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Historical assessment of metal recovery potential from old mine tailings: A study case for porphyry copper tailings, Chile

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ABSTRACT

The metal mining activity has been the source of large volumes of tailings that must be stored in tailings storage facilities (TSFs). Since tailings might contain residual valuable metals, these are often subject of assessment studies aimed to find a feasible way to reprocessing. One of these TSFs was built and operated during the 1930's for the exploitation of a giant porphyry copper deposit in Chile, a deposit that is still under exploitation today. For these old tailings a historical assessment was varied out about the copper recovery potential in a reprocessing scenario by flotation. Based on theoretical concepts and available historical operational data, it can be shown that the main reason for the relatively high copper grades found in these tailings are the corresponding high grades of the processed ores, instead of being the result of an inefficient past technology of flotation with consequential low recoveries. Conversely, the former flotation circuit was optimal concerning the recovery of copper sulphides favoured by the less restrictive high copper content of these sulphides. Consistently, it is argued for the study case that the main advances in flotation circuits have focused on improving selectivity without sacrificing recovery, due to the changes in the mineralogy of the exploited ores. These are relevant facts for a reprocessing scenario, indicating a low copper recovery potential if the current conventional flotation technology is considered; thus other and/or newer processing technologies could be more efficient for recovery of the remaining copper. There are hydrometallurgical potential alternatives for reprocessing but limitations are expected in relation to milling size of the tailings material. The present findings may apply elsewhere, due to the high representativeness of the present study case.

1. Introduction

The mining activity is and has been vital for the economy of many countries, e.g. Chile, especially since the beginning of the 20th century. It has resulted not only in the production of metals but also in the generation of waste products, particularly when processing sulphides ores from porphyry copper deposits. This leads to large amounts of tailings that must be stored in tailings storage facilities (TSFs) (Hansen et al., 2005). These mine tailings are the remaining fine grained (1–600 µm) ground-up rock after the minerals of economic importance have been extracted, mixed with the associated process water which includes dissolved metals and processing reagents (Edraki et al., 2014). Since the solid phase from tailings might contain remaining valuable metals that were not recovered in the past, they represent potential resources and therefore they are objects of assessment studies and eventually of reprocessing.

Reprocessing implies that the tailings material is used as a feedstock for producing valuable products such as recovered minerals and metals (Edraki et al., 2014). According to Gordon (2002), mine tailings can be observed as the single largest source of copper in waste deposits in the US copper cycle and Johansson et al. (2013) categorized tailings as valuable stocks of metals in the "technosphere", indicating that reprocessing could also be an innovative reclamation technology. The reprocessing of tailings for recovery of metals like gold (Bugnosen, 2001), copper (EPA, 1993) or iron (Karlberg, 2010) is a past and current practice. Rampacek (1982) provides an overview of mining and mineral processing waste as a resource; in 1994 for example, 2% of the total worldwide copper production came from reworked tailings (Graedel et al., 2004). In Chile since the early nineties mining companies have been established and exclusively dedicated to reprocess old as well as fresh porphyry copper tailings to recover copper and molybdenum.

Reprocessing of old tailings that contain significant amounts of copper could result in a higher rate of production than processing of

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primary ores (Edraki et al., 2014), especially considering that they were already mined and processed (Lutandula and Maloba, 2013). However, if the copper sulphides minerals are finely disseminated and intergrown with pyrite and associated or occluded with gangue minerals reprocessing may not be feasible due to the high costs involved in both separation and liberation (Kitobo et al., 1999). In addition, the resulting speciation of the remaining copper from tailings and possible chemical changes that might affect the TSF "ore" body since its deposition will condition any recovery process (Dold and Fontboté, 2001; Edraki et al., 2014, Hansen et al., 2005).

Regarding the reason behind the relatively high copper grades that could be found in old tailings some authors have argued that this might be due to a past inefficient recovery technology (Dold and Weibel, 2013; Edraki et al., 2014; Falagán et al., 2017). For such scenario, reprocessing could be a winning bet considering the current available technology, but the underlying reason might not be the lower past recoveries. In fact, according to Gordon (2002) the average worldwide copper recovery achieved by flotation technology has not changed since its beginning in the 1920's. Therefore, a particular and deeper analysis should be performed since finding the reason behind the higher grades could be the starting point in any future reprocessing design.

It is a current practice to assess the metal recovery potential from tailings through the amount and grades of the stored material in combination with metallurgical testwork campaigns, a time - and money - consuming venture. The purpose of this work is performing such assessments for old porphyry copper tailings from Chile in a reprocessing scenario by flotation, only based on specially developed theoretical concepts and available historical operation data as an economically efficient first step of a reprocessing or even remediation initiative.

2. Assessment approach

The methodology combines theoretical concepts developed in this work with the available historical operation data. This combination allows a focused interpretation of the data and thus, an assessment of the copper recovery potential from the studied old tailings.

