of future development, such as Peru and USA, has created the need to supply water from the sea (Northey et al., 2017), which somewhat imposes a new challenge: when resourced from the sea water should be kept to a minimum, not because it is scarce, but because desalination and transport is considerably expensive (Northey et al., 2013). In particular, there is a high energy demand associated to both pumping water from sea level to mountain locations, where most of the concentrators are, and the need to provide the supplementary energy to account for friction losses. Table 1 shows an example of long distance water transport lines connecting desalination facilities with mineral processing plants. A complement is detailed in Philippe (2012), Castillo et al. (2015) and Revista Agua (2016), whereas historical remarks on water supply pipelines for the mining industry can be found in Ghassemi and White (2007). On the other hand, a summary of potential desalinated water supply projects in the context of the Chilean mining is given by Zúñiga (2009). In the particular case of slurry pipelines, some additional operational challenges arise from the handling of segregating solid matter inside the pipeline. In several cases, paths for desalinated (or salt water) pipelines are the same than those of ore concentrate pipelines, which means that part of the water obtained from sea level travels twice the pipeline length. Both in concentrate and makeup water pipelines, power consumptions due to pumps are commonly in exceed of 1 MW. This number can be readily justified considering as a rough (and conservative) estimation of the hydraulic power for transport that it is on the order of the product of the water density, the acceleration of gravity, the altitude difference and the volume flow (i.e. neglecting friction losses and pumping efficiencies). Excluding the Balama pipeline case in that table, more than 70% of the operations in Table 1 consumes more than 1 MW in water transport.

In slurry transport systems using pipelines, from a simple mass balance, discussed below, there might be more than one combination of slurry flow and solids concentration which yields the same throughput. This suggests that it is possible to find, within the set of feasible input conditions, an optimal one given a specific criterion. If such criterion is specific energy consumption (*i.e.* the amount of energy spent per unit mass of solids), the least specific energy consumption occurs near the minimum velocity before a sediment bed appears at the pipeline section (Ihle and Tamburrino, 2012). The minimum velocity is defined as the maximum value between the deposition value and that corresponding to the laminar-turbulent transition, where most often the former controls the minimum velocity condition at small to moderate solid fraction values (Ihle and Tamburrino, 2012). In other words, in most operational long distance ore concentrate pipelines, the least specific energy consumption is controlled by the deposition velocity value.