2.1. Theoretical concepts

Three concepts are highlighted in the following sections as a theoretical base for the assessment of the available historical data.

2.1.1. Commitment between selectivity and recovery

This concept is related to the inherent commitment between the concentrate grade, as a measure of selectivity, and the recovery that both take place in the concentration process by flotation. This commitment becomes clearer when a theoretical grade-recovery curve is used, because it is a way to visualize the trade-off between the two main objectives of flotation, i.e., achieving a high concentrate grade while sacrificing as little recovery as possible (Neethling and Cilliers, 2012). This curve is referred to the combinations of maximal values of concentrate grades and recoveries that a flotation circuit can ever reach limited by feed ore mineralogy and textural aspects after grinding, i.e., liberation degree. Fig. 1 shows a comparison between two hypothetical cases using typical theoretical grade-recovery curves considering in both cases the same textural aspects after grinding.

Chalcocite with a copper content of 79.9% and chalcopyrite with a lower content of 34.6% are considered for this comparison, as they reflect the change in ore mineralogy of typical porphyry deposits throughout the aging of the exploitation, especially of those with secondary enrichment zones.

2.1.2. Mass balance equations (origin of tailings copper grade)

This second concept is related to the origin of the copper grades with which tailings end up after flotation. Even though it is obvious that the corresponding ore deposit and the specific mine sites and processing

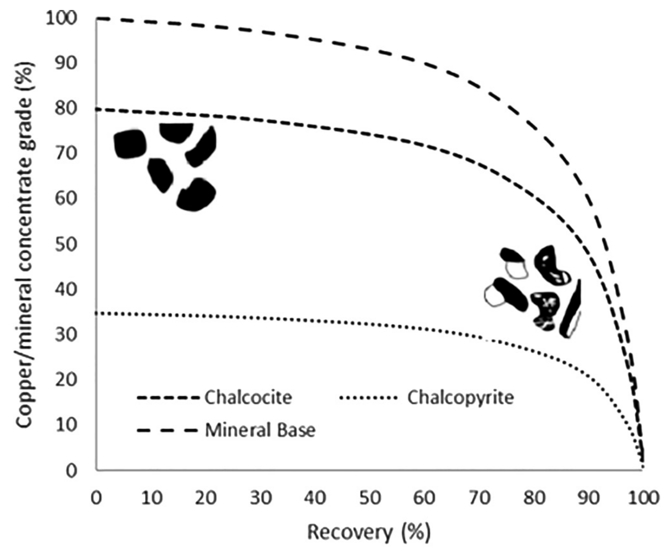

Fig. 1. Typical theoretical grade-recovery curves on a copper and mineral base.

conditions determine this copper content, a focus is needed on the following mass and copper balance equations that govern the concentration process by flotation.

$$F = C + T \tag{1}$$

$$FG_f = CG_c + TG_t \tag{2}$$

The variables F, C and T are the total mass of the feed ore, the concentrate and the tailings, and Gf, Gc and Gt are the corresponding copper grades of the same fluxes.

These two simples mass balance equations are the basis of any metallurgical analysis of a concentration process like flotation. For instance, the recovery (Rec) can be expressed in terms of the feed ore grade and the concentrate and tailings grades reached by the process, as the former two equations lead to the following equation.

$$Rec = \frac{G_c(G_f - G_t)}{G_f(G_c - G_t)} \tag{3}$$

Based on the Eq. (3) an expression for the copper grade in tailings also can be written as follows.

$$G_t = \frac{G_c \cdot G_f \cdot (1 - Rec)}{G_c - G_f \cdot Rec} \tag{4}$$

Eq. (4) represents an expression for the calculation of the tailings grade based on the feed ore grade and the two main objectives of the process: recovery and concentrate grade. Nevertheless, a more detailed analysis of Eq. (4) shows that for the tailings grade there are practically no changes versus changes in the concentrate grade above certain common limits $\left(\frac{\partial G_t}{\partial G_c} \approx 0;\ for\ G_c > 15\%\right)$ as is shown in Fig. 2 for five

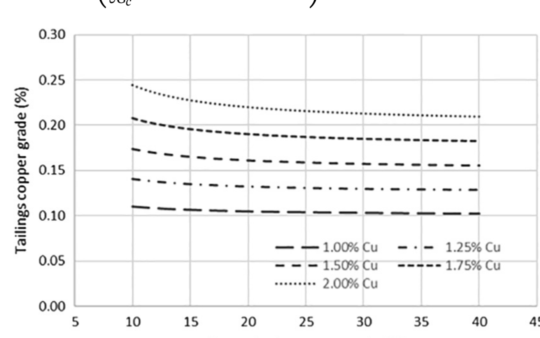

Fig. 2. Changes on tailings grades with the concentrate grades.